THE REFUGEE CAMP FRAMEWORK:
METHODOLOGY AND MODELING THROUGH SYSTEMS VIEW

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ABSTRACT

THE REFUGEE CAMP FRAMEWORK: METHODOLOGY AND MODELING THROUGH SYSTEMS VIEW

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A significant portion of the 20 million refugees of the world lives in refugee camps. There were no holistic and systematic approach on the establishment, management and organization of these refugee camps in the operations research and logistics literature. This thesis first explains the today of the refugee crisis and then how it will evolve with the climate change, in other words, the dimensions of the global refugee crisis that we will need to work on in the future. By setting the boundaries of a refugee camp, with the essential needs as extensions of its location and by examining the economic, ecologic and social sustainability context; the work forms a system model of a refugee camp. The methodological approach on a refugee camp problem is discussed through the problem size, model complexity and representation of human suffering in a mathematical model for a refugee camp. Finally, supported with the system thinking and methodological approach, the stochastic mathematical models for refugee camp location and supply problems are built.
Keywords: Refugee camp location, Refugee camp supply chain, Climate change, Methodology of Modeling, Humanitarian Aid.

ÖZ

SIĞINMACI KAMPI ÇERÇEVESİ:
SİSTEM BAKIŞI ÜZERİNDEN METODOLOJİ VE MODELLEME

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Dünyadaki 20 milyonu aşkın sığınmacının önemli bir kısmı sığınmacı kamplarında yaşamaktadırlar. Bu sığınmacı kamplarının kurulumu, yönetimi ve organizasyonuna hem bütüncül hem de sistematik bir yaklaşım yöneylem araştırması ve lojistik literatüründe bulunmamaktaydı. Bu tez öncelikle sığınmacı krizinin bugününü anlatıp, sonra iklim değişikliği ile birlikte gelecekte nasıl evrileceğini, diğer bir deyişle, gelecekte üzerine çalışmamız gerekecek global sığınmacı krizinin boyutlarını konu etmektedir. Bir sığınmacı kampının sınırlarını çizerek içinde bulunduğu konumun uzantısı olan temel ihtiyaçlarıyla, aynı zamanda da ekonomik, ekolojik ve sosyal sürdürülebilirlik bağlamını da irdeleyerek bir sığınmacı kampı sistem modeli kurmaktadır. Sığınmacı kampı problemine metodolojik yaklaşım; problem boyutu, model karmaşıklığı ve insan acısının bir matematiksel modelde sığınmacı kampı için ifadesi üzerinden tartışılmıştır. Son olarak, bahsedilen sistem anlayışı ve metodolojik yaklaşım ile desteklenen olasılıksal matematiksel modeller sığınmacı kampı yerleşim yeri ve tedariği problemi için kurulmuştur.

Anahtar Kelimeler: Sığınmacı kampı yer seçimi, Sığınmacı kampı tedarik zinciri, İklim değişikliği, Modelleme metodolojisi, İnsani yardım

to millions alone in camps

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CHAPTER 1

INTRODUCTION

There are 26.7 million refugees in the world (UNHCR, 2021). A very small number of countries host many of the world displaced. Most of these are underdeveloped or developing, bearing such a large weight on their shoulders. The severity of the situation back the home countries of the refugees manifests in the trends of the number returning; the hardships of integration in the financial capacity and social constructs are communicated through the number naturalized.

Refugee situations start as emergency situations requiring immediate food, hygiene and shelter solutions, but they then need long-term solutions (The UN Refugee Agency, n.d.). Due to the probabilistic nature and hope that the situation back in their origin country goes back to normal for the families to return, the approach of the organizations is almost always short-term. However, 15.7 million of those are in protracted situations (UNHCR, 2021) meaning that they have been exile for at least 5 years without any naturalization. This number shows us the severity of the refugee problem, in terms of our incompetency of providing long-term stable solutions, still today.

Refugee logistics is not a common subject we work on in our discipline, so it is natural to ask why we decided to tackle this problem. The answer comes back to the philosophy of science and the main drivers of the science itself: why do we produce knowledge? We believe, as scholars, it is a part of our duty to serve for the humanity. One of the aims of this work is to acknowledge the requirement of IE/OR discipline in the topic of refugees, by stating that we need a better comprehension of the camps as a system and attract attention to those in need.

From an altruistic perspective; the best subjects to work are the world hunger, conflict and poverty: to eliminate all the bad that causes people to have a miserable life that they want to flee from in order to solve the problem even before it occurs. But the world is a way larger and more complex system than a refugee camp network. We still have hope that we can get to that point one day, as science, but we are not there yet and a camp is a good starting point, as a model. It must be added that the approaches we take on to help the refugees that are in a desperate need can be applied to internally displaced people, as well. Not crossing the border does not mean that not suffering from instability; their conditions are not fundamentally better, and they are still part of the problem.

This work tries to help the world refugees in refugee camps through four questions: First, what is the global refugee crisis and how it will evolve in the future? The second, what a refugee camp is within the context of its environment and what one needs to sustain and improve refugee stay? Third, how to model a refugee camp concerning the complexity of the refugee camp and long-term human suffering? Fourth, how to mathematically model a refugee camp location problem that concerns the long-term operations and temporal changes?

For the literature review, this work has an extensive research consisting of works from many different disciplines and research streams. To understand the refugee problem, we supported our arguments with many non-governmental organization databases, reports and forced migration studies works. To project the future, our climatology and atmospheric modeling knowledge came into play. For the system model of a refugee camp we looked into the resources in systems thinking and humanitarian logistics, camp surveys as well as the main disciplines dealing with the particular resource or construct. For the methodology we added the works discussing the ethics and equality in modeling approaches. For the novel mathematical model, we utilized the literature on the humanitarian supply chain management and logistics. The works directly related with refugee logistics are listed in the Chapter 2 of this work, the literature review whereas the others are explained when they are utilized in order not to cause repetition.

Chapter 3 of this thesis deals with the first research question. We describe the global refugee situation concerning the number and demographics of the global refugee and other forcibly displaced population, the origin countries and the drivers of the exile, their distribution throughout the world in terms of density and wealth. The short term and long term solutions provided to refugees such as naturalization, settlement in cities and refugee camps is also discussed. All of these infer that global refugee crisis is a long-term problem and it will continue to get deeper and larger.

Also in this chapter we look at the climate change – one of the greatest threats to the world, in order to forecast the future size and dimensions of the problem. To describe what we will face in terms of global resource scarcities and mass migrations, we explain the dynamics of the climate change in terms of energy balance, greenhouse gas and water feedbacks. How these change landscapes, temperature and precipitation patterns and then how biomasses react to the changes in their environments are then studied. In the end, we extrapolate these changes into human and community reaction to weather extremities, sea level changes and resource scarcities to state that more people will leave their homes to seek refuge. As far as we are aware of, this is the first work that dives into such a relationship for an operations research context.

Chapter 4 is the systems model of a refugee camp: a camp that is built for the refugees to sustain their daily essential needs. Why a systems model is needed is that in order to define a problem in a refugee camp to solve, first we must understand the camp. Only then we can propose improvements in the effectiveness and efficiency of the aid in camps. This understanding covers the structures within and surrounding a refugee camp in terms of functions, the relationships, the transformations of entities entering to and leaving from and the economic, technical and cultural paradigms.

In the refugee camp context, we specify the stakeholders and define the relationship between location and climate, considering the shelter, food, water, sanitation, hygiene, and healthcare requirements and supply networks within a camp. The energy, labor and logistics activities to support the needs and their supply are also detailed. The relationships of all of these components of a camp, the means of supply and the transformations are explained through the systems model. The social constructs within the camp like host relations, inequality and crime as a result of these needs forms the cultural paradigm. This is the first work that employs a camp-wide formal systems approach on a refugee camp and explains the dimensions of a refugee camp situation in a systematic method.

Chapter 5 focuses on modeling methodology of a refugee camp as a long-term humanitarian problem. First the question how to represent multiple stakeholders and human suffering in the mathematical model is discussed for ethics. To capture human suffering, a vulnerability metric as an opportunity cost is suggested besides usage of hard constraints for satisfaction and equality considerations. As mentioned, the deprivation of resources affects the societal context and even implicitly considering those effects improves the representation of the real situation in the model.

The decision on size of the system that the problem is defined within is the boundary choice problem. Both the scale and the scope of the system determine the technical complexity and CPU time. Time is the third dimension of a system as the model deals with temporal changes; mainly with refugee arrivals and resource supply bringing a discussion on horizon and duration of the periods. Probabilistic nature of life also brings its own complexities. All of these trade-offs are detailed for a good model for a refugee problem.

Chapter 6 consists of the mathematical model of location and resource supply problem considering local production or outsourcing with hard constraints for minimum targets for resources. The model conveys the relationships between the resources in terms of a deficiency in one having a negative effect on another, to capture reality. This can be mitigated with additional supply of that particular resource. Among direct costs, vulnerability as a result of deprivation is used as an opportunity cost of not supplying the demand.

The first main model deals with the infrastructure and supply decisions of a camp that is already opened and populated in two stages, where the weather conditions have an effect on the supply decisions. The second one chooses the camp location on top of the previous decisions, coming with different supply costs and climate conditions. The third one has multiple periods; the decisions of the previous problems are made considering longer-term prospects under stochastic refugee influx in time.

CHAPTER 2

LITERATURE REVIEW

This work on refugees is not only sourced by the humanitarian logistics stream, but also supported by a diverse range of disciplines and research interests such as sociology, forced migration research, gender studies, humanitarian field work as well as official works of aid organizations. Geosciences and climatology sources are utilized to explain the environmental elements of a refugee camp and the mechanism of climate change since it is a driving force of the refugee crisis.

In this chapter we will mainly review the works from OR literature directly supporting the refugee camp problem and the solution methodology of the novel mathematical model. The work on methodology follows many of the Systems Thinking pioneers. We do not directly follow a particular method, but rather we are internalizing and merging their approaches to construct a good systems model.

The works of other disciplines will not be reviewed here, as they are meaningful for this work in the context. Even the categorical presentation of those in this chapter would cause an unnecessary repetition. Thus, we will cite those to while explaining the current and future refugee crisis and supporting the structure of and relationships between subsystems and components of the refugee camp system.

2.1. Humanitarian Logistics

Humanitarian Logistics covers refugee problems within the context of Operations Research. The current literature on refugees can be divided into three categories: humanitarian work suggesting their approach may work in refugee studies, works aims to raise awareness in refugees and recent works that has a refugee logistics focus without a solid road-map.

2.1.1. General Humanitarian Logistics

Humanitarian logistics literature focuses on the emergency aid in terms of the preparedness, mitigation and response stages. By the nature of the emergencies, the main issue for these stages is the imperfect information about where and when the emergency will happen and how impactful will it be on the victims and the aim is to save as many lives in the case of an event. On the contrary, migration and the act of seeking refuge takes time.

As the internal conflicts of the origin country increases and people start to leave their homes, then, the policy makers have time to be prepared in terms of finding funds and solutions. Further activities focus on how to sustain appropriate living conditions for the refugees. The differences between the contemporary humanitarian logistics and its sub-stream refugee logistics are, therefore, start from the nature of the problem situation.

In Seifert et al.'s (2018) literature review they counted the word "refugee" in articles published. They found that almost all of the humanitarian supply chain management papers containing refugee elements one of two properties for refugee paradigm: they either lean on refugees as a topic but from the perspectives of other disciplines or they utilize operations research practices but focuses on emergency humanitarian logistics without a direct link to refugee crises, Duran et al. (2011) and Perez-Galarce et al. (2017) as such. In the following years, subjects without a focus on the refugee aspect but on the aid in general continued to be studied: the efficiency of the aid organization in general as in Gossler et al. (2020) for outsourcing and procurement decisions in humanitarian logistics, relief supply distribution and routing as in Çankaya et al. (2018).

2.1.2. Humanitarian Logistics Refugee Camp Guidelines

This category of works is the works that has a subject of refugee operations, logistics and camp, but their aim is not to solve a particular problem but to do preliminary research. Seifert et al. (2018), Oloruntoba and Banomyong (2018) and Jahre et al. (2018) form this category by themselves.

The work of Jahre et al. (2018) is a review of four active refugee camps. They explain the operations and policies to present opportunities for the academia to understand what the refugees may require from the discipline and what approaches and actions we may utilize in providing solutions.

The “thought paper” of Oloruntoba and Banomyong (2018) is very important as it started to form the framework of the refugee camp problem. In that work, the type of activities of humanitarian logistics research on refugees are exemplified as feeding and sheltering mobile beneficiaries, settling, resettling to a more permanent settlement, as well as longer-term settlement considering socio-economical factors. They argue the value of OR and SCM for the refugee and internally displaced person care and service delivery at preparedness and logistics planning levels.

Seifert et al. (2018) is the literature review that is discussed in Chapter 2.1.1. Besides presenting the works done, they state that work needed for the refugees. They claim the approach and methods of operations research and management science with an interdisciplinary perspective is required to improve the efficiency of the operations, which are the water and electric supply chain, local sourcing, capacity building refugee-host relations and gender.

2.1.3. Humanitarian Logistics with Refugee Camp Focus

There are also works directly has a topic of refugee camps. Jahre et al. (2016) works on aid organization supply chain efficiency with a distinction between long-term operational needs and emergency needs. Even though the distinction between the demand and supply characteristics of emergency and long term operations is discussed within the body, the paper does not differentiate the two in their location model that combines the supply chains of the two. Pascucci (2021), on the other hand, criticizes works focusing on just the logistics and market efficiency and public sector collaborations rather than actually supplying the required goods and services. Boshuijzen-van Burken et al. (2020) works on value design for aid organizations in terms of refugee well being and public opinion.

The refugee camp location selection problem of Arslan et al. (2021) has the refugee camps as users of a public service planned by the hosting institutions, where service providers visit several camps in trips. The visiting services and what might be their purposes are not defined, and the main focus is the solution efficiency. This work is worthy in terms of an introduction of a refugee camp location and routing problem.

Deneklos et al. (2021) provides a multi-criteria decision making in refugee camp location selection using geographic information system. The paper introduces a combination of slope and elevation with several operational, social and spatial criteria for the distance from the refugee camp to location that is either desired or undesired. The social criterion represents the urban requirements of a refugee for their well-being and for local opposition to refugee settlement. Analytical hierarchy process is used for criteria weighting to find appropriate locations.

Karsu et al.'s (2021) clean water network design paper defines the clean water network of a refugee camp of a water well, water distribution units and pipelines connecting the water distribution units for both the common facility and they are supplied in each shelter. The bi-objective model is solved for the accessibility in terms of the distance between the refugees from the water distribution units and the cost of construction of the distribution units and wells are considered.

2.2. Research Directions

What the literature lacks the most is a proper structure and relationship between the operations, as it will enable us the researchers to understand the refugee camp system. What is also missing is methodology on the refugee aid. As far as the author is aware of, the concepts of ethics in aid, equity, planning horizon, vulnerability and risk are not discussed methodologically for the refugees in terms of the solution approach before this work in the humanitarian logistics stream. With those, the refugee camps should be studied considering broader socio-political and socio-economical factors in parallel to the changing needs of the world. The last need of the literature is models that represent the complexity of the refugee camps and solves the problems with this complexity intact.

CHAPTER 3

THE STATE OF THE GLOBAL REFUGEE CRISIS: TODAY AND TOMORROW

This chapter focuses on the current global refugee crisis and how it will evolve in the future. The formal definition of a refugee is made alongside the number of refugees in the world, their demographics and the organizations responsible of the world refugee population. Then, the reasons for seeking refuge and reasons of not returning are discussed. Following those, climate change mechanism is explained in order to direct the reader to clarify its current and future contribution to the world refugee population since it derives many of the reasons of seeking refuge.

3.1. Current State Of The Global Refugee Crisis

The definition of International Organization for Migration (*Glossary on Migration, International Migration Law n. 34* 2019) for the forced displacement and refugees is presented as follows: Forced displacement of people is the forced movement of people from their locality, environment and occupational activities caused by life-threatening situations such as natural disasters, famine, war and economic challenges. This displacement can be internal (within the borders of a country) or external (to another country). People who are externally displacing might have a status acknowledging their arrival and displacement, or not. If they have, then, they are called a refugee. If not, then, they are an asylum seeker, who arrives without an acceptance and waits for the approval in the country.

We must also differentiate migration from forced displacement: as migration is another term having a broader definition combining all of the permanent and semi-permanent movements of people; from moving to another city for university education to relocating in order to participate in seasonal agricultural activities.

There are approximately 1 billion migrants in the world. The problem of migration or immigration is also different than forced displacement.

3.1.1. Refugee Aid Organizations

The main organizations that protects refugees are United Nations High Commissioner for Refugees (UNHCR: United Nations Refugee Agency) and The United Nations Relief and Works Agency (UNRWA). UNRWA operates for the Palestinian refugees worldwide, where UNHCR is responsible for not only the rest of the refugees but also the internally displaced people, asylum-seekers and stateless people. UN member states gave the authorization to these organizations and they are working at the refugee sites with governments under their approval in provision of protection and durable solutions.

There are also smaller and independent international or local institutions that provide humanitarian aid and support human rights, such the Foundation for Studies and Research on International Development (FERDI). They may supply or monitor the quality and effectiveness of aid or equality in resource allocation. They may also provide soft services such as counselling, education and integration to the host community, such as Refugee Soccer, an organization that connects people through sports in Utah, United States of America (*Afghanistan News.* n.d.)
. The web of research members working on forced migration can also be considered a force as they analyse the dynamics and through this analysis look for better approaches and solutions.

3.1.2. Refugees In Numbers

The figures of refugees and other people UNHCR is responsible of are as follows: (UNHCR Global Trends 2010-2020, UNHCR Refugee Population Statistics Database, 2021) there are 82.4 million forcibly displaced people in the world by the end of 2020. 26.4 million are refugees where 20.7 million of them are having refugee status under UNHCR's mandate and another 5.7 million Palestinians under

UNRWA’s. An additional 4.2 million are stateless. 1.4 million more people seek refugee in 2020 even though the borders of the most of the countries were closed throughout the year, where only 250.000 returned back to their home countries.

