Renewable energy sources in emergency humanitarian medical cold chain for sustainability enhancing

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Abstract:
The purpose of this study is to investigate the opportunities and barriers of increasing the use of renewable energy sources (RES) in emergency humanitarian medical cold chain (HMCC) to enhance the environmental sustainability of the operations, but also from the longer-term perspective. As can be seen in the commercial side, RES is being advocated to mitigate the environmental pressure of the energy intensive supply chains, yet the sustainable perspective towards environment has not been highlighted by humanitarian organisations in emergency relief operations. Therefore, the frame of reference of this study is built on concepts of humanitarian logistics and sustainable supply chain.

HMCC is highly energy intensive due to the requirement of temperature-controlled environment, and sudden onset disasters pose challenges to ensure steady, reliable, and sustainable power supply for cold chain equipment. Currently, diesel-based generators are powering emergency HMCC, mainly due to the already established processes. Yet, it is not considered environmentally sustainable. Renewable energy sources offer one feasible alternative to address the environmental pressures derived from HMCC operations. To answer the aim, this qualitative study maps the actors, activities and energy sources in downstream emergency HMCC, and investigates the environmental implications of increased use of RES. The data is collected through semi-structured interviews from experts with knowledge of HMCC in emergency operations.

The findings indicate that environmental sustainability is not prioritised in emergency HMCC. During emergencies, the key goal is to save lives, hence the cold chain needs to be first reliable, and after that sustainable. However, the findings suggest that the environmental awareness in cold chain management is gradually increasing, and solar energy is seen as the best energy source among all RES options to power emergency HMCC for sustainability enhancing.

Sustainable emergency medical cold chain's opportunity is to act as an entry point to longer-term and broader sustainability. If HMCC was powered with cleaner energy already in immediate response phase, it would have longer-term environmental benefits to the surrounding area. This is because the affected community could benefit from the technology more broadly, because RES can power the whole area instead of merely local health facilities. However, several barriers hinder the wider use of RES in emergency HMCC, such as lack of technological knowledge, resources, and proof from the field of the reliability of RES, as well as volatile sudden onset disaster settings.

The contribution of this study calls for establishing green guidelines and reviewing the emergency HMCC activities' long-standing implications. For future research, it is also recommended to investigate the increasement of RES from the economic and social dimensions and their interlinkages to environmental sustainability for in-field evidence of the reliability of RES.

Keywords: Cold chain, humanitarian logistics, emergency response, sudden onset disaster, sustainable supply chain, renewable energy sources

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KEY DEFINITIONS

Active cold chain: Part of cold chain that use electric or mechanical systems, such as mains refrigerators and off-grid generators, for cold producing (Logistics Cluster, 2015a; Comes et al., 2018).

Energy Supply Chain: A network of energy sources that is being sourced, produced to consumable form of energy, and used to power supply chain activities from point of origin to the end user (Halldórsson & Svanberg, 2013).

Humanitarian medical cold chain: A network of devices, such as refrigerators and cold boxes, that are powered with energy for cooling during the transportation, distribution and storing from upstream to the beneficiary in the humanitarian context (Logistics Cluster, 2015a; Comes et al., 2018; Dolinskaya et al., 2018).

Renewable Energy Sources: Energy sources that are replenished by the nature and derived from sun, wind, biomass or hydropower, or derived from natural movements of the environment, such as geothermal energy (Ellaban et al., 2014). Renewable energy sources are considered feasible alternatives to fossil fuel-based energy sources such as coal, oil and natural gas (Ellaban et al., 2014; Saavedra M. et al., 2018).

Passive cold chain: Part of cold chain that is not powered with active mechanism, but use phase change materials, such as coolants or gel packs that are frozen, or merely ice packs to put inside a box or a carrier to keep stable temperature (Logistics Cluster, 2015a; Comes et al., 2018).

Supply Chain Management: Mutual management of flows of material and information within a network consisting of upstream and downstream actors (Christopher, 2011).

Sustainable Supply Chain Management: Cooperation and management of flows of material, information and capital in a way, which advocates the sustainable dimensions of economic, environment and social (Elkington, 1998; Seuring & Müller, 2008).

Triple-bottom line: A model introduced by Elkington (1998) which contemplates environmental, economic and social dimensions, and suggests that sustainability can be achieved within the intersection of the three dimensions.

ABBREVIATIONS

GHG: Greenhouse Gas

HMCC: Humanitarian Medical Cold Chain

NGO: Non-Governmental Organisation

RES: Renewable Energy Sources

RQ: Research Question

SCM: Supply Chain Management

1 INTRODUCTION

The global energy need is constantly rising (OCHA, 2010), and the increased industrialisation has a direct link to global supply chain activities, comprehending complex supply chain nodes, which emit greenhouse gases to the atmosphere (Halldórsson & Kovács, 2010). According to OCHA (2010), up to 80% of global greenhouse gas emissions are derived from global energy usage. From upstream to downstream, energy is crucial for any node within the supply chain (Halldórsson & Kovács, 2010), yet the energy sources globally derive up to 80% from fossil fuels (World Bank, 2019), such as oil, coal and natural gas (Halldórsson & Svanberg, 2013). Current energy sources from fossil fuels are not infinite, and energy scarcity, price fluctuations, secure energy access, and climate change are among the direct challenges that societies are facing (Halldórsson & Kovács, 2010).

The interrelationship between supply chain activities and climate change is evident, and to combat global warming, actions towards sustainable agenda have received increased attention within the commercial sector (Halldórsson & Kovács, 2010). These include efforts related to supply, manufacturing, and distribution (Saavedra M. et al., 2018). However, the global population is expected to rise considerably in developing countries, accounting also to increasement of energy needs (OCHA, 2010). Also, due to climate change impacts as well as volatile political atmosphere, the growing number of both sudden onset man-made and natural disasters has increased the need for humanitarian emergency operations (OCHA, 2010; Panwar et al., 2011). In 2018, 135 million people needed humanitarian assistance, which is 5% higher than in 2017 (OCHA, 2017). The increasement in energy needs and disasters challenge the non-governmental organisations (NGO) to consider the implications of their response operations.

The dilemma between energy need and available resources in developing countries is to be addressed, and humanitarian organisations providing aid are major contributors for securing clean energy access (OCHA, 2017). For instance, Saavedra M. et al. (2018) noted that sustainable supply chain management as a broader concept has a major influence on changing the global energy industry's performance from fossil fuel based towards cleaner energy from renewable energy sources (RES). For evaluating the sustainable performance, a model of triple-bottom line by Elkington (1998) has been widely used as a base for economic, social and environmental dimensions' evaluation.

In addition to humanitarian organisations' influence on clean energy access (OCHA, 2017), humanitarian emergency operations can reduce their greenhouse gas (GHG) emissions by choosing more environmentally sustainable solutions for logistics operations (Eng-Larsson & Vega, 2011). However, the focus in humanitarian responses has lied on the response effectiveness measured by numerical metrics, including financials and the number of people saved (Haavisto & Kovács, 2014). The sustainable dimension focusing on environmental perspective of the response and the following reconstruction phase have been widely neglected (Haavisto & Kovács, 2019).

The lack of environmental sustainability owes heavily to the perception that humanitarian organisations are already considered sustainable due to their profound existence to save lives (Eng-Larsson & Vega, 2011; Haavisto & Kovács, 2019). However, Panwar et al. (2011) remarked that the energy need is constantly growing in developing countries, also after sudden onset disasters. Therefore, the rebuilding phase ought to be conducted in a sustainable manner, as the use of pollutant fossil-based fuels leads to health risks, adverse impacts on environment, and accelerates climate change (Panwar et al., 2011).

1.1 Research problem

Medical items are part of the supplies needed when responding to sudden onset disasters, yet, emergency medical cold chains are highly energy intensive (GAVI, 2018; Grafham & Lahn, 2018), as the items need to be deployed in a certain temperature to beneficiaries (Comes et al., 2018). In addition to transportation activities, cold chain requires devices for storing the medical items, meaning that energy is required for running the devices, such as refrigerators for storing the items in active cold chain, and freezers for freezing the icepacks used inside the cold boxes and vaccine carries in passive cold chain (Comes et al., 2018; Dolinskaya et al., 2018).

Yet, the current cold chain solutions to deliver the critical medical items to the disaster area are not environmentally friendly as they rely to a great part on fossil-fuel based generators in situations where there is a lack of electricity from national grid (Grafham & Lahn, 2018). For example, UNHCR (2014) remarked that the two most lasting negative environmental impacts resulting from humanitarian response are deforestation and environmental degradation. In addition, the equipment deployed to the field relying on diesel-based generators (Grafham & Lahn, 2018) are, typically, left in the field after the most critical phase of the emergency (Haavisto & Kovács, 2019). Therefore, they are creating dependence on fossil fuel supply, which is not self-evidently available in developing countries and is not environmentally sustainable (Grafham & Lahn, 2018). This leads to continuous health issues as the vaccines, medicines, or other health items that need cold chain cannot be stored accordingly due to lack of electricity for refrigerators (OCHA, 2010).

1.2 Aim of the study

As seen in the commercial supply chains, renewable energy sources offer a feasible alternative to address the environmental perspective of the energy intensive supply chain (Halldórsson & Svanberg, 2013). In humanitarian context, solar energy has been studied to increase the effectiveness of the cold chain and to ensure continuous and robust power supply in the rural health clinics and hospitals (see, e.g., Adair-Rohani et al., 2013; MSF, 2016; Olatomiwa, 2016). However, the sustainability perspective has not been on focus. In contrast, the long-term development projects have included sustainable goals in their agendas, yet the reconstruction phase followed by the immediate relief operation could benefit of already established sustainable activities (Gibert, 2008; Eng-Larsson & Vega, 2011; Haavisto & Kovács, 2019). Hence, the problem owners of this phenomenon are NGOs and their stakeholders (Seuring & Müller, 2008), but the challenge gradually shifts to the local communities coping after the disaster (Gibert, 2008).

As a response to the challenges outlined above to focus on sustainability from the environmental perspective, the aim of this research is to investigate the opportunities and barriers of increasing the use of renewable energy sources in emergency humanitarian medical cold chain (HMCC) in order to enhance the environmental sustainability of the operation, but also from the longer-term perspective. Therefore, this research aims to answer to the following research questions (RQ):

> RQ1: What energy sources are powering the HMCC in emergency operations?
>
> RQ2: How the increased use of RES in emergency HMCC is seen from the perspective of environmental sustainability?

1.3 Method

This qualitative research follows an abductive research design by merging both deductive and inductive elements, which allows to study the phenomenon in a holistic and in-depth manner (Kovács & Spens, 2005; Saunders et al., 2016). The empirical part of this study builds on six semi-structured interviews completed during the period of 21.10.-

21.11.2019, and the case selection was completed by using both key-informant and snowball sampling strategies (Patton, 2015). The semi-structured manner of interviews was to ensure robust results to be reflected to the current academic discussion of sustainability in emergency HMCC (Ponteretto, 2005).

In addition, the interview results were validated by publicly available, independently selected written documents that the researcher searched online with keywords "cold chain management", "cold chain in humanitarian operation", and "renewable energy sources in cold chain" (Patton, 2015). The expected results were anticipated to show the actors, activities, and current and plausible energy sources in HMCC, and what would be the implications of the increased of RES in terms of environmental sustainability. The results were expected to answer the aim of the study – to investigate the opportunities and barriers of increasing the use of RES in emergency HMCC.

1.4 Delimitations

This study's scope is narrowed to focus on sudden onset natural and man-made disasters, therefore excluding slow onset disasters (van Wassenhove, 2006). This chosen delimitation is specifically made against the research purpose to investigate absence of sustainable dimension within humanitarian emergency operations in sudden onset disasters. In addition, the research does not define merely one specific emergency operation within the above-mentioned disasters, such as flood or armed conflict, but instead takes a broader perspective within that category.

Also, the definition of sustainability is chosen to follow Elkington's (1998) explanation of triple-bottom line, which comprises three dimensions: social, economic and environment (Elkington, 1998), and merely the environment position is in the centre of this study. This is due to two defining factors. First, only humanitarian logisticians and HMCC experts were interviewed, therefore excluding the beneficiaries' viewpoint on the social implications of increasing the use of RES. Second, the economic dimension would have required financial figures of one operation by a specific NGO to be investigated, which was not included in the scope of this study.

1.5 Implications

The study strives to investigate the opportunities and barriers of increasing the use of RES to enhance environmental sustainability. As similar triggers of increasing the use of clean energy sources are seen in the commercial side (Seuring & Müller, 2008;

Halldórsson & Svanberg, 2013; Saavedra M. et al., 2018), this research strives to investigate the issue from humanitarian perspective, as HMCC in emergency operations is extremely energy intensive and it has major environmental impact on the disaster area and its rebuilding (Gibert, 2008). Therefore, preserving the environment already during the emergency phase is crucial for current and future habitants (Gibert, 2008). Also, the quality and effectiveness of the aid is expected to improve, and the rebuilding phase can benefit for sustainable investments by the humanitarian organisations (Gibert, 2008; Eng-Larsson & Vega, 2011).

1.6 Thesis' structure

This research is built in two folds. First, the energy sources used in humanitarian medical cold chain in emergency situations are mapped based on the academic literature to gain a baseline of the current situation. RQ1 is formed is to answer this question, and the RQ1 it is expected to be validated and elaborated based on the empirical part. Second, RQ2 is formed to discover the implications of the increased use of RES from the environmental perspective, and to see whether the results of RQ1 would change if the use of RES was increased. For this, a framework by Håkansson & Snehota (1995) is used to establish the implications influenced by relationships of actors, activities and energy sources. The outcome of this thesis does not provide detailed GHG-emission calculations of any specific activity within HMCC, therefore excluding the commonly used Life-Cycle assessment (Saavedra M. et al., 2018). Instead, this study offers an overview of the implications of using RES to achieve more environmentally sustainable HMCC, and what are the opportunities and barriers of increasing the use of RES.

Overall, the thesis is structured as follows: first, an introduction presents the overview of the topic and how this research is structured. Second, the theoretical framework is discussed, after which the chosen methodological approach is argued. Fourth, the empirical part presents the findings of the research. The final chapter discusses the results reflecting them to the current academic literature and concludes the research with theoretical and managerial implications as well as future research recommendations.

2 RENEWABLE ENERGY SOURCES TO ENHANCE ENVIRONMENTAL SUSTAINABILITY

This chapter discusses the key concepts of this research regarding humanitarian logistics, medical cold chain in emergency settings and its sustainability. First, an overview of the field of humanitarian logistics, a research area built on the field of supply chain management (Kovács & Spens, 2011; Tabaklar et al., 2015), is reviewed to set a base for this research. The chapter discusses also the characteristics of humanitarian medical cold chain in emergency response, and maps the actors, activities and current energy solutions in emergency HMCC. Second, the current academic discussion on the topic of environmental sustainability in humanitarian logistics is reviewed, after which energy need in emergency medical cold chain in covered, including the use of renewable energy sources in HMCC and how the increasement would change the baseline for needed actors and activities. Finally, this chapter is concluded in the illustration of the theoretical framework by linking and explaining the key concepts.

2.1 Humanitarian logistics

The field of humanitarian logistics has emerged from the field of supply chain management to respond the unique characteristics deriving from the challenging environment of humanitarian context (Kovács & Spens, 2011; Tabaklar et al., 2015). The definition of supply chain management (SCM) is often differentiated from merely logistics, which is considered to comprehend only the physical movement of material by integrating cross-functional business processes and their management (Cooper et al., 1997; Beamon, 1999; Larson et al., 2007). The business processes are linked with both upstream and downstream activities and actors of the whole supply chain, from raw material supplier to ultimate customer (Mentzer et al., 2001). Throughout the supply chain, information and financials are flown, integrating the whole supply chain into a coherent whole (Cooper et al., 1997; Christopher, 2011). Similarly, functional humanitarian supply chain entails the whole chain from supplier to the ultimate beneficiary, including a range of logistical activities and actors (Kovács & Spens, 2007).

In general, humanitarian logistics reflects to processes striving to help people under distress caused by a disruption, which physically affects the whole environment in question (van Wassenhove, 2006). Humanitarian aid operation's success rely heavily on various robust logistical activities, but whereas business logistics operate in rather predetermined and steady environment, humanitarian logistics takes place in unpredictable, uncertain, and usually volatile settings (Kovács & Spens, 2007). The irregular and unpredictable demand, short lead time, large-scale constraints as well as challenging collaboration with an array of actors with different goals also distinguish humanitarian logistics from business logistics, as do the profound existence for profit and not-for profit (Kovács & Spens, 2007). In fact, humanitarian logistics takes place in the most complex and uncertain settings, which makes it both unique and challenging to manage (Haavisto et al., 2016).

Humanitarian logistics can be divided into two dimensions: continuous aid relief and disaster aid relief (Kovács & Spens, 2007). This study's focus is narrowed down to disaster aid relief over continuous aid relief. The complexity regarding the typology of disaster classification was widely discussed by Mackay et al. (2019), and the authors concluded that disasters can be classified according to the dimensions of speed, time, spatial, number of beneficiaries, likelihood of occurrence, and scale of consequences. The relationship of each of the dimension defines the unique factors of the disaster, which impacts on the humanitarian supply chain design (Mackay et al., 2019). Relating to the supply chain design and classification by Mackay et al. (2019), van Wassenhove (2006: 476) categorised disasters that require humanitarian assistance into natural and man-made as well as sudden onset and slow-onset disasters, based on the source and velocity of the disaster (**Figure 1**). However, Mackay et al. (2019) noted that more complex disasters, such as climate change, can be interpreted from varying angels. Therefore, no universal definition of a disaster exists, but instead the relationships of factors relevant to a specific disaster determine the design for response humanitarian supply chain (Mackay et al., 2019).

	Natural	Man-made
Sudden-onset	Earthquake Hurricane Tornadoes	Terrorist Attack Coup d'Etat Chemical leak
Slow-onset	Famine Drought Poverty	Political Crisis Refugee Crisis

Figure 1 Disaster categorisation (van Wassenhove, 2006: 476)

Despite the complexity of disaster classification (Mackay et al., 2019), disaster aid relief operations are generally divided into two broad categories. First category of disaster relief operation occurs within protracted humanitarian operations (L'Hermitte et al., 2016; Mackay et al., 2019) such as famine outbreak in the prolonged mand-made conflict in South Sudan (UNICEF, 2018a). The second category of disaster relief operation occurs within purely sudden onset emergency (van Wassenhove, 2006; Mackay et al., 2019), which is not connected to any ongoing humanitarian operation (Kovács & Spens, 2007). An example is a set sudden set of earthquakes and the following tsunami in Indonesia in 2018 (Reliefweb, n.d.). The focus of this study falls into the category of sudden onset disaster by van Wassenhove (2006), and reviews the enhancement of environmental sustainability in humanitarian medical cold chain's energy sources in the emergency operations. However, disaster ad hoc operations occur in challenging settings (Kovács & Spens, 2007; Haavisto et al., 2016), which leaves less room for sustainable review due to lack of response time (Haavisto & Kovács, 2019). Therefore, this study reviews also the reconstruction phase following the sudden onset disaster from the perspective of environmental sustainability. The phases of disaster management are discussed in the next sub-chapter.

2.1.1 Disaster management phases

Having classified disasters based on the factors unique to a specific disaster (Mackay et al., 2019), a closer look of managing the relief operation responding sudden onset disaster can be taken. Often, disaster aid relief operations can be managed and reviewed from different stages of the disaster management (Mackay et al., 2019), which are defined by various phases such as preparing, identifying disaster signs, mitigation of destructions, responding and recovering (Kovács & Spens, 2007). However, this study follows a broader categorization of preparedness, immediate response and reconstruction by Lee and Zbinden (2003) that was also adapted by Kovács and Spens (2007: 101) (**Figure 2**).

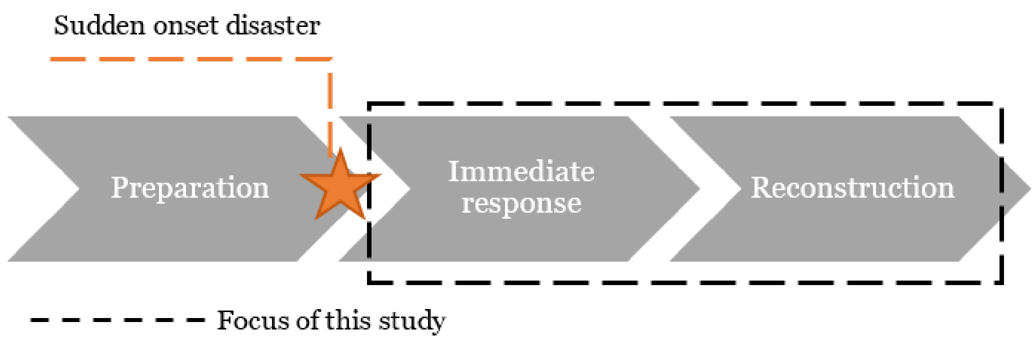

Figure 2 Disaster management phases of relief operations (adapted from Kovács & Spens (2007: 101).

