CARBON FOOTPRINT OF HUMANITARIAN SHELTER: A CASE STUDY OF RELIEF AND CONSTRUCTION MATERIALS USED IN HAITI

by

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DECLARATION

This work has not previously been accepted in substance for any degree and is not concurrently submitted in candidature for any degree.

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DEDICATIONS

To Julie, an amazing tutor and supervisor having that special knack to pin point the issues and providing the most helpful feedback.

To Susan, who managed to turn something 'ok' to something 'wow'.

To Cherry, who has been a willing surrogate aunty.

To Gethin and Anwen, for being very patient while mummy is doing homework.

And, most of all, to my wonderful Duane who has made this past year all possible.

ABSTRACT

The recent increase in the frequency of extreme weather events, such as droughts, floods, and hurricanes, can be linked to the phenomenon of global warming. The frequency of natural disasters has quadrupled since 1975, disproportionately affecting communities in developing countries, which are more vulnerable and less resilient to disruptions. The question arises as to what the humanitarian industry is doing to ensure that its own practices are not contributing to global warming. To what extent are humanitarian practices contributing to the weather-induced disasters that affect the very people they are trying to help? This thesis looks at the humanitarian industry's environmental sustainability and possible ways to reduce its carbon footprint, with a focus on emergency shelter in post-disaster situations. The study draws on a combination of qualitative and quantitative methods including a literature review, interviews, a life cycle assessment of emergency shelter materials and a case study. The findings of the qualitative study indicate that environmental sustainability issues are gaining prominence in the humanitarian industry, but much is still to be done to mainstream sound environmental practices. Focusing on the embodied carbon of typical shelter materials, the study attempted to quantify the amount of carbon emitted by the humanitarian industry in the provision of emergency shelter after a natural disaster. The 2010 Haiti Earthquake operation was selected as a case study and the total embodied carbon of shelter materials used in the Haiti Earthquake response was estimated at 199,737 tCO_2e, which is nearly equal to the annual emissions of the host country. Most importantly, the analysis found that opportunities exist throughout the life cycle of a material to reduce carbon emissions.

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ACRONYMS

BRE	Building Research Establishment
CGI	corrugated iron
CCCM	Camp Coordination Camp Management
CGS	corrugated steel
EC	embodied carbon
EE	embodied energy
FAO	Food and Agriculture Organization
FSC	Forest Stewardship Council
GGBS	ground granulated blast furnace slag
GHG	greenhouse gas
GRRT	Green Recovery and Reconstruction Training
HDPE	high density polyethylene
IASC	Inter Agency Shelter Cluster
ICE	Inventory of Carbon and Energy
ICRC	International Committee of the Red Cross
IFRC	International Federation of Red Cross and Red Crescent Societies
ILCD	International Reference Life Cycle Data System
INGO	international non-government organisations
ISO	International Organization for Standardization
IOM	International Organisation for Migration
IUCN	The World Conservation Union
LCA	life cycle assessment
LDPE	low density polyethylene
OCHA	Office of the Coordination of Humanitarian Affairs
PE	polyethylene
PET	polyethylene terephthalate
ppm	parts per million
QSAND	Quantifying Sustainability in the Aftermath of a Disaster
UK	United Kingdom
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

UNHCR	United Nations High Commission for Refugees
UNICEF	United Nations Children’s Fund
UNOPS	United Nations Office for Project Services
USA	United States of America
USAID	United States Agency for International Development
WFP	World Food Programme
WHO	World Health Organization
WT	wall thickness
WWF	World Wildlife Fund

CHAPTER 1. INTRODUCTION AND STUDY QUESTIONS

RATIONALE: ACCOUNTABILITY FOR HOLISTIC SUSTAINABILITY

Extreme weather, such as droughts in Australia, floods in Pakistan, and typhoons in the Philippines, can be attributed to the phenomenon of global warming (Wernstedt and Carlet 2012; Anderegg et al. 2010). Although there is much debate on the cause of global warming, the fact remains that concentration levels of carbon in the atmosphere are rising exponentially (NOAA 2014). Between 1975 and 2005, the frequency of disasters quadrupled (World Bank 2006). From 1995 to 2005, 90% of these were attributed to weather-related natural hazards. Of these, 98% of the affected populations were in developing countries (IFRC 2005) where communities are more vulnerable and less resilient to disruptions.

With natural disasters growing more frequent and more intense, the demand on international aid continues to mount. Excluding conflict-induced disasters, from which the United Nations High Commission for Refugees (UNHCR 2012) estimates there are over 15.4 million refugees worldwide, humanitarian shelters could be home to a population similar to that of Ecuador or Istanbul. Figure 1 shows that between 2008 and 2012 over 120 million people had to leave their homes due to weather related disasters, more than 5 times the amount of people affected by geophysical hazards. The question arises as to what the humanitarian industry is doing to ensure that its own practices are not contributing to global warming? To what extent are humanitarian practices contributing to the weather-induced disasters affecting the very people they are trying to help?

Non-environmental concerns drive decision-making in the humanitarian industry (Abrahams 2014), which is heavily governed by political, logistical and economic constraints with a focus on the preservation of human life and preventing communicable diseases. Although these issues are important and should remain the primary focus, the humanitarian industry has evolved to the point where it should be accountable for holistic sustainability, particularly given that initial decisions after a disaster can have wide-ranging and long-term effects on the recovery of the environment, economy and society of the country receiving assistance (Johnson 2007b;

van Aalst 2006). One element of the sustainability model that has been neglected or given a low priority is the environment. There are numerous examples where ill-judged responses have had wide reaching, long-term environmental effects (see examples 1 and 2).

Example 1: Haiti Earthquake, January 2010

Typical of other disaster responses, aid agencies distributed plastic sheeting as emergency shelter in Haiti. Structures to erect the plastic shelter, such as poles, are normally procured locally by beneficiaries. While this may be an economical measure for the aid agencies, it led to the exploitation of small trees from the already diminished Haitian forests (Wilde and Solberg 2010), further degrading the top soil, causing slope instability and threatening settlements with landslides. About 12 poles were needed to erect each shelter, for which an estimated 40 to 60 km² of forests were destroyed (Navaratne 2010). Distribution of timber poles sourced from responsible sources would have alleviated the demand for local timber and avoided further life-threatening scenarios.

Example 2: Turkey Earthquake, 1999

In Düzce Turkey, different temporary housing designs were used to house the affected population for a number of years until permanent housing was available. Models requiring a concrete slab foundation left settlement camps with debris and a sense of permanence, and the land was left desolate and undeveloped for years after the population had been permanently housed elsewhere. Temporary housing that is easy to dismantle for reuse and recycling can help raise funds for agencies and ensure that the land is quickly returned to its previous use or available for redevelopment (Johnson 2007a).

How environmentally considerate a disaster response operation is can determine the long-term recovery and resilience of an area. Carbon emissions have global impacts and profound localised effects, which often affect the most vulnerable communities – the very communities that the humanitarian industry strives to protect. This study hopes to be a positive contribution to the growing knowledge of environmental sustainable responses in the humanitarian industry by suggesting ways to reduce emissions. It is hoped that these reduction measures, possible solutions and examples are integrated into humanitarian guidelines and operational handbooks on best practices.

STUDY QUESTIONS

Although the issues and discourse within humanitarian shelter are complex and challenging it is important to examine the impact that the choice of materials typically used in the response and recovery phases of a disaster has on the global atmosphere. This study will explore the embodied carbon of shelter materials through a life cycle assessment (LCA) of the materials typically used at the different stages of disaster response. Designs used in the 2010 Haiti Earthquake will be modelled for the temporary and recovery shelter phases. This study aims to quantify which shelter materials used during the Haiti disaster response had the greatest carbon footprint and suggests ways to reduce this.

The main question that this study attempts to answer is:

> What is the embodied carbon (EC) of shelter materials typically used by the humanitarian industry at different stages of a disaster response operation and how can this be reduced?

In answering this main question, the study also looks at the following questions:

- What are current attitudes in the humanitarian industry and among practitioners regarding the environmental sustainability of humanitarian aid practices?
- How has environmental sustainability been mainstreamed into disaster response operations by the humanitarian industry and how can this be improved?
- What are the barriers to implementing sustainable practices in the humanitarian industry?
- What are some possible strategies to reduce the impact (embodied carbon) of current shelter practices in the humanitarian shelter sector?

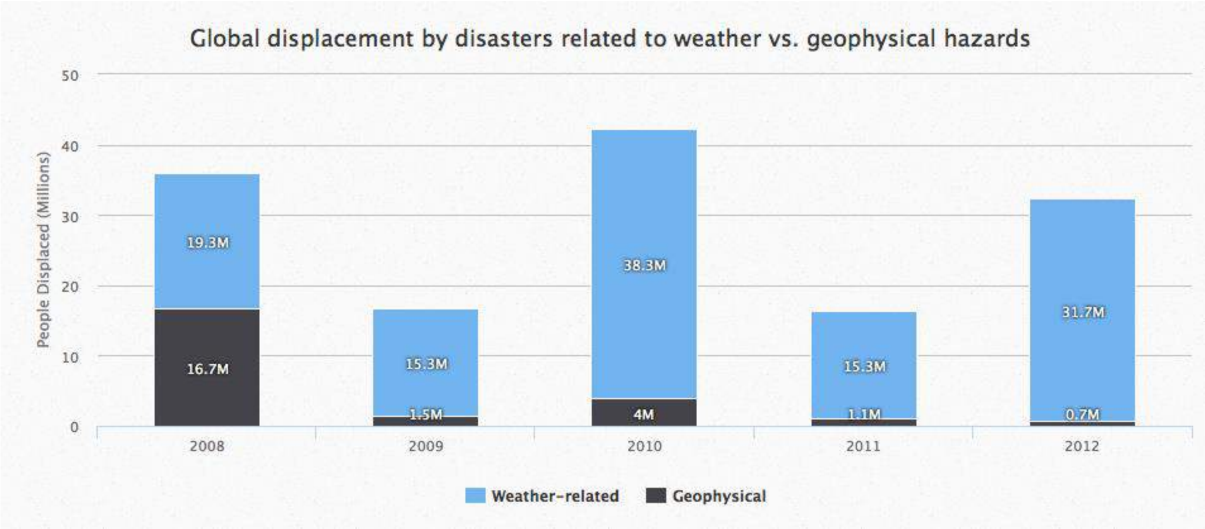


Figure 1: Published figures on internally displaced people by weather vs. geophysical hazards

[Source: IDMC 2013]

The January 2010 Haiti Earthquake was chosen as the case study as it was significantly large in scale with over 220,000 deaths, almost 200,000 homes badly damaged or completely destroyed and 1.5 million people rendered homeless (DEC 2013). Environmental sustainability issues were on the Haiti Shelter Cluster's agenda and interventions to minimise environmental impacts were incorporated into temporary housing efforts. Designs, reports and updates were available on the Haiti Shelter Cluster site, facilitating access to reliable information.

STRUCTURE OF REPORT

To demonstrate environmental sustainability in the different stages of a disaster response, this study was approached in two parts. Part 1 used a qualitative methodology (literature review and interviews) to examine environmental sustainability in humanitarian disaster response aid. Part 2 employed a quantitative methodology in an attempt to quantify the embodied carbon of shelter materials using a method developed specifically for this study.

Part 1 is structured into five chapters: Chapter 2 presents the methodology for the qualitative study. Chapter 3 examines current attitudes and practices relating to environmental sustainability in the humanitarian aid industry, how environmental sustainability can be mainstreamed in the industry, and some of the barriers to implementing sustainable practices. Here practitioner interviews inform the review and added relevance and credibility to the literature. Chapter 4 examines how to measure environmental sustainability with a focus on carbon footprinting and embodied carbon. Chapter 5 outlines strategies for reducing carbon emissions in humanitarian response operations and Chapter 6 presents the findings of the qualitative study.

Part 2 is in four chapters: Chapter 7 discusses the quantitative methodology developed for this study to measure embodied carbon in shelter materials, including the choice of the carbon calculator tool and the ICE data set, as well as their limitations. Chapter 8 contains the data collected for the embodied carbon calculations for the three phases used to frame the study (emergency shelter, temporary shelter and temporary housing). The 2010 Haiti Earthquake was used throughout as a case study for the data collection and analysis. Chapter 9 presents the results of the calculations and the assumptions and limitations. Chapter 10 examines substitute materials that could have been used for shelter in Haiti, comparing the estimated embodied carbon of these alternatives with current materials used.

Part 3 draws on both the qualitative and quantitative parts of the study for the discussion of results and conclusion. Chapter 11 contains strategies that could have reduced carbon emissions in Haiti. Chapter 12 discusses the carbon emissions in Haiti in the global context of emissions. Chapter 13 outlines the limitations of the study. Chapter 14 draws final conclusions and Chapter 15 makes recommendations for further research. The technical specifications of the products analysed, samples of the shelter designs, the detailed spreadsheets used in the calculation of embodied carbon and notes of the interviews are contained in the appendixes.

The structure of the thesis is described graphically in Figure 2.

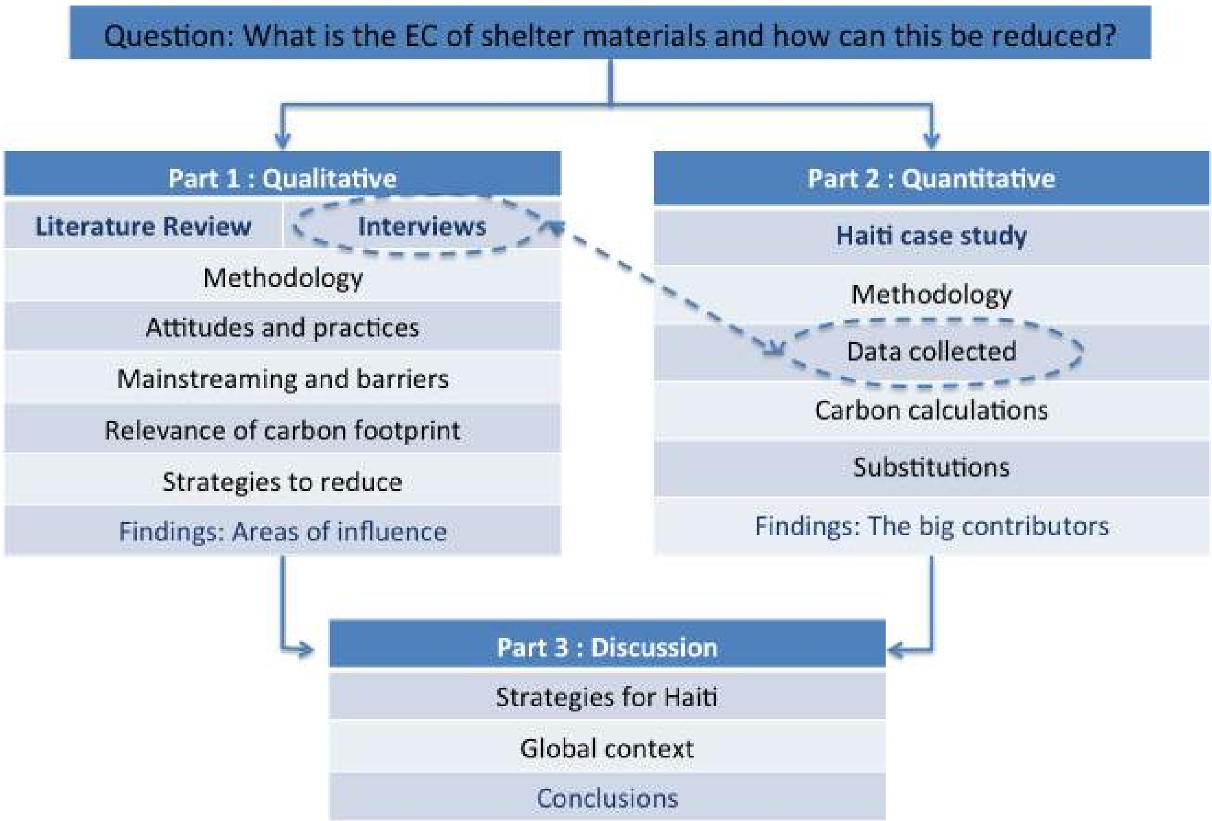


Figure 2: Flow diagram of thesis structure

PART 1: QUALITATIVE STUDY

Part 1 reviews the literature and interviews, which were conducted concurrently, to identify research gaps within environmental sustainability in humanitarian practice. Environmental sustainability in humanitarian practice being a young topic, relevant journal articles are limited Accordingly, interviews with practitioners were sought as part of the methodology. Aid agencies publications and organisations assisted in the formulation of questions for the practitioners. Likewise, the interviews with practitioners guided the direction and focus of the literature review.

CHAPTER 2. METHODOLOGY FOR QUALITATIVE STUDY

LITERATURE REVIEW

Governmental and aid agency publications helped in identifying the most specific and relevant issues in the case study; journal articles provided credible and reliable information on related topics. Web sources served as supplementary evidence or when there was insufficient data found available. Although in some cases less reliable, web sources were nevertheless relevant. The topics dealing with sustainability issues within the humanitarian sector covered by the literature include:

- the history,
- the attitudes, practices and tools that are used to assess and address sustainability issues, and
- lessons learnt from past operations and how these lessons have been integrated into current operations.

INTERVIEWS

Interviews were used to supplement the review and analysis. They added relevance and currency to the issues being researched, confirming and clarifying data assumptions. Humanitarian practitioners working in the shelter sector were interviewed to explore their perspective and experience with environmental sustainability in the delivery of humanitarian shelter. The interviewees were selected from contact information in publications reviewed, the author's professional connections and referrals. The information was used to frame and contextualise the study and to understand current practices and attitudes to environmental sustainability. The interviews did not follow an identical set of questions, but similar themes. Practitioners from the following organisations were contacted:

- Interviewee 1 - Environmental Partnership Director, World Wildlife Fund (WWF)
- Interviewee 2 – Senior Emergency Shelter Officer, UNHCR
- Interviewee 3 – Managing Director, Ecotec Engineers and Consultants
- Interviewee 4 - Executive Director, ShelterProject
- Interviewee 5 - Trustee, ShelterProject

The author's own professional experience in humanitarian response in a number of locations (Myanmar, the Maldives, Indonesia, Sri Lanka and Nepal) was drawn upon for understanding of institutional processes and attitudes. Information from these interviews and the author's personal experience will be cited throughout the thesis.

The literature review and interviews narrowed the topic for research by showing a gap in information on the life cycle assessment of materials used in emergency housing. The 2010 Haiti Earthquake response provided an appropriate case study example on which to base the analysis.

CHAPTER 3. ENVIRONMENTAL SUSTAINABILITY IN HUMANITARIAN DISASTER RESPONSE AID

HISTORY OF SUSTAINABILITY PARTNERSHIPS AND STUDIES ON MATERIALS

Although the links between early recovery and reconstruction decisions are understood from an economic and social resilience perspective, the humanitarian industry is slowly acknowledging the environmental impacts that aid efforts can have, some of which can no longer be ignored. After the 2004 Indian Ocean Tsunami, a handful of aid agencies went into partnership with environmental organisations to address these problems (Navaratne 2010). Some of the partnerships and initiatives have included:

- CARE and WWF Alliance (since 2006): Poverty and environmental degradation for rural communities worldwide
- CARE and the World Conservation Union (IUCN): Programmes in multiple locations assisting societies to conserve the integrity and diversity of nature and to ensure natural resource use is equitable and ecologically sustainable
- American Red Cross and WWF: Green Reconstruction and Recovery Training (GRRT) for stakeholders
- UNHCR/International Federation of Red Cross and Red Crescent Societies (IFRC) and ProAct: Development of disaster-specific guidelines and coordination to address shelter issues and local environmental sustainability
- United Nations Office for Project Services (UNOPS) and United Nations Environment Programme (UNEP): A United Nations carbon emissions offset scheme to benefit India and Columbia
- IFRC and Building Research Establishment (BRE): A points-based sustainability assessment tool for humanitarian programmes

Other initiatives have been as simple as hiring consultants to conduct environmental assessments post-disaster to mitigate further environmental risks or developing training modules on environmental implications (van Breda and Laprade 2008). In 2014, a humanitarian sustainability rating tool called Quantifying Sustainability in the Aftermath of Natural Disasters (QSAND) was launched to give humanitarian programmes sustainability yardsticks. These positive steps are an acknowledgement by the larger agencies that environmental sustainability must be addressed to reduce vulnerability and increase resilience. However, more professionalism, coordination and awareness (Interviewee 1) is needed from all actors for environmental sustainability to be mainstreamed.

Presently, few guidelines exist for environmentally responsible material selection with some material efficient designs by the Green Recovery Organization. Architecture for Humanity has collected innovative shelter designs using different materials addressing context specific situations, such as natural resources availability, climatic risks or logistical challenges (Stohr and Sinclair 2012). However, few scientific studies have been conducted on the environmental effects of different designs and materials. Previous research and developments into tarpaulins and tents has focused on the performance of the fabrics and designs (Chadwick 2012). Considering the growing number of partnerships with environmental agendas, a study using LCA on items used in humanitarian response would be a relevant step towards informing future designs and specifications (Interviewee 3 and 4).

HUMANITARIAN AID AND ITS ATTITUDE TOWARDS SUSTAINABILITY

The concept of sustainable development was introduced internationally through the Bruntland Commission Report (World Commission on Environment and Development 1987), which heralded a new approach to social, economic and environmental development. The report defined sustainable development as: "…development which meets the needs of current generations without compromising the ability of future generations to meet their own needs".

This concept of sustainable development supports social and economic development with strong foundations in protecting the natural resources base and environment. It is based on the tenant that social and economic wellbeing cannot be improved by compromising the environment. Since the introduction of this concept, environmental commitments have dominated (UNECE 2004) in the areas of national governance and business, whereas the humanitarian industry has embraced the social and economic pillars whilst being generally slow to acknowledge the need for environmental sustainability. Abrahams (2014) tried to explain the barriers to incorporating environmental sustainability into programmes, concluding that attempts have been sporadic and inconsistent. This is evident in the limited number of articles and studies on the subject, as well as in the environmental degradation resulting from humanitarian operations from disaster to disaster (Johnson 2007a; Johnson 2007b). Efforts are now being made to mainstream environmental sustainability through charters, policies, frameworks and standard operating guidelines.

Figure 3: The Sphere Project Handbook and CD, available free online and translated into over 12 languages

[Source: Sphere Project 2011]

The humanitarian sector has minimum standards covering a variety of areas including water and sanitation, shelter and settlement, protection and security, food and nutrition. This set of minimum core standards, contained in the Sphere Project (2011), now include environmental guidelines for programmes to follow (Interviewee 1). However, as these standards have no sanctions attached to them, and there are no penalties within the humanitarian industry for non-compliance, they are not always adhered to (Interviewee 5), rendering environmental sustainability within programme design optional.

In the past, the practices and policies of humanitarian aid agencies have been geared towards short-term responses to what are perceived as short-term problems, such as housing for people until a permanent solution is found. This short-term thinking inevitably leads to short-term solutions and environmental impacts that can have long-term effects. This attitude is prevalent among humanitarian practitioners and there is a general lack of appreciation for the environment and the role it plays in healthy lives (Interviewee 1).