Table 1.1. Refugee statistics for the last decade (UNHCR Global Trends, 2010-2020; Refugee Population Statistics Database, 2021)

	Number in millions			
Year	Refugees under UNHCR’s mandate	Refugees returned	Refugees Naturalized	Percent naturalized or returned
2010	10.55	0.20	0.01	1.98
2011	10.40	0.53	0.00	5.15
2012	10.50	0.53	0.01	5.06
2013	11.70	0.39	0.02	3.49
2014	14.38	0.13	0.03	1.10
2015	16.11	0.20	0.03	1.45
2016	17.18	0.55	0.02	3.35
2017	19.94	0.38	0.07	2.30
2018	20.36	0.52	0.06	2.86
2019	20.41	0.32	0.05	1.82
2020	20.65	0.25	0.03	1.38

The data is obtained from the global trends report of UNHCR for the years 2010-2020 and there are a number of discrepancies, mainly caused by poor data collection in camp and handling. We do not have a birth and death rate or numbers, or even number of refugees in protracted situations is only estimation. However, these are clear enough for us to make several important conclusions: The number of refugees and others in UNHCR’s consideration has an increasing trend for the last decade while the percentage of refugees returned or naturalised keeps is decreasing; the number of refugees doubled in the last decade and it continues to grow. One thing to note is that the distribution of the naturalized people to the categories like refugees, stateless people or others is not available. Also we may add the Palestinian refugees that are in protracted situations more than several decades into the mix, rarely getting naturalized (getting a long-term permit or citizenship).

Also, these massive influxes of the refugees are not sudden. The Syrian mass refuge to Turkey, for example, started in 2011 and the rate of inflow did not plummet until 2018 (Registered Syrian Refugees By Date (2021, August 5)), which actually cover one fifth of all refugees. Same can be said about Venezuelans, which a hundred thousand applied for asylum in 2017 before 3 million in 2018 is displaced in 2018, 1 million in 2019 and 300,000 more in 2020 (Population figures, Venezuela (Bovarian Republic of). (n.d.))

During this work, there emerged many human rights violation phenomena in the world, the most significant being the Taliban rule in Afghanistan. The Afghan refugee crises arose after the last report of the UNHCR on refugees, thus, the approximated 0.7 million by the end of September 2021 can be added to the reported 26.4 million by June 2021 to a total of 27.1 (UNHCR, 2021, Afghan emergencies).

In 2020, UNHCR (2021) has the demographics data for 16.9 million out of 20.7 million refugees. 48.5% of those are classified as female (Gender nonconforming individuals are not identified). 13% of all refugees are between 0 to 4 years of age, likely born or conceived in camps. 20% are 5-11 years of age and in total, 47% of all refugees are below 18 years of age. Only 3.5% of refugee population are older than 60 years old. The amount of young and old is quite important as they make the population more vulnerable to the adverse conditions, as they are usually the weakest among them. Here, however, old age may signify more of a short lifetime in camps rather than less of a vulnerability.

3.1.3. Refugees By Origins And Reasons Of Their Refuge

There are several reasons why someone decides to flee and seek refuge from another country (International Organization for Migration, 2019). The reason may be environmental or resource scarcity based such as hunger or thirst, diseases. On the other hand; war, armed conflict, violence or human rights violations may be the motive. They might be caused by internal or international politics, religion or ethnicity. Sometimes the conflicts may be caused by the resource scarcity. All of these situations result in instability and economic challenges.

Syria is the origin country of the largest number of refugees with 6.7 million While the insecurity caused by the civil war being the main motivator of Syrian refugees, it was also reinforced by the economic crises due to lower agricultural production and unemployment due to drought (Food and Agricultural Organization of United Nations, 2017) and increased crude oil prices, as these two sectors made up the half of the GDP of the country (U.S. Department of State, 2010), and the instability that came with it. The following economic sanctions further agitated the situation, encouraged more to seek refuge.

5.7 million Palestinian refugees left their home country due to religious and ethnic differences that has been fuelled their conflict with Israel since 1950s. They form what is called the Palestinian diaspora. 2.6 million refugees from Afghanistan and 2.2 million from South Sudan follow Syrians in numbers. Main motivators for Afghans are instability and insecurity and for South Sudanese armed conflict, hunger, diseases and economic crises altogether.

3.1.4. Refugees By The Host Country

Based on the UNHCR's (2021) records on refugee statistics, we may observe the distribution of the refugees in the hosting countries that in turn helps us make inferences on the wealth and well being of the both communities and the monetary weight on the hosts. 86% of the world's refugees and 3.9 million Venezuelans displaced abroad are hosted by developing countries, where 25% of all are hosted by the world's least developed countries having a cumulative of 13% of the world population for 1.25% of the global GDP meaning that the support for the refugees' needs are hard to be satisfied by the host countries' economy. 39% of all refugees (and Venezuelans displaced abroad) are hosted in five countries with Turkey being the leader with 3.7 million. A large portion of refugee weight is on the shoulders of such a small number of countries.

3.1.5. Refugees By Settlement Solutions

There are several solutions for the refugees most common being the refugee camps. However, refugee camps are not durable solutions. Those are safe return to their home country, local integration and resettlement. Safe return to their homeland is the ideal situation.

Refugee camp is a temporary or long-term solution for a large number of refugees in the host country. The camps should conform to people's activities of daily living such as feeding, toileting, bathing etc. Also, medical and educational services are quite important. Community services such as religion and counselling can also exist in the camps. Local integration refers to the integration to the host country. It is very challenging for both the refugees and the hosting communities, especially when the resources are scarce.

Naturalization refers to getting long-term permit or citizenship, referring to local integration or resettlement. Resettlement of refugees is to settle them in a third location other than the host location and origin country. It provides stability and a second chance at life, if the return is not an option in the foreseeable future. There are work opportunities, but they come with many hardships, as there might be cultural and communicational barriers. Integration to the community becomes way more important than before, as the interaction with the host is almost the only kind of interaction there is: in the workplace, at school, in the marketplace. The number that can be resettled depends on not only the budget but also the number of people already settled at the location in order not to disturb the host's internal dynamics.

Then, we have the protracted refugee situations, referring to 25,000 or more refugees of the same nationality being in exile for five years or longer in any given asylum country. (UNHCR EXCOM, 2009) 15.7 million refugees are estimated to be in protracted situations. (UNHCR, 2021)

3.2. Future State Of The Global Refugee Crisis: Climate Change

Climate directly affects how a person lives in terms of what to eat, what to wear and what to seek shelter from as the air, water and soil surrounding are strongly correlated with climatic properties of where one lives. Any change determines how one lives or how one may not. Acknowledging the climate change, we must investigate how it severely damages the livelihood of a region and stimulates mass migration.

In this chapter, we will explain the relationship between the climate change phenomenon and forced displacement for an audience unfamiliar with either one of the concepts: the planetary balance and the mechanism of global climate change; reaction of a species to changes in its environment and in the ecosystem it belongs to; the effects of the global warming on the physical Earth, its ecosystems and human settlements; the dynamics boosts up the global resource scarcity and refuge crisis.

3.2.1. Global Warming Mechanism

The universe is programmed to be in steady states by the fundamental rules of thermodynamics. Every process that is not in a steady state evolves into one in time. Not being in steady state is what derives a change. The endgame is the lack of movement at absolute zero; any system that is warmer diverges to it in time. The factors affecting the planetary balance are the electromagnetic energy in the form of solar radiation as a function of Earths changing orbit around the Sun and blackbody radiation of the Earth due to its temperature, which is also fuelled by the tectonic activities of its interior. If the balance is broken, then, a new steady state must be formed. The climates will change to facilitate the new balance, thus the name climate change.

A greenhouse effect of a gas is a result of its molecular shape and vibration; almost any gas molecule that is not a noble gas or nonpolar covalent has some form of green house effect. Green house gases emit the photons of sun and blackbody radiation of the Earth, convert the light energy and store heat energy. They are the reason why we do not freeze to death in the night; the energy they store kept us alive for all these years.

For the last 50 million years – which corresponds to the first appearance of primates during the aftermath of the greenhouse gas epoch 66 million years ago causing mass extinction of the dinosaurs - Earth was cooling down about .3 Celsius degrees per million years (Lisiecki & Raymo, 2005; Hansen et al., 2013), following a cyclic ice age and warming down periods of 4 to 7 degrees in 25 to 100 thousand years (Munshi, 2018). Earth had greenhouse gases prior to the industrial evolution. But it did not face an abrupt change in the atmospheric green house gas concentration besides the occasional volcanic activity so it maintained a slow cool down. Then atmosphere's characteristics are suddenly changed by the industrial revolution, by releasing a large chunk of gaseous industrial wastes like CO2, CH4, and chlorofluorocarbons that are strong greenhouse gases. By releasing more into the atmosphere the steady state temperature increases further. Now the world is unstable and this rate of increase in greenhouse effect is challenging for adaptation and evolution.

Unbeknownst to many, the water vapor has a strong greenhouse effect. More the temperature, more the water evaporated, more the energy emitted, creating a positive feedback cycle. Losing liquid water is bad, but losing solid water is worse. Ice is a good reflector of solar radiation. If the planet starts to melt its ice reservoirs, then, less the sunlight will be reflected and more emitted, increasing the surface temperature of the planet: positive feedback cycle of ice.

The amount of solar radiation that enters the atmosphere is an external factor; but the blackbody radiation is a function of the temperature of the object at a fourth degree. Since greenhouse gases emit the blackbody radiation of the Earth, they obstruct it to be released into the space; a warmer Earth means more blackbody radiation emitted and a higher temperature: another horrid positive feedback cycle.

In short, even if the production and consumption practices change for the better, the greenhouse gases released until now will raise the steady state temperature. The humanity will face stark changes in the livelihood of the whole planet. The real bad news is, adaptation may not be possible. Thus, we must science the heck out of reversing the situation, but this is the motivation for sustainable development and production. In the meantime, the world will continue to face the effects of the nature's response. For the purposes of this thesis dissertation, the effects we will put the most emphasis on are the mass migrations and resource scarcities that has already started.

3.2.2. Effects of Global Warming on Nature

The mechanisms causing and strengthening the global climate change is defined, but how the local climates are actually affected and shaped by these global changes is to be answered. To properly explain this, we must note that Earth is not a homogeneous entity, thus, the temperature is not homogeneous throughout its surface. It has many dynamics that determine the climate of a location. What is certain is the average temperature of the Earth is increasing, but it does not necessarily get warmer everywhere. The factors such as Earth formations, proximity to water bodies and underground activity still plays a part in the distribution of this additional energy in the world.

With the changing global temperature average, the local temperature, precipitation and wind patterns – which is crucial due to its heat and water vapor transportation capabilities – will all change. They are also in a mutual causality relationship impacting each other; but they mainly shape other elements of the abiotic environment through the solar exposure and humidity. Concerning the water, thermal expansion of the liquid water bodies will raise the sea levels. Glaciers melting faster than ever will not only contribute to the effect of the liquid water, but also release a large chunk of fresh water into the oceans, changing the saline levels. This will also shifts the ocean currents - another vehicle of heat transportation. The land will also face the impact: freshwater through the flow and regime of the rivers that are fed by rain and mountain waters; the soil in terms of its moisture, salinity level (due to the new water levels) and erosion rate - with a risk of turning into deserts or marshlands.

The next question to answer is how organisms will respond to the changes in their environments. The adaptation skill of a species to changing abiotic conditions depends on the size and at the evolutionary steps of it. Primitive species -the ones that can mutate and proliferate easily- such as bacteria may create a genome that is resilient to the new conditions that are faced. The larger ones that can travel long distances or that can adapt body temperature may have a chance at staying alive to an increase in temperatures. The small ones that have a short life pan and yearly reproductive period have a very small chance of survival. The hardships increase exponentially with the pollution or hunting.

The resilience to abiotic changes does not guarantee the success of the species, since it is strongly bonded with its biotic environment through the ecosystem dynamics. The species sharing the space are linked with each other with direct and indirect trophic links forming food webs. Among the species in the same food web, one shapes it and keeps it balanced, called keystone species. They hold the ecosystem together single handedly, meaning their loss from the system cause a systemic failure. Knowing that a loss of even one species may severely damage the whole ecosystem, the climate change will cause a wave of extinction of many, especially if the keystone species is under threat.

3.2.3. Effects of Global Warming on Refugees

To help us visualize the situation and what will it bring, we may start with comparing the Earth today with its past self. The last time the CO_2 levels were this high the Earth was 4 and the poles were 10 Celsius hotter, the sea levels were 5 to 40 meters higher (Miller et al., 2020) and the human sapiens were yet to be evolved. We will exemplify the effects of climate change on food sources and ecosystems; the sea level will and sudden shift in environment. Then, we will make clear how each of those would bring challenges in human settlements.

With the changing temperatures and precipitation patterns, first some species will get extinct and invasive ones will emerge and further damage the ecosystems. These invasive species can be either a producer, a predator or a parasite (a disease). Some solid examples from today are blue-green algae, Asian carp and Panama disease (also known as banana wilt). Both the natural and food chains such as horticultures and fisheries will dissolve, and such a phenomenon will immediately amplify the existing resource scarcities. This will cause more stress on the societies facing hunger stimulating forced displacements.

If we take the CO_2 level equivalent of the Earth's past as a projection, the sea levels will increase by 9 to 31 meters (Foster & Rohling, 2013). Such a rise would emaciate the coastal and all water ecosystems due to the temperature, O_2/CO_2 composition and density changes. Since 600 million people lives within 10 meters above the sea level (UN Ocean Conference, 2017), the mainland coastline and coastal island settlements will be under water and the residents will be forced to move.

The instabilities that come with the climate change will also result in massive disasters such as flood, storm and wildfire. For example, changing precipitation rates and increased temperatures make trees burn and fires spread far too easily, causing mass destruction of wildlife and oxygen reservoirs. On top of 2019-2020 Australian bushfires, in 2021 we had to deal with wildfires that cannot be taken under control in Siberia, California, Australia and Mediterranean Peninsula for weeks.

Also homes, crops and farm animals are destroyed. If we look further into any location, we might observe how its dynamics will be affected by the climate change. We may consider an inland mountain country, Bhutan, for example. Bhutan has a carbon negative status due to clean energy production and all the government documentation is digitalized following holistic approach in development, doing the best they can. However, they have over two thousands mountain glaciers that melting of each can take down a village.

In short, climate change will cause ecosystem failures with loss of biodiversity damaging all of our food sources. Increasing sea levels will degrade soil fertility and destruct coastal ecosystems, further contributing to the damage in the nutritional security. Disasters fuelled by the sudden imbalances coming with climate will cause destruction on such a short notice. Loss of settlements also worsens the vulnerability of the residents. After a threshold, the resource scarcity likely causes economic crisis and unrest, sometimes reaching to a point of civil war or armed conflict if there is already a political, ethnical or religious friction dwelling within the region. As previously stated, these fuel the desire to leave the country for a safer future, and people start to seek refuge with hopes when even the conditions of a refugee camp seem safer than of their home country's.

3.3. Findings

There are 27 million people in the world forcibly displaced to other countries to escape from inhumane living conditions without knowing if they can ever go back; men, women, children, elders. The conditions are defined as war, armed conflict and human rights violations; economic crisis and instability. Resource scarcities such as drought and hunger can not only cause people to seek refuge by themselves, but also drive any of the other reasons. There are various methods to cope with the refugee populations, such as naturalization or building a refugee camp. Also the countries hosting the refugees are in the midst of an unknown, suboptimal situation that threatens their stability as well.

Climate change enforces and reinforces refugee-seeking reasons. It will damage and destroy ecosystems, both biotic and abiotic elements; the natural resources will diminish. It enforces weather extremes, it will also destroy homes; it raises the sea levels, it will sink cities. More will leave their homes and forcibly displace to unknown: we will see mass migrations. Our actions caused the climate change and both its effects on the nature and human populations will only get worse as we continue our practices.

In short, as scientists, policy makers and human beings, we must understand the dynamics of the seeking refuge since the crises horrid and it is going to get larger due to the current environmental, political and economical paradigms. We must head on the problem of the refugee crisis. We must acknowledge that climate change drives resource scarcities and further fuels refuge crises. We must be ready for its future problems in all dimensions and scales.

CHAPTER 4

SYSTEMS MODEL OF A REFUGEE CAMP

One must understand the refugee camp system in order to better locate the camp and then plan and improve the quality of the camp services. First step is to construct a systems model as the number and variety of dimensions of a refugee camp makes it very complex. We then can construct other types of models like system dynamics or mathematical in order to find optimal solutions for particular problems the decision makers may face. As every problem is unique, we advise a unique boundary and scope decision for any future work concerning a refugee camp in parallel to the problem context with this systems model as a guideline.

We first define the camp and the people involved in this refugee camp entity, the stakeholders, how they function and their relationships. We present the refugee camp system in terms of the needs subsystems as: components of the camp and relationships between; their behavior and activities; the relevant environment surrounding the camp; inputs from and outputs to it. We select the boundaries of this refugee camp system model to cover the main operations and functions in camp like energy and healthcare provisions; the inflows like resource and refugee; the outputs like waste and monetary compensation; the system states like the relationships between the stakeholders, the vulnerability and well being of the refugees.

The detail level of this model is chosen to represent the functions of the components of the refugee camp system and the interdependencies between the components. The relationships between the different daily operations are clear and the fundamental requirements of each major transformation are explained. Both the hard components of the refugee camp such as shelter units or food to be distributed and the soft components like the honor and dignity of the refugees, criminal activity, oppression or power relations, camp culture for gender, age, roles are discussed within the system model.

Due to the detail level and the number of the relationships and actions within the camp and with its surroundings, the system is very complex and the components and relationships they cannot be grouped into mutually exclusive subsystems. While discussing a component, we provide first a literature review on that component if there is enough work to facilitate one, details of the relationships with previously explained components and brief connections with future ones. We discuss the direct relationships between the components of the camp and the environment while explaining each component, instead of separating the environment and presenting it as a whole. In order to facilitate a better understanding, systems diagrams for the sub-systems are drawn and the relationships are repeated for the displayed ones at the end of the Chapter 4, in subsection 12.

4.1. The Definition Of A Refugee Camp

The UN Refugee Agency (n.d.) defines the refugee camps as "… temporary facilities built to provide immediate protection and assistance to people who have been forced to flee their homes due to war, persecution or violence. While camps are not established to provide permanent solutions, they offer a safe haven for refugees and meet their most basic needs such as food, water, shelter, medical treatment and other basic services during emergencies. In situations of long-term displacement, the services provided in camps are expanded to include educational and livelihood opportunities as well as materials to build more permanent homes to help people rebuild their lives."