As **Figure 2** depicts, the first stage of disaster management, preparation phase, aims to prevent and mitigate the effects of a catastrophe by, for example, ensuring resources and planning of distribution models in advance (Kovács & Spens, 2007). In contrast, in the aftermath of the disaster the aid relief focuses on rebuilding the affected area as the disaster may have long-term effect on the area (Kovács & Spens, 2007), and the need for humanitarian aid is continued also in a more stable setting (Mackay et al., 2019). The preparation phase allows time for planning and the lead times are longer, whereas the response in recovery phase entails more established lead times of goods, and the immediacy is absent (L'Hermitte et al., 2016). Both the preparation and rebuilding phases can also be included in the definition of protracted disasters, meaning smaller disasters occurring during an ongoing and more stable aid operation (L´Hermitte et al., 2016). Furthermore, disasters during protracted operations differ from sudden onset disasters defined by van Wassenhove (2006), because resources already exist in the area, therefore the response characteristics are somewhat different (L'Hermitte et al., 2016).

In contrast to slow onset disasters, sudden onset disasters leave little room for forecasting and planning, if any, therefore the preparatory phase and readiness is crucial prior the immediate response phase (Kovács & Spens, 2009). For instance, natural sudden onset disasters may be prepared for, to some extent, because certain natural phenomena occur cyclically, however, climate change has inflicted erratic disasters that cannot be forecasted (Dubey et al., 2017; Haavisto & Kovács, 2019). In addition, governmental restrictions (Kunz & Reiner, 2016), customs and import procedures, and lack of coordination pose challenges in humanitarian ad-hoc operations, despite the preparation (Kovács & Spens, 2009).

Despite the importance of preparation phase, the immediate response is the phase on which the focus typically lies when discussing sudden onset disasters (Kovács & Spens, 2007). Also, the supply chain management disciplines are applied to a great extent in immediate response phase of disaster management (Tabaklar et al., 2015). The stages of immediate aid relief encompass both upstream and downstream logistics activities, and this study focuses on the downstream supply chain, excluding supplier selection and operations in the upstream. Van Wassenhove (2006) also highlighted that sudden onset disasters and the immediate responses are often widely covered by the media, both for donation purposes but also for information sharing about the disaster area. However, Gustavsson (2003) noted that the donors incline to fund short-term responses over longer-term development project, not to mention reconstruction phases.

During sudden onset disasters, among the deployed supplies in immediate response phase are always perishable medical items that require careful distribution with unbreachable cold chain (Dolinskaya et al., 2018). Yet, the settings to deliver them to the disaster area after a sudden onset disaster are challenging and unpredictable (Kovács & Spens, 2009). Often, the sudden onset disaster has destroyed the transport and information infrastructure, creating bottlenecks for distribution (Kovács & Spens, 2009). Therefore, the power supply for keeping the cold chain items at a certain temperature is often unstable (Dolinskaya et al., 2018). The next chapter discusses more in detail about the characteristics of humanitarian medical cold chain in emergency operations.

2.1.2 Humanitarian medical cold chain

Health aid is the second largest sector within humanitarian assistance after food aid, and infectious diseases are causing most deaths and ills in emergencies (Ramalingam et al., 2015). It should be noted that emergency medical assistance differs from the primary health care (van Damme et al., 2002). Primary health care focuses on the ensuring, promoting, restoring, and developing health services according to people's needs in an optimized way, whereas effectiveness is dominant in emergency medical assistance and it aims purely on lifesaving at any cost (van Damme et al., 2002). As noted, humanitarian emergency operations occur in rather unpredictable settings (Kovács & Spens, 2007), therefore, the academic literature of emergency medical assistance has focused highly on logistical and technical activities (van Damme et al., 2002; Tabaklar et al., 2015). For instance, a study by Dolinskaya et al. (2018) investigated thoroughly the logistical challenges concerning emergency medical cold chains.

Once a sudden onset disaster strikes, various supplies to provide medical assistance and to prevent, detect and manage infectious diseases are delivered (Syahrir et al., 2015; Dolinskaya et al., 2018; UNICEF, 2018b), depending on the disaster dimensions and the humanitarian supply chain design (Mackay et al., 2019). In addition to essential vaccines and medicines (Dolinskaya et al., 2018; MSF, 2019), the critical medical assistance includes field health clinics, heath care personnel, protective clothing such as gloves, boots, suits, masks and other medical equipment as well as disease tests packages (Dolinskaya et al., 2018; UNICEF, 2018b). For instance, UNICEF (2018c) has published an extensive list of different emergency health kits of which contents vary from specifically targeted kits for malaria to kits that cover a population of 10 000 persons for a period of couple of months. What is unique with medical items, that some items require temperature-controlled supply chain, which poses challenges in complex emergency situations (Dolinskaya et al., 2018; UNICEF, 2018b).

Once a sudden onset disaster has struck, the immediate emergency medical assistance is critical for the survival of vulnerable people (Kovács & Spens, 2007; Dolinskaya et al., 2018). Despite the significance of successful medical assistance, Dolinskaya et al. (2018) remarked that often the academic discourse in the field of humanitarian logistics focuses on other supplies' distribution, excluding medical response and its management. This owes to the fact that despite sudden onset disasters, such as earthquakes, inflict threat that require immediate medical attention, some disasters, such as floods, do not necessary cause immediate and severe health impact in a similar way (PAHO, 2001; Dolinskaya et al. 2018). Instead, only in the aftermath of the disaster the displacement and environmental changes caused by the disaster risks the spread of diseases (PAHO, 2001; Dolinskaya et al. 2018).

Hence, critical medical items are needed both in the emergencies but also in the reconstruction phase after the disaster (van Wassenhove, 2006; PAHO, 2001). Similarly, Macrae et al. (1995) discussed in the mid-1990s' about the importance regarding transition from emergency to rehabilitation in order to prevent a new humanitarian crisis and to support the local community's sustainable reconstruction. However, the stages of disaster management, mainly immediate response and reconstruction, are often seen separate from each other instead of continuum (Macrae et al., 1995; van Damme et al., 2002; Mackay et al., 2019). Nevertheless, HMCC management is crucial throughout the whole disaster response operation, and the next chapters discuss further this topic.

2.1.2.1 Management of HMCC

Humanitarian medical cold chain (HMCC) management is crucial and one of the most challenging part of the overall medical assistance (Dolinskaya et al., 2018), because the products delivered need to be stored throughout the supply chain at a constant temperature between a range of +2˚C and +8˚C degrees (Logistics Cluster, 2015a; Comes et al., 2018). In addition to the +2˚C to +8˚C degrees' cold chain, some vaccines or medicines can be stored between temperatures from +15˚C to +25˚C degrees' (WHO, n.d.). However, this study is focused on the +2˚C to +8˚C degrees' cold chain, which is considered a network of refrigerators, cold stores, freezers and cold boxes, which are needed during transportation and storing activities so that cold chain items are kept at the right temperature from the point of origin to the point of use (Logistics Cluster, 2015a).

Though, Logistics Cluster's (2015a) definition discusses vaccines, cold chain is not delimited only to vaccines, but includes other medicines, drugs, and tests as well (UNICEF, 2018b). Should the cold chain be interrupted or broken, the items may lose the effectiveness stem from heating or freezing, resulting in risking the inventory and increasing waste (Comes et al., 2018). **Figure 3** by Dolinskaya et al. (2018: 201) illustrates the logistics network of actors. These actors include suppliers who manufacture the medicines, international humanitarian organisations responsible for the coordination of procurement, warehousing and distribution of supplies, and donors who enable the operations of humanitarian organisations with monetary or in-kind donations (Comes et al., 2018; Dolinskaya et al., 2018). In addition, 3rd party transportation companies, governments approving the discharge of supplies and partly responsible for in-country distribution, and beneficiaries are key actors in HMCC (Comes et al., 2018; Dolinskaya et al., 2018).

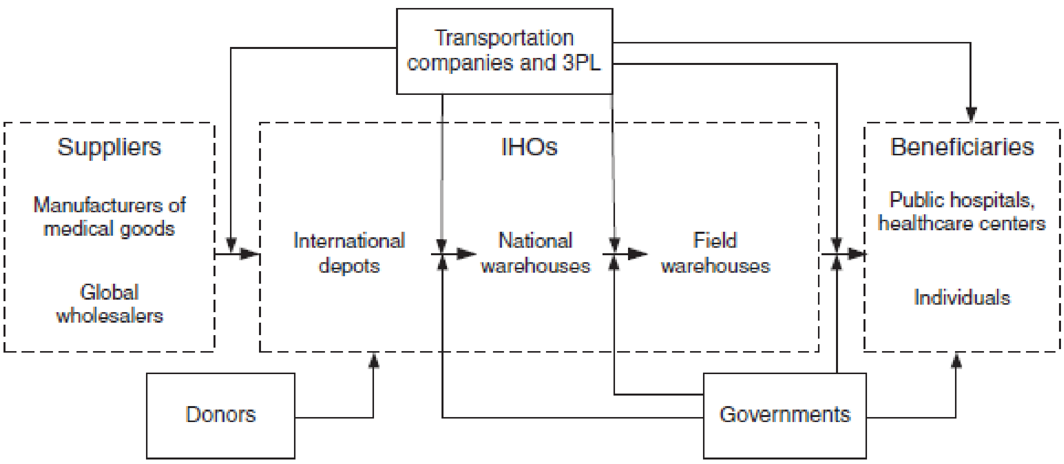

Figure 3 **Humanitarian medical cold chain (Dolinskaya et al., 2018: 201)**

In **Figure 3**, the logistical activities, which comprehend all the activities that require energy, include the transportation and storing activities within and between the supply chain nodes (Dolinskaya et al., 2018). Regarding transportation, energy is required to fuel the transport methods, if vehicles are used, and the required energy derives from fossil fuel-based gas (Grafham & Lahn, 2018). Yet, Rogers et al. (2007) remarked that the supply of oil has already started to decrease, hence biomass-based fuel from renewable energy sources offer a solution to the reduced capacity of oil as well as decreasing the carbon footprint (Ellaban et al., 2014). However, the topic of fleet management is excluded from this study's scope, as the focus is to review the required activities powering the HMCC, therefore transportation is not investigated nor addressed more in detail in this study.

In cold chains the distinctive storing activity compared to other medical items is the requirement for cool environment (Dolinskaya et al., 2018). When looking into emergencies, the needed medical items are collected and packed into cold boxes from the central warehouse's large cool room by NGO or by its supplier (PAHO, 2001; Comes et al., 2018; Dolinskaya et al., 2018). Also, refrigerators and freezers are required to be deployed in emergency operations due to lack of available equipment in the disaster area (Comes et al., 2018; Dolinskaya et al., 2018). In contrast, during long-term humanitarian aid, the supply chain is designed that the replenishment to health clinics is completed through either local purchase or through centred supply centre near the destination country (Dolinskaya et al., 2018). In the long-term aid, the delivery of items might take several weeks to the destination country, whereas in emergency settings time is of essence, and items need to be deployed within a few days from the central warehouse to the field (Comes et al., 2018; Dolinskaya et al., 2018).

The supplies arrive from the international warehouse to the target country by sea, land or air, and 3rd party service logistics providers are often responsible for the international transportation (Dolinskaya et al., 2018). During the travel, the items are typically stored in cold boxes in which frozen icepacks keep them at the temperature between +2˚C and +8˚C degrees (Logistics Cluster, 2015a). At the entry point of the country, the custom formalities are to be completed at the borders, and the national government agency handles the recipient of the emergency consignments (Dolinskaya et al., 2018). Also, the government is often responsible for in-country distribution and running of the field hospitals, however, the nature of the emergency may require assistance from international humanitarian organisations (van Wassenhove, 2006; Dolinskaya et al., 2018). At the entry point, the offloading of supplies is done by relevant equipment, such as forklifts if available, and the deployed supplies are registered and grouped depending on their urgency and categorised at the entry point (PAHO, 2001).

From the first entry point the items are, typically, delivered to regional or national warehouse, and from there to a temporary storage, reception centre, or local health clinic, which in the emergency situations can be anything from existing warehouses, schools to gyms, or even built on the spot (PAHO, 2001). Also, they are located rather close to the centre of the emergency to ensure that as many beneficiaries as possible are reached (PAHO, 2001). The requirement for temperature between +2˚C and +8˚C degrees poses additional challenges to mitigate the risk for cold chain breach, because the access to beneficiaries is unstable due to damaged infrastructure, energy supply is unsecure, and the availability of delivery modes is uncertain (Comes et al., 2018; Dolinskaya et al., 2018). Also, the ambiguity in demand and coordination challenges the robust HMCC management (Comes et al., 2018; Dolinskaya et al., 2018).

Overall, the two highly energy intensive pinpoints of HMCC are at the entry point followed by in-country warehousing (PAHO, 2001; Dolinskaya et al., 2018). At the entry point, the cold boxes need to keep the cold throughout the transportation and unloading (PAHO, 2001). However, Kunz & Reiner (2016) noted that customs procedures and other governmental restrictions may pose delays, and there is a risk that the items are left at the border for hours, if not even days. Likewise, Dolinskaya et al. (2018) discovered in their study that customs clearance with cold chain is among the critical challenges for disaster response's effectiveness. There is a high risk that the icepacks melt, hence a robust HMCC is not guaranteed (Comes et al., 2018; Dolinskaya et al., 2018). Second, the in-country warehousing increases the energy need owing to lack of stable and sustainable energy source (Comes et al., 2018; Dolinskaya et al., 2018).

HMCC is temperature-controlled, and the choice between cold chain strategies - active and passive - is decided based on certain prerequisites (Logistics Cluster, 2015a; Robertson et al., 2017). They first question is whether there is access to electricity (on-grid) or not (off-grid) (GAVI, 2018), i.e., whether passive or active cold chain strategy is used (Logistics Cluster, 2015a; Robertson et al., 2017). Second, the cold chain strategy must match with the disaster characteristics as well as the country profile (Dolinskaya et al., 2018). Hence, both the supply chain design explained by Mackay et al. (2019), and the preparatory phase (Lee & Zbinden, 2003; Kovács & Spens, 2007) are essential. In addition, the volume, resources, storage capacity and accessible energy source are criteria when choosing relevant active and passive cold chain strategies (Logistics Cluster, 2015a; Comes et al., 2018; Dolinskaya et al., 2018). **Figure 4** below depicts the passive and active cold chain strategies, which are then further discussed in the sub-chapters below.

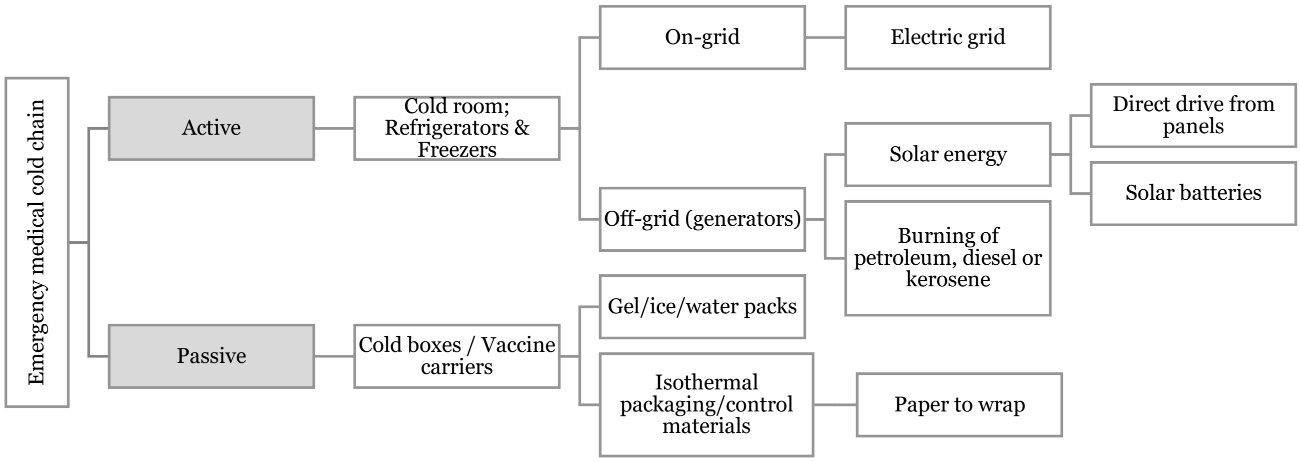

Figure 4 Active and passive cold chain (adapted from: Logistics Cluster, 2015a; Robertson et al., 2017; Comes et al., 2018; WHO, n.d.)

2.1.2.2 Active cold chain

The active cold chain uses either electric or mechanical systems to produce the cold for cold rooms, refrigerators or freezers (Logistics Cluster, 2015a). Refrigerators and freezers that are powered by electricity from the grid or solar panels are called compressions type devices (McCarney et al., 2013; Logistics Cluster, 2015a). The advantage with compression refrigerator or freezer powered by electricity from main is that the temperature is set with a thermostat, which cools the refrigerator or freezer rapidly, keeps the cool steady, do not require complex technological knowledge, and is rather easy to repair (Logistics Cluster, 2015a).

If the refrigerator is powered by solar panels or batteries that have stored power from solar panels, the refrigerators become more expensive and require special knowledge for maintaining and repair (McCarney et al., 2013; Logistics Cluster, 2015a). On the other hand, energy source from solar is more environmentally friendly (Logistics Cluster, 2015a), and solar refrigerators do not adapt any major running costs as no there is no dependence on costly fuel supply (WHO, n.d.). According to UNICEF (2018d), devices powered with solar energy are beneficial in remote areas and areas with limited or no access to national power grid, in which enough sunlight is available during the day. In addition, solar powered refrigerators and freezers may provide power for over two decades (McCarney et al., 2013) with not fuel costs nor additional pressure on the environment (UNICEF, 2018d). Yet, there is a lack of published academic articles of the actual results in the field and the environmental implications from solar-powered cold chain equipment (McCarney et al., 2013).

Active cold chains can also be powered with generators that are powered by burning of petroleum, diesel or kerosene (McCarney et al., 2013; Logistics Cluster, 2015a; Comes et al., 2018). These kinds of refrigerators and freezers are called absorption models, and they are widely used in situations where electricity is at scarce (McCarney et al., 2013; Logistics Cluster, 2015a). Though, the burning of petroleum or kerosene enable medical supplies to be deployed to areas with limited electricity, the fuel needs to be deployed as well, if not sourced locally (Grafham & Lahn, 2018), and the energy efficiency is low (Logistics Cluster, 2015a). To provide cooling with burning of liquid fuel, more energy is needed (McCarney et al, 2013), less cold is produced, and the power is therefore more unreliable (Logistics Cluster, 2015a). This exposes the medical supplies for freezing or heating as the burning of gas creates challenges to the temperature maintenance between +2˚C and +8˚C degrees' range (WHO, n.d.). Similarly, the freezing capacity for ice-making needed for passive cold chain is low with burning of fuel (McCarney et al., 2013). In addition, the burning of kerosene or gas pollutes the environment tremendously, and the use of liquid fuel expose people and surrounding environment to safe hazards (McCarney et al., 2013).

In general, active cold chain ensures more or less continuous electricity to power the refrigerator or freezer, and the cold chain is more robust to possible delays (Comes et al., 2018). However, electricity as well as fuel are often scarce in disaster areas (Grafham & Lahn, 2018) and solar systems to replace them are more expensive (Logistics Cluster, 2015a). The uncertainty of reliable energy sources in disaster areas forces humanitarian organizations to deploy fuel and generators to the disaster areas, and, the generators are, usually, run merely by diesel, which is costly and emits a great amount of CO_2 emissions (Grafham & Lahn, 2018). The high dependence on generators for critical medical treatments results in losses in lives as they are vulnerable to, for example, power disruptions and disruptions in the transportation due to damaged infrastructure (OCHA, 2010; Syahrir et al., 2015).

2.1.2.3 Passive cold chain

Another strategy for cold chain is a passive cold chain. It is a part of cold chain that is not powered with active mechanism, but uses phase change materials, such as coolants or gel packs that are frozen, or merely ice packs to be put inside a box or a carrier to keep stable temperature for a limited time (Logistics Cluster, 2015a; Comes et al., 2018). A thermometer is placed inside the box to measure the temperature, which is monitored daily (Logistics Cluster, 2015a). The advantage with passive cold chain is that no electricity is needed, and they are cost-effective (Logistics Cluster, 2015a). Yet, the monitoring requires constant awareness by the staff, and the chain is prone to variability of temperature and delays, risking the inventory (Comes et al., 2018).

Typically, the endurance of a cold box lasts 2-6 days in extreme hot weather if the box is unopened, inflicting challenges for deployment to remote areas with poor infrastructure, or for longer storing of medicine in the field (Robertson et al., 2017; WHO, n.d.). The endurance of smaller vaccine carrier is even less, approximately one day if unopened (Robertson et al., 2017). Although, GAVI (2018) has presented long-term passive devices that use icepacks for establishing a cold storage for minimum one month without any power source. Yet, the icepacks for passive cold chain need to be frozen upper in the supply chain within active cold chain, which on one hand creates additional challenges (Logistics Cluster, 2015a).

2.1.3 Actors, activities and energy sources of HMCC

The logistical activities, relevant actors and needed energy sources to power cold chain can be depicted as interlinked dimensions, and each influence one another in effective cold chain management (Dolinskaya et al, 2018). These relationships are depicted in **Figure 5** below, which follows a framework by Håkansson and Snehota (1995: 35). Håkansson and Snehota (1995) discussed the existing relationship of actors (companies), activities (technical, administrative or commercial) and resources (technological, material, knowledge) in business relationships, and how changes in one layer influences the whole dynamics and balance of the unity. The authors further noted that there are bonds between different actors, which are formed through varying activities as the reason for actor bonds stems from resource ties (Håkansson & Snehota, 1995). A simplified example would be that Company A (actor) buys (activity) regularly components (resource) from Company B (actor bond) (Håkansson & Snehota, 1995).