. Although some believe that many organisations and individuals are merely paying lip service (Interviewee 3) to the need for environmental sustainability and that the word 'sustainability' is overused and misunderstood, there is much evidence to show that larger organisations are starting to embed environmentally-sustainable practices into their policies, frameworks and guidelines (Interviewee 4).

A reflection of more recent attitudes towards environmental sustainability is embodied in the Haiyan Shelter Cluster (2014), which considers environmental sustainability as integral to resilience to economic viability and future disasters:

... [neither] providing shelter nor building back livelihoods will necessarily ensure environmental sustainability. In fact most traditional livelihoods in a given area may have many environmentally damaging practices. A degrading environment will eventually erode the livelihoods and cause more risk and vulnerability. The challenge is to integrate shelter, livelihoods, environment and climate considerations together in a sustainable way…Typhoon Yolanda response, building environmentally responsible shelter can provide many livelihood options in timber recovery, waste recycling, composting and home gardening and rubble reuse.

The funding available to reach beneficiaries has always been a driver of the quantity and quality of shelter provided by humanitarian response programmes. Table 1 draws statistics from the Disasters Emergency Committee (DEC 2014), which is made up of UK-based international non-government organisations (INGO) and whose appeals and funding exclude those from governments and the United Nations. As can be seen, the scale of devastation is not always correlated with the funds raised. If all agencies and sub-sectors are vying for the same funds, frequently environmental sustainability issues are relegated or pushed off the agenda altogether (Interviewee 5). Embedding environmental sustainability standards into policies and frameworks means that environmental sustainability issues have to be accounted for in the monitoring and evaluation of individual projects.

Table 1: Facts and figures of recent disasters

Disaster name	Date	Deaths	Refugees or people displaced	Homes destroyed	Funds raised
Haiti earthquake	Jan 2010	220,000	1.5 million	105,000	£380 million
Syria crisis	2011	100,000 so far	9.3 million	unknown	£564 million
Pakistan floods	Jul 2010	1,985	12 million	unknown	£71 million
Philippines typhoon	Nov 2013	6,201 (1,785 missing)	5 million	550,000	£94 million

Source: Disasters Emergency Committee (2014)

There appears to be growing awareness of environmental issues among humanitarian response organisations and practitioners. Although some initial efforts to incorporate environmental sustainability standards in high-level organisational documents and user tools, the environmental agenda and its perceived relevance is yet to be mainstreamed and become a principle of the typical practitioner. Much remains to be done to affect environmental change in this area (Interviewee 1).

WHY ENVIRONMENTALLY SUSTAINABLE SOLUTIONS MATTER

Environmental sustainability issues are slowly being addressed in the humanitarian industry with practitioners comprehending that good environmental practices contribute to the resilience of communities to natural disasters and reduce their vulnerability.

Srinivas and Nakagawa (2008) highlight that how well natural resources are managed prior to a disaster plays a huge part in how a country recovers from, and even resists, a natural disaster. They recommend that environmental protection should be central to national disaster preparedness plans and that aid agencies should adopt strategies, policies and tools to assess aid proposals to ensure a balanced and well-considered response. A country's level of deforestation, forest management practices, maintenance of wetlands and coral reefs (Sonak et al. 2008), waste management systems and agriculture systems can mitigate or compound the effects of natural disasters. An earthquake, typhoon, or storm can lead to landslides, flooding, silting and ground or surface water contamination, affecting the ability of governments and communities to recover livelihoods (Srinivas and Nakagawa 2008). The challenge is not only for development agencies to help rebuild these resources, but also for humanitarian agencies to not contribute to the depletion of these resources. The concept of 'do no harm' (Anderson 1999) is central to these studies.

The word 'sustainable' is widely misused in the humanitarian aid sector, with approaches and rhetoric orientated around social resilience and economic recovery, with little regard for the environmental impact of humanitarian aid (Interviewee 3). This lack of regard is evidenced by the environmental impact of relief items brought into

Figure 4: Water bottles and other debris in a fishing port in Maldives

[Source: Bluepeace 2008]

a country (Author, Interviewee 3, 4 and 5). One example is bottled water imported as an emergency response measure, which can lead to the inundation of local waterways or campsites with plastic waste, as was the case after the Indian Ocean Tsunami operations in Maldives and Sri Lanka (author). The toxins from the breakdown of polyethylene terephthalate (PET) water bottles make their way into the environment (Bach et al. 2012; Shotyk et al. 2006.), which is known to disrupt hormonal balances in humans and animals (Chung et al. 2013). The failure of the humanitarian industry to understand this link is further demonstrated by the following examples of how aid can directly affect health and wellbeing.

In the 2010 Haiti Earthquake disaster, 2 to 3 million timber poles were sourced from the already diminished woodlands of Haiti to support plastic sheeting for emergency and temporary shelter. The 40 to 60 km^2 of plantations felled to provide this timber was not replenished with any support or reforestation programme (Navaratne 2010).

In Banda Ache, Indonesia, after the Indian Ocean Tsunami, timber was not only needed for building, but also for firing brick kilns for the rebuilding effort. An estimated 945,000 m^3 of wood was needed and 10,000 hectares of forest were depleted to meet this demand (UNEP 2007). Had strategic measures been taken to manufacture or import high quality blocks for use in construction, it would have provided a viable alternative building material and stimulated the local economic (da Silva 2010).

The large amounts of waste generated by relief efforts can have negative environmental impacts. Examples include packing materials that end up in water streams, which happened in Port-au-Prince, Haiti (Thummarukudy 2010). Contaminated waste infiltrating ground sources can be a particular threat, especially in places with a ground-sourced water supply. Although there is some literature on the management of debris and waste caused by the disaster event, there is little on the waste produced by the relief effort and the impact this may have on the environment. Consequently, the waste produced from relief items has rarely been quantified. The need for humanitarian programmes to consider the safe disposal and removal of waste products generated by relief efforts is undeniable.

Designing programmes for 'cradle to grave' or, even better, 'cradle to cradle' will address this problem with a focus on waste minimisation or avoidance altogether (see Figure 5). The need to have adaptable materials that can be reused, adding value to people's lives is key to addressing problems and prolonging the life of products. The choice of materials is critical in ensuring that their eventual breakdown does not have detrimental effects on the environment or on human life.

Figure 5: Cradle to cradle – closing the loop on products

[Source: EPLCA 2014]

Sound environmental practices after a disaster can provide a blueprint for future practices in that city or country. In previously congested urban areas that have experienced large-scale destruction, support from international agencies to establish new settlements with good infrastructure and livelihoods is becoming popular (Interviewee 2). UNHCR has a programme whereby housing plots, utility services, roads and common spaces such as parks etc. in refugee camps are converted to permanent settlements for the host country's population when the refugees move on (Interviewee 2). Waste composting and separation practices in camps and settlements can have knock on effects such as better nutrition, food security and household income (Environmental Foundation 2010). The need for humanitarian response organisations to be accountable for these affects and to have environmentally sustainable operations is obvious and becoming more widely acknowledged. There is also opportunity for them to model positive and innovative practices in the host country, increasing positive influence and minimising the negative impacts of assistance.

MAINSTREAMING ENVIRONMENTAL SUSTAINABILITY

The need to mainstream environmental sustainability in humanitarian responses is becoming more widely acknowledged and a number of ways of achieving this have been put forward requiring the involvement of all stakeholders at all levels, including governments, local authorities, humanitarian actors and the communities themselves. To mainstream environmental sustainability, we need to understand how things currently operate and what improvements need to be made for environmental sustainability to be a default consideration.

<u>Local/national governance</u> – Environmental sustainability should begin prior to a disaster so that sustainable reconstruction has a platform from which to be administered (Guarnacci 2012, Yi and Yang 2013). Ideally, national and local governments should have environmental systems in place that do not degrade the environment. A country that values and manages its natural resources sustainably will recover from a disaster better than one that does not. Haiti is a good example of chronic poor governance, leaving the country's hilly slopes denuded from over-forestation and vulnerable to landslides, exacerbating the earthquake's impact (Thummarukudy 2010). Although Haiti has over 140 laws concerning the environment (MJPS and UNDP 2002), very few are enforced. The environment sector in Haiti lacks an operational framework able to link public and private institutions (Richener 2011).

If a country enforces national policies and regulations for the environment, aid agencies operating there are obliged to adhere to these. If these policies and regulations are interwoven with disaster management regulations, it sets the stage for sustainable practices by default and compulsorily mainstreams environmental concerns into reconstruction efforts. 'Green' recovery has to first start with 'green' development.

<u>Local/national strategic planning</u> – During times of peace, all stakeholders should put in place a plan for disasters. This is particularly important in urban areas (Pelling 2003; Bull-Kamanga 2003) where there is high population density and where access to people affected by disasters is often restricted by poor infrastructure. Pre-determined evacuation sites, transitional housing designs, pre-positioned goods for disaster relief, disaster waste management planning,, are needed (Brown et al. 2011). Plans should include the reclamation, recycling and reusing of disaster waste and debris as part of the

response efforts. This embeds environmental sustainability into disaster recovery, maximising economic opportunities for quicker recovery (Johnson 2007b). Activating well-conceived, pre-existing plans for disaster management is better than post facto planning after and leaves less chance for environmental issues to be left off the agenda.

A high level of institutional instability, poor governance, limited human and financial capacity, and improper solid waste-disposal practices characterised the waste management sector in Haiti prior to the earthquake. Haiti's waste management policies are not implemented. Port-au-Prince's municipal waste authority is only capable of handling about 40% of the waste generated (Horizon 2014). The remaining waste is left on the street, posing environmental and human health risks. A study comparing 20 cities (Wilson et al. 2012) demonstrated many models of good environmental waste management, the common features of which are an understanding of the composition of the waste through reliable data, good governance and the use of technology and building on the existing strengths of that city. Opportunities in Haiti to develop the solid waste management sector exist in the informal sector where recycling rates can be increased to complement recycling by the municipal authority, saving them a considerable amount on collection and disposal costs. Opportunities exist for income generation for the 40% of people who remain unemployed after the earthquake, alleviating poverty while at the same time clearing debris. Post disaster programmes can set up a culture in which the local population views waste as a resource for energy recovery, income generation, building the economy and ensuring healthier lives, thereby mainstreaming good environmental practices in communities.

<u>Organisational procurement policies</u> – Most large aid organisations have large procurement departments. The procurement of items should go beyond technical specifications for product performance and embrace responsible sourcing principals, including sourcing demonstrated or certified 'green' products with international or local compliance certificates. For example, the procurement guidelines could specify that only timber suppliers with Forest Stewardship Council (FSC) certification qualify for pre-selection. Suppliers could be pre-selected for a multi-tier supply chain feeding global, regional and local demands to reduce transportation footprints. Technical specifications should be sympathetic to local housing designs, using local resources as possible, without compromising the local environment. This point becomes more important in

the temporary housing and permanent housing stages. Procurement policies favouring materials that are easier to recycle or reuse will reduce demand on the world's natural resource stocks. 'Green' procurement is, therefore, another way of mainstreaming environmental stewardship.

Humanitarian coordination – The humanitarian sector, like many industries, is divided into thematic areas called 'clusters' (Resolution46/182 December 1991), which aim to improve pre and post disaster coordination. The clusters provide a clear point of contact and are accountable for adequate and appropriate humanitarian assistance. The platform encourages partnerships between international humanitarian organisations, national and local authorities, and civil society (OCHA 2014). Within the Shelter Cluster, technical support for responsible and sustainable material sourcing is given to assist aid agencies to make better environmental choices (Haiyan Shelter Cluster 2014). The cluster approach is a vehicle for communication, disseminating information and education and through which advice and support can be given.

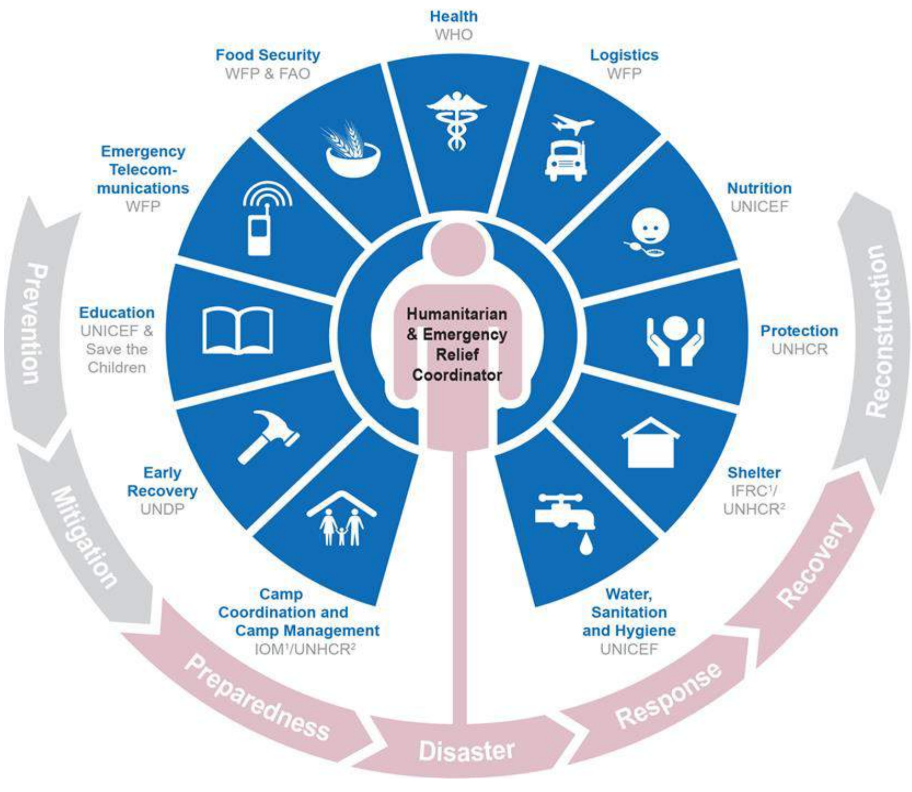


Figure 6: Cluster approach in humanitarian and emergency relief

[Source: Humanitarian Response (nd)]

Awareness raising – Although sustainable environmental development is increasingly discussed at the top levels of governments and institutions, awareness of its importance is still to reach the grassroots levels (Interviewee 3). The Green Recovery and Reconstruction Training (GRRT) is an effort to raise awareness about environmental sustainability, linking current practices and concepts of 'do no harm'. However, knowledge of the existence of this online training toolkit among current practitioners is low. Environmentally sustainable disaster response approaches must be included in entry-level training courses conducted by humanitarian organisations. The Red Cross and Red Crescent Movement's Basic Training Course and Field Assessment and Coordination Training, which delegates are required to attend prior to deployment, would be a good starting point for introducing GRRT.

Beneficiary demands – Re-orientating humanitarian efforts away from 'things' to 'people' is needed to better meet the demands of the beneficiaries. Manyena (2006) argued that humanitarian efforts should be orientated towards building local knowledge and augmenting existing capacities, not towards risk assessments and reactions to negative impacts. Funding agencies should channel support into education, capacity building, psychosocial programmes and people-centred strategies to ensure resilience.

After a disaster, victims and governments often turn their attention to making sure that they are better equipped and better informed on how to minimise the effects of such disasters in the future (Author). This focus on improving disaster risk management is an opportunity to mainstream environmental protection and conservation into recovery efforts. Ultimately, if beneficiaries (national governments and communities) make demands and voice their opinion on how aid is best delivered; humanitarian actors will have to listen.

The above review covers a number of ways of mainstreaming environmental sustainability into disaster recovery efforts. To reduce environmental risks and vulnerability, the agenda needs to be embraced and interwoven into and between all levels of governmental, organisational and societal practices. It is important to realise that risk and vulnerability is not a symptom of disaster, but rather a continuum that needs to be reduced well before any event takes place and that this is not just the responsibility of governmental departments, but of everyone.

CHAPTER 4. MEASURING ENVIRONMENTAL SUSTAINABILITY

HOW CAN ENVIRONMENTAL SUSTAINABILITY BE MEASURED?

Environmental sustainability can be measured in a number of ways. Over the past two decades, there has been a plethora of quantitative methods developed to assess environmental sustainability including the:

- Environmental Performance Index – an outcome base index measuring a the quality of environmental governance in a country
- Ecological footprint – a consumption-based method applied to individuals, businesses or a society
- Life cycle assessment (LCA) – a measure of resource use and pollutants produced during the life of a product

Recently, the IFRC partnered with BRE Global to develop a tool aimed at humanitarian practitioners. QSAND is a scorecard approach to assessment, categorising sustainability issues within eight areas related to the reconstruction of a sustainable built environment: shelter and community, settlement, materials and waste, energy, water and sanitation, natural environment, communications, and cross-cutting issues. Scores earned in each category are weighted and tallied to give an overall performance score and rated as 'excellent', 'very good', 'good' or 'minimum'.

Another commonly adopted methodology in environmental assessment within the built environment is life cycle assessments. This 'cradle to grave' assessment evaluates a product or service's environmental impact from extraction to the end of its life (Bauman and Tilman 2004). This method of assessing environmental impacts has become the building industry's accepted norm and is used widely in the USA, UK and Europe and increasingly in China (Hong 2012). LCA has become the internationally benchmark and standardised by the International Organization for Standardization as ISO 14040. LCAs are used in many industries such as the garment industry, transport industry, pharmaceutical industry and cosmetics industry to distinguish products that are truly 'green'.

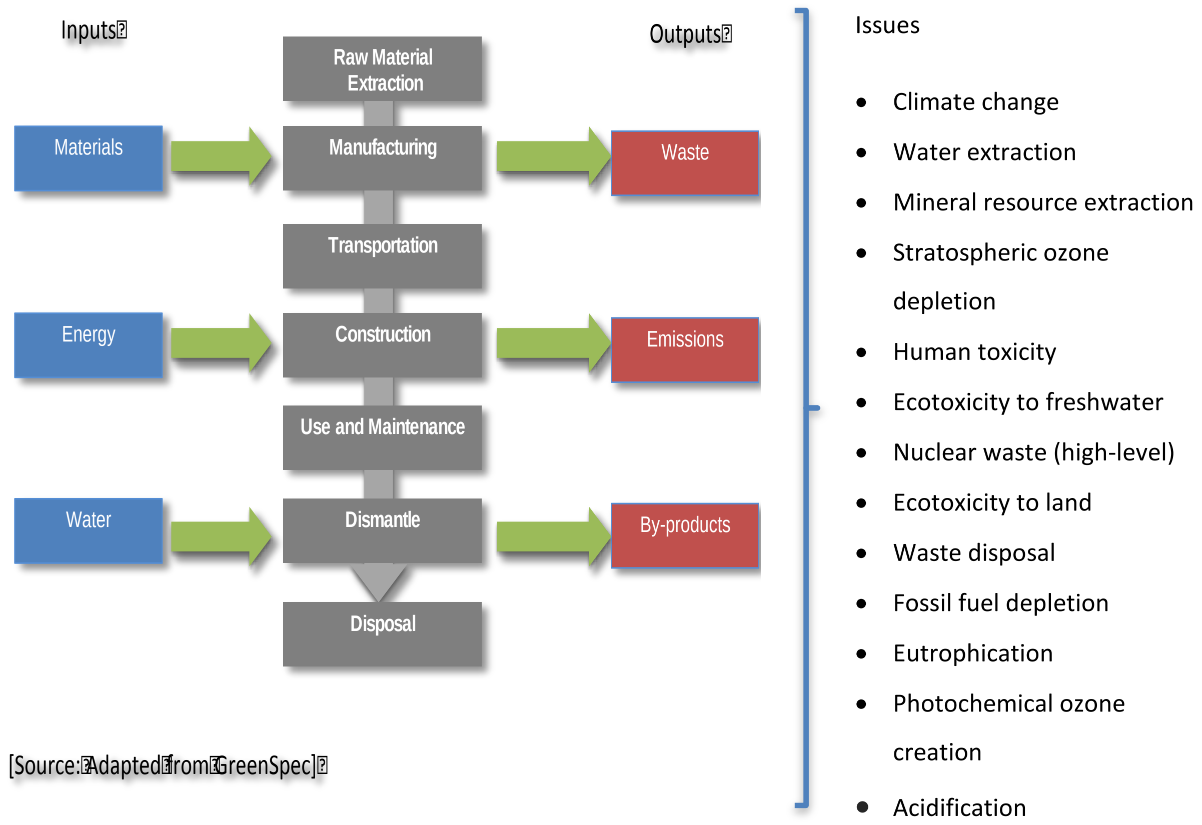


Figure 7: LCA assessment process including issues the methodology can address

[Source: Adapted from GreenSpec 2014]

LCAs are used to assess many environmental issues, which can be best demonstrated by the BRE (2014) concerns expressed in Figure 7. These issues are wide and varied and some are applicable in some locations, but not in others, such as nuclear energy. As humanitarian aid operates worldwide, it is difficult to evaluate all issues with the same weighting for each region or nation. It is neither realistic nor relevant to extrapolate all types of environmental impacts and sustainability to all humanitarian operations. However, one issue that is undeniably a global issue, regardless of where international aid organisations are present, is climate change. This makes the single issue of greenhouse gas (GHG) emissions the most relevant topic for study. Hence, analysing the carbon footprint of shelter materials used in humanitarian campaigns using the LCA methodology is an appropriate way of measuring environmental sustainability.

FOCUS ON CARBON FOOTPRINTING

The focus on GHG emission is highly applicable to the humanitarian response industry. When placing the issue of GHGs within the global agenda to reduce carbon emissions, it highlights what little the industry has done to reduce emissions and what little information exists on the topic.

The rise of carbon dioxide (CO_2) over the last two centuries has been dramatic. At the beginning of the Industrial Revolution in the 1780s, the atmospheric carbon levels were 280 ppm; by June 2014, CO_2 concentration levels had reached 401.14 ppm (NOAA 2014), surpassing the 400 ppm benchmark at which point "governments should be jolted to action" (BBC News 2013). Climate scientists predict that each additional tonne of CO_2 released into the Earth's atmosphere increases the risk of extreme weather (van Aalst 2006; Helmer and Hilhorst 2006).

In December 1997, representatives from Canada, Japan, and many European countries adopted the Kyoto Protocol to address climate change and global warming. Today 192 have signed the protocol. The UK is one of those countries committed to reducing GHG emissions by 80% by 2050 through its Climate Change Act 2008. Figure 8 gives a snapshot of countries' progress in reducing carbon emissions in 2009 when world leaders met at the Copenhagen Climate Change Conference. Although these figures are from 2009, little has changed in the five years that have elapsed since, despite calls by the scientific community for further reductions.