Refuge camps are built for the incoming refugees. They are the most common long-term solution - even though they are temporary by nature – since capacity for more stable solutions such as naturalization is not sufficient for the world refugee population. The main properties of a refugee camp are its population, capacity and location. It contains the refugee tents and communal buildings such as schools, gathering areas or medical tents. Depending on the plan of the refugee tents; kitchens, water taps and latrines may be communal or in-tent. Supply distribution and logistics centers help allocate the resources to the residents. Electricity, water and food systems require their own infrastructure. There might be labor activities and trade with the refugees settling in the new conditions. The surrounding abiotic environment sets the opportunities and challenges, while the host society proposes communication: cultural friction or fusion.

4.2. Stakeholders Of A Refugee Camp

The stakeholders of the camp can be defined as the refugees, aid agencies, hosting governments, hosting populations. They play roles in the camp or around the world affecting the decision-making processes.

4.2.1. Refugees

Refugees are people who left their home country to find shelter in another one due to many reasons such as nutritional insecurity, economic crisis or armed conflict (International Organization for Migration, 2019). They travel with their family unit, including elders and children. They arrive to the host countries after a long travel including legally or illegally crossing lands, seas and borders.

The needs of refugees in the camp are closely tied to the concept of vulnerability: the susceptibility to impact of environmental, economic or social hazards. Due to their living and travel conditions, refugees are very vulnerable. In order to improve their vulnerability, their needs must be satisfied, based on their hierarchy of needs. These needs are not always tangible.

Water, food, shelter and clothing, personal security and health are their basic needs. Following the Maslow’s hierarchy, property one owns is limited in camp conditions. But employment does not only to satisfies the economic activity demand but also improves the mental health of the refugees and even provides a trade for them when they eventually return to their home country.

As they come with their families or loved ones and surrounded by the people sharing the same cultural background, many aspects of the belonging tier is satisfied. Esteem level contains status, dignity and human rights, which also must be achieved in the camp. Many of the refugees come from third world countries that have challenges in equality issues. If managed correctly, camps can improve the civil rights perception and equality of the refugees, in turn decreases the vulnerability even further.

4.2.2. Aid Organizations

Humanitarian aid organizations - either international or local - are helping with the funding, management and operations of the camp. They have responsibilities to the refugees, governments and independent funders. UNHCR is the main actor in refugee aid in most of the refugee camps in the world. For this model they will be described as a single entity aiming for the well being of the refugees.

4.2.3. Hosting Government Of The Camp

Hosting governments get involved in refugees and the concept of a refugee camps when refugees arrive at their countries. They usually feel the humanitarian call, the international pressure or their own political agenda about the incoming refugees. Their decisions and involvement in the refugee camps reflects those drives. They mainly spare land for the camp; law and rules in the camp; the degree of contact between the camp residents and the surrounding communities (International Organization for Migration, 2019). They may directly contribute to the funding of the camp if they choose so, but otherwise they do it through the international fund of UN if they are a member country (UN Turkey, 2015). For this systems model they will be described as an entity willing to host the refugees in need, allows contact between the refugees and host communities.

4.2.4. Camp Workers

Employees of the aid organizations or governments or temporary workers with contract are responsible for operations of the camp. The work content, laws, regulations and labor market determine work conditions and payment. Volunteers may also perform supplementary tasks. The workers might be daily operational ones tasked for logistics, distribution or food preparation; medical staff such as doctors, nurses, or caretakers; a member of managerial and auditing team. They may also serve for counseling, education or human rights.

4.2.5. Host Community

Host community can be defined as the national residents of the area surrounding the refugee camp (International Organization for Migration, 2019). They are the door of communication through different languages or cultural backgrounds, for better or worse. The hosts may fear for security and stability if the cultures are vastly different from one other or if the perceived culture of the refugees are inferior than theirs - if the human rights are not secure in the country the refugees came from. In addition, the refugees and the host community share the same environment; thus, face the same natural threats. Conflict may arise if the resources allocated to the camp are not proportional to what the host community has. Security is a big concern for both. On the other hand, trade and work relationships or marriages between the two communities may improve the relationships.

4.3. Location of The Refugee Camp

The location of the camp is of several dimensions: latitude, longitude, altitude, the country or state it belongs to, Earth formations on and surrounding it. They have extension from climate and natural resource availability to host community and laws. They all together determine the locational properties of the camp like size, capacity, infrastructure, logistics and self-sufficiency operations.

4.3.1. The Relationship Between The Location And Travel Path

The camp is the long-term settlement location of many of the world refugees. So, the location first represents the distance from the origin point to the camp and the travel path with the hardships due to the road conditions - crucial for the vulnerability of the population. The road is never pleasant, especially for the very young and elderly. This is discussed in more detail in Chapter 5, under vulnerability.

4.3.2. The Relationship Between The Location And The Size Of The Refugee Camp

The location available for the refugee camp has several dimensions directly affecting the refugee camp properties. Laws and regulations about the public land may limit the size that can be spared for the camp. The size and the slope of the area, terrain configuration and natural resource capacities determine the size and capacity of the refugee camp to build and operate.

4.3.3. The Relationship Between The Location And Resource Supply Network

The camp is in the refugee camp network consisting of the other camps, suppliers and warehouses - if there are, serving as distribution points for multiple vulnerability groups. The fundamental resources supplied to the camps are energy either renewable or non-renewable; water for drinking and sanitation; food and health services. The proximity to the suppliers or transportation network is important for timely and efficient resource provision, concerning both costs and emissions. Depending on the particular nature of the good or the location of the camp, accessibility and closeness from a national road network, railroads or seaways are crucial; pipelines and power lines especially for electricity and water servicing. If some resources can be produced in the camp, then the in-camp production can also determine the resource supply network.

4.3.4. The Relationship Between The Location And The Resources Utilized In The Refugee Camp

The resources the residents require may be sourced in the camp, as a resort of economic and ecologic sustainability. Camp location cannot be imagined without its climate, and they determine how one lives and sets the amount of natural and man-made resources the camp can utilize itself, such as drinking water from underground reserves, food from agriculture or horticulture, energy from solar radiation. If climate of a location is not uniform throughout the year, then, we need consider seasonality in resource availability.

4.3.5. The Relationship Between The Location And Shelter Units

The environmental conditions surrounding the camp determines from what the shelters are needed to protect the refugees. The location brings these conditions, and thus, the properties demanded from the shelter units. Also the building materials available for the construction work in the refugee camps depend on the location of the camp (Copping et al., 2021).

4.3.6. The Relationship Between The Location And Societal Context

The location brings its surroundings in terms of legal boundaries and people; first being the government and latter the host community.

4.4. Climate Of The Refugee Camp

Climate - a categorization of Earth's long-term average conditions - is one of the most important determinants of the characteristics of a region and the lifestyle of the people living there -including the refugees residing in the camp- from the foods they eat to the clothes they wear.

Climate includes weather averages in terms of temperature, precipitation and wind. Solar radiation is the main heat source of the Earth and amount reaches to the surface is determined by the atmospheric conditions, latitude of the Earth and its angular orbit around the Sun. Humidity mitigates the temperature differences that its levels not only affect the weather but also the yearly and daily temperature differences. Amount, frequency and types of precipitation and wind both provide the natural resources or cause many hardships: either directly as in mountain water and tornado or indirectly like wind power production and agricultural yield.

4.4.1. The Relationship Between The Climate And Location

Climate and location mutually determine each other's attributes but they also affect so many others natural phenomena, which all collectively affects how one lives. Several of these relationships are be exemplified below. Life in a refugee camp is a function of these relationships.

The amount and the frequencies of wind and precipitation a place has – which make up a climate – depend on the location. Location is not only a measure of distance from the equator (and consequently from the poles) and altitude, but also in relation to the bodies of water; Earth formations as mountains, valleys and plateaus as well as underground ones such as thermal waters affect the average weather conditions. Due to the North Atlantic and Labrador ocean currents, England is quite warmer than the West shores of Canada, even though they are on the same latitudes.

On the other hand, climate also affects the soil type and thus, the flora and as a result, fauna. Tundra soil, for example, is the natural result of the Tundra climate, in which the soil is frozen for many months of the year and turns into swamp in the others, which enables very small number of species of plants to grow and animals to survive in the ecosystem.

If we extrapolate the affects of the climate and location on the nature into human life, they affect what fruit, vegetable and livestock to grow and eat, how thick the clothes should be, what outside conditions and dangers to seek shelter from and with the formations of trade and community, what one does daily. This is the same for a refugee. How these factors determine the paradigm of the refugee camp life will be explained in a more detailed way in the following sub-chapters.

4.4.2. The Relationship Between The Climate And Seasonality

If a climate has yearly temperature differences or experiences distinct seasons, then, the resource availability and requirement as well as possible adverse conditions the residents may face in that location may change throughout the year in a cyclic pattern. Under these conditions wind patterns and amount of solar radiation reaches the surface changes throughout the year, affecting natural energy production. Agricultural activities depend on the precipitation rates and temperature patterns, unless additional efforts like irrigation, but it is still a resource-dependent activity. The abundance of the good determines the market price, and it changes from season to season.

4.5. Shelter Units

Shelters are designed to protect people from outside conditions, as well as serving as a home, providing stability. The two main dimensions of the shelter decision are the building size and building type. Building type refers to the material the unit is made out of, the framing and the shape of the unit. These provide structural stability and isolation.

Examples of housing units include camping tent, fabric tent, shacks and containers. In some camps like Kakuma Refugee Camp in Kenya the housing units are improved with mortar and bricks since the makeshift shelters would not suffice (Pape et al., 2021). The shapes of the units also are of a large variety, from circular and domed to rectangular with gable roof. The unit may be as small as to host only a couple of people to one with multiple rooms for multiple family units.

4.5.1. The Relationship Between The Shelter Units And Outside Conditions of The Refugee Camp

The location and climate of the camp determines the “outside conditions”. In hot weather, this can be sun and evaporation, in milder ones rain and heavy wind, and in cold days one might need warmth and the shelter must carry thick snow on the roof. To plan for various conditions a shelter must withstand, we must take climate into account, which is the representation of the yearly temperature, wind and precipitation patterns.

Yearly and daily temperature averages and differences are important in determining the isolation properties. For example, tropical climate yearly temperature difference is 3-5 centigrade degrees – which is easier to plan – in contrast to steppe’s 20-30 needing the units to isolate from both the cold and the warm throughout the year. Another factor that matters is the humidity. If low, the daily difference in the temperature increases from 3 to 40, depending on the climate. Precipitation is significant for the weather because the tents might soak the water or thick snow on the roof may damage the frame.

Without proper planning, weather conditions that are worrisome can escalate and turn into disasters in camps. In Monsoon climate, for example, 85% of the precipitation is in summer months and causes floods. In tropical cyclone and hurricane regions, heavy wind may destroy easily lift the tents and destroy the camp.

4.5.2. The Relationship Between The Shelter Units And The Climate

Yearly temperature and wind speed determines the wall materials and thickness, which provide structural stability and isolation. Roof types, slopes and the material they are made out of differ depending on the need to reflect the sun, rain and snow shedding. Also with climate comes the flora and fauna. Additional solutions for the isolation of the shelter unit may be required if the fauna consists of dangerous animals, such as disease spreading mosquitos and venomous scorpions.

4.5.3. Building Size Of The Shelter Units

The climate conditions also affect the size of each housing unit built. In hot climates, there is a need for ventilation (Albadra et al., 2017); in colder ones, heating. Smaller sizes decreases the energy required to heat the living space and larger ones increase air movement and ventilation. The location affects as it sets the size of the camp. With a high population in a small area, the units must be smaller. Refugee profile also is a factor as it includes the family descriptions in terms of number of members to live under the same roof, level of privacy and space they each need.

4.5.4. Building Materials of The Shelter Units

The building materials determine how the resources are used, and vice versa. For poor isolation more energy would be needed for heating. Depending on the infrastructure of the housing, water and sanitation can be accessible within the unit. If the refugees would be provided with cooking utensils and appliances, then the unit must be fire resistant to a degree.

All of these come with infrastructure and operational costs, thus the financial concerns for the aid project is a determinant for both. Also the building materials available for the construction work in the refugee camps depend on the location of the camp (Copping et al., 2021). In the light of these, the sheltering solution and the infrastructure should be decided on depending on the location and the climate of the camp and refugee population.

4.6. Water, Sanitation And Hygiene

Water is one of the fundamental needs of almost any living creature. Without drinking water, many complications occur and the deficiency results in death. Personal hygiene is the cleanliness of the body and clothes. Sanitation covers the drinking water, hygiene and management of excreta disposal and sewage. WASH is an acronym for water, sanitation and hygiene; it consists of all of the related activities (UNHCR WASH, 2020).

The water requirement has several dimensions in refugee camps: indicators for water are quality, quantity and access; for purposes of drinking, sanitation, personal and menstrual hygiene, excreta and solid waste management. These are for the daily use of households and also are differentiated for the communal buildings like schools and health clinics.

4.6.1. Literature review on Water, Sanitation and Hygiene in Refugee Camps

There are only a few operations work focusing on refugee logistics. These issues that are recognized by these works related to water are in Table 4.1. 3 of these 4 works are camp surveys, literature reviews or thought papers not only their content but also the number of works further emphasizing the lack of effort in OR/MS literature on refugee situations. On the other hand, Karsu et al. (2019) proposes a model for water network design for refugee camp layouts.

Table 4.1. OR work on refugees and water

Article	Issue Considered			
	Sanitation provision	Water supply logistics	Local sourcing	Public health
Jahre et al. (2018)	✔	✔	✔	
Karsu et al. (2019)	✔	✔	✔	✔
Oloruntoba & Banomyong (2018)				✔
Seifert et al. (2018)	✔	✔	✔	✔

However, there is some research on water in the most closely related literature: humanitarian logistics on disaster relief. Water is a common example for a critical resource to be transported to the victims in several of the papers implicitly only for drinking purposes (Barojas-Payan et al., 2019; Camacho-Vallejo et al., 2015; Ivgin, 2013; Mollah et al. 2018; Rabta et al., 2018; Stauffer et al., 2016; Çankaya et al., 2019). In Holguin-Veras et al. (2016), Wang et al. (2017) and Macea et al., (2018); the effects of the dehydration on human body are used to create a cost function, still only as a drinking water. Some papers focusing on other aspects of a disaster situation acknowledged the water borne-diseases and sanitation issues (Heaslip et al., 2012; Jahre et al., 2010; Mollah et al., 2018; Tatham et al., 2015).

The conclusion on the HL literature is that it cannot provide much for water requirements in a refugee situation. The main reason why only the drinking water is considered is that due to the nature of any emergency situation, timely delivery of the critical resources is crucial and sanitation and hygiene provisions can be disregarded for short response times such as days. Thus, these works cannot be implemented for any long-term problem, such as any refugee camp location model, especially for the protracted refugee situations.

For the various WASH activities, Sphere Project (Practical Action Publishing, 2018) and UNHCR WASH (2020) sets standards on the amounts of resources to be provided for emergency and prolonged situation such as amount of water, soap and number of latrines per person.

4.6.2. Drinking water in Refugee Camps

Water regulates several of the metabolic activities such as body temperature, material transfer within the body – in blood – and out of the body – in sweat and urine. Dehydration results in heat injury, urinary and kidney problems, seizures, and hypovolemic (low blood volume) shock, and in severe cases, death (Dehydration, 2019). For that, clean drinking water is a must under any circumstance for any human being. Main risk groups are infants and children, which make up of 40% of the refugees in the world (UNHCR, 2018). Drinkable water is required not only for drinking but also in food preparation. Sphere Project (Practical Action Publishing, 2018) asks for 15 liters of drinkable water available per person at minimum. UNHCR

WASH (2020) also targets daily 15 liters of in emergency situations; but after six months of the situation the target goes up to 20 liters.

4.6.3. Hygiene and Sanitation Provisions in Refugee Camps

Sanitation and personal hygiene is another aspect of the water requirement. Poor hygiene can decrease quality of life and call for diseases. Without proper hygiene and sanitation provisions in refugee camps, even easily treatable diseases like diarrhea may evolve into epidemics in camps - since the healthcare provisions are also mostly inadequate there.

4.6.3.1. Sanitation provisions

Sanitation covers the means of defecation and the treatment of the excreta. There are various methods of toilets to build in emergency cases (Reed, 2011) evaluated for advantages, disadvantages to the communities, performance in various climates and effects on the environment (Harvey et al., 2007). Among these, longer-term solutions must be designed for refugee camps. Dry sanitation methods are not discussed in recent literature in refugee camp solutions besides Aburto-Medina et al.'s (2020) work that suggests it for sustainability; it will be assumed that the camp utilizes wet sanitation methods where water is provided to latrines and public baths.

UNHCR WASH (2020) targets either a toilet or latrine per shelter of 5 people for 85% of the population, or a communal toilet or latrine per 20 people. For schools a toilet per 30 girls and 60 boys are recommended, with additional urinals for boys. If the toilets are not enough in number or not properly cleaned, then, people may attempt to defecate in open areas (WHO, 2011).

4.6.3.2. Personal hygiene provisions

Personal hygiene provisions involve in brushing teeth; washing hands, face, hair and the body. The facilities may be within the shelter unit in toilet or in communal baths. There are also hygiene promoters employed in camps and UNHCR WASH (2020) recommends them to be combined with community health workers and aims to have a promoter for ever thousand person.

UNHCR WASH (2020) targets either a bath per shelter of 5 people or a communal shower per 20 people and access to soap for 90% of the population. 250 g/month is defined as the requirement for personal hygiene per person. Specifications about the amount of water to be supplied to the baths in refugee camps do not exist. Toothpaste and similar items for personal hygiene provisions are considered “nice to have” items, not essentials (Practical Action Publishing, 2018).

4.6.3.3. Menstrual hygiene provisions

Poor menstrual hygiene decreases the quality of life since it may result in urinary and reproductive system infections and cancer. It is also associated with poor academic performance and school dropouts (Belayneh & Mekuriaw, 2019). Thus, the refugees must be provided with and educated on adequate menstrual hygiene management material. UNHCR WASH (2020) committed to provide 250g/month of additional soap per woman of reproductive age. There also are projects that provide reusable pads or menstrual cups to refugees (Thelwell, 2019) and destigmatizing their use.

4.6.3.4. Cleaning

Hygiene also includes cleaning. The dirt on living areas, clothes, cooking utensils and dishes encourage bacteria growth, they must be cleaned regularly. The same applies for latrines, bathing areas and other communal buildings. UNHCR WASH (2020) recommends 200 grams of soap per month per person for laundry and other washing purposes. Washing and drying areas for the laundry and tools to be provided for these washing activities are not discussed as far as the author is aware of.