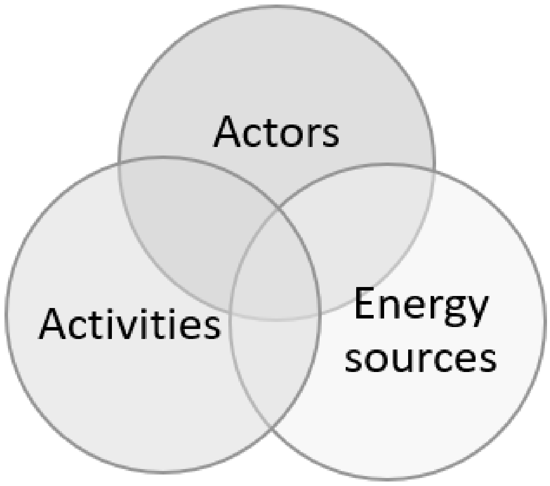

Figure 5 Energy sources, actors and activities of HMCC (adapted from Håkansson & Snehota, 1995: 35).

Similarly, the actors, activities and energy sources within HMCC are interlinked, and their relationship to one another characterises the emergency HMCC (Kovács and Spens, 2007; Dolinskaya et al., 2018). Actors are operators, for example NGOs, donors and beneficiaries, who are collaborating with each other and determining the decisions – which strategy and which energy source to use in which supply chain node (Håkansson & Snehota, 1995; Dolinskaya et al., 2018). Activities, i.e., the logistical activity where energy is needed, are enforced by the actors through energy resources available (Håkansson & Snehota, 1995; Dolinskaya et al., 2018). Based on the academic literature discussed so far, the typical actors, logistical activities and energy sources that power the downstream HMCC in emergency operations, as well as energy intensive nodes, are summarised in **Figure 6** below.

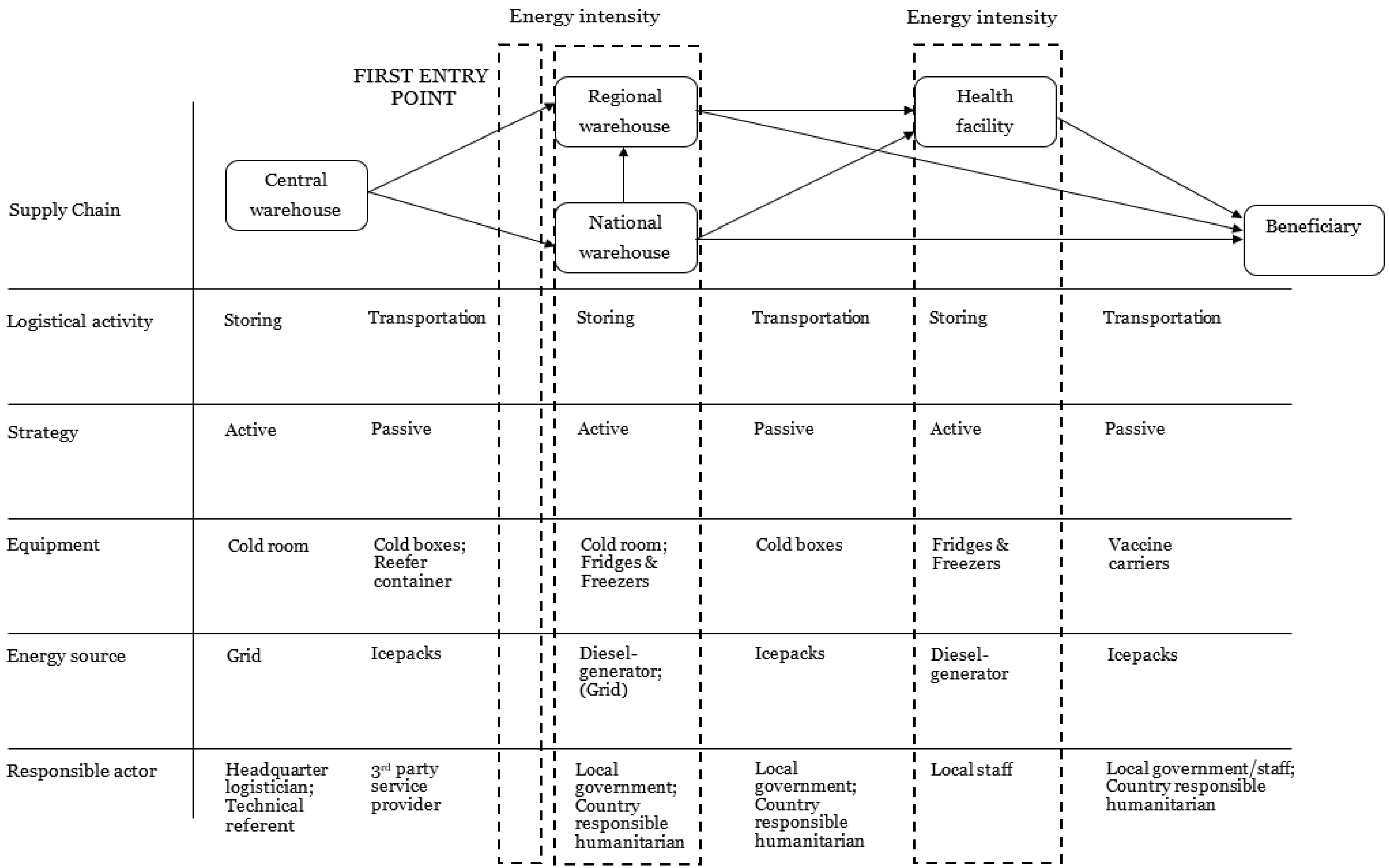

Figure 6 **Typical actors, activities and energy sources in emergency HMCC**

Each dimension of actors, activities and energy sources are interlinked in the wholeness of emergency HMCC, and their relationship results in implication of each choice, which can be depicted amid the **Figure 5** that connects the actors, activities and energy sources**.** These implications can be evaluated and reviewed from varying angles (Elkington, 1998) such as cost-effectiveness, financial or numbers of saved lives (Haavisto & Kovács, 2014; Haavisto & Kovács, 2019), yet, the environmental sustainability of HMCC is the focus of this study. However, the implications for the more abstract level of sustainability have not been included in the short-term objectives of any humanitarian operations (Haavisto & Kovács, 2019). Dolinskaya et al. (2018) remarked that previous literature has focused on medical supply chain's effectiveness and robustness during disasters, yet the environmental impact has not been further studied. On a similar note, Privett and Gonsalvez (2014) identified 10 key health supply chain challenges, however, sustainability was not in the list. Hence, it could be argued whether sustainability dimension is needed to be considered in emergency phase, as the goal of emergency medical assistance is purely to save lives (van Damme et al., 2002; Haavisto & Kovács, 2019).

However, in the aftermath of the disaster, a considerable effort for reconstruction is needed (van Wassenhove, 2006). Hence, the sustainable solutions implemented already during the emergency phase impact on the sustainable local capacity-building for long-term perspective (Macrae et al., 1995; Gibert, 2008; Haavisto & Kovács, 2019). Therefore, the next chapter focuses on the sustainability of humanitarian logistics, and how renewable energy sources offer one feasible alternative to increase the environmental sustainability of humanitarian medical cold chain with short-term and long-term implications, and what are the opportunities and barriers of increasing the use of RES.

2.2 Sustainability in humanitarian logistics

Sustainability can be considered as an umbrella term that is interpreted on multiple levels within supply chain (Seuring & Müller, 2008), and it can be enhanced in various logistical activities, as can be seen in the commercial side (Halldórsson & Svanberg, 2013). One dimension within sustainability is energy supply chain, as the amount and type of energy contributing to sustainability and used by logistics service providers is seen "as the core of supply chain executions" (Halldórsson et al., 2019: 444).

In fact, the global supply chains' responsibility towards environment was already highlighted in mid-1990s' (Wu & Dunn, 1995). According to Seuring and Müller (2008), there are several external and internal triggers that act as intensives and pressures for companies to integrate sustainable actions within their supply chains, such as governmental regulations and stakeholders' pressure. For example, the United Nations Intergovernmental Panel on Climate Change (IPCC) emphasises companies' responsibilities on sustainable practices to mitigate climate change (IPCC, 2018). Also, various regulative actions (Lee & Kashmanian, 2013) such as the Renewable Energy Directive laid down by the European Parliament obligate commercial operators to reduce greenhouse gas emissions stem from supply chains (EC, 2009). For sustainable supply chain management, Seuring and Müller (2008) provided two strategies: to manage risks and performance by focusing on managing suppliers, and/or to invest in sustainable products and processes, i.e., to ensure that the lifecycle of the product or service fulfils the environmental and social standards. Sustainable supply chain management and the implemented strategies can be evaluated from varying angles (Carter & Rogers, 2008), which is discussed next.

2.2.1 Evaluating sustainability

By implementing various non-numerical benchmarks such as quality, time, flexibility and cost (Neely et al., 1995), or resource, output, and flexibility (Beamon, 1999), the more complex strategic objects by the company can be met (Beamon, 1999; Gunasekaran et al., 2004). But, merely the dominant quantitative performance measurements in SCM field (Dubey et al., 2017), such as production volumes, number of transportation activities and inventory performance, are not enough to explain the broader dimension of sustainability (Beamon, 1999; Christopher, 2011), nor to meet and review the broader strategic and competitive objectives of the organisation (Beamon, 1999; Gunasekaran et al., 2004).

Sustainability creates value to the supply chain, and in commercial supply chains, sustainable value is perceived to be created to and by the stakeholders in the company's network (Fisher, 1997; Seuring & Müller, 2008; Christopher, 2011). Though, financial barriers or executives' obliviousness for sustainable supply chain management are examples that may hinder the sustainable development (Carter & Rogers, 2008; Seuring & Müller, 2008; Dubey et al., 2017). Nevertheless, for value creation and sustainability evaluation, the three dimensions of triple bottom line are widely used benchmarks (Elkington, 1998).

The concept of triple bottom line by Elkington (1998) contemplates environmental, economic and social dimensions. The model suggests sustainability to be achieved within the intersection of the three dimensions, hence the company's sustainable performance influences positively the environment and society with long-term economic benefits (Elkington, 1998; Carter & Rogers, 2008). The sustainability from the economic dimension entails innovative and proactive mindset, as reduced packaging waste, recycling and safer working facilities result in cost savings and performance improvements, whereas the social aspect considers diversity among employees and improvements in human rights (Carter & Rogers, 2008). Similarly, environmental perspective advocates companies to take notice to, for example, waste management in production and warehousing, adopt energy-efficient technologies, and optimize the transportation by route, speed and load measures (Dubey et al., 2017).

Despite the commercial side's establishment of more sustainable supply chain practices (Halldórsson et al., 2019), sustainability in humanitarian sector is neglected in emergency operations (Haavisto & Kovács, 2019). This owes to humanitarian sector's essential existence to save lives on a timely manner, but also to lack of monetary, technological, organisational, and knowledge resources (Eng-Larsson & Vega, 2011; Sarkis et al., 2012; Haavisto & Kovács, 2014; Haavisto & Kovács, 2019). The performance of humanitarian operation's success is, typically, concentrated on financial and volume-based parameters to meet the operation's objectives (Haavisto & Kovács, 2014), or to measure the impact and effectiveness of the humanitarian operation (Eng-Larsson & Vega, 2011; Logistics Cluster, 2015b).

Moreover, the complexity of supply chain in humanitarian context does not typically aim for broader value-creation to the actors, but instead focuses on completing the humanitarian mission (Haavisto & Kovács, 2019), despite the additional cost factors contributing to environment pollution, climate change, accidents and noise (Logistics Cluster, 2015b). For instance, some humanitarian operations are reported to have non environmentally friendly activities by using excessively and uncarefully natural resources or depleting groundwater and soil with inadequate waste management and chemical use (WFP, 2017). In a longer period, these activities inflict biodiversity losses, risk human health and stability, and security of nutrition, clean water and economy (Eng-Larsson & Vega, 2011; WFP, 2017).

However, the vastness and complexity of humanitarian supply chains require more complex distribution channels (Haavisto & Kovács, 2014), which for one increase heavily

GHG emissions into the atmosphere (Wu & Dunn, 1995; Dubey et al., 2017). As noted, supply chains are seen vital for improving sustainability (Halldórsson et al., 2019), and organisations and their interrelationships are enablers to meet the global objectives of sustainability (Sarkis, 2019). For example, Saavedra M. et al. (2018) noted that sustainable supply chain management as a broader concept has a major influence on changing the global energy industry's performance from fossil fuel-based towards renewable energy source-based. This also calls for humanitarian operations to include the sustainability dimension within the supply chain activities (Dubey et al., 2017).

Therefore, the gap in the humanitarian logistics literature is whether the successful relief operations are to be achieved at the cost of environment, contributing negatively to the whole ecosystem of the world (Sarkis et al., 2012; Grafham & Lahn, 2018). Currently, the characteristics of humanitarian operations' rapid decision making in immediate relief operations incline to unsustainable decisions, and "—in an immediate response people come first; everything else, such as sustainability, comes second" (Haavisto & Kovács, 2019: 502). The aid effectiveness is, typically, evaluated by the response's effectiveness and rapidity, and humanitarian organisations often aim to achieve merely their individual mandates (Haavisto & Kovács, 2019). For instance, cold chain is required for deployment of the needed medicines, hence, the first focus is on getting the equipment and items rapidly to the field (Comes et al., 2018), not necessarily how sustainably they are deployed (Haavisto & Kovács, 2019). Although, the response activities to save lives are vital and crucial, the discourse has recently started to include environmentally sustainable dimension of the operations, as already promoted by the UN (UNDP, 2019).

Overall, there is a strong link between supply chain activities and climate change, as the many nodes of supply chains pollute tremendously, therefore contributing negatively to the global warming (Sundarakani et al., 2010; Plambeck, 2012; Dubey et al, 2017). Climate change, on the other hand, has inflicted more natural disasters, hence more short-term aid relief operations are needed (Sarkis et al., 2012; Meduri & Ahmed, 2016). Therefore, it is crucial to understand that the response actions have also impact on people not only in the immediate disaster area, but also on the other parts of the world and on future generations (Meduri & Ahmed, 2016). To overcome the harmful impacts, promoting environmentally sustainable activities already in the response phase of the disaster management is encouraged, as it influences the community also in the long run during reconstruction phase as alternative and more environmentally friendly practices can be introduced (Gibert, 2008; Meduri & Ahmed, 2016; UNEP, n.d.). For example, WFP has implemented an Environmental Policy, which calls for adding environmental management systems into both emergency humanitarian aid and longer-term development activities (WFP, 2017).

Yet, the emergency phase and reconstruction phases are not seen as continuum but as separate objectives in which resources are allocated disjointedly (Macrae et al., 1995), and the donors often prefer tangible donations instead of investments in more sustainable and energy efficient logistical equipment (Oloruntoba & Gray, 2006). As the link between short-term response and longer-term relief aid is obscure to donors and stakeholders, they are not encouraged to promote or demand more sustainable logistical activities from the NGOs (Oloruntoba & Gray, 2006). Nevertheless, by addressing the energy intensiveness with renewable energy sources in logistical activities, more environmentally sustainable performance can be achieved (Halldórsson & Svanberg, 2013; Halldórsson et al., 2019). This study's focus is on emergency HMCC, as they are highly energy-intensive due to the requirement for temperature-controlled environment (Comes et al., 2018; Dolinskaya et al., 2018). Hence, the next chapter elaborates the aspect of energy in emergency medical cold chains, after which the use of RES in emergency HMCC is discussed.

2.3 Energy in emergency HMCC

According to Halldórsson & Svanberg (2013), energy supply chain is the network of actors and activities that are needed to source, produce, distribute, trade and consume different types of energy. Among the logistical activities in which energy is needed highly, Christopher (2011) emphasised the transport-intensity, meaning number of vehicles used, and loading capacity, to address the carbon emissions, whereas Halldórsson et al. (2019) highlighted the economic and environmental convergence deriving from the energy sources. Therefore, by improving energy efficiency, i.e., "[…] to reduce energy consumption and substitute the use of fossil fuels with renewable energy resources […]", the focal company will not only benefit from long-term reduced financial resources, but also from reducing supply chain carbon emissions and promoting healthier lifestyle (Halldórsson et al., 2019: 448). Although, Halldórsson and Svanberg (2013) noted in their study that among scholars, the environmental impact of energy sources has focused on transportation and not in other supply chain activities.

In emergency humanitarian operations energy is needed for heating, cooking, powering warehouses, health clinics and temporary shelters, storing and cooling perishable products, water pumping and lightning, as well as fuelling the distribution activities among others (Halldórsson & Svanberg, 2013; Grafham & Lahn, 2018, UNITAR, 2018). Energy is crucial for the success of any humanitarian operation, yet the settings immediately after sudden onset disaster are extremely challenging, and the risk of scarcity of energy increases (Grafham & Lahn, 2018).

During sudden onset disasters, the importance of the deployment of medical supplies is vital (OCHA, 2010; Adair-Rohani et al., 2013), and, for example, medical equipment was listed as one of the most energy needed sources during the response operation of typhoon Haiyan in Philippines in 2013 (ICSC, 2017). The energy needed to power, hence cool, the cold chain is electricity (Panwar et al., 2011). Without electricity the medical cold chain becomes useless (Adair-Rohani et al., 2013). Yet, the current solutions encompass high fossil fuel intensity, despite that they are costly and expose the environment to degradation (OCHA, 2010; Haavisto & Kovács, 2019). For instance, when choosing suitable energy source for cold chain, Logistics Cluster (2015a) provides a guideline that suggests using solar compression refrigerators only if diesel, gas or kerosene is not locally available (Logistics Cluster, 2015a). Although, a change towards solar energy has recently started, and McCarney et al. (2013) noted that solar refrigerators should be used in areas with limited electricity. Furthermore, a public guideline by WHO & UNICEF (2015) recommended solar refrigerators over diesel-based solutions.

Still, without working grid, fossil fuel-based generators are currently main source of power as a default (ICSC, 2017). However, the high dependence on generators for medical cold chain results in losses in lives as the generators are vulnerable to, for example, power disruptions and disruptions in the transportation due to damaged infrastructure (OCHA, 2010; Syahrir et al., 2015). Energy is vital and even rare in disaster settings, and its value increases drastically during emergencies (ICSC, 2017), yet cleaner energy solutions are more of an exception (UNITAR, 2018).

Likewise, OCHA (2010) noted the impacts of relying on fuel-intensive generators, which do not embrace long-term sustainability nor affordability. It is noted that with renewable energy sources, medical assistance and running of local hospitals will make the services more resilient (OCHA, 2010). For instance, a study by Adair-Rohani et al. (2013) showed that public health clinics in Sub-Saharan Africa area, which relied on solar power as the primary source of energy, achieved not only environmentally sustainable performance, but also reduced costs compared to fossil fuel generators in the long-term. Yet, this approach does not extend to short-term operations regarding cold chains and Comes et al. (2018) noted that there is lack of clean power supply research and merely few innovations have been tested in-field in rural areas.

In business logistics, renewable energy sources have been demonstrated to improve sustainability towards environment (Halldórsson & Svanberg, 2013), but they are also considered to shape the economic and social aspects globally (Halldórsson & Kovács, 2010). Yet, energy aspect is not included as an integrated part of humanitarian assistance (UNHCR, 2014; ICSC, 2017). However, lobbying towards less-polluting way of living, a structural shift from major energy producers to local energy providers, i.e., from centralized to decentralized supply chains, and increasing the use of RES, can be advocated to enhance further environmental sustainability (Halldórsson & Svanberg, 2013, Halldórsson et al., 2019). Renewable energy sources provide also security to energy supply, and they enhance energy efficiency, therefore affecting positively on financial performance (Halldórsson & Kovács, 2010). The next sub-chapter discuss more closely about the renewable energy sources and how they can power emergency HMCC alternatively to fossil fuels.

2.3.1 Renewable energy sources

Renewable energy sources do not include fossil-based resources, but are instead wind, marine, solar, hydro, geothermal or bioenergy (Panwar et al., 2011; Ellaban et al., 2014; Saavedra M. et al., 2018). RES can be used in each node of the supply chain: supply, production, distribution, demand, and reverse logistics, and it can be converted to fuels, electricity and heat (power), chemicals or food (Saavedra M. et al., 2018). Ellaban et al. (2014: 749) define renewable energy sources as:

> [...] energy sources that are continually replenished by nature and derived directly from the sun (such as thermal, photo-chemical, and photo-electric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy). (Ellaban et al., 2014: 749)

Currently, the majority of world's energy derives from conventional sources such as oil, coal and natural gas (Halldórsson & Svanberg, 2013; Ellaban et al., 2014; World Bank, 2019), however, fossil fuel based energy is prone to price fluctuations, the resources are limited (Halldórsson & Svanberg, 2013), and stakeholders expect focal companies to mitigate their extensive use of non-sustainable energy (Seuring & Müller, 2008). Though, conventional energy sources are dominant sources due the accessibility and amplitude (Rogers et al., 2007; World Bank, 2019), a change is noticeable and needed as the global need for energy is expected to continuously grow (Halldórsson & Kovács, 2010; Gold & Seuring, 2011; Halldórsson & Svanberg, 2013; Ellaban et al., 2014). Despite that global energy sector is extremely complex and challenging to balance due to the economic, political, environmental, and social dynamics (Nemet et al., 2016), the use of renewable energy sources has grown, and for example, in 2017 17,5% of energy consumed in the EU was derived from renewable energy sources (Eurostat, 2019).