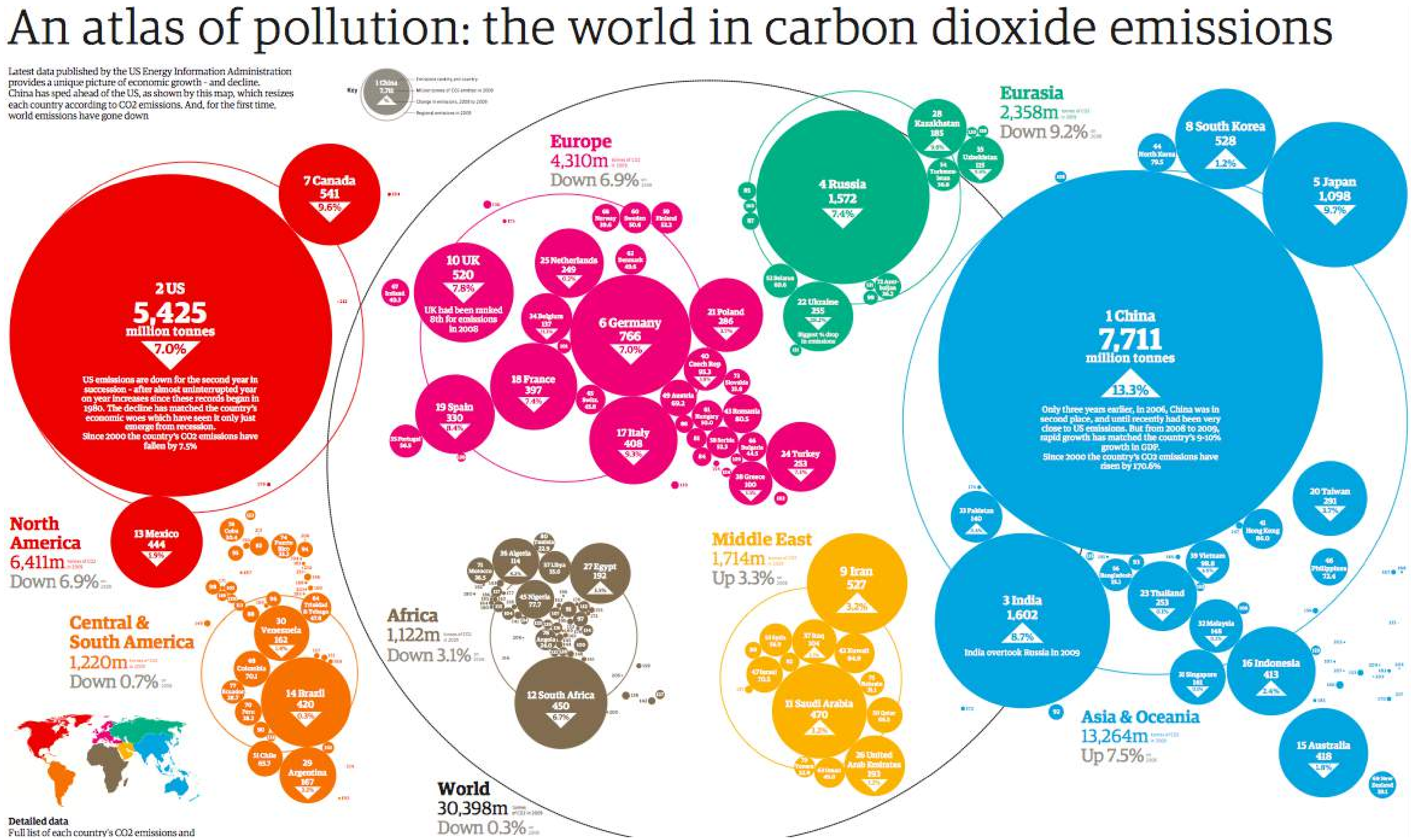


Figure 8: Increases and decreases in CO_2 emissions by country from 2006 to 2009

[Source: The Guardian (2011), based on US Energy Information Administration data]

INGOs and aid actors rarely make any organisational commitments to reflect these global commitments, either in their home countries or the countries in which they operate. Carbon emissions can easily be reduced in the areas of transport, waste management, energy consumption, fuel choices and procurement, particularly during disaster recovery efforts

As explained by Skanska (2010, p.2):

> *A carbon footprint of a building can be defined as the carbon dioxide (CO_2) emissions resulting from construction materials, construction activities, lifespan operation and eventual demolition. A carbon footprint can also be expressed in carbon dioxide equivalent (CO_2e), which is a measure of how much global warming a given quantity of greenhouse gas may cause by using CO_2 as a reference. The term "carbon" is commonly used when referring generically to either CO_2 or CO_2e emissions.*

It can be argued that the embodied carbon of a temporary structure has more significance than its operational carbon, although the energy used by permanent buildings (operational carbon) is often significantly higher than the embodied energy used to construct these building (Sustainable Homes 1999). A building's carbon footprint typically comprises around 20% embodied carbon and 80% operational carbon (Kestner 2009). Hence, many building codes and standards in developed countries focus on minimising operational energy, recognising the need to use less energy during the life of the building. The graph in Figure 9 demonstrates the relationship between embodied and operational carbon in typical buildings, compared to a higher efficiency building. A typical building has a much earlier intersect between embodied and operational carbon as operational carbon emissions increase more dramatically over time than in a higher efficiency building. This means that cumulative carbon emissions are much larger in a typical building than a higher efficiency one.

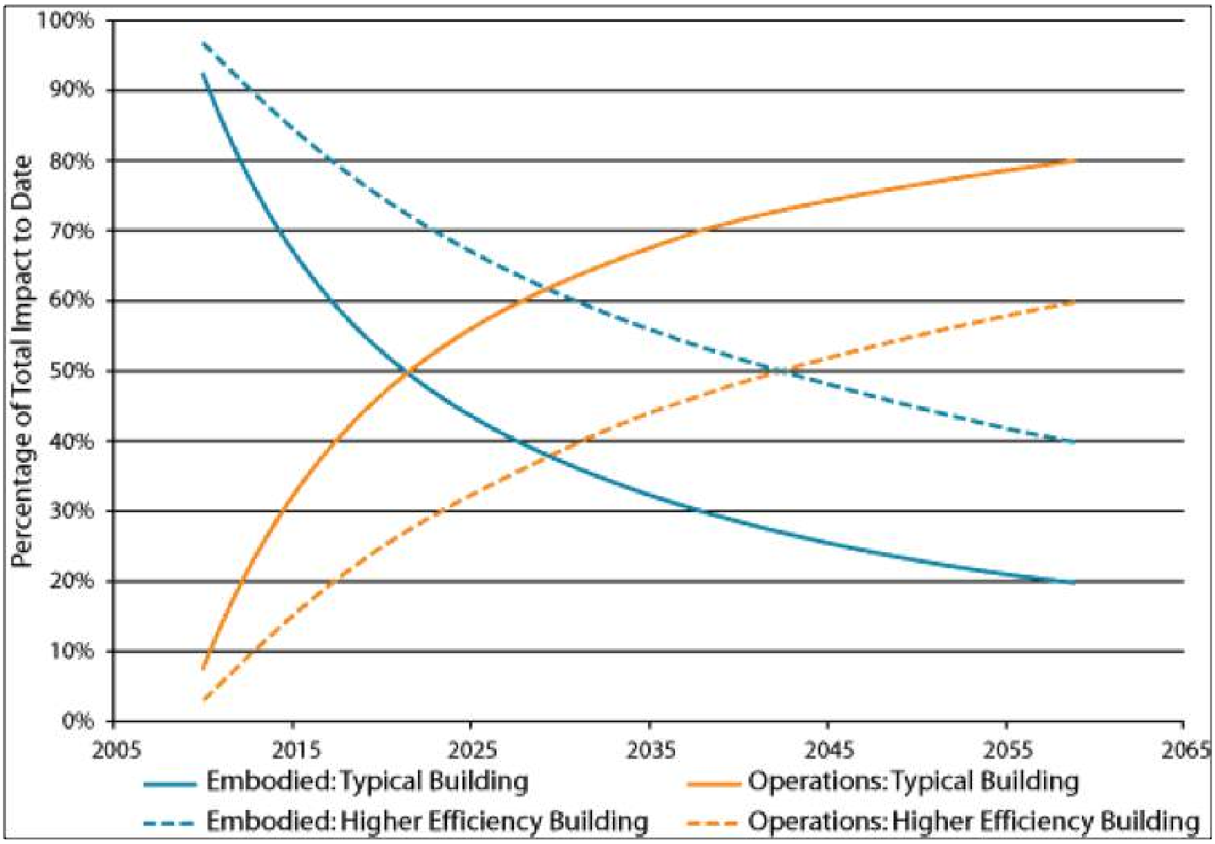


Figure 9: Embodied carbon and operational carbon in a typical building vs. a higher efficiency building

[Source: Kestner 2009]

In the case of humanitarian shelter functions, the reverse would be significant in that the embodied energy of a shelter would play a much larger component in the total energy consumption as the intended longevity of the building is from a few days to five years. The goal would then be to ensure that the point of intersection is much earlier for humanitarian shelters by reducing the embodied carbon curve. For this reason, the study of embodied carbon in humanitarian shelter has great significance and potential to reduce environmental impact.

EMBODIED CARBON IN MATERIALS

As embodied carbon will be the primary focus of this analysis, it is critical to review what materials are typically used in humanitarian shelter and consider potential alternatives. Table 2 compares the pros and cons of general materials for their density and EC. The embodied energy (EE) and EC values were taken from Hammond and Jones'

(2011) Inventory of Carbon and Energy (ICE) database, unless otherwise indicated. The densities are from engineering resources or journals with the citations listed in notes.

Table 2: Embodied energy and embodied carbon of some typical humanitarian shelter materials

Material	Advantage	Disadvantage	EE (MJ/kg)	EC (CO_2/kg)
Canvas (cotton)	Good insulation, breathable, quiet, long lifespan, UV stable	Heavy and bulky to transport and erect, slow to dry, costly, tears easily, low water resistance	143	6.78
Polyester[i]	Lightweight, cheap, quick to dry, low maintenance	Poor insulator, UV unstable, offers low level of privacy, condensation can build up, noisy and not stable in winds	97.4	2.39
Polyethylene	Lightweight, cheap, quick to dry, low maintenance	Poor insulator, UV unstable, offers low level of privacy, condensation can build up, noisy and not stable in winds	83.10	2.04
Nylon	Lightweight, cheap, quick to dry, low maintenance	Poor insulator, UV unstable, offers low level of privacy, condensation can build up, noisy and not stable in winds	138.60	6.54
Poly-cotton[ii]	A mix of the cotton and polyester qualities	A mix of the cotton and polyester qualities	115.5	5.22
Concrete	Cheap, easy to work, strong, resistant to moisture and vectors, local sources	Environmentally unfriendly, not recyclable, permanent	0.75	0.1
CGI	Lightweight, easy to erect, easy to transport	Rusts	18.80	1.3
Softwood	Low carbon footprint, recyclable	Impacts on biodiversity, leads to deforestation	10.40	0.85
Plywood	Standard sizes, adaptable uses, comparatively	Often imported	15.00	1.07

	cheap, offers good insulation, quick construction			
Steel pipes	Strong, adaptable, recyclable	Needs other adaptors and accessories, expensive	19.80	1.37

Notes:

[i] Kalliala and Nousiainen (1999)

[ii] Kalliala and Nousiainen (1999), 50:50 polyester/blend

Table 3: Embodied energy and embodied carbon of potential alternatives for shelter materials

Material	Advantage	Disadvantage	EE (MJ/kg)	EC (CO_2/kg)
Bamboo[i]	High tensile and elastic strength (better than metal), lightweight, fast growing, very low carbon footprint	Absorbs water, prone to splitting when nailed	2.58	0.13
Lime bricks[ii]	Easy to manufacture locally, cheap, good weather protection	Not appropriate for earthquake zones, not compatible with steel rods, weaker than concrete blocks and bricks	1.11	0.163
Concrete with recycled content	Enables use of debris, reduces waste, plentiful source material	Equipment is required to crush concrete debris, labour intensive to salvage appropriate debris, less strength compared with virgin aggregate	No data	No data
Concrete with 30% cement replacement – fly ash	Much lower carbon emissions, less strength	Pre-mixed cement can be difficult to source, limited suppliers	0.47	0.057
Rammed earth	Cheap	Need clay soil type, labour intensive	0.45	0.023

Notes:

[i] Yu et al. (2011), values based on use of bamboo in China

[ii] Assume mortar mix of 1:1:6 of cement: lime: sand

From Tables 2 and 3 it can be seen that the use of alternative building materials can bring about significant energy and carbon savings. The alternatives do not necessarily raise construction costs and can even reduce them. However, some items may be difficult to source, making mass supply an issue and potentially escalating market prices. Despite their possible benefits, these alternative materials are generally not considered in the emergency and temporary shelter phases, mainly due to convention.

CHAPTER 5. STRATEGIES TO REDUCE CARBON EMISSIONS

USE OF ALTERNATIVE MATERIALS

A modelling study showed that choosing alternative building materials, such as slag cement, recycled steel, cullet glass and plywood formwork, instead of the more conventional cement, timber, glass and steel, can dramatically reduce carbon emissions by over a third (Sham et. al. 2010), while another study showed that local materials and vernacular designs can reduce embodied carbon emissions by more than 50% (Ali et. al. 2013). These studies indicate that traditional materials or using waste products could be the key to reducing carbon in construction. But what local materials can be substituted in which shelter types? Between 1998 and 2002, the Shelter for Life Organisation operating in Afghanistan adopted shelters adobe to house internally displaced people at the same cost as winterised canvas tents (Sinclair and Stohr 2006), meaning that that there was no need to import materials, which would have come through insecure areas. A comparison of Tables 2 and 3 in Chapter 4 shows the huge potential in carbon savings that can be achieved through material substitution.

SMARTER LOGISTICS AND TRANSPORTATION

A carbon emission study into the logistical operations of the Finish Red Cross response practices by Anttila (2011) found that the modality of transport had a huge bearing on transport emissions. He proposed the sourcing of goods close to the destination and pre-positioning of stock items for quick response as ways to reduce emissions. The current practice is to purchase goods from distant countries, store them in Finland and dispatch them during emergencies, sometimes to regions where the goods were purchased from originally. Transportation by road and sea also can also lead to a significant reduction in emissions, in comparison to transportation by air. Decentralising stockpiles and placing goods at different regional centres can reduce transport carbon greatly at each step of the life cycle.

'GREEN' PROCUREMENT POLICIES

Policies favouring manufacturers with internationally or nationally recognised 'green' certification will encourage more suppliers to become environmentally conscious and improve manufacturing practices. Supporting suppliers with FSC certification can reduce carbon emissions indirectly as plantations growing trees sustainably means that felled tree are replaced with new trees. The carbon emitted by the felled trees will be sequestered by the growing trees, hence use of sustainably sourced timber can potentially be carbon neutral or even carbon negative (D'Arrigo et al. 1987).

USE OF DEBRIS FOR RECONSTRUCTION

In the 2013 Philippines Typhoon, advocacy for salvaging timber and wood from debris began with an estimate by the Philippines Coconut Authority that 16.6 million coconut trees had fallen. Even with a 50% recovery rate, this equates to 800 million board feet of construction timber (Haiyan Shelter Cluster 2014). Besides reducing demand for virgin timber and clearing debris for recovery, the use of debris for reconstruction has the benefit of providing opportunities for economic recovery for salvage operators. The humanitarian effort could also provide training to the local timber industry on the seasoning and preservation of timber to extend its life and reduce the demand on diminishing tree reserves (Haiyan Shelter Cluster 2014). Other materials that can be used for rebuilding include rubble for course and fine aggregates and recycled glass for concrete. The recycling of debris presents a huge opportunity for recovery, as it eases the burden of CO_2 emissions, aids in the removal of debris, and injects money into the local community, which would otherwise be leaked out to foreign suppliers, thereby helping to develop local entrepreneurship (Hirano 2012).

DESIGN FOR REUSE AND RECYCLING

The life cycle of materials can be prolonged by recycling. Materials can be collected and reprocessed as second hand raw materials for use in other products. In Haiti, one polyethylene (PE) recycling facility was identified (Navaratne 2010) early on in the recovery effort and this facility was able to advise agencies on how to dispose of decommissioned tarpaulins. In other operations, many uses have been observed for tarpaulins, such as bags for recycled waste collection, car tarpaulins, raincoats, personal bags, etc. (IFRC and ICRC 2012b), which can easily be linked with livelihood or education programmes. Tent fabrics have also been used to make shirts in other operations (Interviewee 4).

The ease of dismantling and transporting temporary shelters also needs to be considered in the choice of materials used for their construction. Typically, the ownership of materials is transferred to the beneficiary (Interviewee 4) if the shelter is easy to dismantle it will enable them to reuse, recycle or even sell the shelter's materials.

Other areas of influence are in the design of shelters and structures to suit local conditions and reduce operational costs and carbon.

CHAPTER 6. FINDINGS OF QUALITATIVE STUDY

From the literature review and interviews, areas in which there are opportunities to influence better environmentally sustainable practices can be identified. Strategies should be adopted to reduce carbon emissions across the entire life cycle of humanitarian shelter materials. These strategies include:

- influencing national and local governments
- thinking strategically about local needs and appropriate response items
- specifying responsible sources and suppliers
- having pre-selected suppliers and pre-position items for immediate response

- designing for dismantling to enable reuse and recycling at the beneficiary level, with the added potential for income generation projects

Opportunities to reduce the carbon footprint of humanitarian shelter exist at each step of the life cycle. These strategies can be applied to any almost all aid relief and reconstruction projects and will be applied to the Haiti case study and discussed further throughout this thesis.

PART 2: QUANTITATIVE STUDY

Part 2 of this thesis focuses on the quantitative assessment of typical shelter materials used in humanitarian relief and recovery. This section discusses the selection of the tools and datasets used, the phases within post-disaster recovery being analysed and a summary of the steps followed. The EC calculation is discussed along with the limitations of the data and the assumptions made.

CHAPTER 7. METHODOLOGY FOR QUANTITATIVE STUDY

This chapter describes the methodology followed for the data collection and calculations of embodied carbon in the quantitative part of the study.

CHOICE OF CARBON CALCULATOR TOOL AND DATASET

CARBON CALCULATOR TOOL

The carbon calculator tool used in the study is the July 2012 version of the UK's Environment Agency (Environment Agency 2012). The calculator was developed specifically for the UK construction industry and inherently assumes default values that are applicable there. Using a UK-based carbon calculator and dataset was not considered a major disadvantage as most materials used in humanitarian aid are from the same region or country from which the UK sources its materials. For example, steel and aluminium are predominantly sourced from the same region by the UK (EU) market and humanitarian actors. Where local data was available or more accurate data was found on some materials, default values could be over-ridden with the more appropriate data related to the case study. The MS Excel based tool does not require any licences and is a free online resource which can be downloaded from https://www.gov.uk/government/publications/carbon-calculator-for-construction-projects.

The developers (UK Environment Agency 2012, p. tab-Further Guidance) of the tool state:

> *The uncertainty of individual factors for carbon LCAs of the type used in this calculator is unlikely to be better than the range +/-5%. As a consequence of using default factors and estimated tonnages, carbon footprints obtained from this calculator might be expected to be within +/-25% of the true value. Given the range of values associated with certain materials (cements for example) it is quite feasible that using default values may give results that are out by 100% or more.*

Despite the high level of uncertainty, the calculator provides a good indication of the relative magnitude of the impact caused by each component material used in a construction project. Double-counting of carbon emissions is likely to occur to a small extent because of the way boundary conditions are defined. Care has been taken to avoid using default values particularly where densities are involved. For example, the footprint of aggregate, sand and cement in a concrete mix were entered separately as most of the mixing was done by hand avoiding the default concrete mix classes, which includes fixed content ratios and carbon used in the mixing plants.

ICE DATASET

The Carbon Calculator tool has built in default values primarily from the Hammond and Jones (2011) ICE database, where the data was collected specifically for the UK market. The data sourced were ideally from UK and EU-based LCA profiles; however, many data were for places outside the Europe, particularly for metals. Ideally, if a range of EC data is available, both ends of the range could be modelled to demonstrate the variation in results. For metal materials, the Hammond and Jones ICE 'Rest of World' coefficients were used as almost all of the items in the emergency and temporary shelter phases were imported from Asia, differentiating the default figures, which represented UK-based or European data. There is also the ability to input different materials not listed in the tools, offering further flexibility for more relevant data to be entered. Flexibility is also afforded to choose transportation modes and the recycling percentage at disposal, and not only UK and EU practices reflected.

Though LCAs are considered to be a holistic environmental assessment tool, the data feeding into the LCAs is usually limited by boundaries. These boundaries, as defined by Vogtländer (2011), are:

- ‘Cradle to gate’ – from the mines to the warehouse gate
- ‘Gate to gate’ – to calculate the eco-burden of a manufacturing facility
- ‘Gate to grave’ – to calculate end of life scenarios
- ‘Cradle to grave’ – to calculate the total eco-burden of a product system from mine to end of life
- ‘Cradle to cradle’ – closing the loop in the total product system

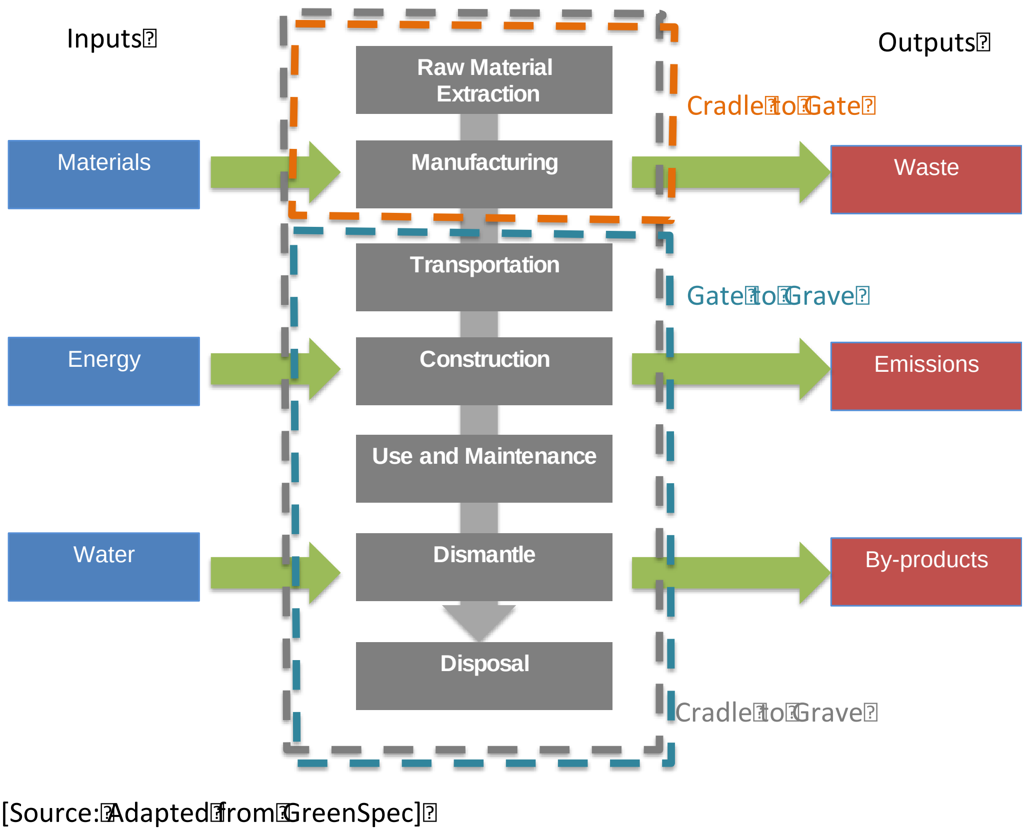


Figure 10: Typical LCA boundaries

[Source: Adapted from GreenSpec 2014]

Most embodied energy and embodied carbon data are bounded within the ‘cradle to gate’ as this boundary tends to be more reliable and easier for manufacturers to calculate (Hammond and Jones 2011); however, a holistic assessment of carbon impacts should be ‘cradle to grave’. It is often left to specifiers, architects and designers to determine the ‘gate to grave’ steps as they have more relevant data for these steps. In this study, a full cradle to grave approach will be adopted. Although it is not also known where the raw materials are extracted from, the manufacturing sites, transportation, construction techniques, use and disposal are supported by evidence from the case study. The default EE and EC inbuilt within the Carbon Calculator relevant to this study is, therefore, 'cradle to gate' and the nominated tool allows for more specific and relevant data to be used for the 'gate to grave' component of the LCA.