4.6.3.5. The relationship between hygiene and sanitation and mental health of the refugees

Not only physical but also mental health requires demand of water, as personal hygiene directly affects the mental well being and dignity of a refugee (Cronin et al., 2007), especially as the psychologies of the forcedly displaced persons are already damaged due to the situation they have fled from and camp life conditions (Kovacs et al., 2010).

4.6.4. Water Supply for the Refugee Camp

The hygiene and sanitation provisions cannot be provided without sufficient and adequate water. The water must be supplied to baths, latrines and toilets in order to wash the body, to general use taps or households for drinking and cooking. Water drawing, distribution, handling, quality and storage are the aspects of the water supply problem.

4.6.4.1. Water drawing method

There are various water drawing methods that can be applied in refugee camp situations, depending on the camp's location and its climate. They are surface waters, ground waters, rainwater harvesting or transportation of water from elsewhere. Emerging technologies are also worth noting, although they are not yet energy efficient or they are capital intensive.

Depending on the time of the year, different methods can be used. One thing to note is that the usage of the water affects the surrounding landscape no matter how it was drawn. The aquatic ecosystems, soil systems and the neighboring regions will be affected by this spatially condensed water consumption.

Surface Waters

Surface waters such as rivers can be used as water sources. Depending on the salinity, pH of the water and the level of stagnation it may be suitable for hygiene activities and even for drinking. But the local communities usually use them for personal and agricultural work. The ownership of the water and relations with the host community affects how much of this water can be used.

Groundwater

The existence and the properties of the groundwater reserve depend on the soil structure and the factors affecting how this reserve is fed by the nature. Hydrological surveys may be required to identify where there is an underground water reserve (Jahre et al., 2018), how much water it has and how deep it is.

Groundwater can be brought to the surface by drilling wells. Depending on the pressure on the water, a pump might be used or it may raise itself – called artesian. The groundwater must be left to replenish itself. If the water is drawn excessively, then the water table falls below the well – it becomes unreachable. Continuing to drill more wells that are deeper increases the drought further. This dynamic must be considered in sourcing the camps with ground water and the system must be optimized accordingly.

Rainwater harvesting

Refugee camps may use rainwater harvesting to locally collect water. A surface or platform collects the water; the roofs of the shelter units can be used as collectors. The water collected must be filtered before it is stored in sufficiently large tanks. Then it must be treated before distribution. Various types of collection and storage system can be constructed. The amount of water can be harvested depends on the location of the camp, its climate and the season of the year.

Outsourcing

The water can be supplied through regional water supply networks through the pipes, if there is an infrastructure. Then, the water quality, treatment and storage might be the responsibility of the supply network, not the camp. Otherwise, due to the high volume - water cannot be regularly transported besides the emergency phase in refugee situations. Only bottled water can be carried through various vehicles, but the emissions and transportation costs must be considered in comparing with other options. In both cases, proximity to logistics networks and supply point – which are dimensions of the location of the camp - are very important. It may be more efficient to open the camp to an adequate location or move it if necessary rather than consider daily transportation of such a volume.

New technologies

There are also new technology methods of water drawing that are energy or capital intensive such as atmospheric water generation, sea-water filtration or artificial rain. Before implementation in refugee situations these needs to be further developed and refined for their efficiency and capacity.

Atmospheric water generators filtrates water vapour from the air and produces pure water, in exchange for a high amount of energy that usually is not in abundance in refugee situations. That water does not include any minerals, it is pure H_2O and comes with additional minerals requirement. Seawater filtration is not only expensive but also produces brine as a by-product that is environmentally hazardous if released; but there is also research on turning brine into salt and use commercially.

Dispersing chemicals from a plane into the atmosphere, which stimulates the clouds to rise, and condensate for precipitation induces artificial rain. However, it is not fool proof, it is expensive and some of the chemicals are hazardous; even though the full extend is unknown (Malik et al., 2018). Thus, how it's hazards compare to other methods of obtaining water is also unknown.

4.6.4.2. Handling of water in refugee camps

Water treatment, storage and quality are integrated with each other and can be together referred as water handling. The water treatment activities are of two stages: treatment before the distribution and after the usage. In between, before and after; the water is stored and the treatment during the storage process is also a part of the system. The water quality is a result of the properties of the water supply and the handling efforts.

Treatment of water

Water should be treated before in use. OECD & WHO (2003) states that filtration - the physical removal of the particles from the water - can be done using various methods depending on the size of the particle to be removed. Coagulation with sulfates, chlorites or ozone is effective against many bacterial pathogens. UV treatment can target viruses. Monitoring and sampling policy for the water is also required to ensure that the quality levels are in control.

Water Quality

The quality of the water is very important in refugee camps since poor water raises many healthcare concerns (OECD & WHO, 2003). The source may be infested with toxins or pathogens such as E. Coli and Salmonella. Ground waters might be contaminated with wastewater and manure. The stagnation in the storage and containers enables bacteria and fungi growth in the water and muddiness. In every stage where the water is in stagnation or in containers, water treatment and quality has to come into the mind. The conditions of the pipelines of the camp water supply network are also very important.

The cleanness of the water is provided adding chlorine of sulfate to it, since they are agents that kill various pathogens. But chlorine decays in time: its content of the water from tap stands is not equal to after transport to the households and the time it is stored there. Ali et al.'s (2015) work on its decaying rate in refugee camps of South Sudan show that even the chlorine content at the taps was lower than the recommended levels after 10 hours of in shelter storage. Factors such as the storage container cleanliness also affect the hygiene levels of the water heavily.

Water Storage

The water may be stored in several stages of the water supply process, which depends on the method of supply and distribution. The water drawn or collected through various methods are stored for long-term if the source is not available throughout the year. It might also be temporarily stored in the distribution points. If the water is supplied through communal taps, then, the water is stored in shelter units.

The storage conditions affects the water quality, as explain in the Water Quality, but the storage has other concerns besides the water quality. The location, size and capacity of the storage units should be determined according to the other aspects of the WASH but also the climate, population and available land.

Wastewater Treatment

The methods of water supply to these facilities, the treatment of the wastewater and excreta disposal are other dimensions of the distribution problem. Water contaminated with dirt, bodily fluids, feces and chemicals such as soap or detergent is harmful to the environment if it is not treated before release. But in regions where there is drought, wastewater is used for agriculture (OECD & WHO, 2003). Nonetheless, the water disposed is a part of the water cycle and affect the quality of the whole WASH system.

4.6.5. The Water Distribution in Refugee Camp

Water must be distributed to the camp residents adequately and equally. There are two main categories of water distribution in camps: public or private.

4.6.5.1. Communal water distribution

In this category, water is distributed to the refugees from public taps. The households are supplied with tanks to collect the water from the taps and store in the shelters. Camp residents walk to these taps and fill their containers to store the water at home, for drinking and cooking purposes. (*Drinking-water household practices: collection, storage, treatment and handling* 2020).

The size of the containers and how many are given to each household also affects the time for access and abundance in shelter unit. There should be two water containers per household (10–20 liters; one for collection, one for storage) according to the

UNHCR WASH (2020). It is discussed in the literature that this collecting process is so time consuming that children halt their education in order to assist (Cronin et al., 2007). During the storage in the shelter, chlorine decays. Thus, the amount of chlorine added should be conforming for hours stored in the container.

The hygiene and sanitation activities are performed in communal latrines and baths, in residency area and in public buildings such as schools. The distance between the housing situation and taps and latrines and number of people assigned to each is also important. Their standards are discussed in water demand chapter.

4.6.5.2. In-shelter water distribution

Water is supplied to each housing solution in several refugee camps (Jahre et al., 2018). This requires the shelter to accommodate this water distribution network infrastructure to be built. If this is the case, then, a bath and a toilet are provided for each household shelter unit and taps are also in-shelter.

4.6.6. Targets and Standards for Water, Sanitation and Hygiene

The Sphere Handbook (Practical Action Publishing, 2018) and UNHCR WASH (2020) minimum standards and targets are widely accepted. But it is argued that they are not only inadequate for a humane life, but also 40% of the camps cannot even satisfy these minimums for water and excreta disposal per capita (Cronin et al., 2007). One should also note that these standards do not consider any spatial factor such as climate, air temperature, precipitation etc., but just recommends to be adopted without a direction. Also, they ignore any temporal changes such as seasonality. In the data collection, UN keeps only annual averages, as well (UNHCR, 2021).

What also disturbing about these standards are the gaps. Reversing the targets: 10% may not have any soap, 15% of households may not have an access to a toilet, 5% may not have treated water. That is okay by these standards; the neglect is normalized and enabled by these very targets.

4.6.7. The Relationship Between The Water Supply And The Host Region

Water is one of the main scarce resources in the world refugee population, mainly in the developing countries, which host 85% of the world refugees (UNHCR, 2018). Nationwide drought – and resulting famine caused by lack of proper environment for agriculture – is one of the main reasons of a person to seek refuge (Jafaar et al., 2019; UNHCR, 2018). Under those circumstances, a neighboring country is usually where a refuge is sought.

Similar environmental conditions result in water being scarce even for the host communities, like in South Sudan, Kenya and Lebanon refugee camps (Cronin et al., 2007; Jaafar et al., 2019; UNHCR, 2018). Thus in such areas, water is a possible reason for conflict between the host communities and refugees. Large quantities of refugee inflow, such as Syria crises (Jafaar et al., 2019) may cause nationwide water crises in the hosting countries or at least increase the severity and degree of dispersion.

4.6.8. The Relationship Between The Climate And Water In The Refugee Camp

The weather conditions have a great impact on the natural water supply and camp water demand. Air temperature increase above normal causes a higher water demand, as water is an agent in body temperature regulation. Also, it increases evaporation; puts a toll on the existing water supply. Moreover, it increases the chlorine decay rate (Ali et al., 2015) making the population more prone to water-borne diseases if the precautions are not taken.

4.6.8.1. Water And Climate Change For The Refugee Camp

Climate change causes drought and famine that increases the worldwide refugee population: a part of environmental refugees are now named climate refugees. This situation also deepens the refugee water crisis at their sanctuaries as well.

4.7. Food And Nutritional Security

Nutritional security is in the first step of the Maslow's hierarchy. Every human has a right to be fed. The food component of a refugee camp is mainly of two parts: the demand and supply dynamics. There are also relationships with other parts of the refugee camp system such as camp shelter structure, energy, water or logistics.

4.7.1. Literature Review

The literature for food supply and distribution in refugee camps has not been delved deep into within the operations research literature, similar to the other topics of a refugee camp. Besides the traditional optimization for agricultural yield under stochastic conditions problems, two disciplines that are worth noting here are the humanitarian logistics and agro-food supply chain study.

In humanitarian logistics emergency track, food is an emergency relief item to be provided for the disaster victims. In network design for emergency, the storage and perishability of the relief units is discussed which is similar to our problem because the items might be stored for a while, as in Ferreira et al. (2018). Without the focus of a camp, Orgut et al. (2017) works on distribution of food donations.

Other group of works related to food security is on outsourcing, even though the works does not particularly work on food. Gossler et al. (2020) reviews multiple steps of the outsourcing activities in a long-term humanitarian situation for the aid organizations. Moshtari et al. (2021), Gil & McNeil (2015) and Trestrail et al. (2009) study outsourcing and procurement decisions in humanitarian logistics, the latter focusing on price bidding. Zhang et al. (2019) brings recycling into the mix.

Agro-food supply chains focus on traditional objectives and a producer profits and market structure; they do not only work on a single producer. For the problem of refugee nutritional security, their work on decision making for agricultural activities under stochastic conditions (Jonkman et al., 2019; Taghikha et al., 2021) and sustainability considerations such as water (Allaoui et al., 2018) and carbon footprint (Accorsi et al., 2016) for that decision making process and logistics of food supply chains is very significant.

4.7.2. Food Demand

Food is one of the essential needs of a human – much like any living creature – to live. Refugees are people; they need food as much as a non-refugee people need. Camp's requirements for food must be satisfied; otherwise, there will be consequences like death as a result of the long-term nutritional deficiency.

4.7.2.1. Diet requirements

A healthy person should follow a diverse diet in order to obtain not only the calories but also the required minerals, vitamins, protein and lipids. Various factors such as age, health, gender and weight have an impact on the personal nutritional requirements. The daily calorie, protein, fibre, mineral and vitamin requirements change depending on the age, health and weight. This is more important when it comes to the children, elderly and sick and pregnant, as they are the most vulnerable.

4.7.2.2. Healthcare and nutrition

The relationship between healthcare and nutrition is discussed many times in various literatures and it is revealed that under-nutrition, deficiency of vitamins and minerals among camp residents – especially infants and children is prevalent. These result in serious health concerns such as development, growth and hormones (Engidaw et al., 2018; Jemal et al., 2016; Shah et al., 2021; Wanzira et al., 2018) including mental health (Manirambona et al., 2021). Thus, it is very important to implement these needs correctly in the decision making of humanitarian aid.

4.7.2.3. Nutrition standards in refugee camps

Sphere Project (Practical Action Publishing, 2018) and International Federation of Red Cross and Red Crescent Societies sets the standards for nutritional requirements and guidelines to determine the required level for a particular person. However, climate conditions are not particularly considered in those, and they do not result in a set level for each age, health and weight group explicitly for planning purposes.

4.7.3. Food Distribution And Consumption

The food needs to be processed before eating, mainly cooking. The distribution of the food, the cooking utensils, infrastructure and other resources required, after use treatment of the utensils are all a part of this essential need provision.

4.7.3.1. Food distribution in the refugee camp

The food supply to the camp is in a form of one or the other: prepackaged food to be eaten or food items to be cooked. But there are always exceptions. In Turkey, refugees are provided with cards to pay to the neighborhood shops and restaurants; in several others, communal or family gardens for refugees are provided.

The food items are distributed as a food ration in refugee camps. The water is required for food preparation for washing the ingredients and it is used in the food itself. After the food is eaten, water is required to clean the cooking utensils and tableware if they are re-usable.

4.7.3.2. Cooking supplies

Most of the food items that arrive to a refugee camp should be cooked; thus, the required infrastructure and furnishing investment must be made. The cooking area/kitchen might be communal where the refugees can come and cook their food or it can be located inside the refugee shelter unit. In some camps the cooking supplies provided might be just gas stoves - which may cause fires inside the tent, so, refugees are forced to cook outside. Depending on the structure of the kitchen, cooking utensils would be distributed to the residents.

4.7.3.3. Cooking energy

As it will be explained in the energy chapter, the main energy source of the camps at the moment is firewood. If there were a shortage of firewood in the camp, then the food would not be cooked and therefore wouldn't be consumed. According to Gunning (2014), refugees may skip up to three meals per week due to lack of fuel to cook or they may trade some of their food rations in exchange for fuel to cook the rest. Also, if the cooking activities are held inside the shelter unit, then, the energy demand and supply for heating and cooking is combined (Lehne, 2016).

4.7.4. Food Supply For The Refugee Camp

Food for a refugee camp usually is purchased from global or nationwide producers, transported via ships or trucks depending on the location and the transportation network. However, depending on the location of the camp there may be other solutions reducing this dependency, mainly, the agriculture.

4.7.4.1. Food procurement

If the food is outsourced, then it is purchased from individual producers, corporations, agricultural cooperatives and such. Either one-time deals or long-term supply contracts can be signed. The buyer is the aid organization responsible from the camp. The goods are then transported to the refugee camp to be distributed and consumed.

The relationship between the location of the camp and food procurement

The location of the camp in terms of the proximity to the suppliers, national or regional railroads, road networks and ports is significant for both the transportation cost and emissions. Relationship between the location of the camp and the climate still applies even though the food items are outsourced: if the location is suitable for agricultural activity, then the suppliers are likely to be in the region and the transportation costs will be lower. Else, the produce will be purchased from far away which will also make the transportation costs higher.

Uncertainties in food procurement

Outsourcing decreases the uncertainty about the amount of food items supplied to the camp because the weather conditions would not affect the single camp production field. The market prices, however, depends on the amount of yield that particular yield, which is a function of the annual weather conditions. Thus, the cost of purchasing is again based on the weather. To overcome this, contracts with producers and cooperatives can be signed. There will also choices in terms of which food item to purchase.

Finance of the food procurement

Outsourcing depends on regular funding - which is not always available, especially when the World is such a chaotic place with full of catastrophes. The next crisis always becomes the priority and the global funding goes to that emergency. The refugee problem being a protracted situation, the funding diminishes in time. Considering that an average refugee camp is active for seven years, it is highly unlikely that the camp becomes less of a center of attention in the early years of its active time, resulting in food shortages and malnutrition.

We can observe this in many refugee camps as Somalian refugee camps in Kenya, and the food shortages was as a policy by the aid organizations and government to starve the refugees back into their home country (Chkam, 2016) since the refugees were a burden.

4.7.4.2. In-camp food production

The food can be produced within the camp by the refugees residing in the camp as an alternative to outsourcing. The main discussion topic of this particular work is horticulture, but the approach can be extended to other agricultural activities such as livestock ranching, herding or aquaculture. The conditions affecting the range, yield and efficiency for those should also be studied if possible. The factors affecting the yield, how to improve the conditions and the decision making process for the type of the crops to produce, the labor and the production activities are the ingredients of this production system.

The relationship between the location, climate and in-camp food production

Climate and the location of the refugee camp are some of the most important factors in the crop potential. Plants need a set amount of sunlight, temperature and water for growth, as in Table 4.2, which the climate deals with.

The annual and seasonal rainwaters and other natural water resources such as underground water reserves or rivers provide water for the crops. Formational materials such as oxides, calcium, iron, salt, sand and alike content of the soil defines its type. Every type is compatible with a set of plants. Those and the type of soil together determine the water holding capacity of the soil. For example, with intense rainwater, minerals may slip through the soil and the soil may become less fertile, as in tropical climate soil. All of these determine what types of crops can be produced and how much.

Table 4.2. Water requirements of various crops over the total growing period (Doorenbos et al., 1996)

Crop type	Water need (in mm)
Barley, oaths, wheat	450 – 650
Bean	300 – 500
Cabbage	350 – 500
Onion	350 – 550
Potato	500 – 700
Rice	450 – 700
Tomato	400 – 800

Horticulture

First the soil should be prepared for the desired crops. The soil can be enhanced using manure, composting or fertilizers. There are mainly two types of crops for the purpose of this work: annual or perennial. For annual species, sowing - which is to disperse the seeds in the soil - comes next. Perennial species may take years to grow fruits, so, a longer-term approach is required unless they already exist in the field. Perennial plants should be pruned. The process continues with irrigation, removal of the weeds, harvesting and storing. Also, some of the goods may need additional operations, such as grains need grinding.