2.3.1.1 Increasing the use of RES in emergency HMCC

To offset the emissions emerging from emergency HMCC's energy intensive activities, the most prevalent renewable source among cold chain is solar energy (see, e.g., Adair-Rohani et al., 2013; McCarney et al., 2013; Lloyd et al., 2015; Robertson et al., 2017; and Comes et al., 2018). This is because to a large part, emergencies occur in countries, which are geographically located in sunny environments (OCHA, 2017). In addition, solar powered refrigerators have been used already in 1980s, and the photovoltaic technology has further developed (McCarney et al., 2013; WHO, 2017b). Other solutions exist also, such as using wind energy in remote locations to create electricity by wind turbines (Panwar et al., 2011; WFP, 2017), or applying hybrid renewable energy sources such as diesel and solar power for powering a generator (Olatomiwa, 2016).

However, the use of solar power in developing countries is significantly viable alternative in stand-alone devices and larger devices and applications, such as fridges and warehouses (Ohunakin et al., 2014). Overall, the transformation towards clean and renewable energy in medical cold chain has started, and McCarney et al. (2013: 6052) even noted that "the of absorption refrigerators in the vaccine cold chain is anticipated to diminish in the future." Yet, there are key issues that needs to be addressed in order to further increase the use of RES in emergency HMCC and to mitigate the dependence on fossil fuel (Ashok et al., 2017; UNITAR, 2018). This requires changes in already established cold chain management processes, and therefore, the next two sub-chapters review more in detail the roles of actors and logistical activities in emergency medical cold chain if the main energy source to power the emergency HMCC was derived from RES.

2.3.1.2 Actors

To tap into renewable energy sources, the access to them needs to be ensured first by the responsible actors (Halldórsson & Svanberg, 2013). In addition, the organisational change to a strategy of using renewables within supply chain is to be set (Halldórsson & Kovács, 2010), because energy in general is not prioritized in humanitarian aid relief operations (ICSC, 2017). According to Björklund and Forslund (2018), sustainability within supply chain can be achieved by fostering an innovative mindset among the employees within the organisation (UNCHR, 2014).

Second, currently HMCC relies on older technologies despite them being costly, often malfunctioning, vulnerable to fuel shortages, low in energy-efficiency, and require systematic maintenance (McCarney et al., 2013; Ashok et al., 2017). Therefore, third party service providers, such as private sector companies with technological expertise and innovations, for example, of solar panels for sustainable and effective cold chain management (UNHCR, 2014), are key stakeholders for humanitarian organisations (Ramalingam et al., 2015; Björklund & Forslund, 2018). It is advocated also to strengthen the relationship and cooperation with local and international energy providers in order to adhere sustainable energy solutions within humanitarian context as status quo (Ashok et al., 2017; UNITAR, 2018).

The importance of international research and data collection to increase the funding opportunities for more sustainable energy technologies and implementation is embraced (McCarney et al., 2013; UNHCR, 2014; Ashok et al., 2017; UNITAR, 2018). For instance, the research by GAVI (2018) called for investments by interlinking public and private operations, and promoting implementation of new technological solutions, such as drones, freeze-prevention technologies to the last-mile distribution as well as increasing the use of renewable energy sources (Comes et al., 2018), to ensure uninterrupted cold chain and its longevity (Robertson et al., 2017). For example, the International Organization for Migration (IOM) collaborated with private sector to establish a solar power plant in South Sudan to replace the diesel needed for generators up to 80-90% (IOM, 2019). The pilot will take place in early 2020, providing power to the humanitarian working the area, and it is designed in a way that the installed equipment is applicable in emergency settings and can be handed over to the local communities after the operation (IOM, 2019).

Third, the role of local staff would grow, as they would be included in NGOs' energy agendas, (UNITAR, 2018). Also, Comes et al. (2018) highlighted that the success of clean power supply stems partly from the capacity of local people. Therefore, the training of local people for maintenance of the more sustainable equipment over time is crucial (McCarney et al., 2013). However, the lack of funding hinders the procurement and usage of new devices, as well as the needed technical expertise and knowledge to implement sustainable energy solutions and to train humanitarian logisticians and local staff to use them properly (McCarney et al., 2013; Ramalingam et al., 2015; Dolinskaya et al., 2018;

UNITAR, 2018). This can be addressed by researching and mapping sustainable energy solutions and their environmental impacts for future financing (UNHCR, 2014; UNITAR, 2018), and to organise campaigns, training packages, and on-the-job trainings to humanitarians and to local staff to promote sustainable cold chain and its continuum after the emergency (Ashok et al., 2017, UNITAR, 2018).

With more sustainable energy strategies, the resources for spare parts ought to be available also during emergencies (McCarney et al., 2013; Ashok et al., 2017). Even though humanitarian organisations may succeed in this due to bigger resources, developing countries may lack financial resources, systematic procurement and storing management (Ashok et al., 2017). But, along the training, local staff can be helped to use relevant tools for stock management and procurement, and when used properly, sustainable energy solutions have longer-lasting life cycle compared to absorption fridges powered by fossil fuels (McCarney et al., 2013). Similarly, OCHA (2010) remarked that humanitarian organisations can influence positively on the local community's economy by promoting renewable energy solutions and collaborating with private sector to increase the access to renewable energy sources and required equipment and spare parts.

Fourth, investments in new technological equipment suitable for renewable energy sources are required, but the financial barriers may hinder the usage of renewable energy sources in larger context (Halldórsson & Kovács, 2010). NGOs rely purely on funds received from donors, and without sufficient data and proof of renewable energy's reliability, receiving funds for equipment needed to use renewable energy sources is challenging (Halldórsson & Kovács, 2010; McCarney et al., 2013; Ashok et al., 2017). Therefore, collaboration with local governments and agencies to identify the need and applicably for sustainable energy to be immediately integrated into the response phase ought to be advocated (Robertson et al., 2017), because government authorities are also in a decision-making role of accepting the relief items during emergencies (Dolinskaya et al., 2018). The topic's importance would also be more strongly advocated to donors, including international governments (UNHCR, 2014).

Currently, renewable energy sources are not seen as priority during the response phase (ICSC, 2017). This stems from that no humanitarian cluster is specifically responsible for ensuring energy needs' adequacy and effectiveness (ICSC, 2017), and in general from humanitarian organisations' perceived reason for existence (Haavisto & Kovács, 2019). In addition, energy is considered merely as a utility, not as something which may contribute to short or long-term objectives (ICSC, 2017). Though, energy from renewable sources is perceived important for environmentally sustainable reconstruction of the disaster area, the implementation does not extend to the current energy strategies in humanitarian ad hoc response (Eng-Larsson & Vega, 2011; ICSC, 2017). The need for assessment of energy needs and availability of renewable energy sources in the destination country are highly advocated (UNHCR, 2014). Having renewable energy strategy already included in the action plan of emergency activities, it is easier to include it in the contingency plan together with the local government or community to ensure flowing distribution of renewable energy also after the emergency (UNHCR, 2014).

2.3.1.3 Activities

By focusing and investing in new cold chain equipment, more environmentally sustainable, reliable and effective cold chain can be achieved, which also has longer-term impact (Comes et al., 2018; GAVI, 2018). Therefore, by focusing on sustainable cold chain activities already in the critical emergency phase, humanitarian organisations can promote sustainability better also in the reconstruction phase (Gibert, 2008; GAVI, 2018). However, GAVI (2018) discovered that most developing countries lack of adequate cold chain equipment due to old or broken devices or not having access to any equipment that keep the items cool (GAVI, 2018). Similarly, UNHCR (2014) remarked that energy is often overlooked by the humanitarian organisations, especially regarding the energy need for health centres. Although, there are some programmes that have implemented renewable energy sources to improve energy robustness and increasement of sustainability within environment with unreliable or non-existent electricity access (see, e.g., Adair-Rohani et al., 2013; Ohunakin et al., 2014; Comes et al., 2018).

Once the medical items arrive at the entry point of the country, the risk for cold chain breach increases (Dolinskaya et al., 2018). Robertson et al. (2017) discussed new long-term passive cold boxes that could keep the cool up to several weeks, as well as freeze-prevention technology. However, there is very limited academic literature about innovations to overcome this challenge with renewable energy sources.

For active cold chain in national or regional warehouses, the power deriving from main or generator is to some extent recommended to be replaced by solar power by academic articles (see, e.g., McCarney et al., 2013; Santori et al., 2014; Comes et al., 2018). Also, UNHCR (2014) mentioned the use of wind and hydropower for clean energy sources, or combining different sources, such as wind and solar. However, the advocation for renewable energy sources is not consistent in the public field guidelines (Logistics Cluster, 2015a).

Typically, the items are transported inside the cold boxes from the entry point to a field warehouse or health clinic, and the fridge and freezer in the health facility can be powered by RES, such as solar energy (Adair-Rohani et al., 2013). For example, solar photovoltaic refrigerators have been used in rural health clinics in Nigeria, which decreases the carbon footprint, responds to the growing energy demand and secures energy access in areas where a margin of people have access to electricity (Ohunakin et al., 2014). Anand et al. (2015) completed a study revealing several alternatives to solar cooling systems, including a solar-powered icemaker by Santori et al. (2014). This addressed the issue of freezing the icepacks for passive cold chain, therefore, health workers in emergency settings have better changes to put the items inside a vaccine carrier and go by walking to the beneficiaries (Santori et al., 2014). Overall, it is estimated that the cost of electricity from solar photovoltaic systems will decrease gradually, eventually becoming highly competitive alternative to diesel (Grafham & Lahn, 2018), as more pilot projects and investments in renewable energy plants are continuously implemented (BloombergNEF, 2017).

Overall, most of the developing countries in which sudden onset disasters occur (OCHA, 2017) benefit highly from solar radiation transferred into electricity (Santori et al., 2014). The technology does exist and has been tested in field to some extent (Santori et al., 2014), however, the awareness, cost factors, better optimization and lack of market-attractiveness hinder the use of RES in emergency operations (Santori et al., 2014). Also, the connection between emergency phase and reconstruction phase ought to be more strongly highlighted to truly see the longer-term environmental benefits (Macrae et al., 1995; Panwar et al., 2011). However, the amount of energy needed does not vanish, and renewable energy sources offer a way to rebuild the area environmentally friendly manner even after the emergency (Halldórsson & Svanberg, 2013; Halldórsson et al., 2019). For example, the rebuilt health facilities still include cold chains after the emergency, therefore, knowing how to use equipment with renewable energy sources sets better opportunities to continue the sustainable way of managing cold chain within the community by the local people (Gibert, 2008; Meduri & Ahmed, 2016).

2.4 Conclusion of theoretical framework

In summary, the theories discussed in **Chapter 2** are illustrated in **Figure 7** below**.** As the literature review showed, supply chain management is an umbrella research area for supply chain sustainability (Seuring & Müller, 2008) and humanitarian logistics (Kovács & Spens, 2011; Tabaklar et al., 2015). Supply chain sustainability includes various activities (Dubey et al., 2017), and this research focuses on energy supply chain and renewable energy sources. This is because in the commercial side, RES has seen to be offering feasible alternatives to address the energy intensive logistical activities to enhance sustainability (Halldórsson & Svanberg, 2013). This phenomenon is depicted in the left-hand side of **Figure 7.** In contrast, the right-hand side of the **Figure** 7 depicts the field of humanitarian logistics and medical cold chains in emergency settings (Comes et al., 2018; Dolinskaya et al., 2018; Grafham & Lahn, 2018). Due to the energy-intensity of emergency HMCC, this study looks the potential use of RES in HMCC by identifying the actors, activities and currently used energy sources, therefore the concepts are answering the RQ1 of this study.

Humanitarian logistics in this research focuses on medical cold chain in emergency reliefs, yet the supply chain sustainability does not extend to the field of emergency medical cold chain (Haavisto & Kovács, 2019). To address the missing interlinkage, this study strives to investigate how the sustainability can be enhanced in emergency medical cold chain by increasing the use of renewable energy sources, hence broader concepts of supply chain sustainability and humanitarian logistics, and their interlinkage, supports the RQ2 of this study. Together, the results from RQ1 and RQ2 are aiming to answer the aim of this study: to investigate the opportunities and barriers of increasing the use of RES in emergency HMCC. The next chapter presents the methodological approach to this research, after which the findings from the empirical study and the reflections to the theoretical framework are reviewed.

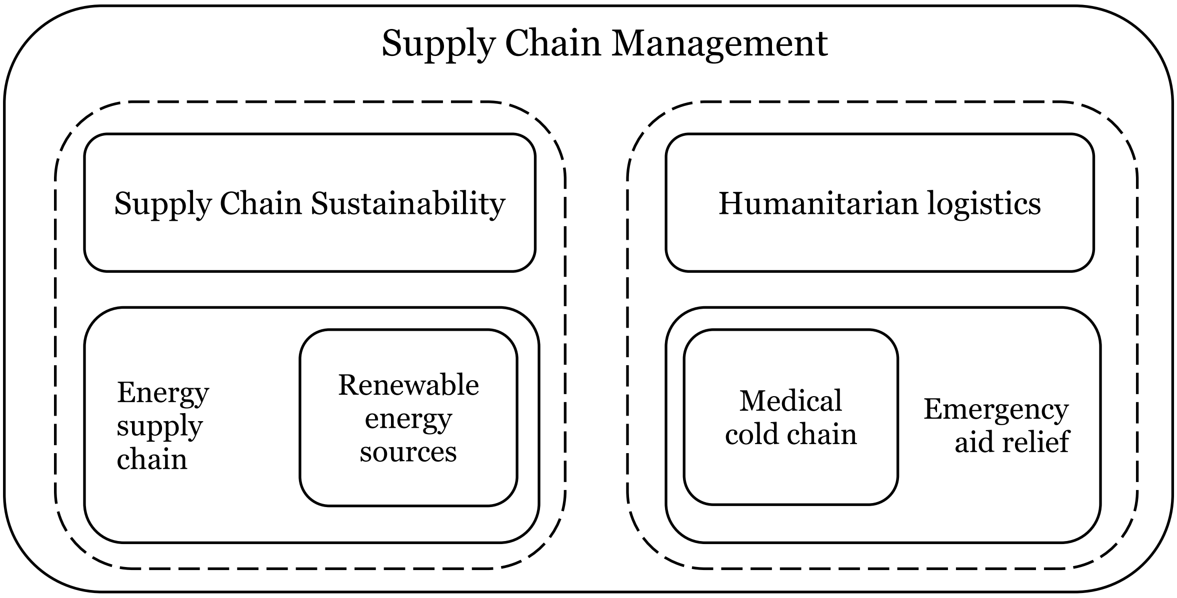

Figure 7 **Theoretical framework of this study**

3 METHODOLOGY

This research follows a qualitative research approach, which is typical for naturalistic inquiry (Belk et al., 1988). The field of logistics has been dominated by quantitative research approach, however, the naturalistic approach has gradually been emerging to address logistical phenomena (Ellram, 1996; Aastrup & Halldórsson, 2008), which cannot be validated by set rules of reliability that are typical within quantitative approach (Halldórsson & Aastrup, 2003). Traditionally, logistics and supply chains are measured with myriad of quantitative attributes to address the physical distribution's key performance objectives (Aastrup & Halldórsson, 2008), including volume and financial flows (Beamon, 1999). However, to understand and explain unknown and more abstract phenomena, such as sustainability (Christopher, 2011), qualitative research approach can be argued to be more relevant (Halldórsson & Aastrup, 2003).

3.1 Research philosophy

The research philosophy explains the assumptions concerning the research design and strategy, how the data is gathered, and how the findings are interpreted (Saunders et al., 2016). Saunders et al. (2016) discussed three research assumption that define the research's philosophy. Ontological assumption explains how the reality is perceived and epistemological assumption concerns what is acceptable and valid knowledge within the reality (Saunders et al., 2016). Finally, axiological assumption includes the values and ethical perceptions during the research (Saunders et al., 2016).

This research builds upon an interpretivist research paradigm**,** which reviews the phenomenon through interpretation and interlinkages of experiences and practices (Belk et al., 1988; Saunders et al., 2016). In contrast to a positivist paradigm, that recognises merely one collective principle or reality for everybody, an interpretivist paradigm seeks to understand and interpret a specific context – sustainability within humanitarian medical cold chain and its enhancement with renewable energy sources (Saunders et al, 2016). Essentially, the interpretivist paradigm considers reality being perceived only individually, and that no one truth exists (Belk et al., 1988).

The ontological assumption for this study recognizes that multiple interpretations and experiences among research participants exist based on, for example, longitude of professional career, personal perceptions, or geographical or organisational culture (Ponterotto, 2005; Saunders et al., 2016). Therefore, the epistemological approach focuses on the perceptions and narratives deriving from the individuals (Ponteretto, 2005). This reflects to the in-depth, semi-structured interviews that give participants an opportunity to describe their views on the research topic (Saunders et al., 2016). Finally, the researcher's axiological assumption acknowledges that research participants' beliefs and values are unique, yet the data is subjectively interpreted by the researcher, because findings emerging from the data reflect the significant beliefs to the research participants, which is considered by the researcher during data analysis (Saunders et al., 2016).

3.2 Research design

According to Saunders et al., (2016), research design describes the process of how the study is conducted. Patton (2015) advocated the purpose being the main force of the research design, whereas Ellram (1996) highlighted the importance of research methodology, including data collection and analysis. This research supports abductive approach, which through exploring interactions and reasoning among data collection and literature results in either testing known theories or generating new ones based on existing theories (Kovács & Spens, 2005; Saunders et al., 2016). Conversely, the dominant deductive approach in logistics research aims to test theories from logical hypothesis to draw conclusions (Kovács & Spens, 2005), whereas inductive approach starts with data collection to build new theories (Saunders et al., 2016).

Kovács and Spens (2005) addressed that whilst deductive approach is dominant in logistics research, it lacks relevant theory building because of the positivist philosophy and quantitative research methods (Kovács & Spens, 2005; Saunders et al., 2016). To this research the purely deductive approach is not applicable as this study does not follow the positivist paradigm nor does it begin purely with testing existing theories, partly due to the lack of academic studies on the topic of sustainability in emergency operations, let alone medical cold chains (Kovács & Spens, 2005; Saunders et al., 2016). Also, purely inductive approach, which starts with data collection and draws then the theoretical framework, was not applicable due to the limited timeframe for carrying out this research (Kovács & Spens, 2005).

Abductive approach starts with empirical observation, and merges then both deductive and inductive approaches to explore the phenomenon and to identify concepts and theories that respond to the research aim (Kovács & Spens, 2005; Saunders et al., 2016). Whereas it is relatively new research approach in logistics research, it offers the researcher to focus on and understand a specific phenomenon – lack of sustainability in emergency HMCC and the linkage to RES – to create hypothesis, propositions, or theories that can be further tested deductively (Kovács & Spens, 2005). Abduction allows also the study to interpret a known phenomenon from another perspective (Kovács & Spens, 2005). This study notes that renewable energy sources have been used in commercial supply chains to enhance sustainability. Therefore, this study strives to investigate similar issue from the humanitarian perspective in order to understand the topic.

Therefore, a qualitative case study allows the researcher to conduct an in-depth study of the phenomenon (Saunders et al., 2016). According to Eisenhardt (1989: 534): "the case study is a research strategy which focuses on understanding the dynamics presented within single settings", and it is, therefore, vital to set frames around the phenomenon of interest (Patton, 2015). Although, scholars do not share a consensus of what is a case (Patton, 2015), case studies have gradually been emerging in logistics research (Ellram, 1996; Aastrup & Halldórsson, 2008) reflecting to the need to conduct qualitative and abductive researches to develop new theories and to understand existing phenomena from new perspectives (Kovács & Spens, 2005). In addition, case studies provide data richness and trustworthiness by matching the empirical phenomena with the theory and the cases (Dubois & Gadde, 2002), and Ellram (1996) remarked the relevance of case study for logistics research to understand new phenomena and the impact of different logistics activities. Hence, this study adheres a qualitative, in-depth method through semi-structured interviews (Ellram, 199; Patton, 2015), therefore applying a multiple-case approach over single case, as the purpose was to study the phenomenon from a broader spectrum (Eisenhardt, 1989).

3.2.1 Sampling strategies

The sampling design to choose the sampled units (Belk et al., 1988) is key element in the research design (Patton, 2015). Patton (2015) highlighted the importance of purposeful sampling strategy in qualitative research, because by choosing informative cases for in-depth study, a comprehensive and thorough understanding of the phenomenon can be achieved (Aastrup & Halldórsson, 2008).

As this research's topic is limited to humanitarian medical cold chains in emergencies and its environmental sustainability, two purposeful sampling strategies were applied (Patton, 2015). First, key-informant sampling strategy was applied as a primary strategy (Patton, 2015). This yields to the fact that the research topic was rather narrow, hence respondents with experience and insight on the subject were trusted to possess a certain level of knowledge required for this study (Patton, 2015). In addition, snowball sampling strategy was applied, as the researcher asked whether the respondents knew other key informants who might provide relevant insight for the research, or relevant public documents to be reviewed (Patton, 2015). Though, both Saunders et al. (2016) and Patton (2015) remarked that bias may occur with snowball sampling strategy, the trustworthiness was confirmed by using key informant sampling strategy meaning that the respondents were ensured to have certain level of knowledge regarding cold chain by asking them to describe their experience regarding medical cold chain (Patton, 2015). **Table 1** presents the case selection strategies and data collection process, and reflects them to the research questions, after which the data collection methods are discussed further in the next sub-chapters.