Hence, the UK's Environment Agency's Carbon Calculator was considered to be an appropriate tool due to its accessibility, cost, ease of use, applicability to construction materials, and flexibility in over-riding default values and inputting materials not listed. Boundaries can be extended to include the 'gate to grave' applying data that was appropriate to the Haiti case study.

LIMITATIONS OF THE CARBON CALCULATOR TOOL

Ultimately, the Environmental Agency's Carbon Calculator tool was developed in the UK for the UK market. Inherent biases towards UK-based products and EU-favoured default values are expected. If different datasets could be selected to input into the tool (such as from the USA or China), the tool would more accurately reflect the countries operation. This is difficult as LCA information is still at its infancy and many countries do not have a centralised organisation that collects this type of information (Dai and Dai 2003).

The carbon footprint tool calculates the material transport of $tC0_2e$ emitted per tonne per kilometre that the material is transported. This generalisation may skew the results as it does not consider the shipment quantities, as smaller batches in a shipment would yield higher average emissions than larger shipment batches. However, these variations are considered unlikely to affect the overall results.

The mode of transportation is also limited by the water, road and rail options in the calculator. Within the humanitarian industry, particularly in the initial period of emergency response, many relief items are transported by air to meet initial needs.

Feedstock energy used by different manufacturers can alter the carbon result dramatically. For example, if the tarpaulins are manufactured by many different suppliers over Asia then, although the technical specification of the products are identical, the feedstock energy used in each factory can be different depending on whether it is coal based or hydropower, for instance. This variation can be significant between countries as governmental policies and power generation differs considerably. Information on the feedstock energy is not easy to obtain as LCAs are only performed in a relatively small number of countries in the world. Many of the countries in which humanitarian assistance is given have neither the will nor the capacity to carryout LCA profiles on the different manufacturing processes or energy generation.

Another shortcoming of the calculator is that reuse and recycling are treated as the same. Recycling entails energy use in the cleaning and processing of the material being recycled, not measured by the calculator, which treats reuse and recycling in the same way, only distinguishing between transportation modes and distances in the calculations. In addition, the EE and EC data for recycling facilities would be different throughout the UK and data difficult to obtain. For the Haiti scenario, it is even more difficult to obtain data for recycled quantities, due to the relative 'newness' of the practice. This being a privatised industry in Haiti for which there are no national regulations, makes EE or EC data extremely unlikely to exist. Therefore, the reuse and recycle percentages assumed are based on arbitrary proportions allocated by the author.

Final disposal is also limited in the tool to disposal as landfill or recycling. Incineration is another popular disposal method in developing countries, but incineration as a disposal method is not an option within the tool. This limitation will have affected the results for waste disposal.

The 'optioneering' function within the tool is another feature, which was found to be limited. This function allows the user to compare alternative designs from the inbuilt list of materials and does not allow for a completely new material to be introduced for comparison. This means that a whole new spreadsheet is needed to compare materials outside of those listed within the tool.

DATA COLLECTION AND CALCULATION

Data collection

- Humanitarian agency documents and reports reviewed for general practices and Haiti specific practices
- Reports, interviews and web sources used to determine the:

- types of shelter used in the Haiti operation and categories use into post-disaster phases
    - material composition of the shelter types
    - quantities of shelter delivered or built
    - source/manufacturers of the materials and identified local seaports
    - disposal methods and reuse/recycling rates

- Material densities determined using technical specifications of product information sheets where possible, otherwise from other similar manufacturers or educational web sources

- Carbon emission data sourced from Hammond and Jones's ICE database (2011) or, where the material was not listed, from academic studies

- Practitioners interviewed to verify some assumptions and the information reviewed

Calculation

Data was entered into the UK Environment Agency 2007 Carbon Calculator with the following steps:

Step1: Determined the weight of materials used and input equivalent tonnage

Step2: Over-ride any material density default values in tools where relevant to the Haiti operation.

Step3: Entered new embodied carbon data where material is not listed in the software.

Step4: Calculated the distances transported from manufacturers site to closest large international seaport and shipping distances to Port-au-Prince in Haiti.

Step5: Recycling/reuse rates entered otherwise distances to landfill facilities entered.

Step6: Results graphed and comparison of total embodied carbon determined in each post-disaster phase.

Step7: Alternative materials re-modelled in design and EC recalculated to determine reduction effect.

PROCESS TREE FOR PRODUCT ANALYSIS

Each shelter unit was broken down to its constituent materials and the life cycle process determined. The majority of the cradle-to-gate data was determined using the Hammond and Jones (2011) datasets. When the processing of the materials was not available on the lists, the material was further broken down into its constituent parts then analysed; however this meant that certain data was not available for processing methods to be captured into the EC calculations.

Plastic sheeting

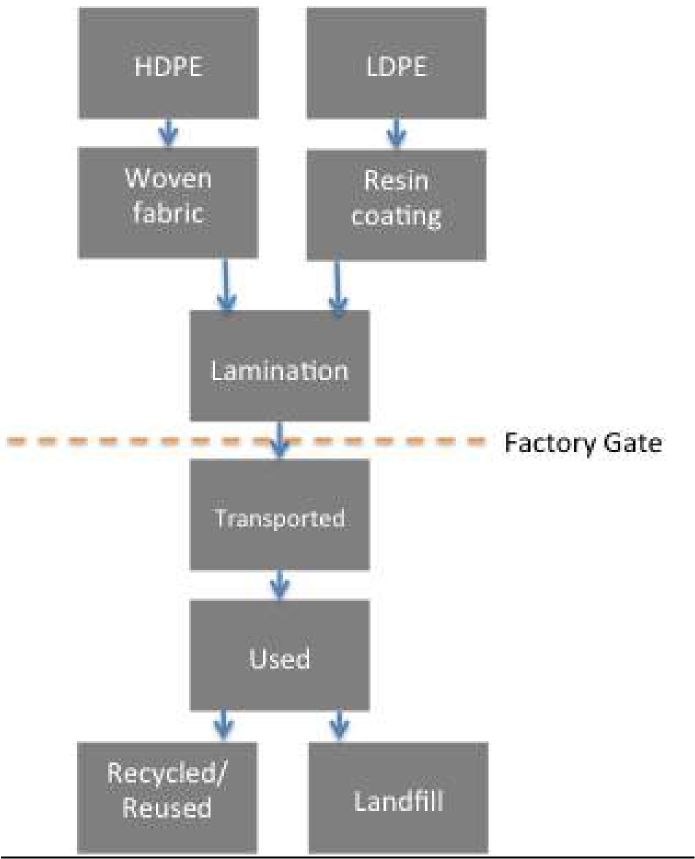


Figure 11: Plastic sheeting process tree

For plastic sheeting, the lamination bonding process was not captured in the carbon footprint.

Family tent

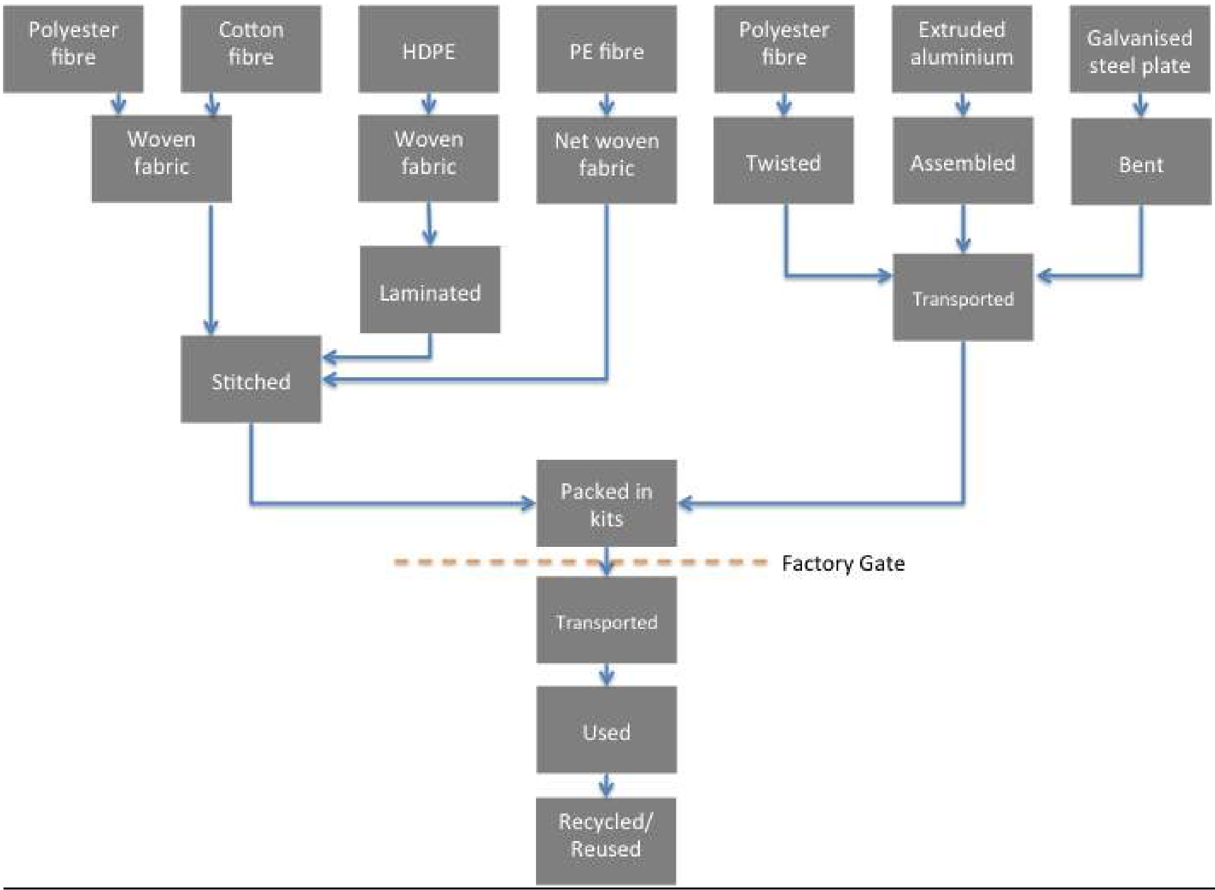


Figure 12: Family tent process tree

The stitching of the tent fabrics, the lamination of the high density polyethylene (HDPE), and the net weaving processes were excluded from EC calculations. It was assumed that the ropes, tent poles and pegs (made from polyester fibre, extruded aluminium and galvanized steel respectively) were manufactured elsewhere and then packed as tent kits by the tent cloth manufacturer. The transportation of these items to be packed was omitted.

Temporary houses

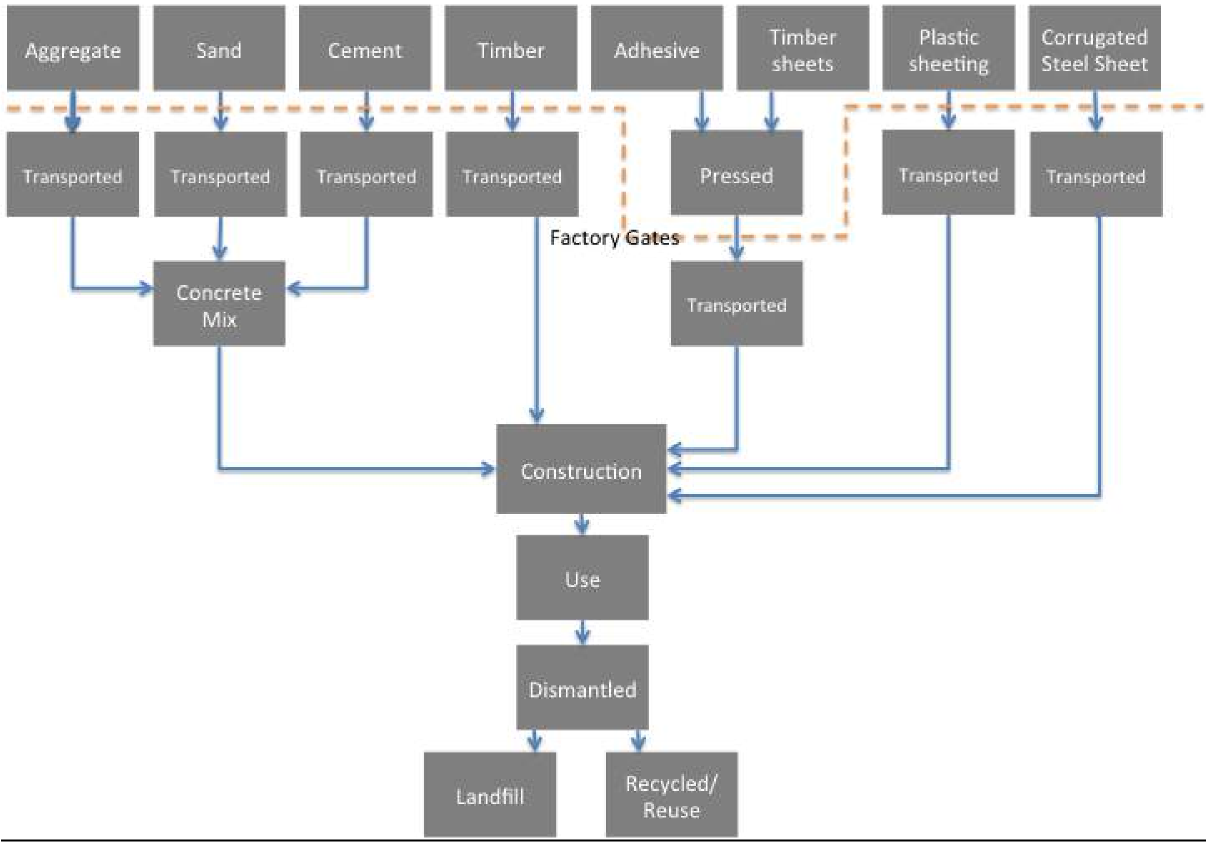


Figure 13: Temporary housing process tree

The concrete ingredients were transported to the site and mixed onsite by hand. The plastic sheeting items were calculated as for the tarpaulin above. It was assumed that the temporary housing would be completely dismantled after use.

FRAMING THE IMPACT IN STAGES OF RECOVERY: FROM EMERGENCY SHELTER TO PERMANENT HOUSING

Temporary housing as described by Quarantelli (1995) is both a *stage in rehousing* after a disaster and a *physical type of housing stock*. In humanitarian disaster relief, 'shelter' refers to the activity of staying in a place during the height and immediate aftermath of a disaster where regular daily activities are suspended, while 'housing' refers to a return to routine activities such as work, school, cooking and washing. This study uses the

Cassidy Johnson (2007a, pp 436–437) definitions of housing and shelter when quantifying amounts of material used in the different phases of emergency shelter, temporary shelter and temporary housing; these definitions are:

- *Emergency shelter:* Emergency shelter may take the form of a public shelter, refuge at a friend's house, or shelter under a plastic sheet and is generally employed for one night to a couple of days during the emergency. Because the stay is so short it does not usually imply the need for extensive preparation of food or prolonged medical services.
- *Temporary shelter:* Temporary shelter may be a tent or a public mass shelter used for a few weeks following the disaster and is also accompanied by the provision of food, water and medical treatment.
- *Temporary housing:* Temporary housing is the return to daily activities of home life and the possible return to work and school, although families will be living in a temporary residence, hopefully awaiting some permanent solution. Temporary housing can take the form of a rented apartment, a prefabricated home or a small shack, depending on the context.
- *Permanent housing:* Permanent housing is the return to former home after its reconstruction or re- settlement in a new home where the family can plan to live on a permanent basis.

It is pertinent to note that changes in shelter and housing phases are not always clear and distinct, but gradual and with overlaps. Often the temporary shelter phase commences concurrently to the emergency shelter phase. It is also clear from institutional reports and observations (Author, Interviewee 3) that materials collected at any stage post-disaster continue to be utilised in the next phase (Interviewee 4). In some instances, phases can be skipped altogether, such as in the 1999 Colombian earthquake, where permanent housing activities commenced without the need for emergency or temporary shelter, and in the 1985 Mexico earthquake, where temporary and permanent housing commenced simultaneously (Johnson 2007a).

In Haiti, because the massive scale of the disaster, the Shelter Cluster was not able to meet temporary housing quotas in a timely manner and many of the temporary shelter structures were upgraded to give similar living standards as a temporary house (IASC

2011). In July 2014, there were still over 69,000 people living in camps in Haiti and a projection of camp closure till March 2015 has been assumed. To analyse the embodied carbon possible, timeframes for the Haiti operation were estimated from the E-Shelter and CCCM Cluster factsheets (http://www.eshelter-cccmhaiti.info/2013/pages/5-cat-factsheet.php). The timeframe of each phase was estimated with the following dates and plotted into the following graph in Figure 14:

- Emergency shelter (January 2010 to July 2010)
- Temporary shelter (April 2010 to July 2011)
- Temporary housing (November 2010 to March 2015)
- Permanent housing (construction commenced in May 2012 and continues to date)

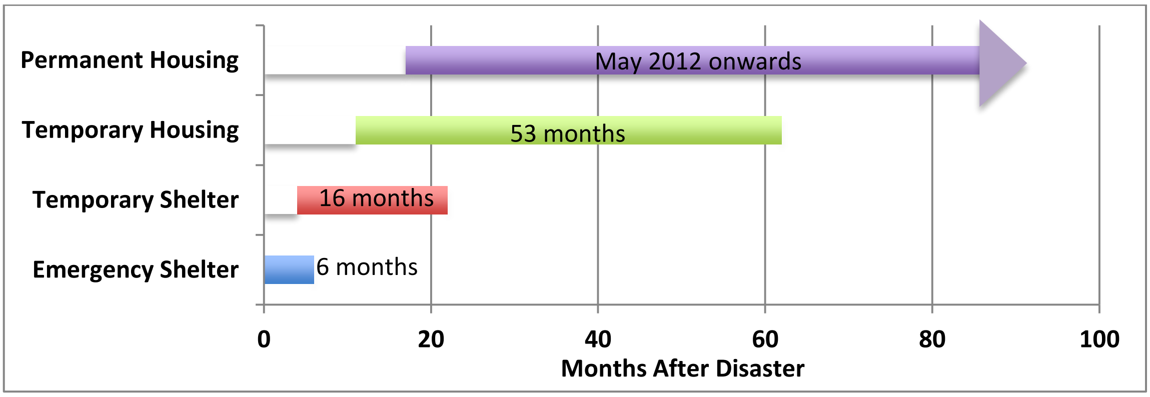


Figure 14: Approximate post-disaster shelter phases in Haiti

The permanent housing phase has been excluded from this study as this phase was carried out by international and governmental assistance and not within the purview of the humanitarian operation for Haiti.

Framing the materials in the different phases is intended not only to highlight the environmental impact of material choices, but to demonstrate which phase is likely to have the greatest carbon footprint so that significant contributors can be further investigated for viable alternatives.

DETERMINING QUANTITIES

Plastic sheeting, also referred to as tarpaulins, is often pre-stocked and prepositioned by organisations, agencies and community groups and used as a first response item. According to the Navaratne (2010) report, 700,000 plastic sheets were distributed by July 2010, 6 months after the earthquake. A further 280,000 plastic sheets were stocked to replace deteriorated sheets in November 2010, March 2011 and September 2011 (Buenza and Eresta 2011). Therefore an estimated total of 1,540,000 plastic sheeting was brought into Haiti for emergency and temporary shelter needs. As emergency shelter is defined as the first few days after the event where no other service provisions exist, due to the scale and nature of the Haiti disaster, it took 4 months before the whole affected population was sheltered. Plastic sheeting continued to be used for the next 24 months while households awaited relocation to temporary housing.

As it is unclear exactly when the emergency shelter stage in Haiti moved into the temporary shelter stage. January to July 2010 was assumed for the emergency shelter phase with the number of 700,000 plastic sheeting. It was also assumed that 12 poles per sheet were needed for the initial 700,000 sheets in the emergency phase to erect the shelter and facilities, which were later used for the same purposes in the temporary shelter phase. Essentially, the temporary shelter phase is an upgrading exercise using the emergency shelter. Extra plastic sheets brought in were used to give more secure shelter using the existing structures and frames, while the family tent also supplemented the demand. Accordingly, the assumed quantities used in the calculation of carbon footprinting are summarised in Table 4.

Table 4: Quantities assumed for emergency shelter and temporary shelter phase

	Timber poles	Plastic sheeting	Family tents
Emergency shelter	8,400,000	700,000	0
Temporary shelter	0	840,000	100,000

There were four designs for temporary housing adopted by the Haiti Shelter Cluster. The numbers of units predicted according to the Navaratne report (2010) are given in Table 5.

Table 5: Quantities assumed for temporary housing phase

	T1	T2	T3	T4
Temporary housing	27,000	27,000	33,750	20,250

In reality, less than half of these were actually built (see Factsheet for July 2014, IASC and CCCM Cluster 2014) due to logistical and financial constraints; however, the above figures will be used to reflect the potential carbon if the constraints not been there and the needs of the population fully met.

CHATPER 8. EMBODIED CARBON CALCULATIONS FOR DIFFERENT PHASES

The data collected and figures used in the UK Environment Agency's Carbon Calculator are presented in the following tables. The types of shelter and their constituent materials have been divided into the post-disaster phases of emergency shelter, temporary shelter and temporary housing. Assumptions in the data and the sources used have been added as notes to the table and are discussed in detail in the section on 'Assumptions and limitations'. The detailed spreadsheets are contained in the Appendix. The over-arching limitations of the tool will be outlined in the next section.

EMERGENCY SHELTER

DATA COLLECTION AND CALCULATIONS

The plastic sheeting used in the LCA calculations is the standard multi-purpose sheeting that can be ordered from the IFRC, International Committee of the Red Cross (ICRC) and Oxfam emergency catalogues (IFRC and ICRC 2012b). The technical specifications of the tarpaulin can be found in the appendix to this catalogue. Although many other types of plastic sheeting were used in the Haiti response effort, most were brought in as part of the initial response effort and eventually replaced by the stronger standardized sheets (IASC 2011). The product has been selected for analysis as it was developed through an inter-organisational research project, its specifications adapted to humanitarian use in regards to durability, waterproofness, sheltering capacity, versatility and recyclability. This multi-purpose sheeting is widely used in Haiti and is a standard item procured by the larger agencies and INGOs in the shelter sector in many countries. A summary of data collected for the emergency shelter materials is presented in Table 6.