The decision on the product mix

For the decision making on what to produce, first information on the climate and terrain configuration, then, the size and capacity of the camp and the nutritional value of each yield should be considered. Depending on how much the host country developed and the budget of the related ministry, the data for the soil might already be at hand. The crop potential and seasonal contribution to food supply can be found using the landscape plan but if not available for that particular area – can be estimated from the topological surveys, typology of the area and climate's known yields.

Monoculture

An approach can be to produce a smaller amount of higher value goods to trade, such as mushroom cultivation, in order to indirectly support the nutritional needs of the camp. The other benefit of a monoculture is the economies of scale: efficiency and expertize comes with specialization. If there is a surplus, then it may be enough to cover other operational costs: some additional level of economic sustainability can be achieved.

Some monoculture activities have already been tried. Very recently cricket farming was introduced to a refugee camp in Kenya (Kamau et al., 2021) to support nutritional security with very little processing need. The project is regarded as successful in terms of providing locally grown food for the families.

Poly-culture

An efficient result can be achieved by poly-culture: with producing more than one type of plant at any time, the soil would not be deprived of one set of minerals coupled species may enhance each other, to have sustainable farming. For perennial plants, resilient species can be planted first, then with other species that are genetically relative of the original one with more nutritional value can be grafted.

Improvements in in-camp food production

The natural crop potential of the location does not limit one. With some additional effort and resources, the range of the goods can be produced can be increased vastly. The temperature and humidity can be increased and the temperature difference decreased with a greenhouse.

The soil can be improved or adjusted using fertilizers and minerals. The fertilizer requirement can be satisfied via composting the biological waste of the camp, also providing a solution for waste management, which is not extensively studied in this work. If both horticulture and livestock ranching/herding activities in the camp, then, the excreta of the animals can be used in manure and the plants can be used to feed the animals, creating a mutualistic environment.

Investments for in-camp food production

The performance of the agricultural activities in a camp also depends on infrastructural investment made. To start with, soil should be prepared. Several machinery and equipment might be required to purchase for various stages in production. The sources of the produces, such as seeds for horticulture or the animals for farming must be purchased. Also the improvements depend on the investments, like for greenhouse building and drip irrigation.

Storage of the locally produced food in-camp

The perishability and durability of the goods is also a concern in the crop selection, as the yield is not consistent throughout the year, but rather seasonal. A storage area in the camp is required not only for the short term storage but also for the long term, as many of the crops are only seasonal and should be stored throughout the year, for locations that have four seasons.

Labor for in-camp food production

In order to complete these tasks, labor is required. As it will be explained later, the labor source can be the host population and the camp residents. Agricultural activities in camp not only decrease the supply costs but also provide a daily work for the refugees. Due to the misconception on refugees as being unskilled, the operations research literature lacks work on in-camp sourcing (Kovacs et al., 2010; Oloruntoba & Banomyong, 2018). However, there are works from other disciplines consider this option.

In order to perform agricultural activities, the methods and techniques should be taught to the refugees. Some of them might already be farmers; those can teach to others. This can be a part of education and labor for the refugees and bring communal approach. However, the agriculture and farming techniques, methods or principles might be different from their origin country and even the knowledgeable farmers might have to be trained, especially in sustainability concerns such as overgrazing, overwatering and excessive use of fertilizers.

Moreover, meeting locals and camp residents in work may also improve their integration process. Such claims about agriculture and community gardens are made in the literature (Claudia & Suzanne, 2020; Dyg et al., 2019; Mejia et al., 2020; Millican et al., 2018; Strunk & Richardson, 2017).

The relationship between food production and host relationships

Nutrition is a flow where there can be many conflicts between refugees and the neighboring region, if the host country has economic struggles. There might be competition between resources. The host-refugee relationships may get damaged if a money flow goes into the camp while the surrounding region suffers from poverty and environmentally ill-conditions. In camp sourcing may lessen this possible conflict.

There is also a concern raised by Pelek (2018) that the agricultural work of refugees together with the host population may cause a strengthening of the social inequalities between the citizens and refugees since agriculture is a sector that is very hierarchically structured. This would be is very dangerous for the latter.

4.7.4.3. Decision Making in Food Supply

In the decision of how to supply the camp; the opportunities and cost of agriculture including machinery, material, labor and energy counterparts can be compared to purchasing and transportation costs, not only in monetary value but also for the externalities. Those would be the damage to the environment for in terms of pollution, emissions and waste – with methane contribution to the air pollution perspective of it, host relationships, self-sufficiency and dependency of the camp.
The probabilistic nature of food production and the living conditions of the host communities are the other primary considerations.

In addition to those, the refugee camps are of a large population and the regular supply of the foods is likely to be stop light buy contracts or a managerial division should be working on the purchasing decisions this coming down purchasing effort should also be considered. With all these, both the supply and the sustainability aspects would be covered.

4.8. Energy

A refugee camp is an entity where people live in there perform daily activities that require energy to power various equipment and appliances for varying daily requirements: heating, illumination, transportation and so on. The amount needed depends on the size of the camp population and where the camp is located. It can be either outsourced in the form of a fossil fuel or renewable converted to electricity, or generated locally, in-camp.

4.8.1. Literature Of Refugee Camp Energy

Gunning's (2014) analysis of the energy provision for the displaced surveys the energy requirement in various camps in various geographies, investigates how it is supplied and suggests how can it be supplied instead with more sustainable methods; it is our main source for the current situation in camps. The author is aware of two additional works closer to operations research discipline that discusses clean energy for refugees: Fuso Nerini et al. (2015) designs a clean energy module for protracted displacement situations whereas Lehne et al. (2016) estimates the energy demand of the camp by assuming that it is similar to non-camp populations for cooking and lighting to show that cleaner energy applications are better in terms of costs and emissions for long term.

4.8.2. Energy Demand

The demand for electricity is proportional to the size of the camp population, camp design, location of the camp, climate and the time of the year. The economic activities of the camp residents and the devices they own increase this demand.

4.8.2.1. The relationship between the refugee camp energy demand and location

Heating and illumination goes hand in hand, as the main source of both is the Sun for the Earth. The location, climate and time determine heating and illumination needs. Hours of daylight changes throughout the year and if there are large mountains nearby, then, the sun may rise later and set earlier: the need to artificial heating and illumination emerges.

4.8.2.2. Illumination

Illumination is required in many places in refugee camps: communal places like latrines, water taps, bathing areas; streets and open areas; in the housing units. There is an unspoken connection between safety and illumination in refugee camps: the possibility of something bad happening in unlit areas is five times of it happening in lit areas. If open areas and closed spaces of refugee camps that are not properly illuminated, night-time activity decreases (UNHCR, 2017). This may reach to a point where vulnerable groups feel unsafe at night even for WASH purposes.

4.8.2.3. Heating

Cold stress deprives refugee health conditions more in camps, on top of the deficiencies in other resources; keeping the refugees warm is of great concern. Depending on the weather and insolation power of the shelter, energy for heating might be required. The amount is also affected by insolation level of the shelter, which is determined by the material it is build out of and its shape. The size of the shelter and number of people residing in the unit also affects the energy needs.

4.8.2.4. Cooking

Heat for cooking is also a must, as most of the food supplied refugee camps should be cooked before consumed: sufficient amount of fuel must be available. Otherwise refugees may skip meals per week due to lack of cooking or if they cook the food themselves, they may sell food rations in exchange for fuel. The energy shortage may cause malnutrition and related health conditions.

However, this depends on where the cooking activities are happening in the camp. Energy requirement for cooking and heating of the house if there are cooking utensils and ovens in the shelter units can be merged, as many refugees rely on cooking warmth for heating (Lehne, 2016). Under a more communal approach, camp kitchens may be responsible for food preparation and cleaning, changing the energy requirement for cooking through efficiency and heating through the relocation of cooking activities.

4.8.2.5. Cooling

The literature on refugee camp energy does not mention cooling for shelter use in hot climates, but cooling is very important for medical equipment, especially for medical supplies with cold chain, to support camp medical services.

4.8.2.6. Energy for labor

In addition to those, people may require energy for personal use, such as cell phones (Gunning, 2014) or freelance work like barbering or digital work, like in Kakuma Refugee Camp in Kenya (intracen.org (International Trade Center), 2019). Logistics activities, mainly the distribution of resources in camp and transportation of the outsourced materials to the camp also require energy. If in-camp agricultural activities are performed, energy to operate heavy machinery and equipment may be needed. In camp energy production decisions also come with their operational energy needs.

4.8.3. Energy Supply Options

There are various energy sources that can be supplied to refugee camps. Most common is to outsource and distribute firewood also known as fuel wood for each shelter (Gunning 2014). Energy from the regional supply network can also be purchased to distribute throughout the camp electricity if the electricity can be distributed through the camp. Sourcing the energy from local green sources is also possible.

4.8.3.1. Energy outsourcing: firewood

The energy needs of the camp are usually outsourced in the form of firewood. These are burned only for heating and cooking; these cannot charge devices with battery unless there is a plant converts the energy into electricity.

Usage of firewood comes with a risk of fire in the camp, which are not easy to extinguish. Water in the camp is limited; the shelter units are closely located; tent materials can easily burn. The fire of the Moira refugee camp in 2021 left 13,000 without shelter (*Moria migrant camp fire: Four Afghans sentenced to 10 years in jail.* 2021).

If there is a firewood shortage, refugees may try to collect in forests themselves creating many issues: environmental hazards like deforestation, conflict with host community, security problems in the forest outside of the camp. It is reported that refugee women are physically and sexually assaulted while collecting firewood in forests (Gunning, 2014).

4.8.3.2. Energy outsourcing: electricity

The energy can be supplied as electricity through various types of power plants. Most produce energy through burning coal, oil or natural gas. It may also generate energy from renewable resources, as well. For both, connection to the regional electricity distribution network is required. The energy distribution infrastructure must be built in order to supply the shelter units.

4.8.3.3. Energy generation in-camp

The clean local energy production possible in camp can be classified into two: that comes from nature or that comes from human activities. We have solar and wind energy for the former, biomass for the latter.

Biomass energy

Biomass energy generation is the conversion of agricultural, industrial or domestic waste into fuel. In the camp, the camp population and the amount of waste one produces determines the biomass energy potential, unless the waste is obtained from the host population as well. The waste is collected into a facility to turn into various fuels. Biomass energy proposes a waste management opportunity in the refugee camp. Since the environment does not directly affects the domestic waste produced, it is available throughout the year; the fluctuations may come from the economic activities of the camp like agricultural production.

Natural energy sources

There are various types of clean energy sources locally available for refugee camps – depending on the location and climate – that a facility can turn into heat and electricity: wind, solar, hydro, geothermal, and tidal. Solar and wind energy production affects the environment the least and are easier to locate near a camp worldwide. The disadvantage of these is the potential changes seasonally, resulting in a possible need for purchasing or storing for the off-season.

Solar energy

Solar energy potential of the camp comes from both location and climate, as proximity to equator and Earth formations determine the number of sunny days and the angle of the lights. In the camp, solar energy panels can convert it into heat in water storage tanks that serve hot water for personal hygiene, or into electricity and distributed to the housing units. Products that can generate the energy they need to operate through built-in solar panels such as lamps and lanterns are also in use in refugee camps (UNHCR, 2017).

Wind energy

Wind energy potential is determined by the climate. The difference in the atmospheric air pressure of two points produces wind – the movement of air from high pressure to low pressure region. The climate includes the annual wind patterns and how much energy can be sourced throughout the year using windmills. Location is also critical as the natural formations of Earth such as mountains and valleys may direct the wind. It can supply the camp with electricity whilst the weather is windy.

4.8.4. Energy Distribution In The Refugee Camp

The energy distribution of the camp depends on the energy source used in the camp. If the fuel is firewood, then, the distribution does not require any infrastructure for distribution; refugees may collect them by carrying them from the distribution point to their shelter. This method requires a method of rationing to disable inequalities, but it is prone to black market exploitations.

If electricity is to be distributed in the camp, then, a network of utility poles connected with electricity cables should be built. The capacities of the wires and the whole network should be considered on the load.

4.8.5. Energy supply decisions

The market price of the energy source that is outsourced, the distance of the camp from the supply point and the methods of transporting this energy source to the camp are the cost items for outsourced energy; whereas the local energy generation costs revolve around the infrastructure and operation. The size and capacity of the local energy production decisions must acknowledge that energy production or purchasing decision has both economies of scale and economies of scope between generation, transmission and distribution.

As for ecological concerns, cleaner energy is preferred instead of the firewood and fossil fuel. While human dependent provides a stable amount throughout the year and manages waste, nature dependent converts directly from the source without logistics activities to collect the waste from multiple points. Producing sustainable energy in camp and purchasing from an outside sustainable energy plant is also good for the environment, but differs for the economical sustainability. Negative and positive externalities should be weighed to decide upon how the energy is supplied to the camp.

4.9. Healthcare

The healthcare provisions in refugee camps are investigated into two categories: indirect healthcare provisions and direct healthcare services. The aim is to acknowledge the significance of the other systems on health of an individual. Not only the physical health, but also the mental health of the refugees and how they should be supported is discussed. Lastly, we explained the disease control activities to cope with epidemics and pandemics in camps. We elaborated on the effects of COVID-19 on camps, both directly and indirectly.

4.9.1. Indirect Healthcare Provisions

Indirect healthcare provisions consist of processes that support the immune system of the individual and decrease the contamination of diseases. Proper nutrition, clean water, proper excreta disposal and waste management, cleaning can be counted as parts.

As many of the refugees flee from unrest, war or economic crisis, they face challenges in their home country and on the road until they set foot in the host country and settled. If famine or thirst caused their run, then, they are already facing the results of malnutrition or water deprivation. Oloruntoba & Banomyong (2018) says that forced displacement often results in secondary crises. Health crises and epidemics are some of those.

4.9.1.1. The relationship between healthcare and water, sanitation and hygiene practices

Inappropriate amounts and quality of drinking water supplied may result in many complications from dehydration, urinary and kidney problems and seizures to death. Studies since 1800s show that basic sanitation and personal hygiene provision is protective against several important contagious diseases such as diarrhea and cholera (Sherman, 2007) further causing dehydration and create an endless cycle of diseases caused by improper water conditions. Even not maintaining clean nails may collect and spread germs easily in camps. All can easily escalate into fatal situations (Cronin et al., 2007).

There are other aspects of the sanitation and hygiene also important for the healthcare of a refugee, such as menstrual hygiene. Without proper supplies and hygiene conditions, it may result in urinary and reproductive system infections and cancer. It is also associated with poor academic performance and school dropouts (Belayneh & Mekuriaw, 2019).

4.9.1.2. The relationship between hygiene and nutrition

Nutrition and healthcare goes hand to hand. Proper nutrition in healthcare is prime, especially for the cases of maternal and child malnutrition (Black et al. 2013; Kau et al., 2011). This becomes more severe in harsh living conditions such as life under armed conflict (Singh et al., 2021) and in refugee camps (Engidaw et al., 2018; Jemal et al., 2016; Shah et al., 2021; Wanzira et al., 2018). While Bhutta et al. (2013) calculates the global scale annual monetary compensation of the intervention for nutritional improvements for children based on empirical studies, Singh et al. (2021) focuses on conflict areas and discusses the challenges of the conditions.

4.9.2. Direct Healthcare Provision in Refugee Camps

Direct healthcare services includes diagnosis, prevention, treatment, cure, or relief of a health condition, illness, injury, pregnancy or disease. The direct healthcare resources that should be considered in the camp condition start with the healthcare practitioners: doctors, nurses and caretakers. The medicines such as serums and antibiotics come next. Healthcare facility accommodating for emergencies and serves as a polyclinic follows these, considering the rooms, beds and the equipment required. The supply and the allocation of these direct healthcare resources is one of the challenges of a refugee camp.

Not only the specialized medical equipment such as electrocardiograph (ECG), dialysis or blood testing machine but also common cooling devices/fridges to sustain the cold cycle of the medicine as their perishability and storage conditions are also crucial for the success of the healthcare operations. Energy to support those activities is vital, but it is not in abundance in underdeveloped countries even for the healthcare operations (Cocking et al., 2012).

Another option is to share the healthcare facilities and resources of the locals or with locals in order to mitigate the probable conflict between them. This approach is taken in the Lagkadikia Refugee Camp in Greece beyond healthcare, extended to education and community service (Jahre et al., 2018).

4.9.3. Mental Health of Refugees

Another aspect of healthcare that is of great importance for not only the human being but also for the camp community as a whole is mental health. The literature of psychiatry acknowledges that the psychologies of the forcibly displaced persons are damaged. Anxiety, depression and post-traumatic stress disorder is very common among the refugees (Silove et al., 2017). They fled from many hardships including death, and they are in an unknown territory with no guarantee of a future that their identities are acknowledged and are citizens of a country. It is natural for them to be scared, anxious or depressed.

Mental health of the refugees affects their physical health as well. According to doctors volunteered at the Greece Moira refugee camp, the stress levels of the refugees also triggered gastrointestinal diseases – one of the most common conditions in that camp (Burns & Brenna, 2021).

In the light of all these, the refugees should be provided with psychological support. Besides professional help such as counselling or pharmacotherapy, allocation of the daily operational tasks to the camp residents or labor opportunities outside of the camp increases the feeling of normality and usefulness to their society and therefore can improve their mental health. This collective work and contribution to the community may strengthen the social interactions among the camp residents and create a better social environment for all.

4.9.4. Disease Control

One of the issues that we should not overlook in a refugee camp is contagious diseases or epidemics. The transmission method depends on the nature of the pathogen. It may be airborne, waterborne, may infect via direct contact with bodies and bodily fluids or indirect contact with contaminated surfaces or food. Hygiene and social distance is vital, both of which are hard to sustain in current camp design and management practices that are of a crowd in close contact and very little water and sanitation provisions. Proper excreta disposal and safe burials (Büyüktahtakın et al., 2018) are also crucial to keep the disease from spreading further.

4.9.4.1. Novel Coronavirus pandemic

The current novel coronavirus pandemic in the world also deserves mentioning. Not only the disease itself but also how the world is affected by social and economic consequences contributes to the welfare and health conditions of the camp.

Even though the borders were mostly closed throughout the year, 1.4 million people still left their countries to seek refuge in 2020 (UNHCR, 2021). The pandemic does not seem to damage the camps as much in terms of Covid-19 cases, as the whole world was alarmed and the access to camps can be restricted, despite many critics claiming the provisions were symbolic (Schmitz, August 2020) and what UNHCR mainly did for hygiene was to increase the number of taps and change their mechanisms to decrease contact (UNHCR WASH, n.d.).