Table 1 A summary of case selection strategy

Research question	Sampling strategy	Method & Data collection	Unit of analysis
RQ1: What energy sources are powering the HMCC in emergency operations? RQ2: How the increased use of RES in emergency HMCC is seen from the perspective of environmental sustainability?	Key informant sampling Snowball strategy	Qualitative: Semi-structured interviews	Experts with knowledge of humanitarian medical cold chains.
	Key informant sampling Snowball strategy	Qualitative: Written documents	Public guidelines and instructions.

3.3 Data collection

According to Arnould and Wallendorf (1994), the two main data collection approaches in ethnographic research are observations and interviews. The data collection methods follow the research philosophy and approach, and one qualitative research method typical to interpretivist paradigm and naturalistic inquiry is interviewing (Ponteretto, 2005). Primary data for this research was collected through in depth, semi-structure interviews, and written documents of public guidelines and instructions were used to validate the data emerging from interviews. The following two sub-chapters discuss the applied data collection methods more in detail.

3.3.1 Semi-structured interviews

The first research method applied to this study is semi-structured interview with interview guide (**Appendix 1)** (Arnould & Wallendorf, 1994; Patton, 2015). According to Patton (2015), semi-structured interviews with interview guide help to gather reliable data in a structured manner yet leaving room for flexibility. The semi-structured approach also reflects to this research's aim to understand interactions between variables (Saunders et al., 2016) in order to gain insight of barriers and opportunities of using renewable energy sources in emergency humanitarian medical cold chains.

An interview provides views on the topic under investigation through the respondent's perceptions, experiences and expectations, hence providing insights on the phenomenon (Arnould & Wallendorf, 1994; Patton, 2015). By utilizing interview guide, the research can investigate the topic through predetermined themes with a possibility of probing (Patton, 2015; Saunders et al., 2016). In contrast to completely informal or structured interviews, semi-structured interviews provide framework to the topic ensuring that time available is used efficiently but is also applicable to abductive approach as it follows a certain structure yet is flexible by leaving room for probing (Patton, 2015).

For this research, six interviews were conducted during the period of 21.10.2019 – 21.11.2019. One interview was held in Finnish, others in English. Also, all interviews were held via audio or video call due to respondents' and researcher's geographical locations, except one face-to-face interview. Each respondent gave their permission for recording the interviews, and the recordings were transcribed for data analysis completed by the researcher. Rapport between the respondents and the interviewer was ensured by keeping the statements anonymous (Patton, 2015). In addition, three respondents declined of having the name of the organisation they were employed by published, therefore none of the organisations' names are published. Also, anonymity was ensured with all respondents, therefore no titles nor other personal information which could identify the respondent is published. All respondents were cold chain or humanitarian supply chain experts from international or non-international NGOs. The only exception was one supply chain expert, who was not during the time of the interview anymore a representative of an NGO, however, the person's applicably to provide relevant insight on the topic was ensured by asking the person's professional experience. **Table 2** sums the interview details.

Table 2 Summary of interviews

Respondent		**Date and duration**
CODE	**SUPPLY CHAIN EXPERTS FROM NGOS**	
1	Manager of supply chain with experience in the field.	21.10.2019, 1 hour
2	Supply manager with experience in the field.	29.10.2019, 1 hour
3	Heading a logistical unit with experience in the field.	29.10.2019, 0.5 hour
	COLD CHAIN EXPERTS FROM NGOS	
4	Provides technical support to medical cold chains with experience in the field.	29.10.2019, 1 hour
5	Supplies officer with special focus on cold chain and health supplies with experience in the field	8.11.2019, 1 hour
6	Officer working in the area of cold chain with experience in the field.	20.11.2019, 1 hour

3.3.2 Written documents

The second research method included review of written documents. According to Patton (2015), written material provides rich and relevant background information, which helps to further draw conclusions emerging from interviews. The documents may be anything from annual reports to meeting minutes, and they generally provide data rigorous and support, validate, and compare the findings (Patton, 2015). The documents reviewed for this research included public guidelines and instructions for cold chain management in humanitarian context, and they were separate from the data of the interviews. The documents were searched online with keywords "cold chain management", "cold chain in humanitarian operation", and "renewable energy sources in cold chain" by the researcher. In addition, some interviewees recommended the researcher to also review some of these documents, because they were publicly widely referred documents. All the written documents listed in **Table 3** were used to validate data from the interviews, and they do not represent the data emerging from the interviews nor the respondents.

Table 3 Summary of written documents

Publisher	**Name of the document**
GAVI, The Vaccine Alliance, 2018	Cold chain equipment optimisation platform, Technology Guide
Global Shelter Cluster, 2019	Global Shelter Cluster – Environmental Working Group Discussion
World Health Organization (WHO), n.d.	Immunization in Practice – A practical guide for health staff: Module 2: The vaccine cold chain.
World Health Organisation (WHO) & UNICEF, 2015	Introducing solar-powered vaccine refrigerator and freezer systems. A guide for managers in national immunization programmes.
World Health Organization (WHO), 2017a	WHO Vaccine management Handbook, Module VMH-E5-01.1. How to develop a repair and maintenance system for cold chain equipment.
World Health Organization (WHO), 2017b	Solar direct-drive vaccine refrigerators and freezers

3.4 Data analysis

Qualitative data can be analysed multiple ways, and it often begins already during the data collection period (Saunders et al., 2016). Data can be analysed with techniques such as thematic analysis, content analysis, grounded theory methods among others, and there are various tools that support the analysis proceeding (Saunders et al., 2016). For this research, thematic analysis was used, which provided more flexibility in the analysis phase, as it is not necessarily tied within a specific theory (Saunders et al., 2016). Thematic analysis allows the researcher to identify crucial findings emerging from interviewees in order to draw further conclusions (Saunders et al., 2016). The chosen method for analysis supports the research questions that aim to answer what energy sources are currently utilized, and to understand the more abstract concept of how the increased use of renewable energy sources contributes to environmental sustainability, which then further supports the aim of this study.

Data analysis began by familiarising with the data, meaning that the during the transcribing process, self-notes and observations were made to develop familiarity (Saunders et al., 2016). The gathered data was then coded for further reconstitution (Spiggle, 1994; Saunders et al., 2016). The categorisation, or coding, aims to identify chunks that represent a certain phenomenon, and shows the interlinkage, occurrence and non-occurrence of the phenomenon of sustainability in emergency HMCCs (Saunders et al., 2016). For this research, four categories were already established in the beginning of the study: actors, activities, energy sources, and sustainability. During the data analysis process, units of data from the transcriptions were colour coded (Spiggle, 1994), and emerged codes were: financials, knowledge, technology, capacity, trade-off, collaboration, attitude, prioritization, reliability, speed, stability, practicality, guidelines, process and planning. In addition, some sub-codes occurred, which were combined to one. For instance, energy sources were first distinguished between fossil-based and renewable energy sources.

The second phase of the data analysis searched for themes, patterns and relationships among the codes (Saunders et al., 2016). The 19 codes were grouped into more broader themes by abstraction, and with comparison, similarities and differences among the themes was investigated (Spiggle, 1994). The initial themes resulting from abstraction were resources, awareness, infrastructure, and pre-set processes.

During abstraction, dimensionalization and integration steps were constantly conducted by the researcher to discover deeper analysis to map the relationships between the identified themes (Spiggle, 1994). Simultaneously, the themes were constantly refined and iterated (Spiggle, 1994; Saunders et al., 2016), as the researcher moved constantly back and forth between the data and theoretical framework to seek similar or differing meanings between themes to collapse them into a one theme (Spiggle, 1994, Saunders et al, 2016). During iteration, the theme pre-set processes was modified to prerequisites.

The final phase of refutation tested and modified the relationships by seeking negative cases and alternative explanations within the data (Spiggle, 1994; Saunders et al., 2016). For example, the code technology could have been under either the theme resources or prerequisites, however, it was strongly related to funding, actors and knowledge, therefore it was decided to belong under the theme resources. This way, more rigours analysis was ensured, and the final themes were resources, awareness, infrastructure, and prerequisites. **Table 4** below summarises the data analysis reflecting them to research questions and providing examples from the data.

Table 4 Data analysis

Type of code	Theme and reflective RQ	Example from interviews
Financials Knowledge Technology Capacity Actors Energy sources	**Resources (RQ1 and RQ2)** The temperature requirement for cold chain poses challenges as a steady power supply is difficult to ensure during emergencies (Dolinskaya et al., 2018). Technical knowledge to maintain the cold chain equipment is a critical task (Dolinskaya et al., 2018), and it requires both financial and human resources from NGO and from local government (Comes et al., 2018).	"So you may end using like passive cold chain because you actually have maintenance problem or staff problem, that there is not technician available to repair the fridge." (4) "So there's whole hosts of the complex issues depending upon the… The capacity of the country, the existing capacity the country before the crisis, the ability of the staff from the different international organizations, or NGOs, to even know that they should be managing it in the first place, but then also have the funds, or the, or the, the infrastructure to manage it well." (5)
Sustainability Trade-off Collaboration Attitude Prioritization	**Awareness (RQ2)** External and internal incentives and pressures increase the sustainable mindset among organisation (Seuring & Müller, 2008), however, sustainability is not at the core of HMCC (Haavisto & Kovács, 2019), because cold chain cannot have a breach (Dolinskaya et al., 2018), therefore renewable energy sources are not necessarily considered as the first choice to increase sustainability in emergency settings (Oloruntoba & Gray, 2006).	"I don't think we're putting special force or priorities in making emergencies more sustainable, it's more how the organisation is working on it, and then that will have an impact on that." (1) "In general, still the community's perspective is 'we need to go in, we need to save lives', which is understandable […], but I don't think that we as a humanitarian community have accepted that […] we are also leaving a huge environmental impact." (5)

Reliability Speed Stability Practicality Activities	**Infrastructure (RQ1)** Humanitarian operations take place in volatile environments (Kovács & Spens, 2007), therefore the reliability of any logistical activity must be applicable to the rapid response phase (Dolinskaya et al., 2018).	“For us, the number one priority is to deliver the equipment fast to the country, install them and run the operation.” (3) “If it’s an emergency, you don’t have time to think. You do that it works. You clean up afterwards, but you just ship... It’s a matter of the first few days of the response.” (2)
Guidelines Process Planning	**Prerequisites (RQ1 and RQ2)** HMCC consists of different activities and actors, therefore the success and robustness for cold chain is ensured with guidelines to be followed (Dolinskaya et al., 2018), as the relationship of actors, activities and energy sources are strongly linked in processes, and they each influence the supply chain design (Håkansson & Snehota, 1995).	“There’s quite some procedures to follow if something happens.” (1) “If something is green itself, we will use, whatever it is on hand. But it needs to be already pre-thought. You don’t think about green in emergency.” (2)

3.5 Research quality

Typically, case studies’ quality is assessed with validity and reliability (Ellram, 1996), and for this research, the validity is ensured by using multiple data sources, which produces more reliable results (Ellram, 1996). The triangulated data, i.e. interviews and written material, was conducted with respondents from different backgrounds and organisations (Wallendorf & Belk, 1989; Ellram, 1996; Halldórsson & Aastrup, 2003). This assessment methods were supported by the purposeful sampling strategy by selecting key informants (Patton, 2015).

Reliability, on the other hand, addresses the study’s potential for replication to achieve similar results, and this is ensured by using a case study protocol, i.e. an interview guide (Ellram, 1996). Furthermore, owing to lack of peer-reviewed articles of medical cold chain in emergency response, the critical literature review was supported by industry-wise reports in addition to peer-reviewed, academic articles (Saunders et al., 2016). This may lessen the study's reliability, however, the researcher concluded it being important for gaining an up-to date and holistic overview of the topic.

As mentioned previously, field of logistics has gradually adhered a qualitative research approach in addition to quantitative approach (Halldórsson & Aastrup, 2003). Hence, merely validity and reliability as assessment criteria in the field of supply chain management (Ellram, 1996) do not verify the research's evaluation regarding trustworthiness (Halldórsson & Aastrup, 2003). For this, this research's quality was also evaluated based on data's credibility, transferability, dependability and confirmability (Wallendorf & Belk, 1989, Halldórsson & Aastrup, 2003). Credibility is based on the notion that reality exists in respondent's minds, and the way the researcher and the respondents understand the context (Halldórsson & Aastrup, 2003). In this research, all the respondents were experts of the research topic, hence they provided a deeper understanding to the researcher's reality of the field of humanitarian logistics and specifically of cold chain management (Halldórsson & Aastrup, 2003).

Transferability, on the other hand, assess the quality in terms of generalisation emerging from the study (Halldórsson & Aastrup, 2003), and as this study is not limited to one specific case, similarities are expected to be found in varying settings. Although, the number of respondents were six, therefore, the generalisation of the findings cannot be completely ensured. Dependability was ensured by following the research design carefully, documenting and presenting it, and this is ensured with interview guide, transcriptions of the interviews and research diary (Wallendorf & Belk, 1989; Saunders et al., 2016). In addition, data analysis process is outlined in the study (Halldórsson & Aastrup, 2003). Confirmability ensures that the researcher's bias has not had impact on the study, and the results are purely drawn from the data (Halldórsson & Aastrup, 2003). For this, an external reviewer typically asserts the results of the study (Halldórsson & Aastrup, 2003), and during the research process, this study was peer-reviewed and supported by researcher's supervisors.

4 SUSTAINABLE EMERGENCY MEDICAL COLD CHAIN

This chapter presents the findings from the empirical research aiming to answer the research questions:

> RQ1: What energy sources are powering the HMCC in emergency operations?
>
> RQ2: How the increased use of RES in emergency HMCC is seen from the perspective of environmental sustainability?

First, the results reflecting RQ1 are presented, which is then followed by presentation of the findings regarding RES in HMCC. In the latter part of this chapter, the results reflecting RQ2 are presented, and finally, the findings of opportunities and barriers of increasing the use of RES in HMCC are presented. Hence, the findings presented in this chapter thus follow the focus of this study, and they lie in the downstream activities instead of upper stream, excluding central warehousing and manufacturing.

4.1 Emergency medical cold chain

According to the interviewees, cold chain can be classified into two categories. The +2˚C to +8˚C degree is often referred as the actual cold chain, whilst the temperature-controlled supply chain between+15˚C to +25˚C degrees is needed for most medical items. Similar to cold chain definition, emergency response and regular, day-to-day humanitarian response were strongly distinguished by all respondents. It was highlighted that even though the emergency response is more visible in the media, it comprises only a portion of all the humanitarian response conducted. With a connection to that, most of the cold chain management takes place in the longer-term humanitarian operations instead of sudden onset disasters.

However, cold chain items are still needed, yet due to the volatile disaster settings, cold chain items are aimed to be minimized within the emergency response supplies, as one respondent explained:

> This cold chain, it is very small thing among the response, and therefore, we have aimed to minimize the items that need cold chain because it needs special arrangements. (3)

The respondents considered emergency cold chain as an integrated process to the main response operation, and the number of medical items that require cold chain is generally small. However, one respondent specifically highlighted the life-saving essentialness of emergency medical cold chains during humanitarian situations:

> […] Often there's no private sector that's functioning. And we are the only source of these high-quality products. So, if we don't provide it… It's not like they [beneficiaries] can go to the pharmacy next door and buy better one. I mean, I think that this is a huge, huge, important issue. (5)

In contrast, another interviewee noted that cold chain management is more crucial in bigger interventions. The respondent further noted that the complexity of cold chain truly emerges when the volumes increase, following the distinction of emergency response and long-term humanitarian operation:

> If you are having five products that needs to be put into a cold chain, then, that is not really a problem, because somehow there will always be a doctor flying there and they can take that in their hand luggage with little bit of a box and go. So, really the complexity comes when the volumes become big. (1)

Nevertheless, cold chain items are needed in emergency responses. Typically, in emergency settings the medical items that require cold chain include insulin, blood grouping tests and other tests, maternity services and vaccines. Although, often vaccines are not considered part of emergency response items, but instead large vaccination campaigns or emergencies taking place in longer-term development projects or protracted operations. However, disease outbreaks are also considered as emergencies, during which ad-hoc vaccine operation is needed, although they do not fall into categories of natural disasters or man-made disasters. Also, the sudden onset disaster may turn into a disaster in which large vaccination intervention is quickly needed.

4.1.1 Infrastructure

Despite the small volume of required HMCC items, they are still considered highly valuable due to their costliness and efficacy. Therefore, the respondents emphasised cold chain stability and security throughout the supply chain from the central warehouse to the last-mile distribution, as was illuminated by one expert:

> The main focus is the reliability of a cold chain. You can't have cold chain breach, because then it's just, just a waste of some many of the efforts. (2)

Yet, cold chains are perceived extremely challenging to manage, precisely due to the strict temperature requirement. Once a sudden onset disaster strikes, cold chain is often considered as part of the emergency response process with explicit procedures. The cold chain management is challenging, and all the activities need to be in line with cold chain robustness in rapid response operations. Therefore, energy sources in emergency HMCC need to be proven practical and stable throughout the logistical activities by the actors.

4.1.1.1 Actors and activities

Cold chain items are, typically, stored at a central warehouse, for example in Europe, in large cool rooms. Once a disaster strikes, an order is placed by the logistics coordinator or a technical referent to the central warehouse, and within a few hours, the requested items are packed and ready to be sent from the central warehouse. NGO cannot always decide by itself which equipment are sent, because the country under distress can place an order to the NGO by requesting for assistance, and the government of that country may opt for certain equipment and medicines if they, for instance, have or have not relevant equipment available at the site. Although, this is not always the case, and the NGO can also recommend certain equipment to be deployed. For example, NGO can suggest deploying solar powered generators over diesel-based generators if applicable. In addition, some NGOs do not stock medicines nor cold chain equipment at a central warehouse, but instead order the supplies straight from the supplier or manufacturer who is then responsible for the transportation to the point of entry.

Instead of ordering individual medicines, the orders may consist of several different kits that form modules providing a minimum primary health services in crisis. The kits are ordered and packed based on the specific scenario and available information about the country, disaster type, number of affected people, season and physical environment of the destination. The kits include not only the medical items, but also equipment needed for cold chain management: fridges, freezers, monitoring devices and generators, when necessary.

The packing is done by experts as it is rather advanced and needs to be completed carefully to avoid cold chain breach. Therefore, a strict protocol has been designed that the cold chain actors are required to follow. Often, the actual medical items are packed inside a cold box filled with icepacks, or sometimes in a reefer container. The cold chain products are always transported by air, and in some cases, there might be a cold space in the plane itself that is being kept cold at a right temperature. As one respondent stated:

> Cold chain we always transport by air. Because there is no way today to ensure an active cold chain by transport fully. We never transport 2 to 8 degrees by sea, or by truck. This is always transported internationally with air. (1)

The rapidness, sensitivity, reliability, and practicality illustrate the cold chain management and infrastructure in emergency settings. Therefore, there are no room for errors regarding packing. The emergency response expedites the whole procurement and distribution process, and typically, the items are delivered within 24 to 48 hours from the central warehouse to the entry point. According to the respondents, the cold chain box can hold temperature up to 72 hours. Although, some models of cold boxes were described to hold temperature for 7 days, or even up to 30 days. The monitoring of the temperature is crucial, and the temperature of the boxes is followed on regular intervals by utilizing log tags and freeze tags, as the products need to be maintained at the right temperature without freezing or becoming heated. The importance of the strict protocol was highlighted by all the respondents to ensure the effectiveness of resources and response. This was explained by one manager:

> So, of course, we do all this because we have to know that the drugs have efficacy when they are reaching the patient. Otherwise, there's a lot of money and time spent and in the end, there's no effect. (1)

The passive cold chain is vulnerable to cold chain breach once it reaches the entry point and items are unloaded off the plane. The items need to be customs cleared by the local authorities, and due to the lack of time, many items are tried to be free cleared or post cleared. Although, the risk of losing the inventory at the entry point is extremely high. Usually, the staff from the humanitarian organisation, local personnel, or government officials is responsible for unloading the plane, yet the customs procedures forbid the timely unloading. As one respondent put it:

> The real problem for cold chain is when you have, and it's out of everyone's hand so far, when you have an unloading done on an airport tarmac. [...] When its airport security blocking it, and you cannot remove it yourself which is often the case in bigger airports, your cargo can be left on a tarmac under 50 degrees for three or four days. Then you have nothing. You have no power apart from the negotiation with the authorities. (2)

In addition, the country's varying capacities impact on the passive cold chain's robustness at the entry point:

> This is where the different capacities will start to show themselves. In some settings, you have the port of entry the adequate facilities for cold chain, but, [...] often times, there is not capacity for storing those temperature-regulated products while the customs clearance process is taking place. (5)

After unloading, the boxes are opened, and the log tags are read by local staff. In some cases, the document showing the temperature readings are sent to the NGO's headquarter, which gives a permission to use the medicines. If deviations among the temperatures are noticed, the manufacturer, supplier or a technical referent is contacted to verify whether the items can still be used or whether they have destroyed.