Table 6: Summary of data for emergency shelter

	Emergency shelter (6 months)			
Details	Shelter type	Plastic sheeting 4m x 6m on timber frame Covered floor area[i] is 8 m^2		
	Image	[Source: IFRC and ICRC 2012b] 		[Source: Wilde and Solberg 2010] 
	Estimated number of units	700,000 sheets		8,400,000 poles
	Expected lifespan	Min. 2 years in strongest tropical storms		Min. 5 years untreated
	Shelter component	Roofing and wall skin		Ad hoc frame
	Material composition and process	Woven High Density Polyethylene (HDPE) laminated both sides with Low Density Polyethylene (LDPE) coating with 6 x 7.5mm width reinforced webbing of woven HDPE with LDPE coating		Local[ii] timber – usually different varieties of pine sawed using hand tools and light chainsaws
Quantities	Material density	HDPE = 190g/m^2	LDPE = 0.919g/cm^2	480 kg/m^3 [iii]
	Material quantity	26.7m^2	26.7m^2	0.053 m^3 Timber poles 4m, φ= 12.5cm
	Material weight	5.07 kg	0.02 kg	25.44 kg
	Total tonnage	0.00507 x 700,000 =3,549 t	0.00002 x 700,000 =14 t	0.02544x8,400,000 = 213,696 t
Distances	Place of manufacture	Shandong, China[iv]		Jérémie woodlands, Haiti
	Distances[v] and modes of transport (factory to site)	Shandong factory to Qingdao port by road = 370 km Qingdao port to Port-au-Prince port by sea =17,650 km		Jérémie to Port-au-Prince by road = 160 km

	Landfill, reuse or recycle and distances	Landfill = Truitier, 11 km PE Recycling = Lathan, Port-au-Prince, 6.4 km Reuse/recycle = 80% [vi] Landfill = 20%	100% reuse

Notes:
[i] Based on dimensions of sheet providing 2 m high walls on 2 sides and a 2 m x 4 m roof with 2 open ends
[ii] Sourced from forests in Jérémie, approximately 160 km by road from Port-au-Prince according to googlemaps.com
[iii] Average density of pine species from www.engineringtoolbox.com and Wellwood (1946)
[iv] Other manufacturers in India and South Korea
[v] Ports and distances from searates.com
[vi] Estimated figure based on high levels of reuse in developing economies and adaptability for use; it is expected that the tarpaulins would have been used until completely degraded and disposed of in landfill

ASSUMPTIONS AND LIMITATIONS

Design – In the early stage of the emergency, there were inadequate supplies arriving promptly. The design of shelter was ad hoc, people using what they could salvage and any aid items supplied. From the early reports of the quantities of tarpaulins delivered against the number of affected people, it seems that there was only one tarpaulin per shelter, although at least two pieces were needed to properly shelter a family of four. Extra tarpaulins were delivered during the temporary shelter phase, thereby upgrading the existing emergency shelters.

Supplies and shipping – In the early part of the emergency, supplies arrived by air (Interviewee 4). As it was not possible to obtain information regarding the proportion of items that arrived by air, road or sea, the sea modality was assumed for all items arriving during the emergency phase. This is supported by the quantities delivered, which would indicate shipment by sea as the main mode of transport, as well as reports that the airport at Port-au-Prince was a bottleneck for goods arriving (Interviewee 4), making it likely that the bulk of the tarpaulins arrived through the seaport. Some prepositioned response items such as tarpaulins would have likely been shipped to the intermediary warehouse at Port-au-Prince, meaning that most of the emergency items would anyway have embodied carbon attributed by ships.

Web searches indicate that Chinese suppliers were the most plentiful hence a Chinese supplier from Shandong was chosen. Manufacturers of plastic sheeting to this specification can also be found in India and South Korea. From Shandong, the closest large shipping port is in Qingdao (using the web based seaport.com calculator).

Timber poles to support the sheeting were sourced from the woodlands in Haiti including Jérémie, Baradere, Grand Goave, Leogane, and Hinche (Navaratne 2010) and the nearby Dominican Republic. For ease of calculation, the Jérémie woodland was chosen as representative of average distances timber poles were being transported at 160 km from Port-au-Prince.

EC data –Chinese CO_2 data and LCA profiles of plastics were difficult to source. Although these datasets exist, most are available only through Chinese journal databases and websites in Chinese language, which prevented the author from being able to look up the material. Unfortunately, the proxy values used were the default EU-based data from the Association of Plastic Manufacturers in Europe (Hammond and Smith 2008), where the energy sector uses more non-fossil fuel-based generators. Therefore, the CO_2 from the plastic-based constituents would in reality be higher than those in the results. However, the Hammond and Jones (2011) ICE database lists HDPE and LDPE separately and the more accurate EC values were used in the Carbon Calculator tool.

Material densities – Where material densities were not available on the technical specifications of the sheets, other sources were used. In the case of pine timber, the density was obtained through an engineering web-based database and an academic journal. For the polyethylene fabric, the manufacturing process is not represented in the tool, thus its constituent materials were calculated. This means that the manufacture of the HDPE and LDPE is accounted for, but the lamination process is not included.

Plant and equipment emissions – As the timber poles were mostly sourced within Haiti, the EC data would include the upstream carbon of machines used in the felling and processing of lumber as it is a cradle to gate inventory. The Hammond and Jones (2011) ICE timber proxy data is likely to be higher than those in Haiti. The UK timber industry is likely to use larger plants and equipment, rather than the hand tools and chainsaws used in Haiti; hence, the proxy EC value is likely to be higher than the actual value used.

Reuse and recycling – It was assumed that 100% of the timber poles would have been reused and recycled in Haiti, being a valuable commodity. If the timber were not used to build permanent structures, it would, at the very least, be used as fire wood, the main cooking fuel in the Haitian camps (Thummarukudy 2010). The calorific value of burning the wood is not included in the calculations.

Port-au-Prince's largest landfill site is located in Truitier, some 11 km away from the centre of Port-au-Prince. This distance was used as the representative distance from all the camps to the landfill.

There are a number of recycling centres and initiatives in Port-au-Prince, which have grown as result of international aid schemes since the earthquake (e.g. Executives without Boarders, Samaritans Purse and the Clinton Foundation). Prior to the earthquake, the central government only collected about 40% of the capital's garbage, the remainder left to rot in streets (Horizon 2014). The largest and privately owned recycling facility in Lathan handles most of the city's recycled waste. The company recycles PE, ferrous and non-ferrous metals, cardboard and paper. It is affiliated with international accreditations, Bureau of International Recyling (BIR) and the Institute of Scrap Recycling Industries. The company's facilities are located in Lathan some 6.4 km from the city centre, which is the distance used as the representative distance for the recycling of the PE tarpaulins.

TEMPORARY SHELTER

DATA COLLECTION AND CALCULATIONS

The temporary shelter used in the LCA calculations is the standardised family size tent that can be ordered from emergency items catalogues (UNHCR. 2012; IFRC and ICRC 2012a). The technical specifications of the family tent can be found in the appendix. Accessories and minor materials such as stitching, hooks, straps, eyelets and strings have been excluded from the calculations because the relatively small quantity used in the material composition of the tent is considered insignificant. Only major components of the tent were included. Packing materials were also excluded from the calculations, although the waste produced from these could have a significant environmental impact.

In the 53-month duration of the temporary shelter phase in Haiti, a further 840,000 plastic sheets were brought into Port-au-Prince to replace deteriorated sheets or used to upgrade and reinforce inadequate shelter. The family tent lifespan was extended in most cases and tarpaulins used as an additional cover. A summary of the data collected for the temporary shelter materials is presented in the table below.

Table 7: Summary of data for family tents

	Temporary shelter (53 months)									
	Shelter type	Family tent – 23 m^2 floor + vestibules								
Details	Images	[Source: UNHCR 2012] 				[Source:UNHCR 2012] 				
	No. of units	100,000								
	Estimated lifespan	Min. 1 year in all weather conditions								
	Tent component	Outer roof	Outer wall	Inner shell	Mud flaps	Ground sheet	Mosquito netting	Guy ropes	Tent poles	Tent pegs
	Material composition	Polyester-cotton blend yarn (60:40)	Polyester-cotton blend yarn (60:40)	Polyester-cotton blend yarn (60:40)	Woven HDPE laminated both sides	Woven HDPE laminated both sides	PE	Polyester	Extruded aluminium	Galvanized steel plate
Quantities	Material density	350 g/m^2	200 g/m^2	130 g/m^2	130 g/m^2	180 g/m^2	38 g/m^2	1380 kg/m^3 [i]	2,600 kg/m^3 [ii]	7,850 kg/m^3 [iii]
	Material quantity	22.82 m^2	16 m^2	46 m^2	14.9 m^2	15 m^2	8.7 m^2	$7x10^{-5}$ m^3 Ropes: 6 x 3m, φ=8mm, 4 x 3m, φ=6mm	0.00153 m^3 Centre uprights: 3 x 2.2m, φ=25mm WT[iv] =1.2mm Ridge: 1 x 4m, φ=30mmWT=1.2mm Side uprights: 6 x 1.25m, φ=19mm WT=1mm Doors: 4 x 1.4m, φ=19mmWT=1 mm	0.00058 m^3 Large: 6 x (350x3x50mm) Medium: 4 x 300mm, φ=10mm Small: 26 x 230mm, φ=6mm
	Material weight per kit	7.98 kg	3.20 kg	5.98 kg	1.94 kg	2.70 kg	0.33 kg	0.10 kg	12.01 kg	4.54 kg
	Material weight	0.00798 t	0.0032 t	0.00598 t	0.00194 t	0.0027 t	0.00033 t	0.0001 t	0.01201 t	0.00454 t
		0.0172								
	Total tonnage	1,720 t			194 t	270 t	33 t	10 t	1,201 t	454 t
Distances	Place of manufacture	Karachi, Pakistan [v]								
	Distance [vi] and mode of transport (factory to site)	Karachi factory to port by road = 10 km Karachi port to Port-au-Prince Port by sea = 15,920 km								

	Landfill, reuse or recycle and distances	Landfill = Truitier 11 km Metal, PE recycling = 6.4 km to Lathan, Port-au-Prince	Reuse rate: 100%

Notes:

[i] Density from marlowropes.com
[ii] Density range for melted aluminum: 2,560–2,640 kg/m^3 from engineeringtoolbox.com
[iii] Density for iron from www.engineringtoolbox.com
[iv] WT is wall thickness
[v] Other manufacturers in India and China
[vi] Ports and distances from searates.com

Table 8: Summary of data for plastic sheeting used during the temporary shelter phase

Details	Shelter type	4x6 plastic sheeting – Replacement of plastic sheeting	
	Image		
	No. of units	840,000	
	Material component	HDPE – woven fibre	LDPE - coating
Quantities	Material weight per unit	5.07 kg	0.02 kg
	Total tonnage	0.00507x840,000= 4,259 t	0.00002x840,000= 16.8 t
Distances	Distance and mode of transport	Shandong factory to Qingdao port by road = 370 km Qingdao port to Port-au-Prince port by sea =17,650 km	
	Landfill, reuse or recycle and distances	Landfill 20% = 11 km in Truitier Reuse/recycle 80% = 6.4km in Lathan	

ASSUMPTIONS AND LIMITATIONS

Shipping and supplies – From web searches, a Pakistani supplier from Karachi was chosen for the tent manufacturer. There are also manufacturers of this tent specification found in India and China. There is an international shipping terminal in Karachi and the distances between ports were calculated from the web-based searates.com calculator. All other assumptions in relation to tarpaulin used in the temporary shelter phase apply to the emergency shelter phase.

Material densities – The polyester guy rope density was sourced from a rope manufacturer for boats and was 1,380 kg/m^3. This value was considered credible as the manufacturer tests the ropes against BS EN ISO 2307.

Tent poles are made from an extruded aluminium pipes. The density range found on a web based engineering database for melted aluminium is 2,560 to 2,640 kg/m^3. The average of this range was assumed for the tent pole density. The same source was used to find the galvanized steel plate density of the tent pegs, which was 7,850 kg/m^3.

EC data – Polyester ropes and polyester-cotton blend fabrics are not typical building materials and are, therefore, not listed in the UK Carbon Calculator or the Hammond and Jones (2011) ICE database. A study conducted by Kalliala and Nousiainen (1999) determined that the carbon emissions for polyester and polyester-cotton blend fabrics are as follows:

- Polyester = 2.387 kg CO_2e/kg
- Polyester-cotton blend fabric (50:50) = 5.225 kg CO_2e/kg

The tent fabric used in Haiti has a 60:40 blend, not a 50:50 blend, as in the Kalliala and Nousiainen study. However, the carbon values from the Kalliala and Nousiainen study were considered an adequate approximation for this analysis.

The tent pegs used in Haiti were made of galvanized steel plate and were likely to have been manufactured outside of the UK and Europe. Therefore, the more appropriate 'rest of the world' value of 2.31 kg CO_2/kg (Hammond and Jones 2011) was used.

Recycling and reuse rates – The reuse of family tents was assumed to be 100% as these products and components of the tent are often donated to local non-government organisations or to local governmental authorities. They are normally washed and stored for other emergencies (Interviewee 3), unless they are degraded beyond use, in which case they are disposed of by the camp refuge management, sometimes by incineration (Interviewee 4).

Similar to in the emergency shelter phase, assumed recycling/reuse rates of 80% and landfills rates of 20% were adopted for the plastic sheeting. All distances and waste facilities assumed were the same as those in the emergency phase.

TEMPORARY HOUSING

DATA COLLECTION AND CALCULATIONS

In Haiti, there were four major designs adopted by the Haiti Shelter Cluster. The layout of each design is similar with the major difference in wall skins, floor and foundations. All four designs used timber frames and corrugated steel roofing sheets. The temporary housing provided two rooms, some including a porch area. The four designs were developed through the Haiti Shelter Cluster, the inter-agency standing committee set up for the coordination of the shelter and housing after the earthquake. Although not all shelter and housing designs followed these four designs, the four T-shelter designs had approximately 80% coverage (ISAC 2011). The floor area also varied from design to design and a representative figure of 17.5 m^2 was used in the calculations after review of the three designs, which can be found in the appendix.

ASSUMPTIONS AND LIMITATIONS

Timber products – Legal and responsible timber sourcing was a major concern during the temporary housing phase of the operation. IASC and WWF campaigned for the procurement of certified timber sources and offered technical advice and information to aid agencies on timber sources. Consequently, much of the timber was sourced from certified timber sources from North America, Chile and Brazil (IASC and WWF 2011). Due to the proximity and high number of suppliers to choose from in north America, Canadian suppliers were chosen as the primary source for timber. The 4x2 and 2x2 timber was used for the frame of the temporary housing with Canadian pines at 350 to 560 kg/m^3 (SI metric), the average of the range assumed in the calculation of the temporary housing frames. FSC certified 6 mm plywood suppliers were found in Shandong China, and then adopted as the source during the analysis. The density of plywood being 6.93 kg/m^2 for 6 mm thickness (Blattenberger 2014) used as the over-ride figure from the default value in the Carbon Calculator. The timber frame and the plywood panels were intended for beneficiaries to dismantle and reuse in their permanent housing; therefore, 100% would have been either reused or recycled (Interviewee 4).

<u>Metal products</u> – The CGI sheets were used for roofing and walls in the T4 model. The source was assumed to be China as many production plants can be found through web sources in China and Chinese plants offered the most competitive rates. The EC value used in the calculations were from the worldwide assumptions made for steel sheets of 1.85 kgCO_2/kg (Hammond and Jones 2011). The reuse of the CGI sheets is assumed to be 100%. Other metals such as hurricane straps, nails and plates have been excluded from the calculations due to their relatively small quantities.

<u>Concrete</u> – Concrete, consisting of aggregate, sand and cement, was sourced locally from the various rivers and streams (Navaratne 2010). With a cement: sand: aggregate ratio of 1:2:4. Cement was imported from mostly the neighbouring Dominican Republic, but other main suppliers included Cuba (Milfort 2012). For the calculations, quarry materials from the Antibonite River and cement from San Pedro de Marcoris were used. Concrete was used for the foundations and for the concrete floors of the T1, T2 and T4 temporary housing. It is assumed that 100% of the concrete will end up in landfill and will not be reused or recycled.

<u>Plastic sheeting</u> – Same assumptions as for the emergency and temporary shelter phases.

<u>Plant and equipment</u> – The shelters would mostly have been built by hand or by small-mechanised hand tools, as most rebuilding programmes utilised community labour to engage the community with the re-build effort, encourage ownership and provide income generation for households. Therefore, little or negligent plant emissions were produced. This is typical of rebuilding practices in most operations (Interviewee 4, Author).

Table 9: Summary of data collected and calculated for temporary housing phase

	Shelter type	**T1** (Floor area: 17.5 m^2)	**T2** (Floor area: 17.5 m^2)	**T3** (Floor area: 17.5 m^2)	**T4** (Floor area: 17.5 m^2)
Details		[Source: IASC 2011] 	[Source: Haitigrassrootswatch 2012] 	[Source: ShelterCaseStudies 2012] 	[Source: Shukri. 2012] 
	Estimated number of units built	27,000	27,000	33,750	20,250
	Estimated lifespan when in use	5 years	5 years	Up to 3 years	5 years
	Material composition	Timber frame, concrete floor, CGS roof, plywood walls and concrete foundations	Timber frame, plywood floor, CGS roof, plywood walls and concrete foundations	Timber frame, compacted earth floor, CGS roof, tarpaulin covering and concrete foundations	Timber frame, concrete floor, CGS roof, CGS walls and concrete foundations
Quantities	**Weight per unit**				
	Timber	275.00 kg	275.00	275.00	275.00
	Plywood	269.50 kg	385.00	-	-
	CGS	135.00 kg	135.00	135.00	300.00
	Cement	628.57 kg	285.71	-	571.42
	Sand	1,257.14 kg	571.42	-	1,142
	Aggregate	2,514.28 kg	1,142.85	-	2,285.71
	Plastic sheets	-	-	8.75	-
	Total tonnage (% reuse or recycle)				
	Timber (100%)	7,425 t	7,425 t	9,281 t	5,569 t
	Plywood (100%)	7,277 t	10,395 t		
	CGI (100%)	3,645 t	3,645 t	4,556 t	6,075 t
	Cement (100%)	16,971 t	7,714 t		11,571 t
	Sand (100%)	33,943 t	15,428 t		23,126 t
	Aggregate (100%)	67,886 t	30,857 t		46,286 t
	Plastic sheet (30%)			295 t	
Distances	Place of origin	Timber = British Colombia, Canada by road and sea Plywood = Shandong, China by road and sea CGI sheet = Hebei, China by road and sea Sand and aggregate = Haiti by road Cement = Dominican Republic by road Plastic sheeting = Shandong, China by road and sea			

	Distance[i] and mode of transport (factory to site)	Timber = Kamloops mill to Vancouver Port = 350 km, Vancouver Port to Port-au-Prince port = 9,010 km Plywood = Shandong factory to Qingdao port by road = 370 km, Quingdao port to Port-au-Prince port by sea =17,650 km CGS sheets = Hebei factory to Tianjin port = 350 km, Tianjin port to Port-au-Prince by sea = 17,550 km Sand and aggregate = Antibonite River 155 km Cement = San Pedro de Marcoris Cement Plant = 403 km Plastic sheeting = Shandong factory to Qingdao port by road = 370 km, Quingdao port to Port-au-Prince port by sea =17,650 km
	Landfill, reuse or recycle and distances	Landfill = Truitier 11 km Recycling facility = Lathan 6.4 km Reuse = In situ 0 km

Note:
[i] Ports and sea distances from searates.com and road distances from googlemaps.com

The results of each shelter phase after computations using the UK Environment Agency Carbon Calculator are presented in tabular form in this section. The total tonnes of CO_2 emissions (tCO_2e) are presented as calculated values, both tabulated and graphically, including by percentage.

EMERGENCY SHELTER PHASE

Table 10: Results of emergency shelter phase

Emergency Shelter		
Sub-totals	**tonnes CO_2e**	**%**
Quarried Material	0.0	0%
Timber	42739.2	79%
Concrete, Mortars & Cement	0.0	0%
Metals	0.0	0%
Plastics	6885.1	13%
Glass	0.0	0%
Miscellaneous	0.0	0%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	27.0	0%
Portable site accommodation	0.0	0%
Material transport	4755.5	9%
Personnel travel	0.0	0%
Total	**54,406.88**	**100%**
per unit	*0.08*	

$$EC_{phase} = 54{,}406.88\ tCO_2e$$

$$EC_{unit} = 0.08\ tCO_2e$$

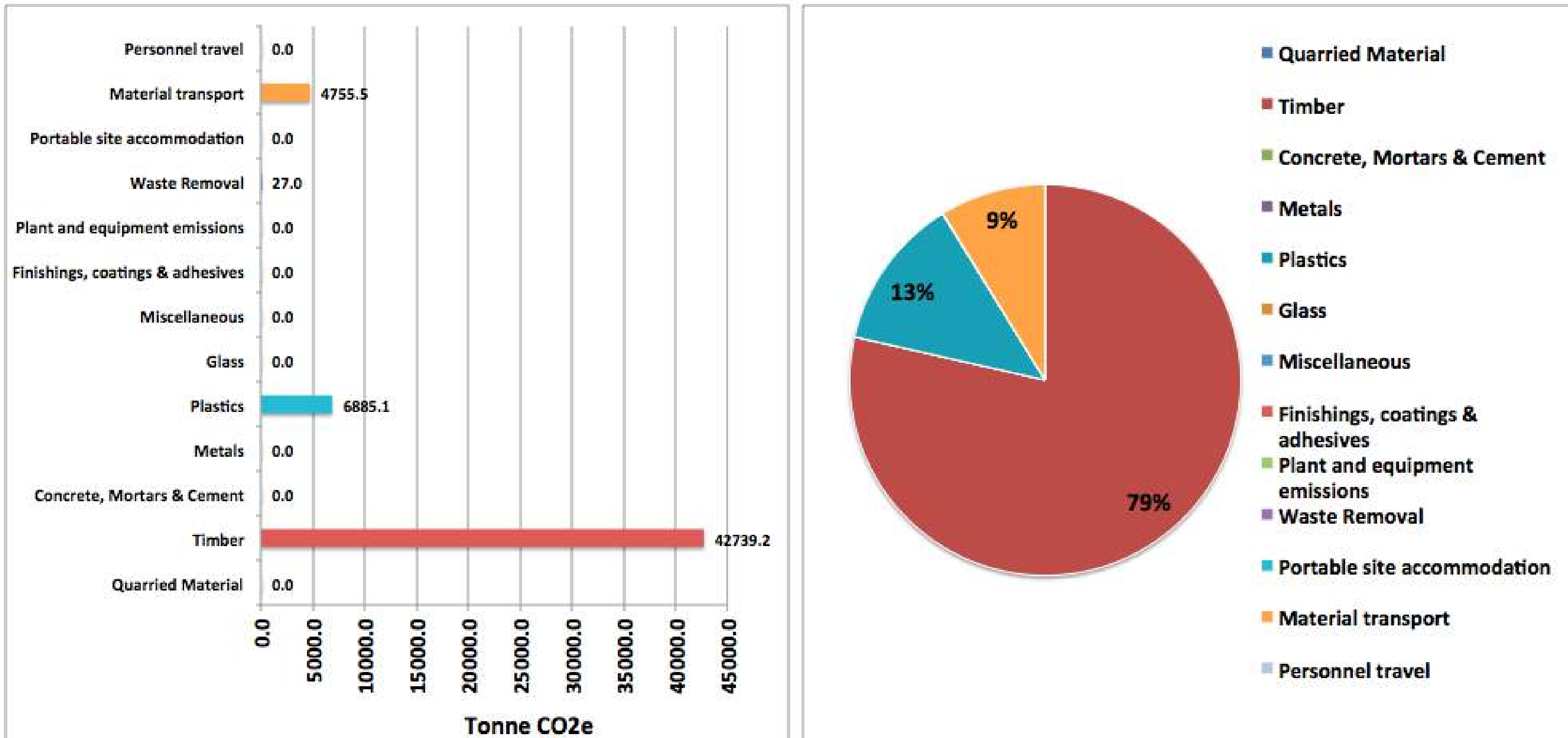


Figure 15: Carbon footprint of emergency shelter phase by tCO_2e and %

The results show that the timber posts are the largest carbon contributor at 79% (42,739 tCO_2e) of the total embodied carbon in the emergency phase. The other contributors were the transportation of materials at 9%, almost matching the carbon output of the plastic sheeting itself, which was 13%. Opportunities to reduce the carbon load will be investigated using bamboo from China as an alternative to Haitiain pine.