The global funds for humanitarian aid and especially for food shifted from the camps to the sick worldwide, resulting in food shortages in refugee camps (Manirambona et al., 2021; WFP, 2021). As the healthcare and economic crises emerged and the resulting unemployment rates, people’s incentives to donate for others decreased and they allocated their funds in saving in this unstable environment, or donated for medical research and aid for Covid19 patients and the countries that are severely hit by it. The shift of media coverage to the Covid19 also contributed to this, as it was one of the main sources of awareness of the refugees in the public.

4.10. Labor

The labor supply of the camp is of the host region population and camp population that are capable of joining the labor market and willingly so, as well as members of international aid organizations and government officials, assuming that the last two categories are already employed in the camp. The size of the labor supply depends on the size and demographics of the population and the location of the camp, as the location comes with the host labor supply.

4.10.1. Reasons for work

If one considers Maslow's hierarchy, safety needs are to be satisfied next right after the basic needs. After the initial settlement and the physiological needs are provided, one needs security, health, employment, resources and property. The camp provides security and for the most part, health, at least compared to the origin country's conditions. For the rest, work and trade comes into play.

Even in the small number of works in the OR literature on refugees it is mentioned that the psychologies of the forcibly displaced persons are damaged (Kovacs et al., 2010) and a daily work will not only improve their mental health (Mejia & Miraglia, 2020) but also provide a trade for the refugees when they eventually return to their home country.

4.10.1.1. Finance of the refugee camps in labor context

Another reason to employ camp residents in the camp is that 80% of all refugees are hosted in the developing regions, and one third is hosted by the world's poorest countries (UNHCR, 202). They suffer from lack of financial power even for their own citizens. Using the labor force of the camp is a solution alternative.

4.10.1.2. Host relations

There are some additional benefits of refugee labor as well, especially for social concerns. First, the potential of the camp to produce goods to trade with the host community increases the positive interactions while decreasing the possible tensions due to limited resources that they -if must- share. (Jahre et al., 2018)

4.10.1.3. Social and gender equality in refugee camps

We must also consider that many of the refugees in the world come from third world countries that have challenges in equality issues. Literature of forced migration (Turner, 2015) claims that camps can improve the civil rights perception and equality of the refugees by inclusion of groups once marginalized into the labor force. We may count some as women, ethnic groups, religious groups, disabled people, people with different sexual orientation and attraction. In order to do that, the structure of the camp not only in terms of the tasks assigned, but also the power relations, hierarchies and social life should be restructured (Turner, 2015). A model representing this also tries on social sustainability.

However, there are works in the social sciences literature claiming that participation of these minority groups is not an act of equality. Olivius (2014) criticizes that the main reason why women are included in the labor force in refugee camps is to increase the efficiency of the operations, and gender equality is seen as a by-product. Another warning comes from Turner (2015): the work states that while the camps may offer new dynamics, they also can reinforce the old power structures. In these regards, not only the participation in labor but also the underlying power structure in the design should be considered.

Gendered tasks in the workplaces and camp might emphasize the gender roles, if women do the cleaning, food distribution, hygiene promotion, and caretaking work but men do more manual and logistics work, and if they are not in equal places in the organizational hierarchy. There should be a gender balance in operations. This involves assumptions on men and women. According to Olivius (2014), women were assigned to tasks open to corruption with an underlying assumption that they are less prone to do it. Also, if the women continue to be the sole responsible of the house chores and childcare, the equality would not be reached.

4.10.2. The Work Opportunities for Refugees

Due to the misconception on refugees as being unskilled, the OR literature lacks work on in-camp sourcing. (Kovacs et al., 2010; Oloruntoba & Banomyong, 2018) But this is not the case. They were contributing to their workforce and economy in their origin country. They have various skill sets that are able to conform to numerous works in camps, from agriculture and logistics to social services and education.

4.10.2.1. Gardening and agricultural work

Gardening activities for refugees is discussed well enough for the social integration aspects (Dyg et al., 2019; Millican et al., 2018). Meija et al. (2020) and Strunk et al. (2017) study gardening as social agents in integration, the former also devolves into the their effects on physical and mental health of the refugees. But the relationship structure is vastly different from a camp context as in these the refugees are settled in a city and are very few in numbers, making the integration much easier. Claudia and Suzanne (2020) investigate the possibility of integration of refugees and asylum seekers under social work perspective in Italian agricultural sector. However, Pelek (2018) reveals that there is a threat of strengthening of the social inequalities between the citizens and refugees in a sector such as agriculture that is very hierarchically organized.

4.10.2.2. Camp services

The labor is required not only for the management and organization of the camp following the construction, but also for the daily activities such as transportation, food preparation and distribution, cleaning, security, medical services, education, and so forth.

4.10.2.3. Self-sufficiency

Self-sufficiency in this context is the ability to supply the demand with camp sources or trade with the profits earned through camp activities. If there are agricultural activities in the camp, there is a need for labor for activities such as cultivating, planting and storing. If the energy of the camp comes from local natural resources within the vicinity of the camp, there is also a labor demand to run the energy plant.

However, if the energy and food is supplied in-camp, then, the labor demand depend on not only the population size which makes up the food and energy demand, but also the climate and location conditions affecting the energy type, resulting in different amounts of labor requirement at different times of the year: seasonal labor demand.

4.10.2.4. Other work

Another work opportunity is crafts and trade. There can also freelance work efforts, such as barbering or digital work, like in Kakuma Refugee Camp in Kenya (intracen.org (International Trade Center), 2019). But to produce goods or services, one requires an appropriate environment, materials, tools and energy.

4.10.3. Laws and Regulations

There are also several issues to consider, first being the laws and legislations for refugee work. Necessary legal actions should be taken for the employee-employer relationships, the content and extent of the work, occupational health and safety and insurance in the camp. Also the framework of this works should be structured enough so that there will not be any exploitation of the refugees.

4.11. Host Relationships

The relationship between the refugees and the hosts is important in keeping peace in the region and local integration. Similarity of the social structure, religion and genetic resemblance to the refugees are important determinants of the success of the integration. Another aspect of this relationship is economical, in other words, on the basis of allocation of the resources. Considering the fact that approximately 80% of the refugees are hosted by a neighboring country (UNHCR, 2018), displacement caused by factors like famine, drought and natural disasters may likely exist in the host region and may lead to a conflict over the resources.

However, previously suggested self-funding opportunities such as agriculture may mitigate the negative effects. Adding that, the potential of the camp to produce goods to trade with the host community increases the positive interactions while decreasing the possible tensions due to limited resources that they -if must- share.

The possibility of employing the host community in the camp is up to consideration. Working together may improve the host-refugee relationships, increasing the positive interaction between the two groups, although it depends on the sector (Pelek, 2018). Host community's population and economic structure determines the labor it can supply to the camp. If enabled, the economy of the host region can grow with the economic activities of refugees, as Jansen (2019) claims.

4. 12. System Diagrams

To showcase the attributes and the relationships between the elements of the sub-systems that are in discussion, we provide diagrams for the sub-system and constructs that are not in that system but have effects on. These diagrams are to display the complicated relationships of a sub-system in a more concise way; they are drawn for the more complex parts of the system. After we facilitate the required level of understanding, we conclude with the camp-wide diagram that combines all these constructs.

4.12.1 Location, Climate and Resource Supply Causal Diagram

Figure 4.1 shows the relationships between the Location, Climate, and the Resource Supply sub-system. In the environment there is also the Refugee Profile, consisting of the race, ethnicity, number, demographics, the origin location and culture of the refugees. Resource Supply consists of supply of the resources water, food, energy and healthcare within the camp or via outsourcing.

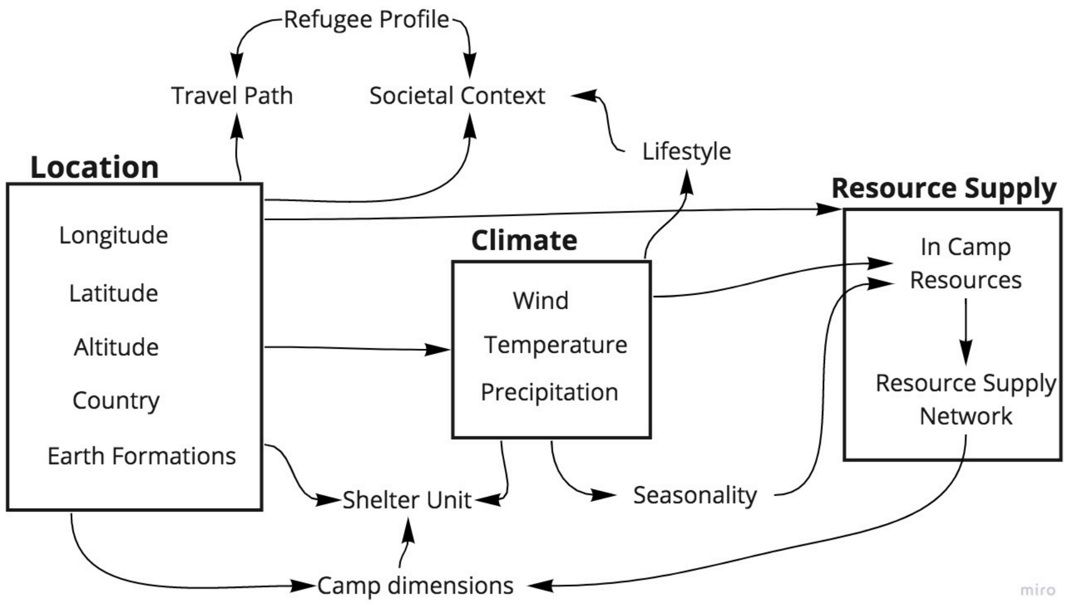

Figure 4.1. Causal Diagram for Location, Climate and Resource Supply

The entities and their connections are as follows:

- The relationship between the location, climate and the resource supply is provided.
- The effects of the location on the refugee camp size and the shelter unit are shown.
- Climate has a direct effect on the shelter unit, but in-direct effect on the camp size through the resource supply.
- The refugee profile – consisting of where the refugees come from, the hosting country – a function of the location of the camp determine the travel path from the origin point to the camp they are settled in, with the distance and conditions as the attributes.
- Refugee profile, hosting country and lifestyle – a function of the climate – affect the societal context of the camp: camp culture, sociological dynamics, power relations etc.

4.12.2 Shelter Unit Causal Diagram

Figure 4.2 shows the relationships between the shelter unit and the entities in its environment: location, climate, refugee profile and the resource supply sub-system.

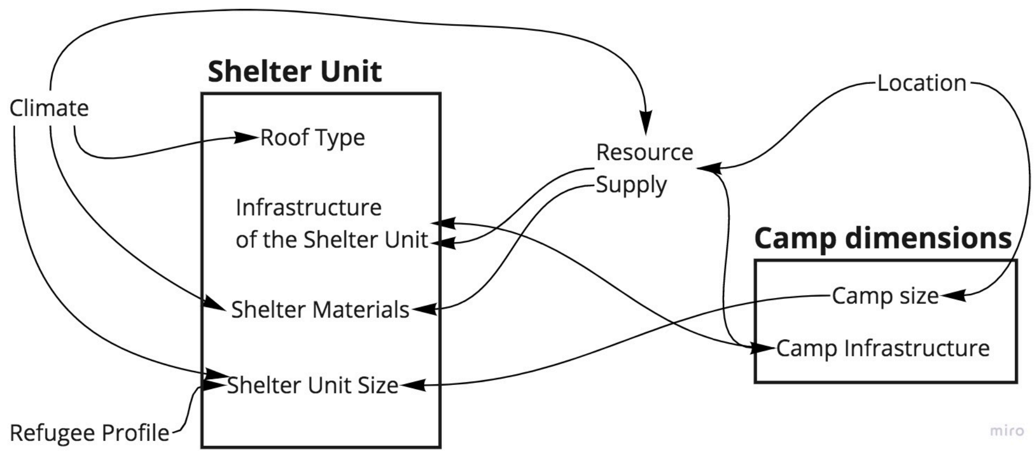

Figure 4.2. Causal Diagram for Shelter Unit

The entities and their connections are as follows:

- The shelter unit has attributes roof type, infrastructure, materials used and size.
- Climate has a direct effect on the roof type, materials used and size of the unit.
- The resource supply subsystem – affected by the climate and location – has an effect on the infrastructure of the unit, as the supply system sets the required infrastructure investments and plans for the method of supply distribution within the camp.
- Location affects the camp size that then contributes to size of the shelter units depending on the amount of refugees hosted in that area. Refugee profile in terms of the family size also has an effect on the size of the shelter units.

4.12.3 WASH System Causal Diagram

Figure 4.3 shows the components of the WASH System and the relationships between these components as well as their connections with the entities in the system's environment: location, climate, and health.

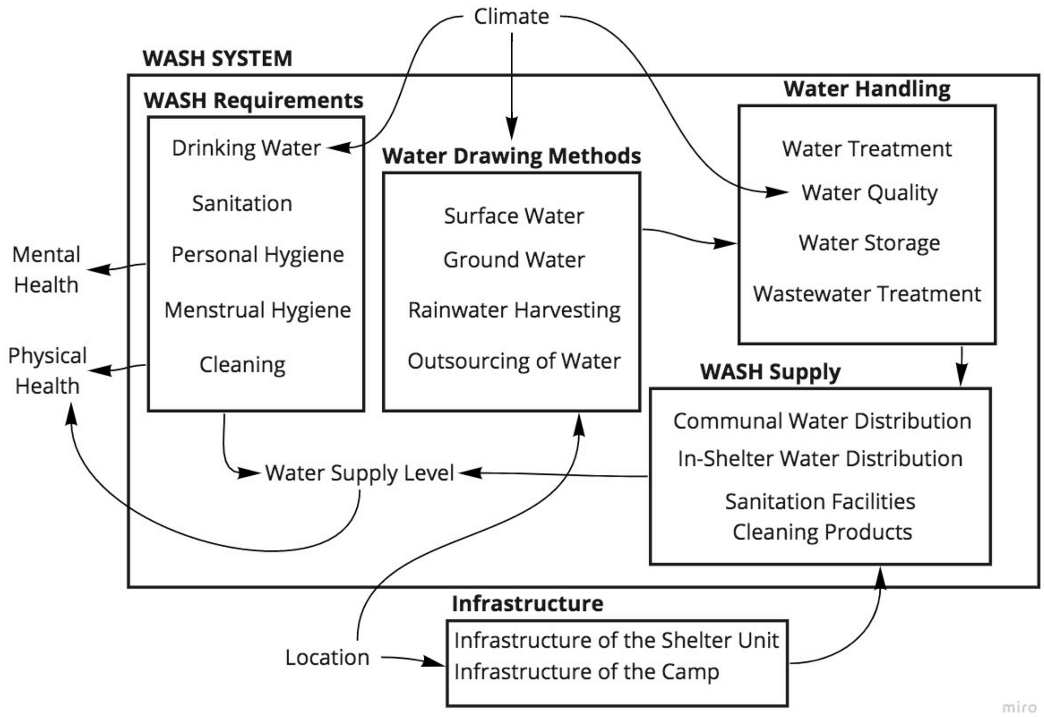

Figure 4.3. Causal Diagram for the WASH System

The entities and their connections are as follows:

- The requirements with the drinking water, sanitation, personal hygiene, menstrual hygiene and cleaning aspects are given.
- The climate has an effect on the drinking water requirement, since the temperature and humidity aspects of it changes water use in the body.
- Clean drinking water, hygiene and sanitation activities affect mental and physical health.
- Location of the camp and the climate has an effect on the water drawing method, local or outsourced.

- The location determines attributes of the shelter as previously described, thus, the infrastructure is affected by it.
- Climate affects the water handling process in terms of quality since it sets the conditions the water should be protected from and the chlorine decay.
- Hand in hand with the handling processes the WASH supply is distributed to the refugees in the camp.
- The requirements and their satisfaction through the distribution make up the water supply level.

4.12.4 Food System Causal Diagram

Figure 4.4 displays the components and the relationships Food System has as well as its connections with the entities in its environment: refugee profile, location, climate, water, energy and healthcare.

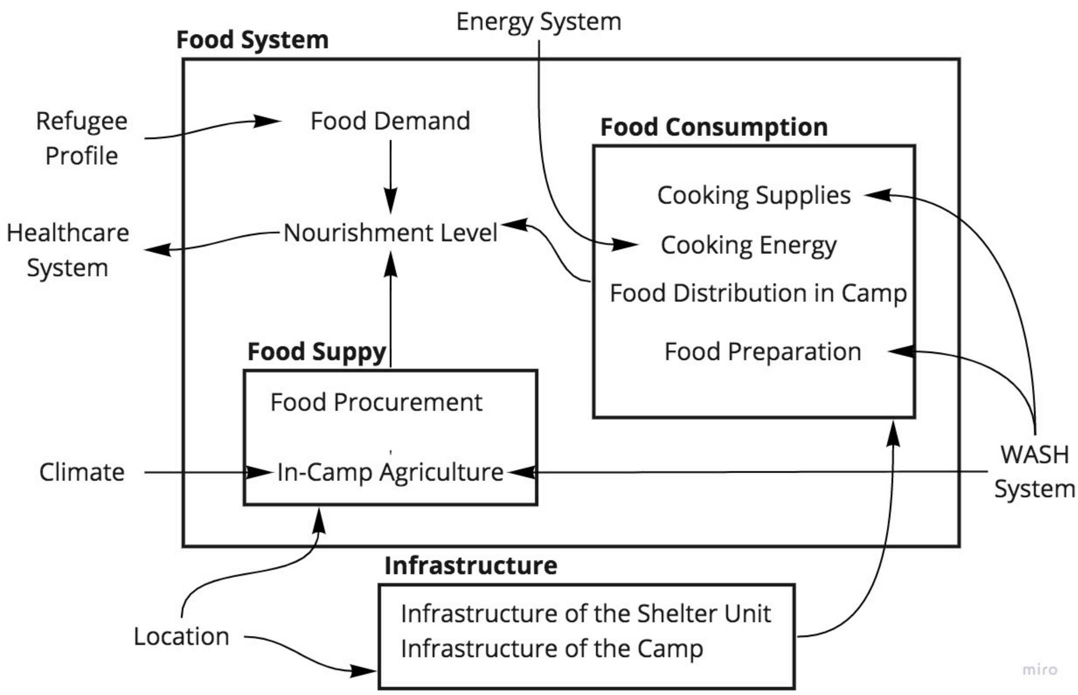

Figure 4.4. Causal Diagram for the Food System

The entities and their connections are as follows:

- Refugee profile has an effect on the food demand due to its attributes for the number and demographics.
- Location of the camp and the climate has an effect on the local food production possibilities. Location also affects the procurement opportunities.
- Water is required for agricultural production as well as cleaning the food and utensils.
- The infrastructure of the camp and the shelter unit affects the food consumption in terms of how and where the foods are prepared and consumed.
- Energy system affects the food consumption through the energy required for cooking.
- The nourishment level, which is a function of food demand, supply and consumption affect the health of the refugee.