In emergency settings, the second most critical node comes once the items are released and delivered forward from the entry point. The government may be responsible for the in-country distribution, however, if they are lacking relevant capacity, the humanitarian organisation's country office may assist with the distribution according to the funds available. Depending on the country's geographical location, infrastructure, disaster type or country's capacity, the items are delivered to central warehouse at a capital level, from which they are delivered to regional warehouses or straight to remote health facilities, reaching ultimately the beneficiaries. The country's capacity and nature of disaster influences whether the items are transported in the cold boxes or in refrigerated trucks, although, they are not always available as one respondent mentioned:

> There's a lot of issues where you can't always find refrigerated trucks for the transportation. When we are giving these supplies to our partners, they might not even be bringing the truck, you know, they might be bringing a car or a boat or, you know, depending on the response, and if there's flooding. Sometimes they are carrying these things up to the mountains on donkeys. [...] There's no sustainable way to ensure that their refrigeration and transportation is there. (5)

Usually, cold chain equipment is not installed in country's central or regional warehouses, as they are merely storage points with often available electricity. In cases where there is no existing warehouse, it has been destroyed, or there is a scarcity of electricity, a local warehouse is set up. Like packing and transportation process taking place in the upper stream, the trained personnel are requested to follow strict guidelines of how to set up a temperature-controlled warehouse, fridges, and freezers as well as the generator, and ensure that the temperature is followed on regular intervals.

However, cold chain management in challenging and requires extra knowledge also from the local personnel. All respondents noted that the knowledge resources are one major challenge in cold chain management. According to one cold chain expert, there are situations when the country logisticians are restrained to access the local facilities due to the dangerous settings, and they must rely solely on local resources:

> It's very difficult for us to be able to go to the health facilities to monitor, is there a functioning cold storage unit, because we don't have physical access, because its insecurity. In some places, if we don't have staff who are familiar with pharmaceutical commodity management, they might not even know that that's what they should be monitoring for in health facilities. (5)

Depending whether the deploying organisation has ongoing projects in the country or what is the country's capacity and resources, the capital level warehouse may have a dedicated cool room for cold chain items. From the capital level warehouse, items are deployed to health facilities, or through regional warehouse from which they are further distributed to lower level health facilities. The regional warehouse may also have a cold room dedicated for cold chain storing.

Finally, the medicines are delivered to rural health posts or small villages with vaccine carriers, or the beneficiaries are treated in the local or set up health facilities. In cases when the beneficiaries are not able to reach the health post, the medical items can be delivered to them with vaccine carriers, or with portable generator in active cold chain, as was described by one respondent:

> We deliver hospital services to places from where people cannot necessarily reach the hospital. For these deliveries, we have these portable generators. (3)

As noted, depending on the disaster situation, a warehouse may need to be set up, either in more downstream health facility or more regional level. There are pre-set processes of how to set up the warehouse, and guidelines are to be followed regarding how to pack a fridge to ensure that the drugs are held at the right temperature and there is enough air inside the fridge. For example, WHO's guideline for vaccine cold chain (WHO, n.d.: 27) described in detail how different drugs should be arranged in front-opening and top-opening refrigerators, and what are the general rules to be followed, such as:

> If vaccines or diluents are supplied in their original cartons, arrange the boxes so that there is at least a two-centimetre space between stacks. Mark the cartons clearly and make sure the markings are visible when the door or lid is opened. (WHO, n.d.: 27)

Regardless of whether there is existing storage capacity or whether the warehouse needs to be set up, all respondents emphasised that fridges and freezers are always ready in place, especially for security and back-up. As one interviewee stated:

> There's always a contingency plan in the place, there's always back-up fridges. [...] Even if it is enough with just one fridge, you will always have a couple of back-up fridges because if one breaks down, you have to be able to change over quickly. [...] We always have to have freezer full of frozen icepacks. So, if the active cold chain is breaking down, we can still move it over to cold chain boxes and have it as a passive cold chain. (1)

Similarly, guidelines for effective cold chain management emphasised that in emergency situations, including stable settings in which a power or equipment failures occur, a practical and unambiguous contingency plan must be established. For example, WHO (2017a: 6) guided in the cold chain management handbook what, especially, needs to be pre-thought in emergencies, which are also situations when the cold chain breach is occurring:

> Due to the temperature sensitivity of vaccines, any interruption to the normal functioning of cold chain equipment is an emergency situation. Emergency situations are typically due to either power failures or equipment failures. The risks from these emergencies can be minimized by developing a contingency plan and ensuring that all relevant staff are aware of the plan. (WHO, 2017a: 6)

Overall, sudden onset disaster was characterized as extremely challenging and complex from the perspective of cold chain management by all the respondents. Owing to this, the sensitive emergency medical cold chain is carefully pre-designed and strict guidelines have been drafted by technical referent within the headquarter to ensure practical

HMCC. All the actors managing the cold chain are required to follow the protocol, and risk mitigation is vital, which was summarised by one respondent:

> So, we are always trying to the very maximum to keep it in active cold chain. So as soon as you move over cold chain to passive cold chain you are increasing the risk of cold chain breakdown. Both because it's much more complicated. Or, because it's much more complicated, it's much easier to have a human error. And throughout these process, cold chain is always tracked with several different devices. (1)

Having reviewed the characteristics of emergency HMCC, including activities and actors, the next sub-chapter presents the findings of current energy solutions for powering cold chain, benefits and challenges of current solutions. Also, prerequisites regarding energy solutions in HMCC are presented, which was briefly covered when presenting the characteristics of emergency HMCC.

4.2 Energy in HMCC

When asking from the interviewees about factors influencing the energy solutions, the responses were often followed by descriptions of stability, security and reliability. As mentioned, sudden onset disaster equals challenging environment to manage cold chain, and the energy reliability needs to be ensured. According to all respondents, the energy intensive nodes in emergency settings exist at the warehousing activities in the field, including the air conditioning to have a temperature-controlled warehouse, and the equipment needed in the field for storing the medicines in fridges and generating icepacks in freezers for passive cold chain. Although, one interviewee noted that as cold chain is treated part of the main response' supply chain, the energy need is low:

> Energy is consumed, but very, very small amount when talking precisely about the cold chain. (3)

Nevertheless, all respondents described that in the central warehouse, the cold chain items are stored in cold rooms or large fridges, the icepacks in the freezers, and the needed energy derives from the grid. During transportation from the central warehouse to the field, the passive cold chain itself is not considered as an energy-consuming activity, but once the items are transported to the country warehouse, regional warehouse or health facility, energy is needed the most for freezers for generating icepacks and for fridges or cold rooms for storing the medicines. One respondent remarked, though, that the energy need is reliant on whether one looks at one specific point or takes a broader perspective. This is because one cold room consumes more energy than one health facility in the field, whereas several health facilities spread across the area consume together more energy compared to one cold room:

> So, in terms of energy intensiveness, had one specific spot, the cold rooms are probably the ones, they are using the most electricity. And as you go down, the cold rooms get obviously smaller. Because they, yeah, they don't need to store so much vaccines. So, the energy needs go down, accordingly as well. And then you go into health facilities. And for a health facility, you would, typically, only have one refrigerator there. So, for the health facility the energy needs are pretty low. But you do have a lot of these health facilities spread all over. So, if you add up all the energy that they are using at the lower level, that's probably much more than what you would use at the central level. (6)

Rural health facilities are also the points where energy supply becomes unstable, and back-up processes need to be set, as one respondent described:

> At some strategic point, you will have an active cold chain, and everything plugged in. According to the nature of the disaster, it's the amount of energy back-up that you will send with that cold chain. (2)

This means not only back-up equipment, but also back-up energy sources. Though, in the field, the fridges and freezers are mainly powered by diesel-generators with no backup solutions. Although, it was noted that cold rooms in country and regional warehouses plugged in a grid would be optimal solutions for storing large volumes of perishable medicines with a back-up energy source by diesel-generator. However, this is not always possible, and the more the volumes increase, the more challenging it is to manage with fridges and generators.

The often-used energy source for HMCC in emergency operations was stated to be diesel for generators. All respondents mentioned the need to ensure constant power supply, and the stability is often ensured with back-up solution or mixing different power sources, such as diesel generator and electricity from grid. One supply chain expert stated city-power being the most used over diesel generator, whereas another cold chain expert considered city power being unreliable and not often used.

> Of course, the first choice is always city power. Second, is the generator. (1)

> I think, very few, are [powered] by the public electricity system in the city where they are. But normally, this not very reliable, this power supply from the country. So, most of the time, it's like a fuel generator. (4)

All respondents mentioned also pilot projects of refrigerators powered by solar energy, however, they seemed to be considered as minority. For example:

> More and more, you are seeing solar, but it's not anywhere you think what it's yet. It's not uncommon to see something that's solar powered, but, it's not like systematic where you see it everywhere. (5)

Supporting this response, another interviewee also noted:

> We are more and more working on solar power, but I would say that the cold chain would probably be the last to move over to solar power. (1)

In contrast, one respondent specifically stated that more and more solar powered refrigerators are being requested and deployed, and the traditional, absorption modelled fridges that use gas or kerosene as energy source are being dissipated:

> There's a lot of solar fridges going out. [...] But there's a definitely a very big push to get rid of all the absorption fridges and get solar fridges in there instead. (6)

The perceptions for most viable energy solution divided respondents' opinions. No one claimed one option being the most viable one, but instead highlighted the mix of two energy sources for ensuring power security. Nevertheless, the first choice for most viable energy solution for cold chain equipment was indicated to be mains powered by one cold chain expert, and diesel-based generator by two supply chain experts. They emphasised the lower costs compared to renewable energy source powered alternative. In addition, reliability was highlighted by them, which can only be ensured by current, existing technical solutions, as was elaborated by one expert:

> There's not a different solution than a general fridge for the standard medical ones to keep a cold chain running on. (2)

One supply chain expert remarked that solar power would be the first option, however, the balance between efficiency and long-term sustainability with solar power is difficult to ensure:

> The first reaction is, of course, solar power, especially in Africa where it becomes more and more common. But in the same time, it is so new. It is one thing to have a couple of solar panels to be able to charge your phone, and it's a different thing to be able to run bigger supply chains. I think it's too new. (1)

Conversely to the four other respondents, two cold chain experts remarked quite strongly that solar power would be the most viable energy solution due to its sustainable nature and cost-effectiveness in longer-term, because solar itself does not cost anything. However, the two respondents also remarked, that solar power also creates a need for special expertise for maintenance. Furthermore, they highlighted that not every disaster happens in countries where solar power is constant, therefore, a mix of two different energy solutions might be feasible. This was illuminated by one expert:

> I think solar has a lot of really great potential. You can put it on top of structures, they don't have to take up space. I mean, to be honest, most humanitarian settings are in quite sunny environments. Of course, you have many places where you have monsoon season and that might cause problems so you might have to have a mix. (5)

Regarding future energy outlook, three respondents mentioned that the energy solutions may be completely different in the future, and the portion of solar will likely increase.

> Probably, in the cold chain that we'll need, we'll definitely still see solar, because in general, I think it operates really well. You will probably see more solar panelled cold rooms. (6)

Despite the conversing views on most viable energy solution, no clear distinguished factors between the respondents' experience was identified, which could have helped to interpret reasons why certain solutions were advocated over others. However, the respondents who opted for solar energy were specifically cold chain experts, whereas the others were both supply chain and cold chain experts. Nevertheless, all six respondents elaborated strongly the prerequisites for energy sources that need to be considered when managing HMCC in emergencies, which is next presented in the sub-chapter below.

4.2.1 Prerequisites

The factors influencing energy strategies were described to be the disaster type, infrastructure and location, and access to stable electricity and local resources, including available funds and knowledge to fix and maintain the equipment generating power. Hence, a myriad of prerequisites was described by the respondents for energy solutions in emergency HMCC, and all factors are interlinked to each other. It was emphasised by all the respondents that planning and existing instructions guide the cold chain management process, which for the most part relies on diesel-based generators.

As noted in the previous chapter, diesel-based generators are often used power source in emergency HMCC. Diesel fuel needed for generators is mainly sourced locally and seldom deployed from the central warehouse along the medical items. However, one supply chain expert noted that in extreme conditions, the fuel is possible to be delivered as well, though, it is not advisable. In contrast, another supply chain expert remarked that fuel is never deployed due to transportation restrictions. In addition, one respondent mentioned the coordination between humanitarian organisations and individual organisations' mandates and priorities, which influence the funding earmarked for cold chain management, being factors influencing the cold chain energy strategies:

> I think sometimes it's lack of coordination. I don't think it's a purposeful thing, I think it's just the fact that every organisation has different priorities because that's their jobs, is to have different priorities. And it's not necessarily the vaccine sectors' job to provide cold chain for the rest of the health. Our jobs' as health actors is to convince all the different actors at different levels of the supply chain to recognize the importance of cold chain and budgeting for that cold chain infrastructure and maintaining it. (5)

The benefits with the most commonly and widely spread energy source, diesel fuel for a generator, were often described to include easiness and security. For example, diesel is easily accessible all around the world, and the diesel generators are rather standardized and spare parts were described to be easily available. Therefore, the process of using diesel-based generators already exists. As one supply chain expert summed it up:

> Reliability, and that you can quickly hook it up. (3)

This note was also supported by another respondent, who also highlighted the established process and control of the energy supply:

> Security and stability, for sure. You have a control of it, and we know how to fix it. And if it's not working, we have a back-up, and you have a full control about the electricity supply. (2)

Similarly, the independence was appreciated by another interviewee:

> It's independent from the public electric system that might not be available and might not be very reliable. So, you can run a health facility and a cold chain independently if the place has like good power supply. (4)

Despite the diesel-based generator being the most common source of energy to power the cold chain in the field in emergencies, several challenges were expressed by the respondents. Generators consuming diesel were described being loud and breaking down easily, sometimes within a month in extreme conditions. Also, one respondent noted the bad fuel quality in developing countries that impacts the functioning of the generator, despite the filters.

Furthermore, one cold chain expert raised the issue of old absorption refrigerators existing in the field, which neglects the use of more sustainable equipment as the countries may opt for using already established processes despite the negative factors:

> Also, you have a lot of legacy fridges in the field that are still operating on either gas or kerosene. Which is an absorption type of refrigerator. Because these, like, over the thirty years, forty years, they've been used widely. But they do have issues of breaking down, and they do have issues with the fact that you have to make sure that there is always gas available, and always kerosene available. (6)

In addition, the dependence on diesel was mentioned as a challenge as it needs to be continuously supplied to have the generator running to avoid cold chain breach. This requires money, and one interviewee remarked that this is often neglected in the budgeting:

> It's very difficult to, in general, with logistics in humanitarian settings. Particularly, because donors want to fund the items, they don't necessarily want to fund the management and operation of getting the item where it needs to be, and the quality it needs to be. So, in general, even when people write donor proposals or they ask for money for certain things, they are not necessarily budgeting for cold chain and the management for cold chain. And this creates a lot of problems. (5).

Still, the HMCC powered by diesel-based generators was not seen effective, creating an urge to move towards alternative solutions, as the cold chain expert continued:

> The benefit of using diesel or gas, is that, it is, kind of a low tech, so, countries know how to deal with it, they often already have like supply chains in places in order to get the diesel or the gas to go where they need to go. The supply chains are often not very effective unfortunately, but, yeah. It's, something they have been dealing with for years. So, the process, to a certain extent, it has been established. Although this process is not being executed very effectively. So, that's why there's a big push to get away from the diesel and the gas, because it is not working the way it's supposed to work. (6)

These statements were also supported by WHO and UNICEF's (2015: 2) guide of using solar powered refrigerators as an alternative to traditionally used gas or kerosene powered fridges for cold chain storing:

> For the last 30 years, refrigerators powered by gas or kerosene (known as "absorption refrigerators" and described in Section 1.3.2) were considered the most appropriate option to store vaccine in areas without – or without reliable – electricity. However, various drawbacks with these devices can make keeping temperatures within the safe range for vaccines of +2°C to +8°C both difficult and expensive. (WHO & UNICEF, 2015: 2)

In addition to the established supply chains that can be considered both challenges and benefits, technical knowledge to install, fix and maintain the equipment was mentioned to be one of the benefits with fossil-based generators, as the process has been prevalent for many years, and technology is not too complex. However, two cold chain experts noted technical knowledge being also a challenge as a lack of local expertise hinders the secure cold chain management. The lack of local staff and expertise was also reflected to the lack of budgeting for cold chain management.

> Most of the time when I visit health facilities and I check cold chain, or regional warehouses, I see that those are not, sometimes it's not very well maintained. [...] So, you don't have somebody that knows really well, this is not working because it's a problem of the generator the way it's plugged in, or it's because the fridge is broken already, so nobody knows about it. There is really not a staff available on that. (4)

Furthermore, the dependency on fuel and the constant cost related to fuel supply was raised as a challenge with fossil fuel powered refrigerators, which is interesting as one of the benefits it was mentioned that diesel generators provide sufficient stability and it is easily accessible. Also, the environmental sustainability was noted by all the respondents as one of the challenges with fossil-fuel based generators as they pollute and emit considerably CO_2 gases. The current, mainly used energy source was not regarded as an environmental choice, and three respondents noted specifically the longer-term environmental and economic impacts on the local environment. For example, the country needs to manage the waste afterwards during rebuilding. Also, one cold chain expert stated that despite the initiatives to reduce the amount of plastic and have more reusable items, the energy source for life-saving supplies has a significant impact on the local environment of the country:

> In general, still the community's perspective is "we need to go in, we need to save lives, and we're going to do everything we can to save lives, which is understandable, but I don't necessarily think that we as a humanitarian community have accepted that, not only are we flooding, we are destroying private sector markets that might have existed when we flood with these things with free products. But we are also leaving a huge environmental impact. That, when a country hopefully transitions into a recovery situation, has to manage and deal with. So, of course, you have this kind of global impact around the use of greenhouse gases and diesel and versus fuel, and all of this kind of things. But then you also have the actual environment of the country itself, which is also, you know, that's a piece we have to consider this when we are doing humanitarian response. (5).

Likewise, the mains refrigerator powered by electricity was opted by most respondents as either a stand-alone solution or as a back-up, however, its environmental sustainability was questioned by one respondent:

> Even compared to a mains operated refrigerator, that electricity still comes in a lot of these contexts from coal fired power plant as well. (6)

To conclude, several prerequisites exist when choosing the most relevant energy source, which currently is diesel for generators. However, it comes with both benefits and challenges, one of being the non-environmentally friendly dimension. Hence, the next sub-chapter takes a closer look to the environmental perspective within medical cold chains in emergency operations and presents the findings of how renewable energy sources are alternatives to power the emergency HMCC.

4.3 Renewable energy sources in HMCC

In general, renewable energy sources were considered by the respondents a desirable source of energy. However, when talking about emergency medical cold chains, the reliability, efficiency, stability and competence among supply chain knowledge and resourcefulness were considered important criteria that steer the decisions for powering the cold chain. The findings of these prerequisites are discussed next further.

4.3.1 Prerequisites with RES

All respondents noted that no renewable energy source was to be implemented just for the sake of green logistics if there was a risk that it would jeopardize the life-saving activities. Therefore, the timeframe of a disaster and the lead times to set up cold chain equipment were highlighted to be ensured, as was summarised by one cold chain expert:

> Because then you are dealing with a situation where people are dying because you do not have cold chain equipment available. Or people can die because you don’t have cold chain equipment available. (6)

Among the renewable solutions, solar was the most common mentioned source. This owes to the fact that most emergency operations take place in sunny locations, and solar power is something that the humanitarian community is moving towards to. In addition, one cold chain expert also remarked that the use of absorption refrigerators was decreasing, and WHO and UNICEF (2015: 2-3) also strongly advocated of not deploying refrigerators powered by fuel:

> Operating cold chain equipment in areas without grid electricity has long presented a serious challenge. Immunization programmes have addressed the problem by using absorption refrigerators, but there are various disadvantages to using these devices. (WHO & UNICEF, 2015: 2)
>
> In light of these considerations, WHO and UNICEF recommend that in off-grid locations with sufficient solar irradiance, solar refrigerators should be considered. (WHO & UNICEF, 2015: 3)

One supply chain expert remarked that no other feasible solutions have been emerging. Although, two cold chain experts stated that wind might offer a solution where solar power is low, yet, the technology does not support wind being used in ad hoc emergency situations.

> I think when you are talking about more active situation, you can't really have that [wind] as a solution, but maybe in a more stable situation. (5)

Apart from solar and wind energy, biofuel was mentioned as an alternative to diesel, however, its convenience was heavily questioned, because biofuel is more expensive and not easily available in developing countries.

> If it's not available in the country where you act, or close-by, it's going to be a tremendous cost, which mean less patients being treated just for a greener energy. So, the whole thing is like the access of green energy fuel, we need to be already like onsite. Or in the country nearby. (2)

Although solar was considered the only realistic option by the respondents, discussion on other energy solutions has already started. For example, Global Shelter Cluster's (2019: 1) Environment Working Group discussed recently during their meeting about energy in humanitarian community and its importance, and called for further research:

> Energy is not just solar – what are the other options our there? (Global Shelter Cluster, 2019: 1).
>
> Research needed: Pros, Cons, Options, Value Chain (Global Shelter Cluster, 2019: 1).