Table 11: Results for temporary shelter phase

Family Tents		
Sub-totals	**tonnes CO_2e**	**%**
Quarried Material	0.0	0%
Timber	0.0	0%
Concrete, Mortars & Cement	0.0	0%
Metals	11953.8	52%
Plastics	1007.7	4%
Glass	0.0	0%
Miscellaneous	8987.0	39%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	0.0	0%
Portable site accommodation	0.0	0%
Material transport	953.4	4%
Personnel travel	0.0	0%
Total	**22901.9**	**99%**
per unit	*0.229*	

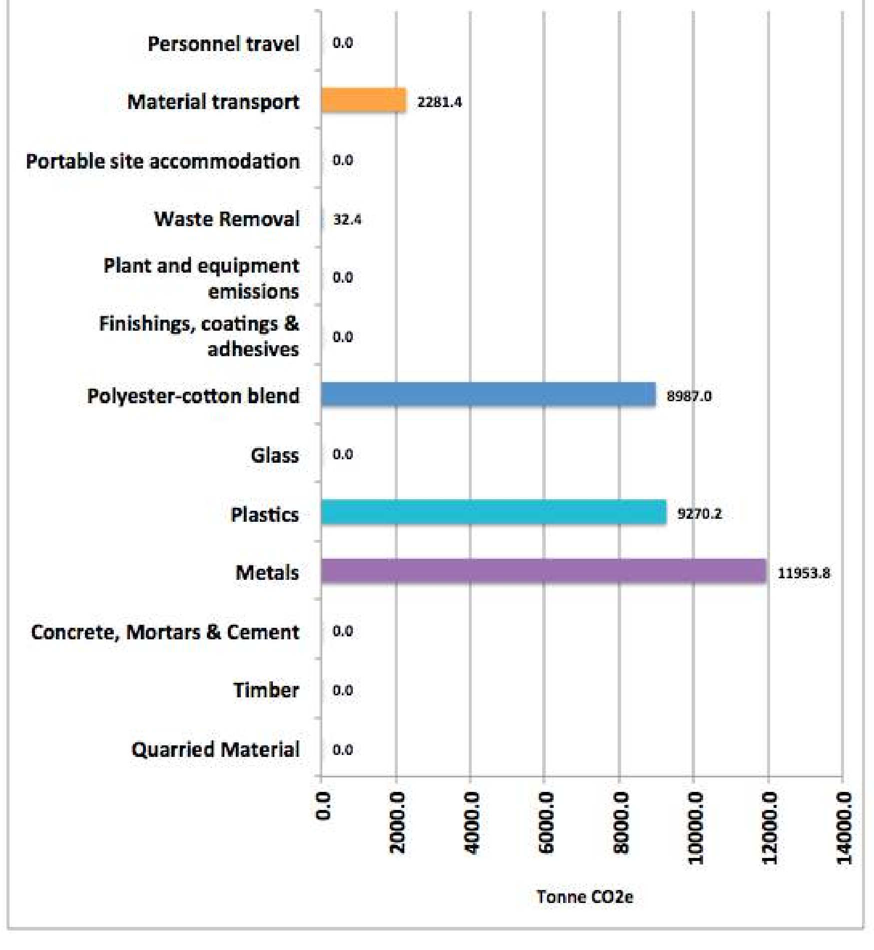
Tarpaulins		
Sub-totals	**tonnes CO_2e**	**%**
Quarried Material	0.0	0%
Timber	0.0	0%
Concrete, Mortars & Cement	0.0	0%
Metals	0.0	0%
Plastics	8262.5	86%
Glass	0.0	0%
Miscellaneous	0.0	0%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	32.4	0%
Portable site accommodation	0.0	0%
Material transport	1328.0	14%
Personnel travel	0.0	0%
Total	**9623.0**	**100%**
per unit	*0.014*	

$EC_{phase} = 32,492\ tCO_2e$

$EC_{tent} = 0.229$

$EC_{tarpaulin} = 0.014$

Combining all materials used in the temporary shelter phase, the total EC can be represented in the following graphs:



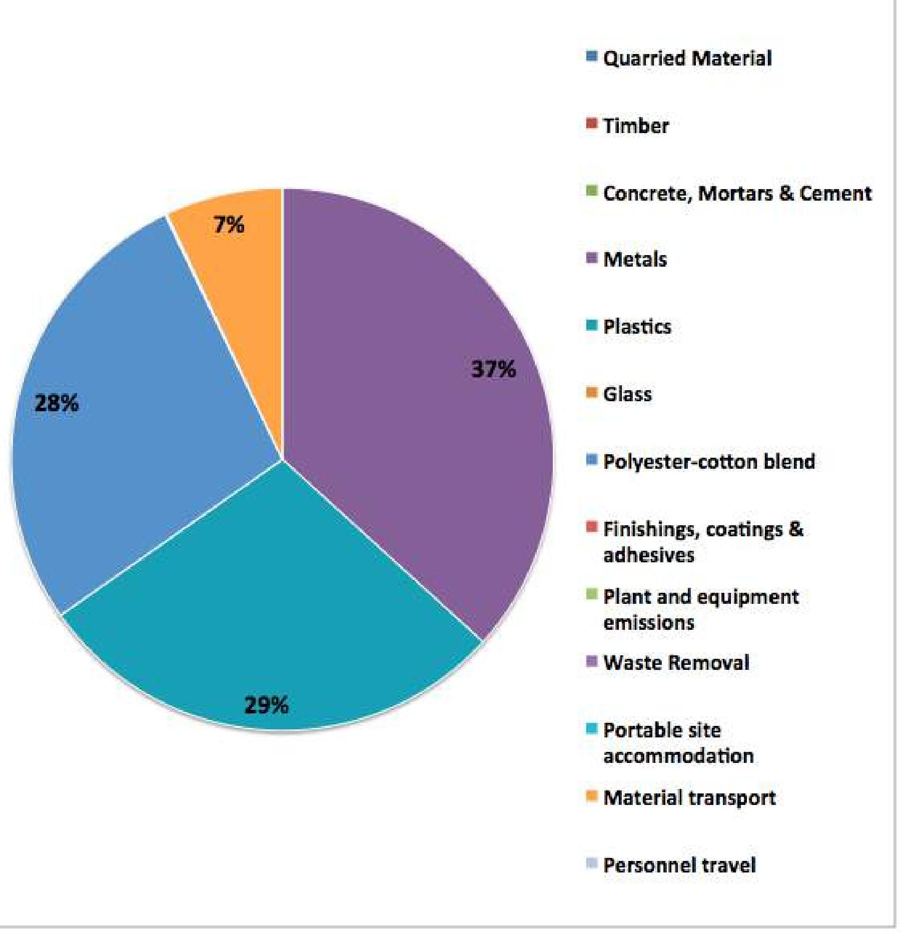


Figure 16: Carbon footprint of temporary shelter phase by tCO2e and %

The family tent has a significantly higher carbon footprint per unit compared to the plastic sheeting with timber supports. As a functional unit, the family tent does not necessarily offer better shelter or more security than the plastic sheeting, nor is it more adaptable, and it does not offer a greater lifespan. The main benefits of the family tent is that it is quick and easy to erect requiring no further tools or equipment, whereas the tarpaulin structure needs separately sourced poles and additional fasteners such as ropes or nails. An alternative scenario will be simulated in Chapter 10, in which fewer tents are brought into Haiti (say 50% less) and replaced with plastic sheeting and timber poles.

Table 12: Embodied carbon for each temporary housing type (T1, T2, T3, T4)

T1 Models: 27,000 units		
Sub-totals	**tonnes CO_2e**	**%**
Quarried Material	512.5	1%
Timber	5576.4	16%
Concrete, Mortars & Cement	14934.5	43%
Metals	6743.3	19%
Plastics	0.0	0%
Glass	0.0	0%
Miscellaneous	0.0	0%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	27.9	0%
Portable site accommodation	0.0	0%
Material transport	7098.1	20%
Personnel travel	0.0	0%
Total	**34,892.67**	**100%**
per unit	*1.29*	

T2 Model: 27,000 units		
Sub-totals	**tonnes CO_2e**	**%**
Quarried Material	233.0	1%
Timber	6979.5	25%
Concrete, Mortars & Cement	6788.3	25%
Metals	6743.3	24%
Plastics	0.0	0%
Glass	0.0	0%
Miscellaneous	0.0	0%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	63.4	0%
Portable site accommodation	0.0	0%
Material transport	6749.6	24%
Personnel travel	0.0	0%
Total	**27,557.04**	**100%**
per unit	*1.02*	

T3 Model: 33,750 units		
Sub-totals	**tonnes CO_2e**	**%**
Quarried Material	0.0	0%
Timber	2877.1	19%
Concrete, Mortars & Cement	0.0	0%
Metals	8428.6	56%
Plastics	749.3	5%
Glass	0.0	0%
Miscellaneous	0.0	0%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	7.3	0%
Portable site accommodation	0.0	0%
Material transport	3121.0	21%
Personnel travel	0.0	0%
Total	**15,183.38**	**100%**
per unit	*0.45*	

T4 Model:20,250 units		
Sub-totals	**tonnes CO_2e**	**%**
Quarried Material	349.4	1%
Timber	1726.4	6%
Concrete, Mortars & Cement	10182.5	36%
Metals	11238.8	40%
Plastics	0.0	0%
Glass	0.0	0%
Miscellaneous	0.0	0%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	11.1	0%
Portable site accommodation	0.0	0%
Material transport	4627.7	16%
Personnel travel	0.0	0%
Total	**28,135.81**	**100%**
per unit	*1.39*	

$EC_{phase} = 105{,}768.9\ tCO_2e$

$EC_{average\ unit} = 1.00$

The models demonstrating the lower carbon emission results are those requiring less concrete. Model T3, which uses compacted earth floors was the lowest contributor to EC, with 0.45 tCO2e per unit. Combining all materials used in the temporary housing phase, the total EC can be represented in the following graphs:

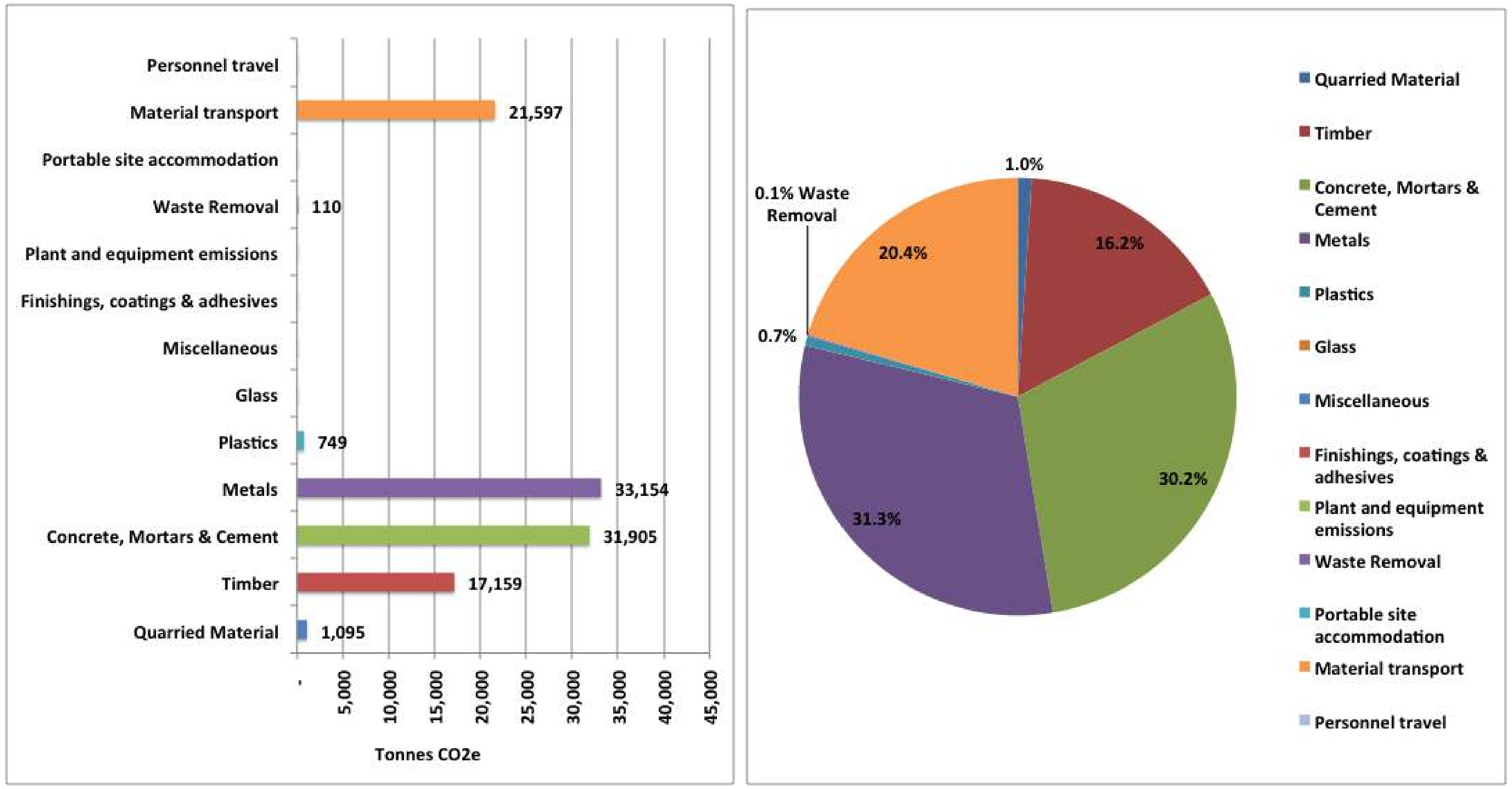


Figure 17: Carbon footprint of temporary housing phase by tCO_2e and %

Metals were the biggest contributor to EC in the temporary housing phase (31.3%), being marginally greater than concrete, mortar and cement (30.2%). Transportation of materials contributed a large share of EC at about 20.4%. An obvious carbon reduction strategy in this phase would be to use crushed debris for the flooring in Model T1 and T4. The foundations for the timber frame posts can also be substituted with recycled aggregate and cement using 50% fly ash. Timber frames will be substituted with bamboo in Chapter 10 to model the impact of carbon reduction when using alternative designs.

COMPARISON OF EMBODIED CARBON FOR EACH PHASE

The total EC for each post-disaster phase is further analysed in this section. In Table 12, a comparison of the post-disaster phases is presented showing the EC produced per month, per unit, per square metre and per occupant. These were ranked in the Table 13. The normalised data is then graphed in respect to the different factors to allow for interpretation. The number of occupants at each phase is taken from the E-Shelter and CCCM Cluster Factsheet July 2014 (IASC and CCCM Cluster 2014).

Table 13: Embodied carbon of humanitarian shelter in each post-disaster phase

	Emergency shelter	Temporary shelter	Temporary housing	Total
Total EC (tCO_2e)	54,407	32,492	112,838	199,737
Duration (months)	*6*	*Up to 16*	*Up to 53 months*	*60*
EC per month	9,068	2,031	2129	3329
EC per shelter unit	0.08	0.04[i]	1.04	0.22
EC per m^2	0.01	0.003[iii]	0.06[iii]	-
EC per occupant	0.035[iv]	0.030[v]	0.190[vi]	-

Notes:

[i] Based on (100,000 tents x 0.229 + 840,000 tarpaulins x 0.014)/800,000 units

[ii] Total floor area= 700,000 units x 12 m^2 + 100,000 tents x 23 m^2

[iii] Total floor area= 108,000 units x 17.5 m^2

[iv] Displaced persons as at July 2010 = 1,536,447

[v] Displaced persons as at November 2010 = 1,068,882

[vi] Displaced person as at November 2011 = 519,164

Table 14: Rank order of embodied carbon per phase (best = 1; worst = 3)

Rank order (best to worst)	Emergency shelter	Temporary shelter	Temporary housing
EC per phase	2	1	3
EC per month	3	1	2
EC per shelter unit	2	1	3

EC per m^2	2	1	3
EC per occupant	2	1	3

The rankings demonstrate that the temporary shelter phase is consistently the best performer in terms of the carbon burden and temporary housing the worst. However, from the literature and reports on Haiti, the materials used in the emergency phase were carried over and used in the temporary shelter phase, so, in effect, the emergency shelter materials are supplementing the next phase. The emergency and temporary shelter phases can therefore, be combined; the proportions are illustrated in the graph in Figure 18.

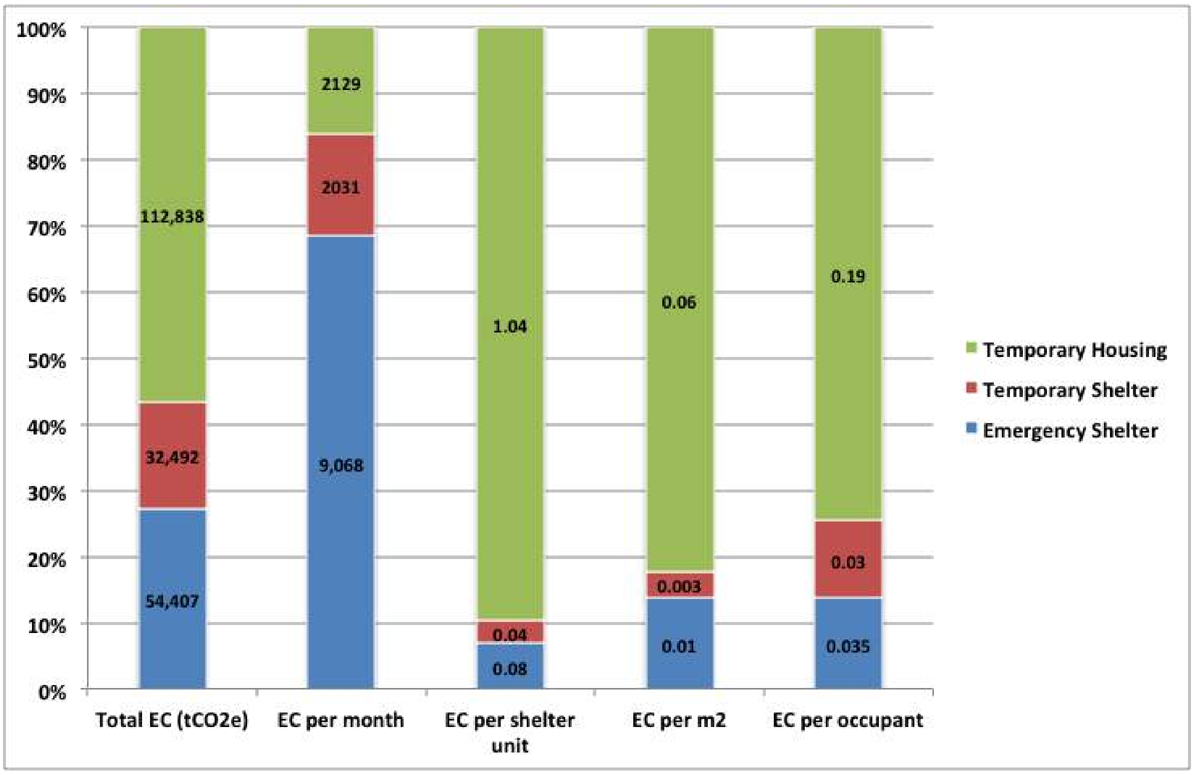


Figure 18: Percentage of embodied carbon for each phase (per month, shelter unit, square metre and occupant)

When looking at total EC, the combined EC for the emergency and temporary shelter phases is less than half the total used in the temporary housing phase. When analysing the EC per month, emergency shelter uses more than double the other two phases combined. The EC per shelter unit in the emergency and temporary shelter phases is only about 10% of the total, suggesting that the carbon released is well spent during these early phases. This is similar for the floor area and for each person housed.

Extrapolating the Haiti results globally will give an indication of the total embodied carbon the humanitarian industry emits each year. The United Nations High Commission for Refugees Report (UNHCR 2013) states that there are over 15.4 million refugees worldwide. If tents were used to shelter all of the refugees at six people per tent (based on Sphere Project min. standard of 3.5 m^2 per person), 2.56 million tents would be required, which would add a massive 587,800 tCO_2e to the atmosphere, not including the operational carbon and other activities related to humanitarian efforts.

The study estimated that the total embodied carbon of the shelter materials used in the Haiti Earthquake response was 199,737 tCO2e.

From the literature review, the humanitarian industry can have influence in all of the steps in the carbon life cycle. There are opportunities in every phase to reduce the carbon footprint. The most significant areas of influence are in the design of shelter, procurement choices and transportation routes. There are fewer opportunities to reduce EC at the manufacturing phase, but influence can be exerted by selecting manufacturing companies that produce 'green' products or from countries that have demonstrated results in terms of lower carbon emissions through good governance and investment in clean energies.

CHAPTER 10. EMBODIED CARBON FOR SUBSTITUTE MATERIALS

This chapter simulates alternative practices and substitute materials drawing on Part 1 of the thesis. These alternatives are not intended to suggest a new design for any of the shelters currently being used by the humanitarian industry, but simply to substitute different materials in existing designs to demonstrate carbon differences by changing materials.

BAMBOO SUBSTITUTE (EMERGENCY SHELTER PHASE)

In the emergency shelter phase, timber poles were by far the greatest contributor to carbon emissions. There are few opportunities to reduce carbon emissions during this phase as timber already provides a comparatively low EC compared to traditional structural frame materials such as metal or plastic posts. The use of quarried or earthen materials may yield a lower EC, but most earth-based products will not offer the same ease of transportability and speed in erection, both imperative attributes in the emergency and temporary shelter phases. All engineered timber uses more energy to produce than lumber. The advantage of engineered timber is that it can be lighter and uses less timber, making it a more sustainable option to conserve timber forests.