4.12.5 Energy System Causal Diagram

Figure 4.5 displays the components and the relationships Energy System has as well as its connections with the entities in its environment: Location, Climate, WASH, Food, Healthcare and Labor.

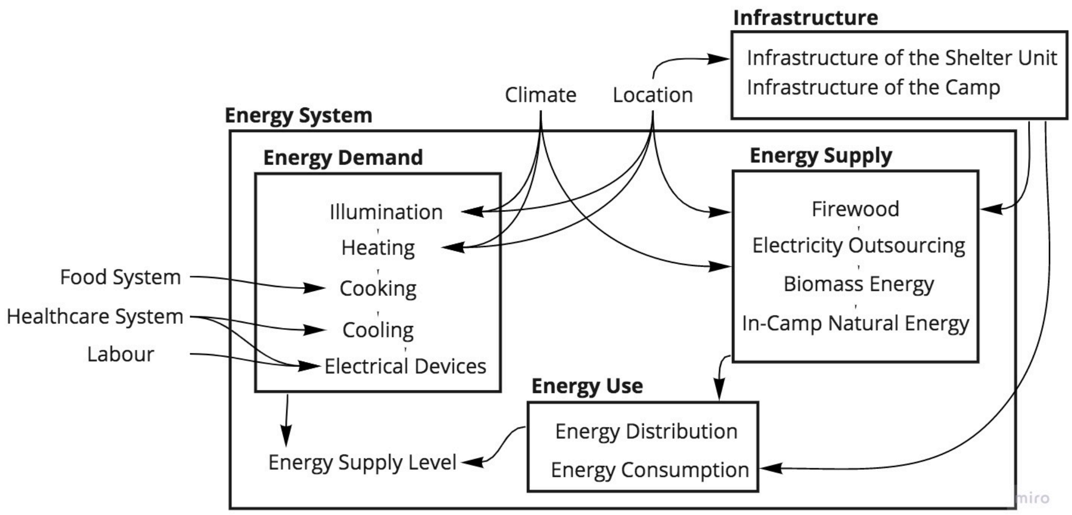

Figure 4.5. Causal Diagram for the Energy System

The entities and their connections are as follows:

- Climate and energy sets the natural conditions of the camp affecting the illumination, heating and cooling needs.
- The medical supplies that should be protected in a cool setting requires energy for cooling.
- The business activities and the healthcare equipment in the camp determining the electrical devices to run form the energy demand of the camp.
- The location and climate affects the natural energy production possibilities and the energy outsourcing in terms of distance and type.
- The infrastructure of the camp and energy supply determines the energy use, for the utilities and devices can run with that energy typ.
- The energy supply level is a function of energy demand and use.
-

4.12.6 Healthcare System Causal Diagram

Figure 4.6 displays the components and the relationships Healthcare System has as well as its connections with the entities in its environment: WASH, Energy and Food systems

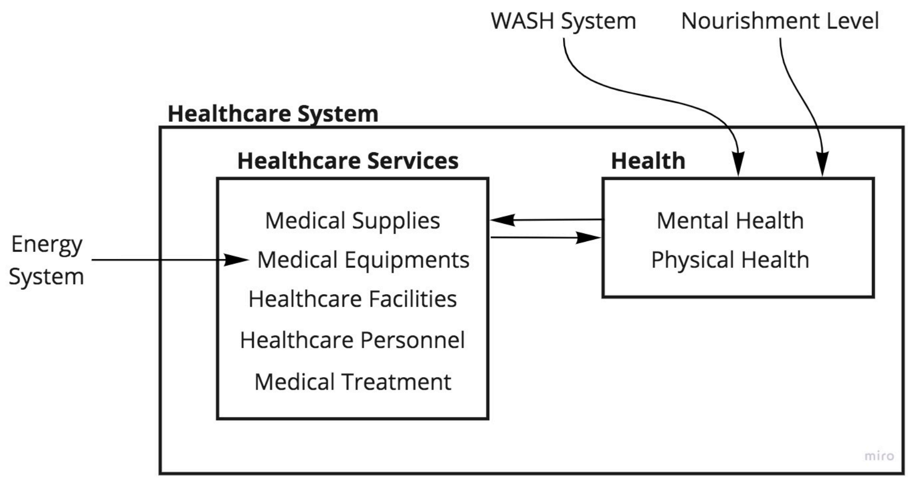

Figure 4.6. Causal Diagram for the Healthcare System

The entities and their connections are as follows:

- The medical supplies that should be protected in a cool setting and the equipment to run require energy.
- The nourishment level affects the health of the refugee.
- WASH System through clean drinking water, hygiene and sanitation activities affect mental and physical health.

CHAPTER 5

METHODOLOGY OF A MATHEMATICAL MODEL FOR A REFUGEE CAMP

According to Daellenbach et al. (2012), a good mathematical model should be "simple, complete, easy to manipulate and be communicated with, appropriate for the situation studied, adaptive and produces information that is relevant and appropriate". How to formulate a good mathematical model a refugee camp based on these criteria is discussed throughout this chapter. The three dimensions of a problem situation one must consider for modeling – technical, probabilistic and purposive complexity – are described for the refugee camp in this chapter. The term refugee camp problem does not refer to a single pre-defined problem but rather it covers problems for a range of refugee problem situations concerning the camps; such as locating the camps, providing safe passage to those, long term resource supply for well-being of the hosted and hosting population.

5.1. Technical And Stochastic Complexity

The refugee camp is a large system and the mathematical model size to represent it depends on the complexities it involves, the detail level and time span it covers. All of the entities concerned in the model are also not deterministic, since it is a model for a human interaction system with various unknowns. The paradigm of the technical and stochastic complexity for a refugee camp model, as well as the conscious decisions to make on whether to or how to capture these complexities is explained or guided hereafter.

5.1.1. Technical Complexity

In general, the technical complexity of a system modeled can be separated into three dimensions: the elements included, the detail level of the representation of those elements and the structure of connections those have in the system defined. The technical complexity of the refugee camp problem, whether it deals with operations planning, management infrastructure or social constructs, involves many of its subsystems and surroundings, which covers the whole of the Chapter 4, the system model of the refugee camp.

Each of the operations and activities of the refugee camp system require their own system definitions and should be investigated within the system they are in, the refugee camp. Coincidentally, the refugee camp itself should be investigated within its surrounding system, due to the interactions between the camp and its environment. The surrounding system consists of but not limited to the suppliers and producers of the resources the camp utilizes, the aid organizations, hosting government, the host population, origin country, global public, as well as the land, environment, conditions, limitations and paradigm of those – they all have effects on the refugee camp. All of those make a refugee camp a very complex system.

The mathematical model a refugee camp should be built based on conscious decisions on the technical complexity after careful considerations of those factors explained, with the unique structure of the situation. Several of the factors will be directed hereafter.

5.1.2. Stochastic Complexity

Refugee camp problem has a structure consisting of various unknown structures, being an extension of a political, criminal or humanitarian crisis. Probabilistic nature of the life also brings its own complexities. The mathematical model for the refugee camp should capture various probability sources of the refugee camp problem to be a good representation of the reality. Here we discuss first the refugee influx, the second the weather conditions for the most significant of those to capture, and the easiest to integrate into a refugee camp problem.

5.1.2.1. Refugee Influx

Since every complex human activity system is unique and the situations that drive refugee crises that are discussed in the Chapter 3.1.3 are extremely complex phenomena, no two refugee crises are the same. The arrivals are not sudden, but distributed in time. The densities are also changing in time. An example is the Syrian refuge mobility to Turkey, that in 2011 and the arrival rate fluctuated until 2018 where the population reached a near-steady state (UNHCR, 2020). Even for the same group of refugees started in the same country, the road is different if they start from different points and if they end up settled in different countries. These can only be forecasted – based on other forecasts for the various directions the crises in the origin country may follow – not be known completely in advance.

The decisions for a refugee camp location and resource allocation are primarily based on the refugees themselves, on their number and their needs are proportional to that. For the refugee camp mathematical model, we can easily say that we cannot expect a static refugee influx in time and space. The model should cover for the unique arrival structure and its probabilistic nature. Even when the objective is to provide a universal approach for the refugee camp decisions, the model should be robust to changes in the size of the crisis.

5.2.1.2. Weather

The weather conditions throughout the time – mainly the temperature, wind and precipitation – directly or indirectly affect the yield of various resources the refugee camp demands. If we exemplify by the temperature, a direct effect of it is the agricultural yield. For the hydrological energy generation, it does not have a direct effect since the natural capacity is up to the precipitation pattern for the rivers fed by rain and melted snow from mountains. Even though the main determinant is the precipitation, temperature pattern determines when the snow will melt. Thus, it exerts an indirect effect on the amount of hydrological energy production. As explained in the Chapter 4, there are methods of artificial support when the nature itself is not sufficient, such as irrigation for horticulture. However, these reflect on the costs and also bounded by their own capacities.

The weather conditions also affect other aspects, such as the functions of the shelters or storage. Extreme weather conditions may require contingency plans. Another implication on the weather conditions is the global climate change, as explained in the Chapter 3.2.

The pattern of the weather can be forecasted to a degree, but not certain unless it is realized. The probabilistic changes the real life parameters for the infrastructure, capacity planning, local production and the purchasing for the resources demanded for the daily life of the refugees. In the end, these probabilistic complexities make the decisions harder and more complex. The mathematical model for a refugee camp system should consider these and tackle them well without compromising other aspects of it, especially as the camps mainly function for the supply of these resources.

5.1.3. Temporal Complexity

The model size is a function of the boundary decisions for the size of the system represented and the detail level. Most of the technical and stochastic complexities in the refugee camp are discussed previously throughout the Chapter 4, and for the scope of the boundary decisions, in Chapter 5.1.1 and 5.1.2. How to handle the fourth dimension – time – is a hefty part of the boundary decisions that we will look into here. Time spanned in the mode, in this perspective, becomes a part of the size whereas the length of the time unit, as in the planning slots over the planning horizon, represents the problem detail. Time is both affected by the previously discussed complexities, and also affects those. The approaches presented here should be acknowledged while building mathematical models for refugee camp planning.

5.1.3.1. Planning Horizon

Chkam (2016) says " The main problem with the camp paradigm is that it dictates that refugees should be treated as a temporary phenomenon, causing resource expenditure to be minimized until refugees can go back to 'productive' life after exile". Current influences on camp design still follows this idea (Jahre et al., 2018), stuck in short term thinking and planning. Thus, we must open a discussion on how long the camps should be designed for and how long should be the planning horizon in order to think and plan accordingly.

For a new refugee crisis – which is of an emergency nature – where there is no infrastructure available for sheltering the refugees, the size of the first group arriving is relatively small, and they can be treated as signal for a larger issue, the movement of a larger group in a large period. During the emergency settlement, the decision makers have time to plan for the longer-term settlement and even the movement of the refugees from their origin gives enough time for a better decision-making process. Also to compare with other emergency situations; during a refuge crisis there is more time to collect data, understand the situation and forecast the future than natural disasters that hit immediately; such as earthquakes and tsunamis.

In the nature of emergencies there is a high chance of shortage in resource supply. The time scope of the refugee camp problems, consisting of years as in Chapter 3.1, enables the decision makers to get funding for the operations: the size of the budget is a function of the size and acuteness of the crisis facilitated by the media coverage. Even though it diminishes in time, how the resources can be efficiently used can be planned with the most efficiency at any point in the crisis. Even with unknown funding amount the distribution patterns can be studied to plan for.

On average, the refugee camps are active for 7 years (Jahre et al., 2018). But statistic is not enough to have a conclusion, as closing a camp does not necessarily mean that the refugees have returned or a long-term sustainable solution like naturalization is provided, but rather the residents are moved to another camp. A solid example is Kenya's Dadaab camps, where 420,000 Somalian refugees that entered the country in 1992 and temporarily settled in 17 camps were gathered in the three camps located in Dadaab in 1993. Still, 340 thousand of them are in protracted refugee situation as of 2016 (Chkam, 2016). Also by 2020, 75% of all refugees are in protracted refugee situations (UNHCR, 2021), and the percentage of refugees returned or naturalized keeps has a decreasing trend for the last 10 years.

An approach can be to plan for at least 5 years, which corresponds to the protracted refugee situations. Protracted situation represents a level of stability, meaning that it may represent a requirement level not different from of a refugee camp that has been active longer. For a more concise approach, a work on active and previously active camps may reveal the pattern for the time it takes for the camp requirements go into a steady state for services such as energy, healthcare, education and employment can be found. Not the performance of the past humanitarian aid efforts, but the refugee influx patterns can also be studied, as the performance of the humanitarian aid and the camp management affects when to reach a steady state. These studies are also important to capture the probabilistic nature explained in Chapter 5.1.2.1.

Another approach is to design a self-sustainable camp considering energy, food and water needs, with the approach of “this settlement will be active for a number of years if it is designed sustainably (it will not be one of the ones that will be closed as it is inefficient) and if the current socio-political context continues (based on the return trends we unfortunately assume no other option)”. If the design is sustainable, then, the camp will not demand funds for many years and have a burden on the hosting government and agencies, which itself diminishes the planning horizon required from a large number of years to time until it becomes self-sufficient.

Finally, we would like to suggest an unconventional idea: the camps may not be useless after the refugees return need to be abandoned if they are designed humanely. The production facilities and buildings can still be utilized for various purposes if they are well planned, as production sites, accommodations for homeless people, humane detention facility for minor criminals, or as a contingency plan for the regions prone to destructive natural disasters.

5.1.3.2. Time Unit

Length of planning unit should be chosen enough short that it can capture the time-variant differences without sacrificing the solution time. There are many time-variant factors we must take into account, either cyclic or linear.

Refugee influx and outflow as well as birth and death rates result in changes in the current camp population and future expectations, important in both the short-term needs like water and the long-term decisions such as camp utility network structure and facility capacities. Even if the population size is steady, the demand still changes in time due to seasonal effects. The amount and type of demand of air conditioning changes based on the humidity and the temperature, which follows may have an annual cycle depending on the climate. Depending on the latitude, the hours of daylight may change drastically in time, resulting in differences in illumination.

Movement of Earth around the Sun also affects the supply. The agricultural yield is also a function of time, following seasonal trends unless there is a greenhouse and watering – in which case the abundance of water as a function of time is a consideration. Even if the goods are purchased, the prices are affected by the changes. If the energy is sourced locally, there are many other considerations. The solar energy potential is affected by the hours of daylight and solar angle that changes throughout the year depending on the latitude. If the power supply is a reservoir feeding type, climatic rainy and drought times should be explicitly considered. That is similar for the wind power alternative, as well.

The length of the planning time slots also measures of how much the demand and supply is agglomerated in time. As the slots get longer, the level of pooling increases and the stochastic elements gets easier to deal with in terms of easier computation and estimation, in exchange for a good representation of the reality. Working with the pooled data can also mislead the researcher in determining the requirements of the particular situation. UNHCR uses and collects annual data and presents annual averages, for example, which may easily cover up shortages if the supply levels are below the required at any point in time.

The period length decision also brings implicit assumptions or simplifications on other aspects such as storage as well. If the nutritional and medical purchasing decisions are made seasonally, for example, we need to consider perishability or how long and where they can be stored longer terms.

The periods should be chosen small enough to represent the demand and supply paradigm of the resources considered in the period and large enough not to compromise the model complexity and solution time. This is a function of the size of the problem situation captured, or in another words, a boundary decision.

5.1.4. Model Size

The complexities of the system one chooses to model reflect on the model complexity and solution time. First, one should ask what to model and then how best to model it, should not fit a problem situation to a predetermined solution method. The choice comes down to the purpose of the model. For a modeling perspective, we must distinguish between short term and long-term decisions. If a decision is short term, meaning that it must be made regularly and most of the uncontrollable inputs and system components cannot be changed, meaning that the overall system performance does not change with this decision. In the long term, most of the system components can be changed. These grand changes affect the overall system performance, including the performance of the short-term decisions. The overall system performance is the function of these system components and how they are utilized best, the short-term decisions.

Locating a refugee camp, infrastructure investment, shelter building – structures to build and use for multiple years – are longer-term decisions to make; they shape the overall system. The allocation and storage decisions are shorter-term ones. A refugee model that contains the longer-term decisions should not avoid complexity, because they will affect the performance of the shorter-term ones in continuous time.

On the contrary, the model should avoid the trade off between the comprehensive models and time altogether: there is enough time to model and solve a complex problem for refugee situations. The decisions can be made throughout a large amount of time, in months or in years (Chapter 5.1.3.1). A refugee camp long-term decision model that is consists of a more concise analysis of the system and requires a large solution time is worth more than one that is fast but simplifies too much.

To use models in decision-making, the aim is to sustain the best decision for the situation at hand; this includes the effort of the model formulation and solution. Acknowledging the importance of obtaining the solution fast, the complexity sacrificed should be a logical decision. At this point in time, we are in need of models that we can use for policy makers for refugee camps in various subjects. For now, the research effort is much needed in the comprehensive model building: it is better to spend in the complexity of the system modeled rather than its solution time, even though we must definitely work on that in the future.

5.2. Divergence of Views in The Refugee Camps

The refugee camps are of multi-actor systems where they have diverse worldviews and purposes. This increases system complexity, as the diversity of these stakeholders and their interdependencies make the system less predictable. The understanding of the problem situation should consider this complexity prior to the mathematical model formulation phase. In the formulation, those should be represented in the scope, in addition to the discussion in 5.1, different objectives and performance measures.

5.2.1. Multiple Viewpoints

In a refugee camp system, there are multiple stakeholders, as explained in Chapter 4.2. The stakeholders may either be located in the refugee camp, such as refugees and aid workers working in the camp, or they may be remotely working for the aid activities. Hosting governments has their saying in the decision-making and the neighboring population of the refugee camp is right outside its borders. They are diverse in their worldviews, purposes and as a result, their perception of the system. They respond different to events and this makes the system understanding more challenging.