Overall, renewable energy sources were considered appealing alternatives because humanitarian community was described starting to be more and more environmentally conscious when it comes to logistical activities. One cold chain expert compared humanitarian sector following commercial side a little bit behind, partly due to funding challenges. Yet, the developments made in business supply chain are possible to implement also in humanitarian settings, which was explained by the cold chain expert:

> The humanitarian sector is a little bit, you know, like the analogy sector and the digital world. Especially when it comes to supply chain related things. (5)

Several prerequisites were pointed out to be ensured before renewable energy sources could be implemented wider in emergency medical cold chains. For instance, the proof of reliability and stability of new energy source ought to be available as well as local access to spare parts in case the equipment breaks. The functionality and practicality were described to be pre-thought carefully, and guidelines of using different renewable energy sources should be available before further implementation. This is mainly because sudden onset disasters are complex, and the cold chain requires stable power source, which is not given in emergency settings. According to one supply chain expert:

> You don't have the luxury for green. Because you don't even have the resources to do the basics. If something is green itself, we will use, whatever it is on hand. But it needs to be pre-thought. You don't think about green in emergency. (2)

Based on the results, it can be concluded that the process of using RES in emergency HMCC is not established at all, in contrast to current diesel-based solution. However, the awareness has increased, yet the required resources influence on which logistical activity may use RES and which not. The issue with available and needed resources was strongly highlighted by the respondents when it came to current energy sources and replacing them with RES. The next sub chapter reviews this topic more in detail and presents the findings of which cold chain activities RES could be feasible and whether that impacts the actors currently operating in the emergency setting.

4.3.2 Resources

Despite the environmental benefits emerging from increasing the use RES, internal and external resources were considered as defining how and with which energy source the HMCC would be managed. For instance, all respondents did acknowledge the longer-term environmental benefits emerging from usage of renewable energy sources in emergency HMCC. However, financial and knowledge resources define whether RES is feasible to use in which cold chain activities, and to which extend the local capacity is strong enough to use RES.

4.3.2.1 Actors and activities with RES

When asking about in which supply chain node the respondents would use renewable energy source, emergency settings were not emphasised. Instead, the more stable humanitarian operations were acknowledged, because the biggest environmental savings was indicated to be achieved in capital levels in big warehouses. This was illuminated by a supply chain expert:

> I would always start where it's the most stable, you know. So, yeah, in the capitals, and for me it's... Even if it could make sense to have it out in the rural area, I think still we need to start where we have the most access to fix things. [...] And that's where you have the biggest effect as well. (1)

Nevertheless, the respondents did provide insights where RES would be feasible to use. According to the respondents, among all renewable energy sources, solar would best be used to power either the generators or providing energy to the electric grid in the field. The solar panels would be installed on top of the roof of the warehouse, or next to it in case the set-up warehouse was more fragile. For instance, one cold chain expert described an innovation of inflatable cold storage unit, which receives the power through solar panels installed next to it. Likewise, several cold chain guidelines instructed how solar panels are to be installed and how the power is generated to the refrigerator or freezer. For instance, a guide by GAVI (2018: 11) noted that:

> Solar panels can be mounted on either the roof of the facility, if strong enough and receives adequate sunlight during the day, or on a separate mounting pole (GAVI, 2018: 11).

However, a general overview by the respondents was that during sudden onset disaster, time is of essence, as one respondent put it:

> In an emergency, you don't have time to set your solar panels. You just go with fuel. (2)

In addition to time, a general perception among the respondents about renewable energy sources was that extra workload would be needed, or the local technological knowledge to maintain solar powered equipment is not high enough. Therefore, extra resources from the headquarter would be needed for training, although, should the renewable energy be implemented on capital-level warehousing, more resources to train staff might already be available. This was explained by interviewee:

> Because these are new technologies, you might have lesser staff available to maintain it. (4)

In addition to extra competence needed, there is a lack of information about the sustainability in general as well financial factors that influence on the actors' choices of using RES. For example, one respondent noted that merely environmental reasons are not enough to get RES implemented into emergency cold chains, but the cost-efficiency needs to be proven also:

> It's always better to have something which is more sustainable. [...] Just for environmental purposes, it will be good, but I'm not sure you will convince that many people to change what is already in place. (2)

As the responses presented above indicate, actors influence highly on the cold chain activities and whether RES is considered a feasible power source in emergencies. Yet, it was emerging several times from the data that the environmental awareness is increasing among humanitarian community, although several barriers hinder the wider implementation. The next chapters discuss more in detail the findings concerning the overall sustainability in emergency HMCC and concludes with the opportunities and barriers of increasing the use RES in HMCC.

4.4 Sustainability awareness towards emergency HMCC

Sustainability was perceived by the respondents as a holistic topic that takes the environment and climate change mitigation into consideration, includes long-term sustainability with non-polluting activities with waste management and energy-efficient activities with green energy choices. However, environmental sustainability was generally not considered being included in emergency responses, as was illuminated from the following responses:

> I think in emergencies, sustainability is not prioritized. (1)

> There's none. You are efficient and that's it. If it's an emergency setting, you don't have time to think. You do that it works. You clean up afterwards, but you just ship. It's a matter of the first few days of the response. So, you will not be green. You're efficient. (2)

Similar views also reflected the respondents' view on the importance of medical cold chain in emergency settings. If medical cold chain in emergency settings was considered merely part of the overall response, the emphasise on sustainability was not highlighted by a respondent. For example:

> Our main goal is to save lives, and we cannot make solutions, we cannot think sustainable or green values if it means that our operation will slow down or become more difficult, resulting in people dying. That is not an option. (3)

All respondents highlighted the reliability and practical functionality needed to be well in place and established before using renewable energy sources in medical cold chain or before thinking about the environmental impact of the operation. However, three respondents noted, that even though sustainability is not prioritized in cold chains in emergency operations, it is extremely important and should be addressed more strongly, especially when considering the longer-term environmental impact.

> I think it's very important. [...] If you are not, kind of, trying to have a sustainability scope, like teaching the staff of how the international experts are doing now and managing the resources, and when all this international staff leave, you may end up with a massive project and not really staff being able to manage it. Because you would not have a sustainable scope like of saying, okay, let's make it like long-term being maintained by the local staff as well. (4)

Similarly, the connection between climate change and unsustainable humanitarian activities was highlighted, which was explained by one cold chain expert:

> Climate change induce this displacement and disasters increasing our work every single day. When we contribute to these things ourselves, by continuing to use unsustainable sources of energy, we're shooting our own responses in the foot. And we're creating, you know, we're helping to contribute to the creation of these things. (5)

According to the respondents, transformation towards RES powering HMCC has already begun, and all respondents gave examples of pilot projects, mainly regarding solar power in more stable operations and projects. Although, one respondent noted that the emergency medical cold chain would be more resilient if powered by renewable energy sources:

> I think, when you talk about renewable energy, I think it's really important as well to mention, that in a many crisis settings whether from in barter reasons or people stop trading or it's insecure or you know, fuel can be used for bombs so its regulated by the government, you know. You don't have always sustainable access to fuel, and by finding, you know, some alternative solutions, you actually make the response more resilient. Not just about the environment, it's also about, you know, supporting the response to be able to exist despite the crisis. (5)

The perceptions of renewable energy sources in humanitarian context can be divided two folds: emergency response and longer-terms operations. In emergency response, medical cold chain comprises small volumes, whereas longer-term operations include bigger volumes with development projects and vaccination campaigns. Generally, the biggest impact on environmental sustainability was seen to be in the more stable, long-term operations, whereas sustainability is not currently prioritized in emergency operations, despite the longer-term implications towards environment and communities.

4.4.1 Opportunities of increasing the use of RES

All respondents acknowledged that the use of renewable energy sources, mainly solar power, has gradually been increasing among humanitarian community, although, it was noted that we are not fully there yet. Due to the increasement of environmental awareness, several pilot projects with new innovations are already taking place, as one respondent described:

> Environmental awareness is becoming stronger and stronger. [...] There are today much more groups working with this to really find new ways of finding better solutions. (1)

Likewise, a guideline by WHO and UNICEF (2015: 7) remarked that before implementing new technology, adequate evaluation and pre-studies should be conducted to avoid any unnecessary risks:

> Introducing solar vaccine refrigerator or freezer systems will involve significant adjustments to cold chain operations and maintenance, requiring planning, budgeting, logistics and staff training. Conducting a pilot project can provide invaluable insights into how best to prepare for the transition, including more precise planning and budgeting information, staff preparedness and familiarity with the new technology. (WHO & UNICEF, 2015: 7)

Following the two above-mentioned statements, one respondent highlighted the collaboration with private sector as well seeking for best practices and innovations that have been tested in the commercial side, representing the more stable settings before implementing the innovations to emergency response operations. However, as the organisations' operations rely purely on funding, external pressure and influence from donors and hosting governments were highlighted:

> It costs more to build a solar farm than to supply a generator. And then donors need to recognize this and give, allow us the flexibility and with a little bit more funds, if they view that as a priority. (5)

> It needs to be pushed from the donors and sponsors. Because they demand cost-effectiveness from us. (3)

The longer-term economic benefit was also emphasised as financials act key factors in humanitarian organisations' operations, as one supply chain expert highlighted.

> A lot of these solutions have economic benefits, and that will always be the strongest driving factors. (1)

It was also noted that economic dimension might be the strongest driver, yet it also hinders the increased of use RES owing to the costliness of equipment. Similarly, two cold chain experts noted that the pricing of solar-powered equipment has drastically decreased over the years and will most likely continue to become cheaper.

> We are seeing the prices coming down, for the solar powered equipment as more suppliers come into the market. (6)

> I think that there's been of, as things have developed over the last few years, especially the pricing has drastically decreased for things like solar. You know, even five years ago the price was so much higher than it was for solar panels and things like this. (5)

Renewable energy sources were also seen contributing to the building of local markets, which continues also after the immediate emergency response. Overall, the link between emergency phase and rebuilding phase was noted by the respondents as an opportunity with RES. For instance, the fridges and freezers needed for cold chain management are donated to the local community or local actors once the emergency has subsided. Therefore, the local staff would already know how to use the equipment to run the health facilities. As one respondent explained:

> Maybe renewable energies may not be perceived as priority. But I think, if it's not a priority, it's a responsibility. [...] The emergency thing is to take care of the people and provide health services. But with the maintain of wastage, and you need to manage that. So, think it is the same: if you're not applying renewable energy sources, you may end up with a lot of wastage with a lot of struggles, so you will not be able to maintain the long-term process because it's very costly. So, yeah, even if it's at first side it's difficult to see, I think, in the mid long-term, you have a big impact. (4)

Following that statement, another respondent noted that if renewable energy sources were implemented already in the emergency phase, the countries can spur the knowledge to the rest of the area, which can encourage other nearby communities and countries to become more progressive and sustainable, and to invest more in new, sustainable equipment. Similarly, some actors might opt to keep the donated, prefabricated health facilities and equipment running and build it further as a more permanent facility. Therefore, the energy choices made already in the emergency phase influence the longer-term environmental sustainability of the area.

> You know, like, luckily, when it's a crisis ends, you know, with they should be able to use those to help rebuild back their health system. Strengthen their health system. (5)

Similarly, the Global Shelter Cluster's (2019: 1) Environment Working Group acknowledged that health system acts as entry point to providing energy at a larger scope:

> An example – cold chain operation, needs energy but some of the energy generates can be used by/shared with other (Global Shelter Cluster, 2019: 1).

4.4.2 Barriers of increasing the use of RES

Despite the many opportunities and benefits emerging from increasing the use of RES in emergencies, several barriers were raised by the interviewees. The most often mentioned barrier was the extremely challenging and volatile settings, which characterises sudden onset disasters, and secondly the funding. Among these barriers, the reliability and functionality of stable power supply was emphasised to be ensured and informed before further sustainability considerations could take place.

> We need, first of all, ensure the running of activities, and we are not working in very easy environments. I think that's the biggest barrier. (1)

Following this statement, another respondent stated that the current technology is not advanced enough to power a whole health clinic or field hospital but could be used for lighter needs.

> Generating electricity fast, temporarily and cost-effectively with renewable energy sources, with other equipment than diesel generator that provides enough power for the whole field hospital in a matter of minutes... Those solutions do not exist yet. (3)

In comparison, a guide by WHO (2017b: 2) remarked that new technologies generating enough power do exist, for instance replacing solar energy batteries that were not efficient enough:

> A new approach to solar refrigerator design has emerged, eliminating the need for expensive (and problematic) energy storage batteries used to power solar refrigerators. SDD technology uses solar energy to directly freeze water or other cold storage material and then uses the energy stored in the frozen bank to keep the refrigerator cold during the night and on cloudy days. These appliances include refrigerators, water-pack freezers and combined refrigerator water-pack freezers and are called solar direct-drive because they are wired directly to the solar array. (WHO, 2017b: 2)

The funding was also viewed as one of the barriers, as solar powered equipment costs more than fossil fuel-based generators. Although, two respondents mentioned that the prices have drastically decreased over the years, and will keep on decreasing continuously, therefore contributing to the driving forces of using RES. Nevertheless, more resources were presumed to be needed to maintain, fix, and train people, which also equals more financial resources needed.

As mentioned, the local country's capacity to use cold chain technology in emergency, and in the longer-term perspective, was considered a barrier. In addition, the regular maintenance and the knowledge to maintain the equipment was considered a barrier, in addition to the risk of equipment being stolen.

> Things like solar panel often get stolen. In some of the resource constraint countries. Because it's a valuable commodity. (6)

Interestingly, the barrier of people was mentioned as not everybody is keen on trying new things nor they have the information of whether an alternative solution is better and whether it will work on even the most extreme settings, despite that the environmental awareness was also acknowledged being increased among humanitarian community. The people who might hinder the use of RES were indicated to be both the logisticians in the field as well as the senior management who do the higher-level decisions. This was also reflected to the agencies' mandates, prioritizations, and financial resources and budgeting, which was summed up by one respondent:

> If I'm going to tell my country officers to buy this inflatable cold chain unit [powered with solar energy] right now, I'm going to advise them to purchase the generator version. Not because I don't think the solar version is great, but I know that we are so strapped for financial resources, and its significantly cheaper. So, it's, you know, finances and prioritization among different organisations. (5)

In emergency situations, the equipment and supplies are needed extremely fast in the field, and the response's effectiveness and environmental sustainability is a trade-off. A decision may be against a known solution that can be set up extremely quickly, instead of more sustainable option that takes more time to install. In other words, it's a balance and regular communication between actors and the pros and cons of each logistical activity need to be wisely evaluated.

> So, if you have an emergency response. It's always a balance between, like I said earlier, getting the equipment out there as soon as possible. The cost involved. But also, the sustainability of the solution. So, if you are sending a mains refrigerator out there powered by a generator, that's something that's pretty easy to get up there. But in terms of longer-term sustainability, that's maybe not the best solution. (6)

Another interesting aspect was new innovations regarding medicines and vaccines. Two respondents mentioned that many manufacturers are currently studying temperature-stable vaccines that would not need cold chain. Once the products would be affordable and used widely, it would impact the whole cold chain management's effectiveness in emergency situations. Although, new innovations in drugs would not reduce the need for temperature-controlled cold chain, i.e., cold chain between 15-25 degrees, yet more effort should be put into that field of study of these new innovations, as one respondent summarised:

> So there's not a lot of money being put into make these drugs non cold chain, but we know that, at least, a lot of them could become non cold chain dependent, if there was science put into it and studies, but that's not prioritized today. (1)

The opportunities and barriers of increasing the use renewable energy sources in emergency medical cold chain are compiled in **Table 5** below**.** The findings show that the environmental awareness is increasing, however, not all experts agree strongly whether RES is feasible energy source for HMCC in emergencies. This owes to the concern of the required technical knowledge, needed resources, and the lack of evidence of its reliability. Nevertheless, RES was considered environmentally friendly and a desirable option with an opportunity to build the local markets. However, the needed funding for new cold chain equipment was seen the biggest barrier, especially, because stakeholders in general are not pressuring NGOs to address their environmental impact during emergency operations. In addition, the mindsets among NGOs and the humanitarians towards using RES in emergency settings was considered as a barrier, because the change from fossil fuels to RES starts partly from the inside of the organisation, and partly from stakeholders' pressure.

Table 5 Opportunities and barriers of increasing the use of RES

Opportunities	**Barriers**
Environmental awareness increasing	Mindset and lack of knowledge
Long-term economic benefits	Currently available resources
More efficient and resilient cold chain	Proof of practicality and reliability
Building local markets	Local capacity's competences
Environmentally friendly	Funding and lack of stakeholder pressure
Entry point to local community's rebuilding strength	Lack of technological knowledge
	Volatile disaster settings
Responsibility	

It is evident from the findings that the longer-term sustainability was emphasized by all the respondents. However, when discovering how strongly each respondent would increase the use RES, the responses varied. Emergency situations are complex, and there is no extra time available, therefore RES per se would not be ideal solution in emergency operations. On the other hand, cold chain management in challenging, risky and often not very sustainable in ad hoc situations, therefore, renewable energy sources offer an alternative for increasing the environmental sustainability, but also a broader and more effective aid response. For instance, one respondent noted that in the future, renewable energy sources can be used to power not only the cold chain, but also the surrounding area, therefore contributing to broader sustainability.

> What we will also start seeing, most probably, is where there will be a move away from individual equipment solarization, but more towards a facility level solarization. Like, when we talk about the use of, let's call it mini grids, where it's either a small village or that is entirely solar powered. And then you would use a normal mains powered refrigerator to cool from that mains grid. Or the whole health facility is powered by solar panels. And then you get additional benefits of being able to cover other health related activities, or other economic activities inside the mini-grid area that can be covered as well. Not just cold chain related. (6)

5 DISCUSSION

Medical cold chain in emergency response is vital in the life-saving activities, and the cold chain management requires resources and energy to function effectively (Comes et al., 2018; Haavisto & Kovács, 2019). Due to unreliability of electricity in disaster situations, the cold chain robustness in emergency settings has for the most part been ensured by deploying refrigerators and freezers that are powered by diesel run generators (OCHA, 2010, Comes et al., 2018; Grafham & Lahn, 2018). Yet, they are considered extremely energy intensive (Halldórsson & Kovács, 2010; GAVI, 2018), contributing also negatively to climate change (OCHA, 2017).

Despite the humanitarian emergency response's significance in sudden onset disasters, the ad hoc operations' environmental sustainability has not been prioritized by the humanitarian community (Eng-Larsson & Vega, 2011; Haavisto & Kovács, 2019). Although, the concern of climate change and of humanitarian ad hoc operations' negative environmental impact has been increasing (Haavisto & Kovács, 2019). The change towards sustainable supply chain management has been seen in the commercial side (Seuring & Müller, 2008), and energy intensive activities have been addressed by increasing the use of renewable energy sources instead of fossil-based sources (Halldórsson & Kovács, 2010). Therefore, the aim of this study was to investigate the opportunities and barriers of increasing the use of renewable energy sources in emergency humanitarian medical cold chains in order to enhance the environmental sustainability of the operations, but also from the longer-term perspective. The following research questions were formed to answer the aim:

> RQ1: What energy sources are powering the HMCC in emergency operations?
>
> RQ2: How the increased use of RES in emergency HMCC is seen from the perspective of environmental sustainability?

5.1 Sustainable emergency medical cold chain

As Kovács & Spens (2007) remarked, humanitarian operations often take place in complex and volatile settings, which poses challenges to the supply chain management, including cold chain (Comes et al., 2018). Kovács & Spens (2007) distinguished emergency response from regular aid relief, and the findings indicated that despite sudden onset disasters are widely covered in the media, the regular aid comprises the majority of all humanitarian operations (Gustavsson, 2003; Kovács & Spens, 2007). This also reflects van Wassenhove's (2006) disaster categorisation to sudden and slow onset disasters. The findings supported academic discussion, which indicated sustainability being included in slow onset disaster responses and development aid relief. It was emerged from the findings that emergency response to sudden onset disasters is considered too uncertain and risky environment to implement environmentally sustainable operations.

Though, the global concern for climate change has forced NGOs to evaluate their operations' sustainability, and renewable energy sources, mainly solar, has been suggested to replace fossil fuels. Yet, following Elkington's (1998) framework of sustainability, the findings showed that the economic dimension is the driving factor when concerning increasement of sustainability within humanitarian operations. No new technology nor more expensive equipment will be used unless the cost-effectiveness has been proven beforehand. Therefore, green guidelines and data from the field need to be available for humanitarians to design their emergency medical supply chain more environmentally sustainable. Similarly, Lee and Zbinden (2003) noted the preparation phase in disaster management being extremely vital for efficient response.

However, the question of why the emergency medical cold chain's sustainability should be enhanced is arguable. Based on the empirical results, it clearly divides opinions among humanitarian community. Sustainability in general is considered important and something to go towards to in emergency HMCC, however, the findings suggest that attitudes to implement new technologies is polarized among humanitarians. Others acknowledge more strongly that climate change mitigating actions need to be implemented already in response operations by using renewable energy sources as unsustainable cold chain management has also harmful longer-term implications. On the other hand, others seemed to be more sceptical about the current technology's reliability and feasibility to be included in cold chain management in emergency settings. The findings and the current literature follow both van Damme et al.'s (2002) and Haavisto and Kovács' (2019) view that sustainable dimension would be included broader in emergency operations if it didn't hinder the goal of saving lives, and it is proven to be easy to set up and functional.