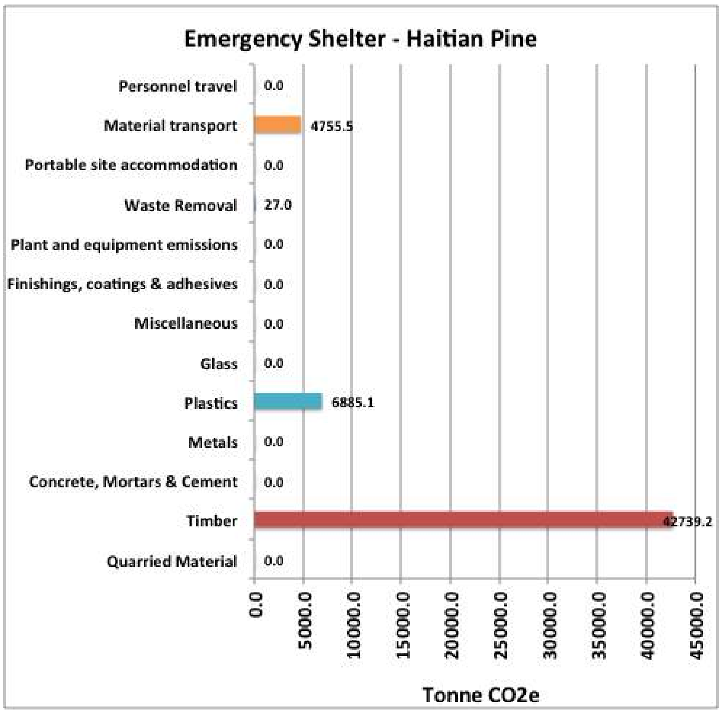
A solution would be to avoid the emergency shelter phase altogether by skipping straight to temporary housing, or even permanent housing. Skipping phases means considerable strategic planning and putting infrastructural support in place prior to any disaster. Haiti had neither. Hence, as in many cases the emergency shelter phase cannot be avoided, bamboo will be modelled as an alternative to timber posts. However, in the Haitian context, the bamboo would have to be imported. For the purpose of the simulation, Shandong China was assumed to be the source and the transportation mode by sea. A small percentage of the bamboo would have arrived by air in the early days of the response, which has not been included in the calculation.

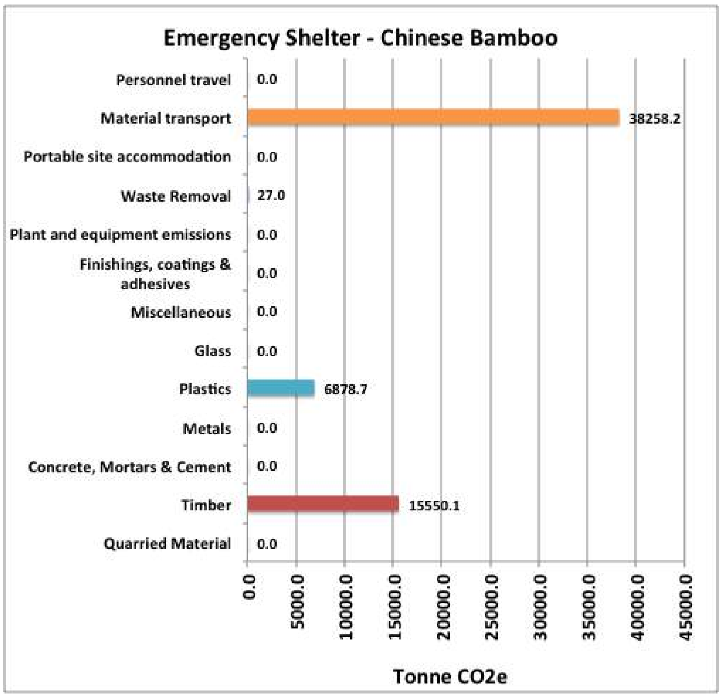
Table 15: Characteristics of bamboo as substitute material

Material	Density	Quantity	Weight	Transportation distance	Carbon emission
	kg/m^3	m^3	tonnes	km	kg CO_2/kg
Bamboo	Wall = 800 [i]	0.0178 [ii]	119,616	By sea = 17,650 By road = 360	0.13 [iii]

Notes:
[i] Ray et al. 2004
[ii] Based on length = 4 m, outside diameter = 12.5 cm, inside diameter = 10 cm
[iii] Yu et al. 2011

The substitutions were made into the UK Environment Agency Carbon Calculator and the results (being 54,407 for Haitian pine and 60,715 for Chinese bamboo) are presented in the graphs below.





EC_{timber} = 54,407 tCO_2e

EC_{bamboo} = 60,715 tCO_2e

Figure 19: Comparison of embodied carbon for Haitian pine and Chinese bamboo

An estimated 64% reduction can be made by using bamboo instead of pine, however, as there are no bamboo forests in Haiti, the import of these meant that the trade-off was in the cost of material transport, which was about 8 times more for bamboo than for timber, giving an overall higher carbon output than for the original scenario using

Haitian pine. If bamboo were available locally, or even regionally, then this would be a viable solution.

REPLACEMENT OF 50% FAMILY TENTS WITH TARPAULINS (TEMPORARY SHELTER PHASE)

In the temporary shelter phase, the family tent components combined to produce more than 65% of the carbon emitted during the temporary shelter phase. The main constituent of the tent is polyester cotton fabric, making up over a quarter of the total carbon and in itself considered a fabric choice as it offers all the benefits of natural and artificial materials, as outlined in Table 2, Chapter 4. Cotton has an equivalent or higher carbon load than some of its artificial counterparts; therefore, opting for a higher cotton rich blend will not necessarily yield a reduced carbon footprint. The other main tent components are the metal poles and pegs. By reducing the density of the poles and pegs or specifying a higher recycled content (from 35.5–59% recycled content) in the steel pegs, one can expect a 0.65 kg CO_2 e/kg reduction in EC, which, in the case of Haiti, would reduce the EC of the family tent by a total of 295 t CO_2. However, reducing the number of tents by half and replacing them with a tarpaulin equivalent would provide a viable alternative and the resulting ECs can be compared.

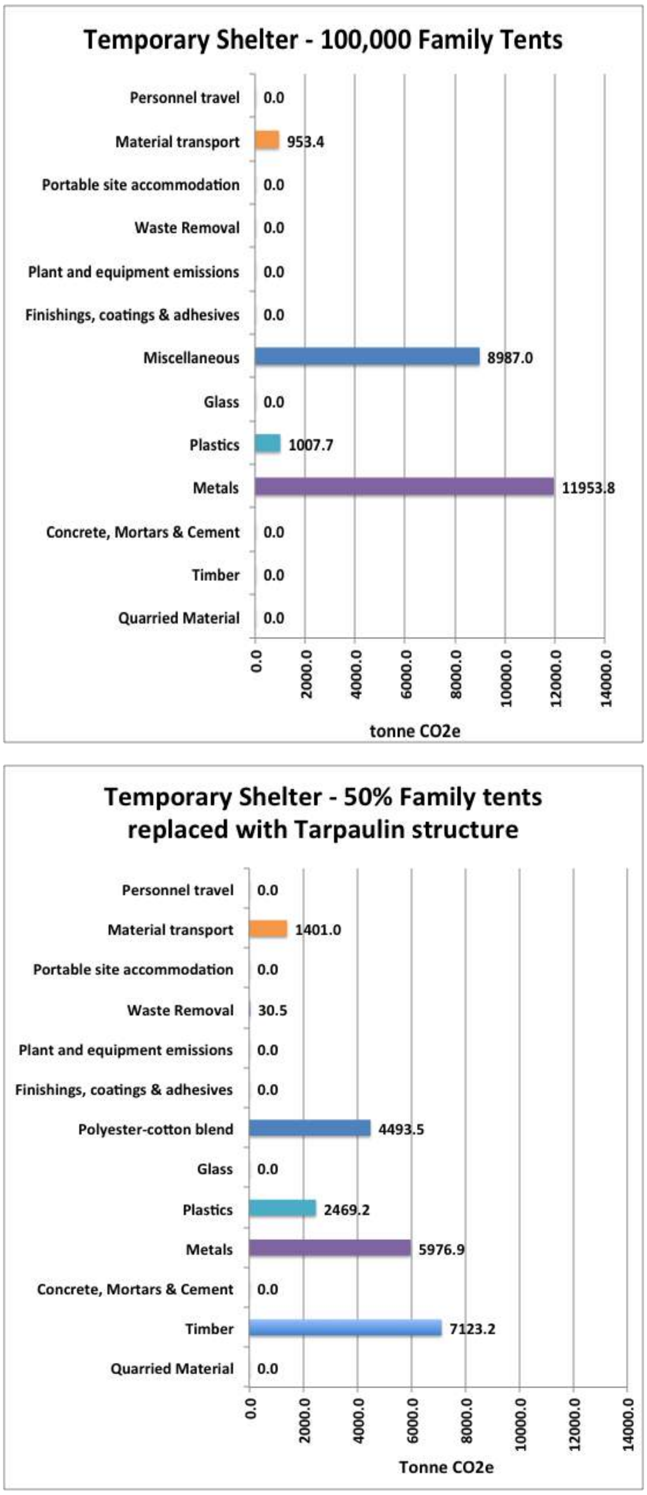
The equivalent materials required to give the same floor area and privacy as the family tent offers should be considered first. The floor area of the family tent is 23 m^2, while the current tarpaulin configuration is 8 m^2. It is estimated that, to provide a similar living space, four tarpaulins and 28 timber poles would be required to replace each family tent.

Table 16: Characteristics of tarpaulins and timber poles

Material	Density	Quantity	Weight	Transportation	Carbon emission
	kg/m^3	units	tonnes	Km	t CO_2/m^3
Tarpaulin	HDPE = 960 LDPE = 920	200,000	HDPE = 1,014 LDPE = 4	By sea = 17,650 By road = 350	HDPE = 0.96 LDPE = 0.92
Timber poles	480	1,400,000	35,616	By road = 160	0.48

The substitutions were made into the UK Environment Agency Carbon Calculator and the results produced were 22,902 tCO_2e for the original tent emission and 21,494 tCO_2e

for a 50% reduction in tents and replacing these with the equivalent tarpaulin shelters (see Figure 20).



$EC_{100\%\ tent} = 22{,}902\ tCO_2e$

$EC_{50\%\ tent} = 21{,}494\ tCO_2e$

Figure 20: Comparison of embodied carbon for replacement of 50% of family tents with tarpaulins and timber posts

Therefore, reducing the number of family tents by 50% and replacing them with tarpaulin structures only yields a marginal reduction in EC of about 6%.

USE OF DEBRIS FOR CONSTRUCTION (TEMPORARY HOUSING PHASE)

Almost all materials used in the temporary housing designs in Haiti have high reusability and recyclability. As commodities are typically in short supply during the re-building efforts and market prices also rise, whatever building materials are brought in by the aid agencies are reused for as long as possible. This is further encouraged if the beneficiaries have ownership of the materials and the structures are easy to dismantle and transport to their permanent sites. Components that are not typically reusable or recycled are concrete floors and foundations and, from the modelling of the four designs, it is clear that concrete is a significant contributor to carbon. A strategy to reduce the carbon footprint in this phase of the recovery effort is to recover resources from earthquake debris for use as components of materials for floors and foundations.

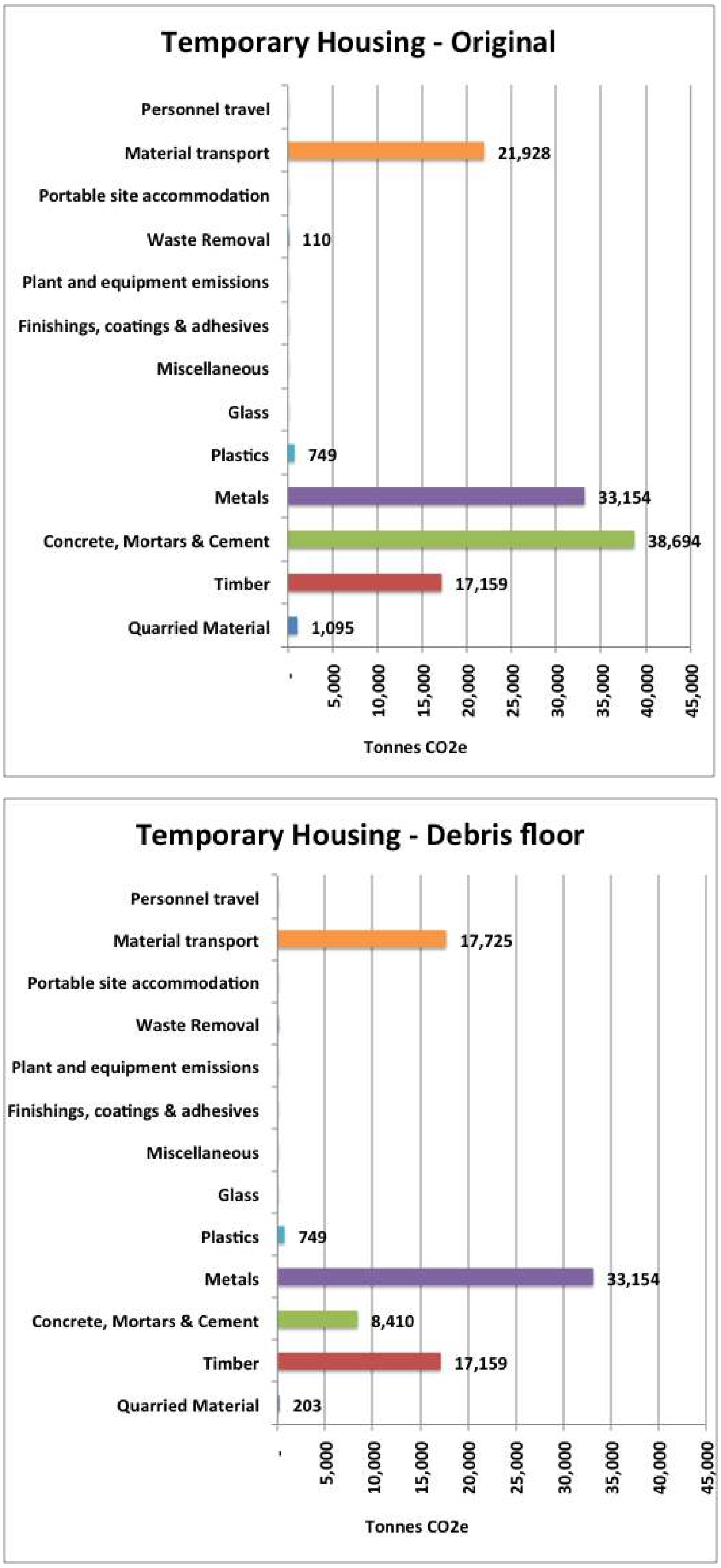
A number of aid actors recognised this opportunity and brought in stone crushing plants and equipment for this purpose (UNOPS 2013; Hirano 2012). Crushed debris can be used in non-load bearing structures, such as the hard core of floors. For the T1and T4 house designs, ordinary concrete can be used for the outside form of the base as well as for the footing of the walls. The crushed debris can also be used as the infill, compacted and levelled. All this can be done using manual labour and equipment.. Floor coverings, such as woven coconut palm mats, can be used to make the floor easier to walk on. Reducing the amount of concrete needed will result in a reduction in CO_2.

To further reduce carbon, eco-cement could be considered. Haiti has a small cement production industry, relying heavily on imports from the Dominican Republic and Cuba to meet its demand. There are some cement substitutes available locally. Fly ash, a by-product of coal power generation, is not available in Haiti, as power is generated by oil (USAID 2014). Blast furnace slag, another cement substitute, a by-product of the production of iron and steel, are not manufactured in Haiti at present. However, neighbouring Dominican Republic relies heavily on coal power for its electricity and has a thriving steel production industry (Smidth 2005). Substitutes cannot replace cement 100%; however, replacement of to 35% by fly ash and 80% by ground granulated blast furnace slag (GGBS) is typical in the UK. Therefore, if cement with 80% GGBS content was ordered instead of pure Portland cement, carbon reductions can be expected.

Table 17: New quantities of concrete ingredients needed

	T1	T2	T3	T4
Cement (t)	3,139.64	1,427.09	0	2,140.64
Sand (t)	6,279.46	2,854.18	0	4,278.31
Aggregate (t)	12,558.91	5,708.55	0	8,562.91
Note: New quantities of concrete are based on 18.5% of original volume. A value calculated based on a perimeter ring to hold in the crushed debris infill 20 mm height and 15mm width.				

The substitutions were made into the UK Environment Agency Carbon Calculator and the results were 112,889 tCO_2e for the original temporary housing designs and 77,455 tCO_2e for the substitute concrete designs (Figure 21).



$EC_{original} = 112,889\ tCO_2e$

$EC_{debris\ floor} = 77,455\ tCO_2$

Figure 21: Comparison of embodied carbon for debris and fly ash cement

The CO_2 reduction from using a concrete floor frame with debris infill gave a combined value of 8,613 tCO_2e resulting in an overall 31% reduction in the EC of the shelter designs.

In summary, in each post-disaster phase there are opportunities to reduce embodied carbon. The largest reductions can be realised in the temporary housing phase by changing conventional concrete mixes to mixes using cement substitutes and by using earthquake debris for non-structural elements. Timber remains a large component of building materials: 79% for the emergency phase and 15.2% for the temporary housing phase. Targeting timber sources and using local resources is not always the best solution, as can be seen from the Haiti case, but timber alternatives must be considered prior to a disaster event if a reduced in EC is to be achieved.

PART 3. DISCUSSION AND CONCLUSION

Part 3 integrates what was learnt in the qualitative review in Part 1 with the quantitative results in Part 2 to discuss strategies to reduce carbon in the Haiti scenario and some of the challenges involved. It also looks at the quantity of carbon released by the humanitarian industry in the global context of carbon emissions. The limitations of the study are examined and, finally, conclusions are drawn and recommendations suggested for further study.

CHAPTER 11. STRATEGIES TO REDUCE CARBON IN HAITI

Use of alternative materials – The standard IFRC/ICRC/Oxfam plastic sheeting or tarpaulins were not substituted in the analysis because the item is highly versatile with its functionality suitable for all of the different phases of the humanitarian operation. The sheet comes in 60 m rolls that can be cut to suit different frame dimensions and uses. The sheeting can be used as a moisture proof membrane on the roof, walls or floors and is applied in many different designs globally today. The EC of one plastic sheet from 'cradle to factory gate' is 9.8 $kgCO_2e$, roughly equivalent to a human being breathing for 9 days. The sheets are made of PE and have a comparatively low embodied carbon for a plastic; changing to a different plastic composition is likely to yield higher results. Furthermore, the ability to reduce EC by changing the weight or composition of the constituent materials of the sheeting is limited and could compromise the functionality, strength and lifespan of the sheeting. Other ways to reduce the carbon burden of the plastic sheeting must be found, e.g., in their manufacturing, transportation and end of life. The hi-spec design of the sheeting has a minimum lifespan of 2 years (IFRC and ICRC 2012b) and the recycling potential is high due to the recycling initiatives brought into Haiti through INGOs and the United Nations.

The high impact item was the locally procured timber poles, which produced a total of 42,739 tCO_2e. The EC of the timber used in the emergency shelter phase was more than twice that for the entire temporary housing phase, which was 17,159 tCO_2e. In Haiti, the local procurement of this resource is unsustainable and efforts to replenish the supply must be made through support to the forestry industry and government. This in turn will have other positive carbon effects with the trees sequestering carbon and neutralising or offsetting the carbon emitted by harvesting the poles. The chronic problem of deforestation in Haiti was exacerbated during the emergency phase, but the importing of a low embodied substitute, such as bamboo, would not have yielded the desired reduction in carbon due to transportation distance. As such, it is critical to find a much closer source of poles to meet the demand at the early stages of the recovery process that both reduces carbon totals and does not cause further landslides or threaten biodiversity.

Limestone, abundant in Haiti, is used widely in the construction of buildings as fine and course aggregate. Ideally, this would be an environmentally sustainable material, but limestone is unsuitable for load bearing elements and incompatible with the reinforcing bars in concrete elements (Thummarukudy 2010) making this material an inappropriate building material for an earthquake prone country. This illustrates the complexity in finding environmentally sustainable solutions for humanitarian responses.

Hollow limestone blocks are another material common in Haiti prior to the earthquake. However, its incompatibility with metal ties or reinforcing steel relegates this material to a more lightweight construction material. Originally, it was considered that limestone blocks could be used to form the outside perimeter of the floor slab in the temporary housing models to hold the crushed debris core. However, as some of the models require steel rods or metal hurricane straps to tie the walls to the floor to meet high wind standards, this idea was abandoned in favour of using granulated ground blast furnace slag cement to reduce the carbon footprint. There is an argument that, for temporary housing, in which the aggregate or blocks will only need to perform for 5 years, limestone aggregate could serve as a viable substitute but is not recommended for permanent housing. Another problem with limestone mortars or limestone cement is that curing takes considerable time, hindering the need for quick construction timeframes. Curing can only happen in dry conditions, eliminating limestone as an option for floor slab construction during the two rainy seasons in Haiti.

<u>Smarter logistics and transportation</u> – As seen from the bamboo example, transportation carbon can play a large part in the sustainability of humanitarian aid. The CO_2 emissions increased from 4,755 to 38,528 to accommodate the bamboo being transported from

China. Importation of materials will always be necessary however; opportunities exist to rationalise procurement and logistics. Were disaster management planning institutionalised, replacements for local timber posts would ideally have been solved prior to a disaster happening, sustainable regional sources investigated and a number of suppliers identified. Appropriate stock would have been prepositioned in a Haitian or Caribbean warehouse in anticipation of a disaster, enabling faster response time and less shipment miles.

<u>Procurement policies favouring 'green' suppliers</u> – Environmental sustainability can easily be mainstreamed globally into green procurement and smarter logistics. Such mainstreaming would require the sectorial clusters in the humanitarian industry to work with service providers to develop 'green' specifications and identify suppliers meeting such criteria. Furthermore, favouring countries that have ratified the Kyoto Protocol would send a signal to those countries and governments that have yet to give this initiative a serious platform. Again, these activities are best done during 'peacetime' or in disaster preparedness, not post-facto when the humanitarian imperative will over-ride environmental concerns.

In Haiti, the effects of deforestation and the chronic vulnerability of the population were well understood early in the relief effort and campaigns were launched by environmental agencies urging FSC products to be used. Aid actors took up these concerns and mostly 'green' timber products were imported. This environmental stewardship may have added some extra costs to the shelter; however, the longer-term effects if this practice had not been followed may have plunged Haiti into further environmental degradation.

<u>Use of debris for reconstruction</u> – Numerous opportunities exists for salvage, reuse and recycling operations, including for metals, plastics and composting. These types of programmes could have multiple benefits, such as clearance of debris, income generation, and reducing demand on natural resources; they can bring about a positive change in future environmental practices within a community and nation. Some salvaged materials can be used for the reconstruction effort, particularly rubble. From the results seen in Chapter 10 where concrete slab flooring was substituted by a GGBS concrete frame with a crushed debris infill for the temporary housing phase, the CO_2 reductions were dramatic – from 38,694 to 8,410 tCO_2e.

In 2010 Haiti, UNOPS conducted a very successful rubble reuse operation where debris was collected and ground to fine and course aggregate for non-structural reuse. Crushed debris produced from 81,335 m^3 of good quality rubble was used for floor slabs, gabion baskets, base layers in road reconstruction, building height in flood prone areas and even in coloured pavers for gardens (UNOPS 2013). This is a positive learning experience that should be replicated in other appropriate recovery programmes.

Some INGOs also conducted debris-crushing programmes using manual crushers for the purpose of floor slab construction enabling income generation at the community level. Rubble reuse requires a high level of coordination, willing labour and the swift enactment of safety practices in the salvaging process. It may hinder rubble clearance if programmes do not wish the debris to be removed promptly so that resources can be reclaimed. It also requires heavy machinery to be brought into the country promptly. This can have knock on effects such as a slower start to rebuilding.

<u>Developing and funding in-country reuse and recycling facilities</u>– A number of initiatives commenced in Haiti with international aid sponsorship focusing on community labour collecting recyclable waste and depositing it at recycling facilities, which could generate income for the unemployed population. Waste brought to the centres is weighed and purchased by recycling firms, the government municipal waste facilities being mostly landfills. To capitalise on this opportunity, the Clinton Foundation has invested in recycling plants for Haitian entrepreneurs. The support given to business enterprises acknowledges that the Haitian government does not have the capacity to drive sustainable recycling solutions and that the shortfall has to be addressed by the private sector.

Such initiatives can be a standard response programme. Investing in the capacity to recycle typical shelter materials such as polyethylene tarpaulins, polyester-cotton tents, and their associated metal pegs and poles would reduce the carbon footprint of response efforts, as well as creating a valuable blueprint in the community for recovery and resilience.

CHATPER 12. IN THE GRAND SCHEME OF CARBON EMISSIONS

It is pertinent to measure humanitarian activities against other activities to understand its carbon contribution from a global perspective. A comparison of the ECs of modern buildings, national annual emissions and humanitarian operations is presented in Table 18. This worldwide extrapolation is based on the UNHCR refugee statistics and the UNHCR standard family tents being distributed to house the refugee population worldwide. The emissions produced by countries are from the World Bank (2014) databank. The values for modern buildings are from Skanska (2010) and RICS (2012) publications.

Table 18: Comparison of embodied carbon between humanitarian aid, countries and modern buildings

	Location	Development	Function	tCO_2e	tCO_2e/m^2	tCO_2e/person
Humanitarian aid	Port-au-Prince, Haiti	Earthquake recovery	Post-disaster shelter	EC 199,737		0.130[i]
	Worldwide extrapolation	Humanitarian aid – Family tents	Refugee shelter	EC 587,800	0.010	0.038
Countries	China			Annual emissions 828,689,200		6.195
	UK			Annual emissions 49,390,900		7.863
	Haiti			Annual emissions 212,000		0.214
	Paraguay			Annual emissions 507,500		0.786
Modern Buildings	Helsinki, Finland	Skanska House	8-storey office	EC 7,481	EC 0.390	
	Nesodden, Norway	Nesodden Community Centre	School, library, leisure centre and administration	Total carbon 17,545 over 60 years	Total 1.5	
	Gävle, Sweden	Nyhamn-Gävle Strand	24 residential apartments in 6 storey	Total carbon 2,664 over 50 yrs	Total 0.854	
	London, UK	Two Kingdom	13 storey office	Total carbon	Total 2.6	

		Street		92,230 over 60 yrs		
	Okehampton, UK	Okehampton Business Centre	13 offices, 3 workshops, training & meeting rooms	EC 1,050	EC 0.874	
	London, UK	Ledenhall Building	51 storey office building with slanting glass façade	EC 76,159		
	UK	Passiv-haus semi-detached dwelling	Residential dwelling	EC 20.49	EC 0.227	

Note:
[i] Based on the registered camp population (1,536,447 persons) as at July 2010 (E-Shelter and CCCM Cluster Fact Sheet July 2014, IASC and CCCM Cluster 2014)
Sources: World Bank (2014), Skanska (2010) and RICS (2012)

This information is better illustrated in the figures 21 and 22. The carbon emissions are graphed logarithmically to capture the scale of the data.

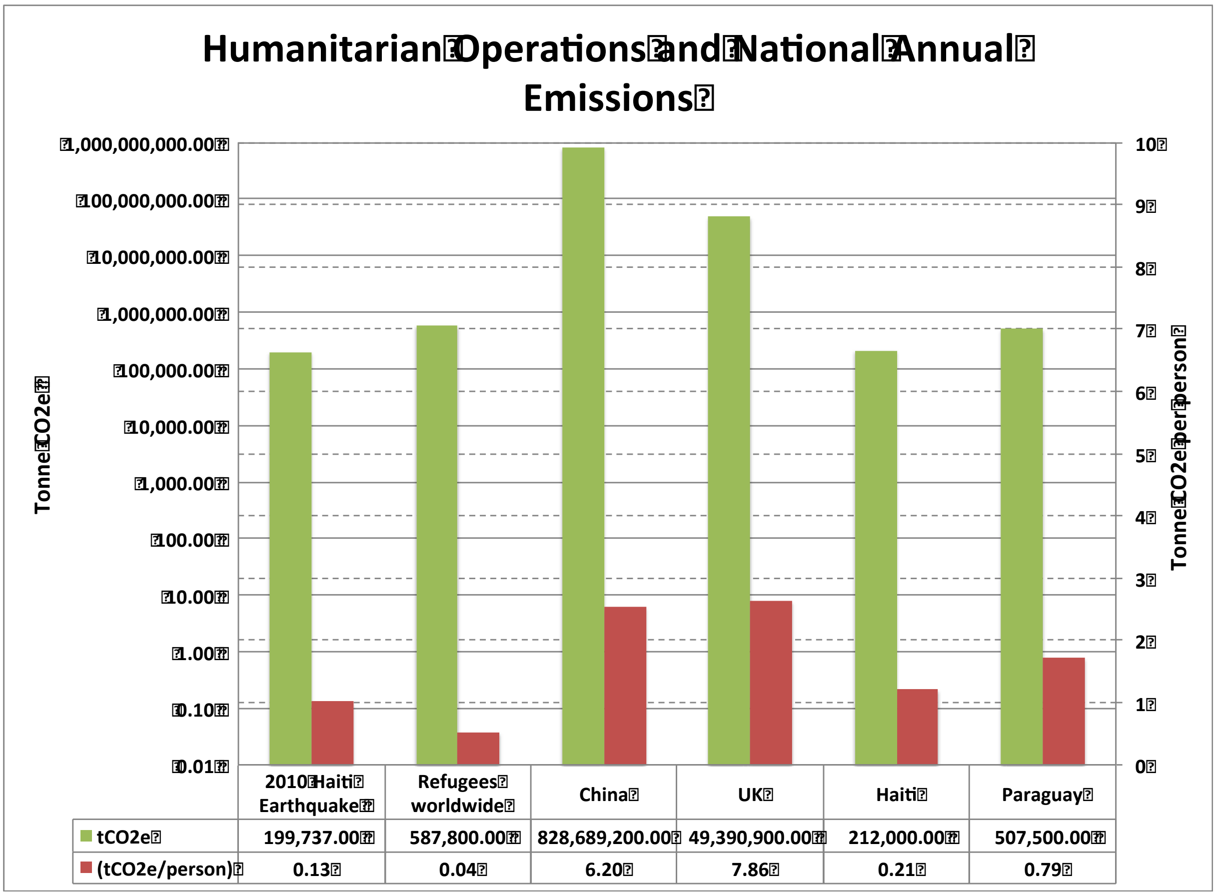


Figure 22: Total carbon emissions and emissions per person for humanitarian operations, refugees worldwide and specific countries

The estimated EC of all the shelter materials required for the earthquake response in Haiti came to 94% of the annual emissions that Haiti typically produces. In the context of the host country's national emissions, this is very high. However, normalising the data in terms of the amount of people it would serve, the estimated EC of shelter materials used in the response was only about 60% of the emissions produced annually per person in Haiti. When looking at the worldwide extrapolation for refugees, it compares to the total annual emissions for Paraguay, but is only 5% of the emissions when comparing per person. The annual emissions produced by China, a rapidly growing economy ,are about 10 times the amount then that produced by the UK, but China produces less carbon per person than the UK. This indicates that the carbon produced by developed countries is greater than that produced by developing countries on a per person basis. The carbon produced by humanitarian shelter is spread across a very high population.

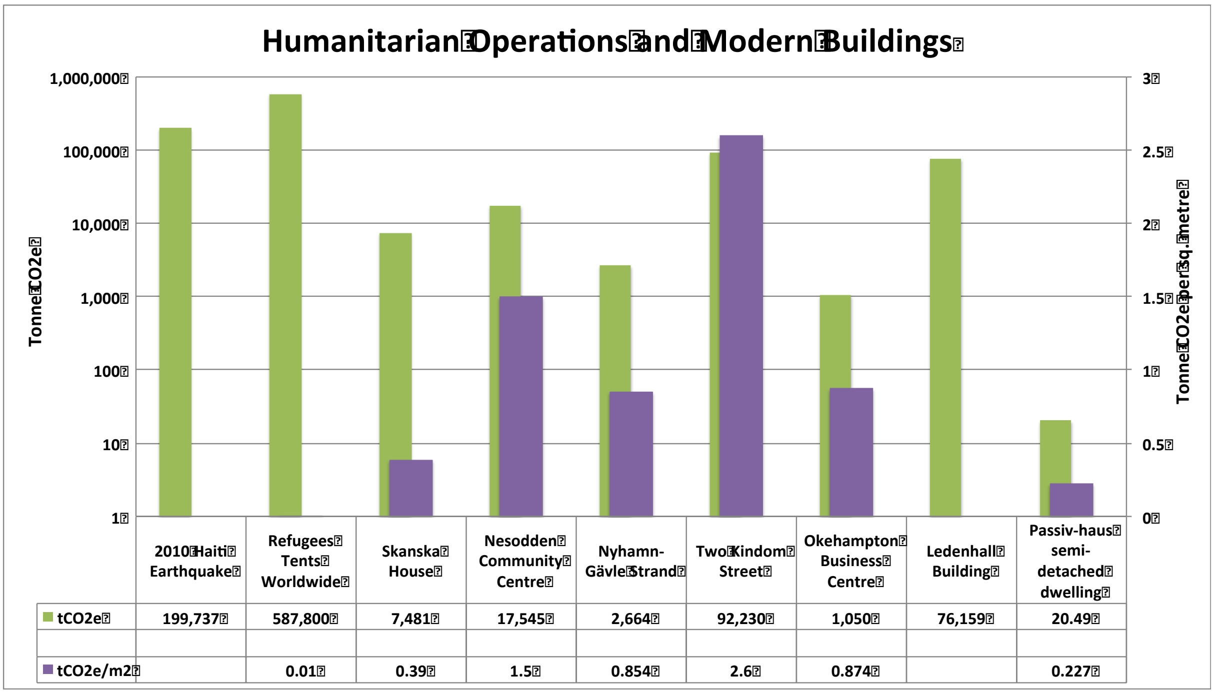


Figure 23: Total carbon emissions and carbon emissions per square metre for humanitarian operations and modern buildings

Sources: World Bank (2014), Skanska (2010) and RICS (2012)

In comparison to a modern building, which is designed to last more than 60 years, emissions by a humanitarian operation are very high considering its lifespan of 5 years. It even outstrips the Ledenhall building, a steel-framed, glass façade building, by almost three times. This indicates that the total carbon emissions for humanitarian shelter are high when considering the lifespan of its function, but almost insignificant when considering the sheltered living area it provides.

From the literature review, we can summarise that the humanitarian aid industry has awoken to the links between sustainable natural resource management and the risk and vulnerability of a society. As an industry, it is beginning to understand that climate change is affecting more people and causing more severe and frequent extreme weather events. The higher levels of management are attempting to build in sustainability measurements into policies and frameworks, but awareness and appreciation by typical practitioners is weak. From the carbon calculations, one large humanitarian operation can equal the annual emissions of its host country and the estimated emissions for all refugee operations worldwide equal the emissions of some developing countries. It has also been shown that there are opportunities at all steps of the life cycle of a material for the humanitarian industry to change or influence the carbon footprint of humanitarian shelter, which could be mainstreamed through strategic planning and procurement. The humanitarian industry can also affect the end of life stages of materials by influencing recycling and reuse practices and infrastructure. The back end (recycling) has achieved some success, but the front end (strategic planning for location specific humanitarian shelter) is still to make its way onto the agenda.

One large humanitarian operation can equal the annual emissions of its host country.

CHAPTER 13. LIMITATIONS OF STUDY

Limit of scope to environmental sustainability – Holistic sustainability themes consider the pillars in the humanitarian sector to be: social, economic, environment and health (BRE 2014). This study is limited to a single issue indicator regarding carbon emissions through the life cycle of various shelter types. The narrow scope of the study aims to demonstrate an environmental impact relevant to all nations and all humanitarian operations. The focus on the environment sought to contribute to a theme to which little attention has been paid and little information and literature exists, namely, the carbon footprint of humanitarian shelter.

Limited sample of shelter types – It is also acknowledged that this study has only analysed a sample of shelter types, whereas, in practice, a variety of materials and shelter designs are used. The IFRC/Oxfam tarpaulin was only one type of tarpaulin used in Haiti, among a myriad of different plastic sheets. These other materials would have caused some variance to the carbon calculated.

Limited to Haiti as a location – The Haiti case study is not representative of all post-disaster situations and contexts. Therefore, extrapolating the results to worldwide effects can give skewed indictors. Firstly, although the 2010 Haiti Earthquake disaster was large in scale in terms of the affected population, its response was also well funded and received two thirds of the appeal funds it needed (DEC 2014). Many other post-disaster operations only receive a fraction of their appeal funding and practitioners are forced to use inferior items to meet the humanitarian demand in lieu of environmental concerns (Interviewee 4 and 5). The case study was based on a natural disaster context lasting 5 years, whereas a refugee camp can typically house populations for around 14 years (IDMC 2013). Therefore the extrapolated data should only be treated as an indication.

Choice of LCA methodology in quantification – The study of the embodied carbon of materials is a very small fraction of LCA and cannot be the sole criterion to consider a material environmentally sustainable. It is only the tip of the iceberg in terms of sustainable development (see Figure 24). LCA considers regional or local impacts, whereas specific local environmental issues may not be highlighted.

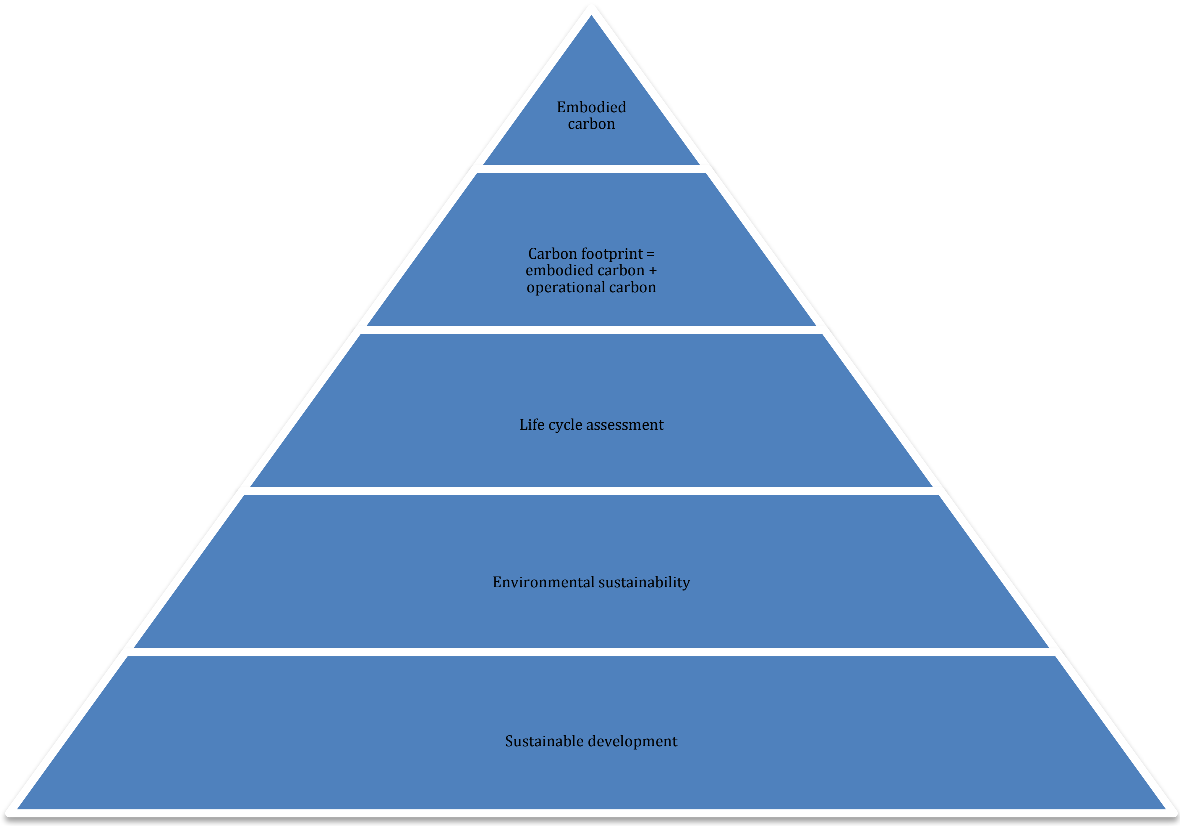


Figure 24: Embodied carbon, the tip of the sustainable development iceberg

Use of UK-dataset – In this study, the dataset is a UK-developed set and, therefore, weighted and rated for impact in the UK context. Data are difficult to find or non-existent in developing countries and, as such, the LCA results do not exactly capture the impact in countries such as Haiti. For example, in Europe many quarry materials, such as sand and gravel, are extracted from rivers and quarries in a highly regulated and sustainable manner, whereas in a country such as the Philippines, where the population growth is 1.81 compared to 0.54 in the UK (CIA 2013), the building demand is far greater and government regulations may not be as stringent in the construction industry.

CHAPTER 14. CONCLUSION

This study looked at the environmental sustainability of the humanitarian aid section with a focus on the embodied carbon of the shelter materials used in the different phases of a disaster response. The main question posed by this thesis was: what is the embodied carbon (EC) of shelter materials typically used by the humanitarian industry at different stages of a disaster response operation and how can this be reduced? To answer this question a methodology was developed for measuring the embodied carbon of humanitarian shelter and strategies formulated to reduce this. Using the 2010 Haiti Earthquake as a case study, the embodied carbon involved in the delivery of shelter materials was analysed. The typical practices of the industry were reviewed to identify opportunities to improve practices for environmental sustainability and fill knowledge gaps

The investigation of the Haiti case study found that the emergency shelter phase had a material embodied carbon of 54,407 tCO_2e, while the temporary shelter and temporary housing phases yielded 32,492 and 112,838 tCO_2e, respectively. The temporary housing phase was the biggest contributor to the carbon footprint of reconstruction materials, but, within the context of carbon emitted per month, the temporary housing phase emitted only a fraction of the carbon emitted during the emergency phase. In general, the carbon spent in the earlier phases was more economical in terms of the amount of units, the floor area provided and the number of occupants housed. When comparing the total humanitarian EC for shelter materials in Haiti (which was 199,737 tCO_2e) with national annual carbon emissions, it almost matched Haiti's typically annual emissions.

In relation to the other study questions, the study found the following:

- What are current attitudes in the humanitarian industry and among practitioners with regards to the environmental sustainability of humanitarian aid practices?

  The uptake of issues of environmental sustainability has been slow in the humanitarian aid industry, although the industry has begun to understand the links between sustainable natural resource management and risk and vulnerability of a society.

- How has environmental sustainability been mainstreamed into disaster response operations by the humanitarian industry and how this can be improved?

  Attempts to mainstream and improve sustainable practices in the humanitarian aid industry have been made at the institutional policy level, but awareness and appreciation are lacking among typical practitioners. Improvements can be made through national and local governance and strategic planning, organizational procurement practices, and awareness campaigns, particularly if the beneficiaries of humanitarian assistance demand environmentally considered solutions.

- What are the barriers to implementing sustainable practices in the humanitarian industry?

  The barriers to sustainable practices include the lack of awareness and the absence of sufficient planning prior to disasters.

- What are some possible strategies to reduce the impact (embodied carbon) of current shelter practices in the humanitarian shelter sector?

  The life cycle assessment of the impact of typical shelter materials used in the 2010 Haiti Earthquake response showed that substituting different materials and changing minor practices could have profound benefits, although trade-offs in carbon in other areas must be considered. Strategies to reduce the carbon impact of current practices include the use of alternative materials, smarter logistics and transportation, green procurement policies, use of debris in reconstruction, designing for reuse and recycling and supporting recycling infrastructure and programmes.

Although the study was limited to the study of embodied carbon within the context of the environmental sustainability of humanitarian shelter, it qualified and quantified the practices and carbon emissions involved in providing humanitarian shelter aid. The study estimated that the total embodied carbon of the shelter materials used in the Haiti Earthquake response was 199,737 tCO2e. Although this is considered high, normalising the data in terms of the amount of people it would serve, reduced it to about 60% of the emissions produced annually per person in Haiti, which is more reasonable. Most importantly, the study found that opportunities exist throughout the life cycle of shelter material and within all levels of government, aid agencies, suppliers and delivery providers to reduce carbon emissions in the provision of emergency shelter after a natural disaster. It is hoped that the findings of this study and the suggested strategies to reduce emissions can contribute to humanitarian best practice.

CHAPTER 15. RECOMMENDED FURTHER STUDIES

This thesis is only a small contribution to the study of the environmental impact of humanitarian shelter. Further studies are needed on the energy and carbon burdens of the humanitarian industry to add to the existing knowledge base on materials and practices in emergency responses, including:

- The operational carbon and embodied carbon of a shelter camp or emergency response operation can be compared to determine where carbon reductions can be made. Diesel generators typically power camps, while cleaner alternatives are rarely considered. A comparison of the carbon footprint with equivalent demands on alternative fuel bases, including a cost benefit analysis, would be beneficial.

- Packing materials warrant inclusion in future calculations as these items could have a significant impact on the humanitarian industry's carbon footprint. Research into packing materials could assist in the reduction of packing materials, innovative logistical solutions or the use of packing materials as part of shelters (e.g., wooden pallets).

- Quantifying waste and studying the composition of waste produced by the humanitarian industry and how this resource can be reused, recycled and properly disposed of will benefit the disaster management sector in strategic planning and the livelihood sector in designing income-generating initiatives.

- Structural and stress studies can be performed on different types of debris materials that have the potential to be reused in new shelter construction (e.g., crushed concrete as aggregate and crushed limestone as a lime mortar additive). Recycled debris used for non-structural members, such as flooring or road fill, could also be looked at in terms of its performance to inform future interventions.

- Carbon footprinting calculations can be extended to include case studies representing different contexts and practices to give results representing global scale operations, which would give more accurate figures on the contribution of humanitarian aid to global warming.

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APPENDIXES

Appendix 1.	IFRC tarpaulin catalogue item and technical specifications
Appendix 2.	UNHCR family tent technical specifications
Appendix 3.	Haiti T-shelter design samples
Appendix 4.	Interview notes
Appendix 5.	UK Environment Agency carbon calculations