However, sustainable emergency medical cold chain is considered as a responsibility of the humanitarian organisations. Once the disaster shifts towards more stable settings, the responsibility of sustainable reconstruction gradually moves from NGOs to local communities. Therefore, the sustainable solutions advocated already in the emergency phase have valuable implications for local capacity-building (Macrae et al., 1995; Haavisto & Kovács, 2019). For this, renewable energy sources provide a feasible option, not only in the response operation but also for rebuilding phase. However, the importance of medical cold chain in emergency settings is not unambiguous, as some responses and public guidelines still advocate using traditional power sources for cold chain, because they have been proven efficient in emergencies. Yet, a change of mindset to overcome the issue of uncertainty by searching reliable and more sustainable solutions is gradually emerging among humanitarian community. In addition, environmentally sustainable cold chain has a possibility to help local communities to prosper after the sudden onset disaster.

5.2 Renewable energy sources in emergency medical cold chain

Research question one was formed to answer what energy sources are powering the HMCC in emergency operations. The emergency humanitarian medical cold chain is, currently, widely powered by diesel generators. This is due to the established process, known technology and cost-factors. However, the most viable energy solution would currently be either mains or solar energy, or a mix. This indicates that, though, diesel generators are being widely used (Logistics Cluster, 2015a), the experts generally would prefer other solutions. Yet, at the same time it was emphasised that the current solutions are proven to be functional and no new technologies should be used before proven efficient.

However, should the environmental aspect be considered stronger, solar power was seen the best option. Often, electricity from grid is not reliable, and the energy to the grid can be provided by fossil-based power plants, such as coal. Also, diesel-based generators are unsustainable, and the fuel dependence inflicts challenges for stable power supply. When looking purely the environmental perspective, solar energy is currently the most viable one among all the renewable energy sources, because most of the operations occur in geographically sunny locations. Furthermore, solar energy itself is free, no running costs would be needed, the equipment would be non-dependent and more resilient in the longer-term, and the technology is most advanced regarding solar powered equipment compared to other RES options.

5.2.1 Actors and activities

If more solar energy was included in emergency medical cold chains as the energy source, the roles of the government and donors would grow. Similarly, Oloruntoba and Gray

(2006) noted the importance of collaboration with funding sources and other stakeholders in humanitarian operations. As Seuring and Müller (2008) noted, one of the biggest triggers to increase the sustainability is the pressure from stakeholders, which was heavily supported by the respondents.

The findings showed that should the pressure come from the funding partners and from the government to demand more environmentally sustainable activities, the humanitarian organisations would be pressurised to start investing and using more cleaner power solutions, similar to Comes et al.'s (2018) and UNITAR's (2018) views. However, the responsibility of having sustainable operations should not rely purely on donor's shoulders, but humanitarian organisations are encouraged to be proactive and promote the benefits and implications derived from using renewable energy sources in their cold chain management (Ashok et al., 2017). However, the findings noted that some people are more engaged and want to be proactive, whereas others are more reactive.

In addition to the collaboration with government and donors, the technical referent's role would grow, as clear guidelines would need to be drafted due to the more complex installation and maintenance of the solar powered equipment. Also, more training to both the headquarters' logisticians and to the local staff would be needed, reflecting the need to have more funding earmarked specifically to sustainable operations (Ashok et al., 2017; Comes et al., 2018). Reflecting the academic literature and the findings, it was clearly seen that the problem owners of this topic are humanitarians but also their stakeholders concerning the planning and immediate response phases (Kovács and Spens, 2007).

The findings indicate, that should the energy be replaced to solar energy, the energy intensive nodes would remain the same and those would also be the nodes where the risk of cold chain breach is at the highest. These nodes would be the entry point and the in-country warehousing. However, the results also showed health equipment acting as an entry point to energy supply to the whole community, following the academic discussion (see, e.g., Gibert, 2008; Eng-Larsson & Vega, 2011; Meduri & Ahmed, 2016; Haavisto & Kovács, 2019). This would also widen the energy intensity concerning the whole local community, making the beneficiaries the problem owners in the reconstruction phase (Kovács and Spens, 2007). If the energy was derived from solar, and the needed equipment would be used in the rebuilding phase, the energy hotspots would also transfer from warehouses to the beneficiaries' community, as the solar energy could be used to power the whole area. This would strengthen also the longer-term economic and social aspects, as less continuous humanitarian aid would be needed, and the community would be able to rebuild the area in a resilient manner. Also, the available energy would provide energy to several activities within the community, such as cooking and lighting, therefore addressing for example famine or children's possibility to go to school. Hence, **Figure 8** below compiles the actors and activities needed in the emergency HMCC should RES be used. It also addresses the environmental implications on the right-hand side by widening the energy intensity involving the local community instead of only the health facility. This also answers the RQ2, which is discussed further in the next sub-chapter.

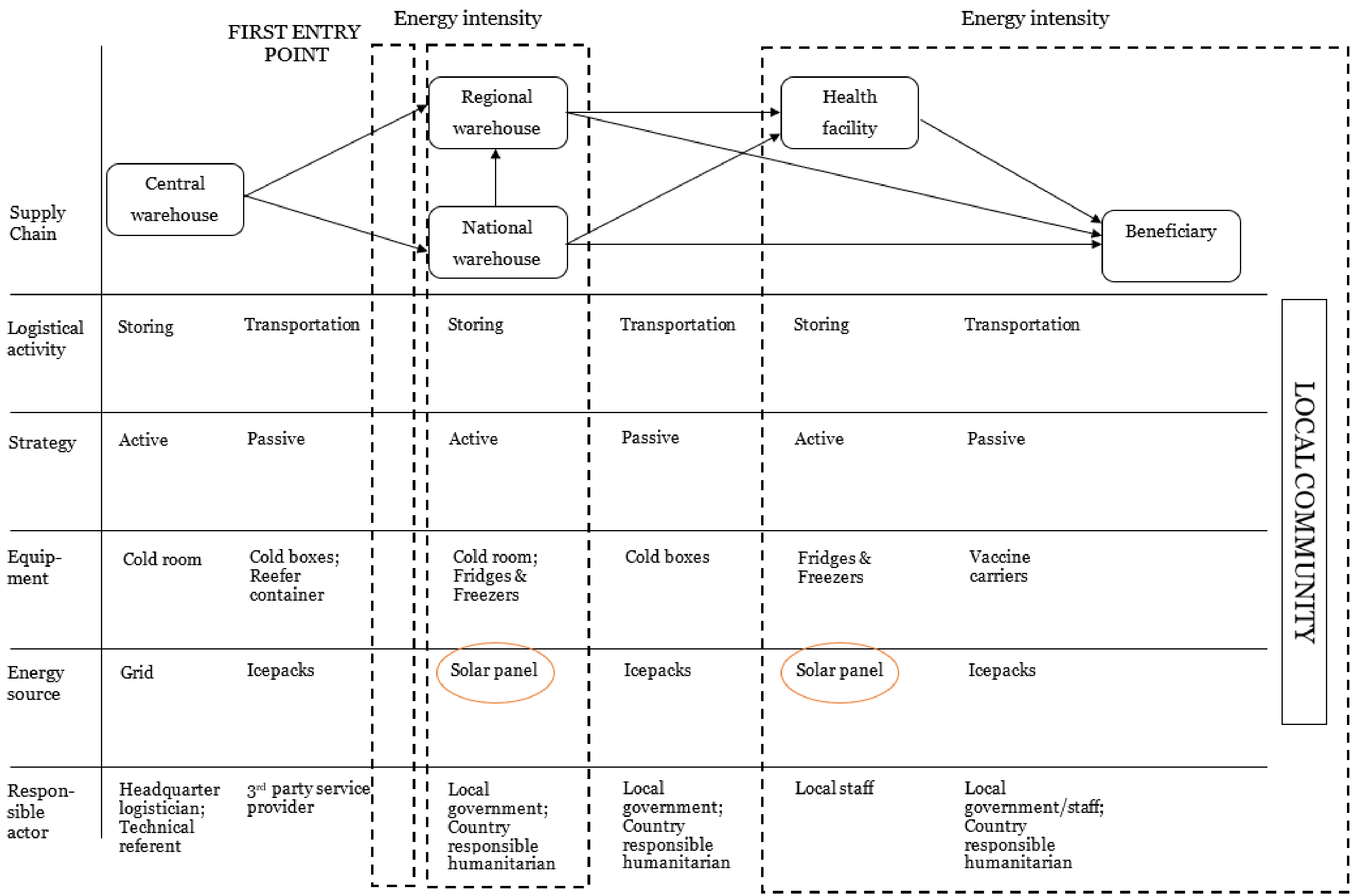

Figure 8 **Typical actors, activities and energy sources of increased use of RES in emergency HMCC**

5.2.2 Environmental sustainability of increased use of RES

The *second research question* was formed to answer how the increased use of RES in emergency HMCC is seen from the perspective of environmental sustainability. Following the framework by Håkansson & Snehota (1995), the environmental implications of increased used of RES are influenced by the relationships of the actors, activities and energy sources. The key finding of the implication of increased use if RES in HMCC is that the countries affected by a disaster benefit for humanitarian investments once the immediate crises has passed. Though, the link to the rebuilding phase is not prioritized by everyone due to the sole goal to save lives and funding issues (Haavisto & Kovács, 2019), the environmentally sustainable cold chain allows the local governments to rebuild and even strengthen their health systems after the crises. This creates healthier and more sustainable community that is not necessarily reliant on external aid.

However, the findings showed that no specific examples were provided of how the increased use of RES would contribute to environmental sustainability. Instead, the answers remained on a general level, and focused more on the cost-effectiveness and possible social dimension's improvement (Elkington, 1998). This reflects to the finding that sustainability is unprioritized in emergency operations as Haavisto and Kovács (2019) and Eng-Larsson & Vega (2011) noted. Also, the findings suggest that the value creation for stakeholders promoted by Christopher (2011) follows the quantitative performance measurements (Beamon, 1999; Gunasekaran et al., 2004), therefore excluding the broader sustainability dimension. Despite the researcher's attempts to gain practical and specific examples, the practice in humanitarian emergency operations seems to be behind of the theory of sustainable supply chain management considering the environmental perspective. Although, already implemented sustainable practices in steadier operations suggest that sustainable emergency medical cold chain is under development, but not yet strongly established.

5.3 Barriers and opportunities of increasing the use of RES

The biggest barrier of increasing the use of RES is resources, including funding and technical knowledge. Also, the humanitarians and local staff's lack of knowledge regarding RES hinders the use of more sustainable energy sources. These barriers are seen in the preparation phase (Kovács & Spens, 2007), and in the energy intensive nodes in first entry points, regional and national warehouses and in the local community in emergency HMCC (**Figure 8**).

As Oloruntoba and Gray (2006) noted, donors and other stakeholders do not demand NGOs to implement sustainable activities if the benefits are not known or evident. Similar view can be seen in general cold chain management guidelines, as others promoted the use of traditional diesel-powered generators for cold chain robustness (see, e.g., WHO, n.d.; GAVI, 2018), whereas others remarked stronger the benefits of solar powered equipment (see, e.g., WHO & UNICEF, 2015; WHO, 2017b). In general, humanitarian organisations should be offered more data from the field, so the proof of stability can be understood better in emergency settings.

A clear opportunity of renewable energy source is that it does not pollute the environment, therefore is not contributing negatively to the already fragile environment after the disaster (Eng-Larsson & Vega, 2011). Also, depending on the disaster, solar energy offers more robust power supply, which flows through the HMCC from central warehouse to the beneficiary in **Figure 8**. For instance, in case of flood, a risk of disease outbreak is high (PAHO, 2001), yet the situation often does not allow the use generator, or the fuel supply is difficult due to the flooding. In cases like this, solar energy mitigates the spread of disease and more patients can be treated owing to steady power for cold chain equipment.

Also, the results of this study suggest the humanitarian organisations' responsibility to promote healthier lifestyle and more sustainable rebuilding. Similar to remarks by OCHA (2010), McCarney et al. (2013) and Robertson et al. (2017), the findings also identified the link of emergency phase and reconstruction phase, and how the learned skills to maintain solar powered cold chain equipment in the emergency phase can spread the knowledge even further of the affected area. It does not embrace only more robust and environmentally sustainable cold chain, but stronger economy that advocates other mandates, such as gender issues, malnutrition, and children's and especially girls' rights for school. Also, the collaboration with governments and private sector in the local country would strengthen, as the energy would be decentralized and the spare parts and technological knowledge would be accessible locally (Halldórsson & Kovács, 2010; Halldórsson & Svanberg, 2013). This opportunity is depicted in the right-hand side of **Figure 8**, showing the energy intensity widening to the whole local community.

The awareness among humanitarian organisation about their activities' impact on climate change has increased, and organisations can mitigate their GHG emissions deriving from humanitarian operations. Communities in the post-disaster phase start to rebuild their economies, and these emerging economies continue to need energy.

Renewable energy sources offer affordable power solution for cold chain equipment, therefore the emergency response's impact to the community's longer-term sustainability increases. As was interpreted from the findings, emergency response goes beyond of saving lives, because it is humanitarian organisations' responsibility to ensure safe living also after the emergency. The findings also reflected the humanitarian community's discussion of health being an entry point to long-term environmental sustainability, hence the sustainable emergency medical cold chain is something to go towards to (Global Shelter Cluster, 2019). In the future, cleaner energy solutions would also decrease the need for regular humanitarian aid, which today comprises most of the humanitarian aid (Gustavsson, 2003; Kovács & Spens, 2007). Based on the connection between academic discussion and the findings, this study acknowledges the link between supply chain sustainability (left-hand side of Figure 9) and emergency HMCC (right-hand side of Figure 9). Hence, **Figure 9** amends this study's initial theoretical framework by acknowledging the actors, activities and implications of increased use of RES into a framework of sustainable emergency medical cold chain.

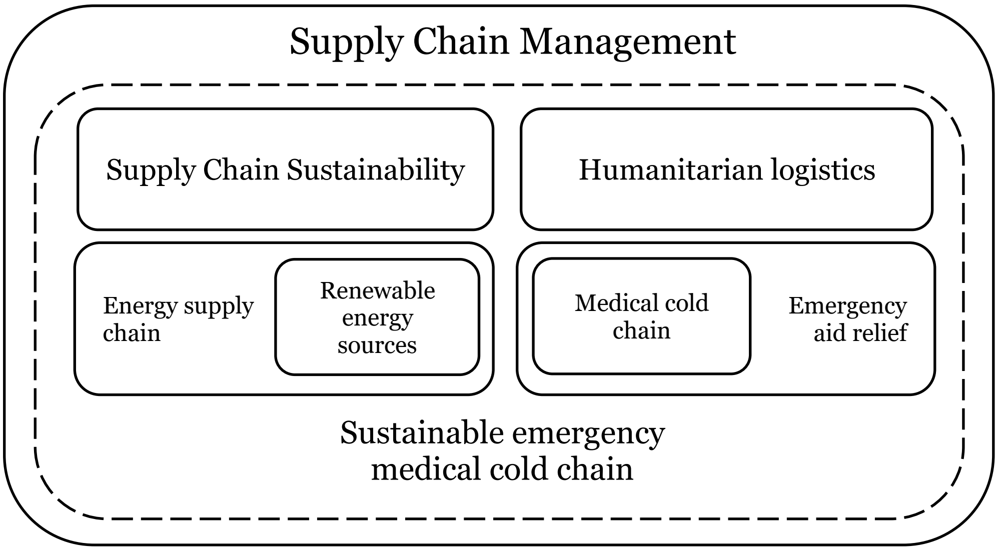

Figure 9 **Sustainable emergency medical cold chain**

5.4 Concluding remarks

The aim of this research was to investigate the opportunities and barriers of increasing the use of renewable energy sources in emergency medical cold chain to enhance the environmental sustainability of the operations and from the longer-term perspective. To answer RQ1, diesel fuel for generators is the widely adopted practice to power HMCC in emergency response operations due to already established guidelines and practices, as well as local countries' capacities. However, electricity and solar energy for powering cold chain was advocated over diesel generators, indicating the transition phase is happening among humanitarian community. Yet, the infrastructure in emergencies is challenging, and the medical cold chain ought to be practical and reliable to ensure robust response and to reach the beneficiaries. Therefore, prerequisites are carefully evaluated when choosing the feasible energy source for cold chain.

Should fossil-based fuel be changed to RES, RQ2 was formed to discover how the increased use of RES is seen from the environmental sustainability's perspective. The findings were supported partly by literature as it was clearly indicated by both sources that sustainability is not prioritized in emergency operations, despite the extensive literature on sustainable supply chain on commercial side. However, environmental awareness is rising among humanitarian community, and the immediate and long-term sustainable benefits emerging from using more RES were acknowledged, according to the results. Yet, the lack of practical responses regarding environmental implications indicate that the change is happening, however, more research and evidence on the practicality and reliability for cold chain is needed to fully establish new ways of operating. To sum up, the biggest barrier of increasing the of the RES is the awareness and lack of resources because sudden onset disaster settings are volatile, whilst the strongest opportunity would be to rebuild the local community in an environmentally sustainable manner after the emergency.

5.4.1 Theoretical and managerial contribution

This study's contribution to research provides relevant insights of the perceptions of sustainability in emergency operations. Health activities act as entry point to enhancing environmental sustainability both in the response operations, similar to what has been seen in the commercial side (Seuring & Müller, 2008; Halldórsson & Svanberg, 2013), and in the community's capacity building in the reconstruction phase. Therefore, renewable energy sources used in emergency medical cold chain offers a feasible alternative for sustainability enhancement from environmental perspective.

However, this study was built on Elkington's (1998) triple-bottom line framework, adhering the environmental dimension. Yet, the results indicate that environmental sustainability is not prioritized in emergency operations, and the economic dimension would be the strongest, mainly due to funding and resource issues, which steers humanitarian organisations' operations. Therefore, the theoretical implication of environmental sustainability and its interlinkage to other sustainability dimensions calls for future research due to the limitations of this study.

As the theory review and the results of this research showed, the performance measurement lies strongly in the numeric metrics. Based on this research, managers in humanitarian organisation are advocated to extend the response operations' implication concerning the rebuilding phase. This could be established by promoting the importance of environmentally sustainable operations of medical cold chain to funding partners and stakeholders, and to investigate and draft green guidelines for using renewable energy sources in HMCC.

Also, employees need training for using new technology, therefore the stronger collaboration throughout the chain is recommended, also with private sector which may already possess relevant knowledge and technology. Although, this study acknowledges the hindering factor that no renewable energy source will be fully implemented within emergency operations without practical evidence from the field. Therefore, the managerial contribution is to consider using both renewable energy sources and current energy solutions simultaneously in emergency response. This provides back-up energy source, ensures the reliability, and leaves room for learning to use the technology. By adapting new technology in different stages of the sudden onset disaster response, a change towards fully environmentally sustainable energy usage can gradually start.

5.4.2 Future research recommendations

This study acknowledges its limitations to environmental sustainability in sudden onset disasters. The study showed the lack of resources and awareness being barriers of increasing the use of RES, therefore, further studies on the economic perspective is recommend conducting. It is also recommended to conduct studies on RES in emergency HMCC from the social perspective, as the longer-term implications were identified as key benefits of increased use of RES in emergency medical cold chain. These results would also provide proof and evidence of the reliability and practicality of renewable energy sources, which is today seen as a barrier. Also, this study is recommended to test by, for instance, investigating GHG reduction percentages by calculating both the actual GHG values and GHG reduction levels of various energy sources in similar response operations.

Finally, this study was limited to six interviews; hence the findings are limited to robust generalisation. Also, long-term humanitarian operations were excluded in this research's scope, despite that the respondents, in general, opted for RES being implemented in long-term operations over emergency response. The findings suggest that renewable energy sources would rather be used in steadier settings, hence the findings could have included more practical results should that have been within the scope. However, the gap in the literature and the results from interviews illuminated that despite environmental sustainability is not prioritized in emergency operations, the awareness is increasing. Therefore, the theoretical framework of this study was revised to a sustainable emergency medical cold chain, supported by the literature.

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APPENDIX 1 INTERVIEW GUIDE

General information

1. What is your position in the organisation?
2. How long is your experience in that position / related to medical cold chain in humanitarian emergency operations?

Humanitarian medical cold chain (HMCC) in emergency operations

3. Could you describe the medical cold chain process in emergency situations?
    a. Actors
    b. Activities that require energy.
    c. How does the nature of a disaster influence on your cold chain process?
4. What kind of medical supplies are deployed to disaster areas that require cold chain?
5. What factors influence on the strategy (passive or active) regarding medical cold chain processes?

Energy in emergency HMCC

6. Could you describe the current energy sources you have in the HMCC in emergency operations?
7. In which cold chain related logistical activities energy is needed the most?
8. What kind of benefits there are regarding the current energy sources?
9. What kind of challenges there are regarding the current energy sources?
10. What would be the most suitable energy solution in HMCC?

Supply Chain Sustainability (SCS) & Renewable Energy Sources (RES)

11. What does sustainability mean to you?
12. What are your thoughts about the sustainability in emergency HMCC?
    a. Environmental sustainability, especially?

13. How do you see renewable energy sources contributing to the environmental sustainability in emergency HMCC?

RES in HMCC

14. In which logistical activities in HMCC would you use RES?
    a. What kind of RES?
15. Could you describe the driving forces to increase the use of RES in HMCC?
16. Could you describe the barriers of increasing the use of RES in HMCC?

SCS & long-term sustainability

17. What are your thoughts about the importance of medical cold chain in emergency humanitarian operations?
18. How do you see the connection between emergency phase and reconstruction phase in terms of environmental sustainability?

Other

19. Do you have anything you'd like to add?
20. Is there someone I should be speaking with?
21. Are there some reports/written material I should read?