These different points of view cause conflicts in objectives and methods: we need to find middle grounds while understanding the situation and act accordingly while modeling the camp situation. An approach conveying only for the perception of one does not suffice. Depending on the points of view, mathematical models should be adjusted, or the models should be robust to various demands of these different stakeholders.

There are various methods for that. First, the boundaries of the system to be modeled, with its technical and stochastic complexity should be chosen according to this perception of inclusion. The context of the model should be for the unique problem situation understood. Since the refugee camp is a human interaction system, a lot of simplifications and assumptions need to be made in order to model it mathematically. Those should not remove the needs of different stakeholders, but rather include without compromising the simplicity of the model. For the considerations of different groups, different objectives can be mathematically defined and the performance of the solution can be analyzed with various different performance measures created for the diverse range of demands of these groups.

Traditionally, in a refugee camp, the problem owners and the decision makers of the camp are interchangeably or collectively the aid organizations and the host government whereas the workers and volunteers are the problem users and the refugees are the problem customers. However, the increased involvement of refugees in their own lives may improve their satisfaction. Even though the initial decision makers do not have the input from the refugees besides the daily needs, the demographic and social norms, they should be represented more in the decisions modeled. In the shelter sizes, for example, the family sizes and structure, or communal areas for educational and social conventions should be considered. Also not only the amount of resources supplied themselves, but also how they affect their satisfaction or suffering should be encompassed in the decision models.

In the camps, on the other hand, the hosted population may be assumed to be homogeneous and their needs are limited to essential supplies in decision-making processes. But this approach disregards their needs and desires by assuming the fulfillment of the described resources by the authorities should suffice. Even if the only measure is the amount but not the equity in distribution, the inequality in distribution that is unplanned may also result in power dynamics affecting the whole society. Also, lack of these essential needs may cause undesired outcomes such as criminal activities towards woman in the cases of insufficient lighting and firewood (Chapter 4.8).

Another important stakeholder to include in the models is the host population. An example can be to consider the well being of the host population for the resource allocation decisions if the region the camp is located suffers from malnutrition or water deprivation, by including aid efforts for the hosting population for those resources to the plan and budget while serving for the camp, in order not to have tension in the region. By doing this, the model complexity covers the decisions for the hosts, as well. Another approach is to have their demands represented in the objective function. For example, Deneklos et al. (2021) adds a social criterion for the local opposition in the location decision in order not to create or fuel political turmoil, for the populations that have negative feelings against new refugee settlements due to various reasons.

5.2.2. Human Suffering and Equality in a Refugee Camp

Humanitarian logistics is a quite sensitive subject compared to commercial based logistics operations, where the immediate relief saves lives. Refugee logistics has a similar emotional connotation as the suffering of the people is already described in the word “refugee”. Oloruntoba and Banomyong (2018) state that forced displacement often results in secondary crises. Then, it is only natural for one to look for means to represent the operations under the suffering and hardships the refugees have to bear or not have to anymore, especially for the distribution of the nutritional supplies, shelters, water and other resources, to avoid those secondary crises. In the commercial logistics models, stakes are never this high.

Here we first lay out the concerns and past works regarding the representation of human suffering and equality in humanitarian and development contexts. Based on these, we then discuss the considerations for a good representation of equality and suffering for a model. Then, we propose a vulnerability metric approach to capture human suffering for a refugee camp, which is applied in Chapter 6. In the end, we present our findings.

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5.2.2.1. Ethical Dilemmas of Resource Supply

The ethical dilemmas about the supply distribution is recognized in the early ages and discussed by many philosophers since then. For a group with equal needs, who to save if the supply is limited? What makes a life more valuable than others? Should the decision made randomly or should there be a logical process? If it comes to the survival of the group, what should it be done? Similar to the trolley experiment, what is the ethical responsibility on one if they are given the chance to make the decision on take from who and give it to whom?

When the recipients are recognized being of several different groups depending on age, gender, health conditions, weight and such; it is realized that the needs for each individual in need and the relative effects of each unit of supply on each individual differs. For example, a unit required for an adult may be enough for two small children. Or else, should one take the unit from the adult and give it to the two children? But, what happens to the ones that are not chosen? Should we not represent their shortage in any way?

5.2.2.2. Literature Review of Human Suffering in Humanitarian Logistics

Holguin-Veras et al. (2013) categorizes proxy approaches of past operations research humanitarian logistics articles on post disaster phases of their inclusion and sufficiency of the representations of human suffering. They mainly divide the approaches into three: minimization of unmet demand, hard equity constraints and penalty constraints, the latter is divided into two as constant or variable penalty models. Minimization of unmet demands is mainly criticized for not including the urgency of the disaster situation. For the penalty models the unit penalties or the thresholds set; for the hard constraint models the tightness of the constraints are the main determinants of the success of the approach; as they may be too loose and have no effect, or be too tight and result in solutions that are not meaningful.

Social cost is the sum of the costs resulting from a transaction and external costs in order to make informed decisions in the cases of externalities. The external costs can be negative or positive. The aim is to guide policy makers for social welfare in the aggregate level.

Holguin-Veras et al. (2013) in the second half suggests a deprivation cost approach for the hysteretic and non-hysteretic effects of the deficiency of the supplies on the human body. Its social cost is the sum of logistics cost and this deprivation cost, capturing direct and external costs that captures the stakes but compromises the computational efficiency. Since then, there are many works adapts this idea in their performance measure, such as Macea et al. (2018), Holguin-Veras et al. (2016) and Wang et al. (2017).

5.2.2.3. Vulnerability

Another way to look at the human suffering is vulnerability assessment, which aims to understand the weaknesses of the community towards hazards and shocks, and a measure that can be used to provide fairness in aid. United Nations Office for Disaster Risk Reduction's (UNDRR) definition of vulnerability is "The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards." (UNDRR, n.d.). Cutter et al. (2003) states that first of the three perspectives on vulnerability is that it is "Identification of conditions that make people or places vulnerable to extreme natural events". Populations are as weak as their weakest link, and vulnerability measures the populations "inability to take care of its most vulnerable" (Sodhi, 2016).

Refugees are from very vulnerable populations and they travel long distances with very little resources. On the road they are susceptible to diseases, and usually arrive at the host countries in a very bad health. If they are settled in the camps, they face other hardships depending on the camp conditions they have a different vulnerability. Their settlement, amount of nutrients they get, the healthcare measures and the education (that is hopefully provided there) affect their vulnerability as well. If there is not enough support for the camps, they are susceptible to fluctuations in resources and weather conditions resulting in camp-wide drought, hunger, and epidemics as secondary shocks.

Vulnerability metrics

On vulnerability of natural hazards, Wisner et al. (2014) states that disasters are a product of not only natural events but also social, political and environmental conditions, and the social and environmental aspects of vulnerability are inseparable. To determine the vulnerabilities of the populations, factors for economic, demographic and housing characteristics are used, mainly age, race, health, income, employment, education, type of dwelling unit (Cutter et al., 2003; Wisner et al., 2004). There is no single vulnerability index for all groups. For various cultural, socioeconomic and demographic characteristics of different regions, the social vulnerability method can and needs to be adjusted (Eroglu et al., 2020).

Several of the simpler metrics can be suggested as United Nations Development Programme's (UNDP) metrics such as Human Development Index, Inequality Adjusted Human Development Index for the life expectancy, mean years of schooling and gross national income per capita (UNDP, 2020, Technical Notes). United Nations Department of Economic and Social Affairs (UNDESA) and Foundation for Studies and Research on International Development (FERDI) collectively created Human Assets Index for education and health, calculated using the percentage of people undernourished, mortality rate for children under age 5 and under, gross secondary school enrollment and adult literacy rate. Also, other factors such as incident of tuberculosis for a given year per 10,000 people (Sodhi, 2016) is used for vulnerability to natural hazards. UNICEF uses various other indicators for different age groups for 5-7 years old school attendance and for females only, the first sexual intercourse and early marriage (UNICEF, 2014).

UNHCR, International Detention Coalition and Oak Foundation developed a vulnerability screening guideline aimed at individual refugees in camps in 2016, which is neither conclusive nor aims to be but a guideline. The domains and indicators are for children are suggested as follows: "unaccompanied or separated child", "child accompanied by parent/s, other family members or guardians"; for sex, gender, gender identity: "sexual orientation", "pregnant woman or girl, or nursing mother", "sole or primary carer/s (of dependant child, elderly person or person with a disability)", "woman at risk of sexual or gender-based violence, or adult or child experiencing family violence, exploitation or abuse", "person at risk of violence due to their sexual orientation and/or gender identity; for health and welfare concerns: "physical and mental health", "risk of suicide", "disability", "elderly person", "substance addiction", "destitution"; for protection needs: "refugee and asylum-seeker", "survivor of torture and trauma", "survivor of sexual or gender-based violence or other violent crime", "victim of trafficking in persons", "stateless person"; for other.

Vulnerability Assessment Framework of UNHCR Jordan gathers data on and identifies urban Syrian refugees' vulnerability (Brown et al., 2019; Washington et al., 2015) People with specific needs are also considered following UNHCR guideline (Akodjenou et al., 2009). Even though these are great at guiding, the refugees in this work are settled in the cities and the data is collected via home visits, not resides in camps or on the way to the hosting country. Also in an urban setting, UNHCR and International Rescue Committee (2016) measured the vulnerability of working Syrian refugee man in Lebanon.

The problem with the vulnerability guidelines and studies presented is that they focus on refugees that are settled, thus, are useful for improvements but not before they arrive or first get the humanitarian aid. The works, however, helps for an index of arriving refugee vulnerability and initial camp conditions. As the data is not able to be collected from the refugees on the road, a simple index to cover a variety of factors or forecasting (Eroglu et al., 2020) using the vulnerability assessment of other refugee groups from all over the world can be used.

5.2.2.4. Requirements of a good representation of suffering for a refugee camp model

There are several dimensions that determine the vitality of the refugees in the refugee camp: the origin location, on the road, of the refugee camp. The facility and the conditions of the hosting region also affect how to approach on the refugee camp model for the wellbeing. The paradigm of the conditions is previously discussed in Chapter 3.1 and the Chapter 4. These factors have a different effect in time: as the time spent in the camp increase, the importance of the origin and road conditions decrease while the impact of the camp and host conditions increase.

In order to understand the requirement from the refugee population and then facilitate a good aid model, these conditions should be investigated. This investigation can be implicit in the model, such as a decision on prioritization of one aspect of the camp, or explicit, like accounting for the changing impact on the population of the aid.

Origin conditions

The problematic situation in the origin location of the refuge reflects in the conditions in the hosted country even though they are not there anymore. The relationships are previously discussed in Chapter 3.1.3 and Chapter 4. For example; if the reason of the refuge is resource based, such as water or food, then, the malnourishment and immune system deficiencies reflect on the conditions further since they have long-lasting effects on the body; if the reason is violence or armed conflict based, people may have physical and mental trauma.

Road conditions

The refugees arrive where they are settled with the effects on the road. The effects depend on the distance travelled, means of travel and the refugee themselves, since the health conditions, age and body structure determines how the individual is affected.

The refugees first travel to the border of their own country through the hardships they are trying to escape. Then, they cross the borders and travel on foreign lands. Countries may not grant a refugee status due to socio-political reasons, and the borders are usually illegally crossed. Since they are desperate, they are overcharged for everything, sinking their funds.

The road is usually on foot or by boats that are inappropriate for long-distance travel. For land travel, they carry all they can carry have on their backpacks, that does not allow space for many things. They get exhausted on walking and malnourishment. For boat, the refugees are stacked on top of each other, without sufficient water, food or sanitation provision. In the past refugee crises the boats sank too many times.

Camp conditions

After the refugees are settled in the camps, the facilities and the resources provided determines the additional impact made or the amount of relief of the previous impact on the suffering of the refugees. If the camp does not provide for these, then, the population would be more susceptible for the next crisis.

Essential needs provision of factors such as shelter, water and food helps regain and sustain their health. Adequate and equal access of the supplies results prevents asymmetrical power relations over those resources within the camp. A stabile and secure life without fear with additional counseling regains their dignity and mental health. Joining the workforce and having an education make a population stronger.

Host conditions

There is also a discussion of equality between the two stakeholders: camp residents and host community. For some cases, especially when the reason of the refuge is directly or indirectly environmental (lack of food and water, unrest and war due to hunger and thirst), and if the host country is also suffering from the same climate or environmental conditions, the deprivation of supplies may still continue as the funding of the host government may already be insufficient for its citizens. Under these circumstances, especially in protracted refugee situations where the funding decreases in time as the media coverage diminishes, an approach and a consecutive model targeting only refugee camp is not appropriate. Instead, a region-wide approach to cope with and mitigate the effects of the deprivation of the whole region should be targeted.

5.2.2.5. An Appropriate Metric For Refugees in Camps

There are several dimensions of vulnerability, such as physical, social, economic and environmental (UNDRR, n.d.). Economic vulnerability is not going to be discussed under refugee logistics perspective, as there is not usually a market in the refugee camps – although there emerges one in time. Thus, the economic strength and weakness of the individuals in the camp is omitted.

For the social, physical and environmental conditions, a vulnerability metric that captures the origin locations' and road conditions' vulnerability for the arriving refugees and the camp vulnerability of the settled refugees can be obtained. In the beginning stages of a refugee camp, these are very significant. As the vulnerability is a term measured for a community, vulnerability can be assumed to be homogeneous in the same camp for modeling purposes. This approach enables the model with the information of how to best utilize the limited resources. As time passes and the camp conditions progresses, this vulnerability levels can be updated for good or bad to reassess the supply levels.

For the population in dire need of aid – a very vulnerable population in other words – a vulnerability metric that captures the damages of the essential resources that are not supplied to the camp can be argued to be sufficient. These resources directly fight with the commonly used vulnerability factors of various vulnerability metrics discussed in Chapter 5.2.2.3 such as incident of tuberculosis, physical and mental health, percentage of people undernourished and infant mortality rate. As the deficiency of the resources makes the population more susceptible to future hazards, the decision maker that aims to have minimum negative effect on the vulnerability considers the possibility of further shocks and how these will affect the population. Vulnerability, in this fashion, becomes a measure for the future state of the population. This approach achieves a repetitive game from game theory, forcing the decision maker to play against their future selves.

Besides the vulnerability metric, we also endorse the supply limits when the appropriate relaxation is possible in order to represent the reality. For those, the limits on the hard constraints should be chosen appropriately, such as standards determined by the international organizations and their adaptation to the specific conditions of the region or the demographics for refugee camps.

CHAPTER 6

MATHEMATICAL MODELS FOR REFUGEE CAMP LOCATION AND SUPPLY

In this chapter we form mixed integer mathematical programming models for several refugee camp problems considering the system complexity in various demand items in the refugee camp supply network. The stochastic complexity comes from temporal and climatic changes. The first main model deals with the infrastructure and supply decisions of a camp that is already opened and populated. The second model chooses the camp location on top of the previous decisions. The third model has multiple periods, the decisions of the previous problems are made considering longer term prospects. Each of these problems are also investigated for additional considerations: extensions for these main problems are also modeled. These extensions can be applied to the following main problems if the problem situation calls for; their use is not limited to the particular problem that they are extending.

The problem owners and the decision makers of the camp – implicitly – are interchangeably or collectively the aid organizations and the host government. Traditionally, the workers and volunteers are the problem users and the refugees are the problem customers. This top-down approach does not fit to our perspective, believing the increased involvement of refugees in their own lives improve their satisfaction, but, considering a new refugee camp to be built, we do not have the input from the problem customers besides the demographic and social norms.

The objectives are to supply the needs of the refugees and minimize their vulnerability and the monetary cost of supply, given the number of refugees to settle, demand, capacity, prices and the budget. Opening the camps, procurement and local production of the resources are the main decisions. The vulnerability is exerted through the deficiency of the supply items. This deficiency not only causes a deprivation on its own unsatisfied demand, but also negatively affects the satisfaction from other resources. This is to capture the interdependencies of the various resources, detailed in the Chapter 4. These negative effects – systemic deprivation - can be mitigated with additional supply of that particular resource in the models.

In the base model, The Two-Stage Supply Model For A Refugee Camp, the production and outsourcing decisions for their investment and amount obtained are made for a single period. It is assumed that the camp is previously opened at the required capacity. This model introduces the effects of the weather conditions of the period in the yield and demand capturing the stochastic nature of the resources. Vulnerability incurs as a function of resource deprivation.

The second model is The Two-Stage Location and Supply Model For Refugee Camps, in which the camp location decision is made. The locations differ for the different costs – both fixed and variable – for the camp and shelter building as well as resource supply. The aim is to showcase the difference in terrain configuration, weather conditions to seek shelter from and the distance from the outsourcing facility. Climate conditions that affect the resource supply and demand also depends on the location. For this model, a significant extension is whether to have a camp network or not; where a network may allow resource flows between the camps besides the supply points, given the infrastructure made for this transportation. Also simplifications in the model for location alternatives that are close to each other are presented.

The third model is The Two-Stage Multi-Period Location and Supply Model For Refugee Camps, in which different decisions are made through the different periods. The camps can be opened and the investment for the supply can be made at any period, given they are planned in the first stage. The number of refugees to settle in camps is a stochastic parameter to reflect the temporal changes in the population size. In reality; first, the refugees may arrive at different times and with different densities; and second, they have changes in population since they give birth to new ones or some may pass away. For the climatic factors, the model is built to include the deviation from the average weather conditions throughout the periods. Another extension introduces smaller periods, enabling representation of seasons and months. In the climate change extension, the link between the change in the weather conditions and time is formed, constructing a trend in the weather conditions.

The other applications or realistic conditions for various different camps – such as the camp network extension – and how the variables and parameters should be chosen to reflect those conditions in the specific mathematical model are explained after the formulation of the particular model, wherever possible. These applications can be inserted into the following variations of the models, as well, but they are not detailed in the following ones in order not to cause any repetition.

For each model, the broad description of the problem situation and an overview of the model are provided before the mathematical formulation. The constraints are detailed after the mathematical formulation with discussions on how and why these constructs are modeled in that manner. The detailed assumptions for the problem context and the choices for the parameters under these assumption sets are explained with the constraints they concern. Then, the extensions for additional considerations for the model are listed. As stated, the main models are built on top of each other. Thus, the discussions for the aspects that are previously detailed are omitted in order not to cause repetition; they can be found in the previous models explained.

One may notice the detailed assumptions are made after the mathematical model formulation, not before. The refugee camp models of this work are designed to be robust to a wide range of refugee camp problem situation attributes, consisting of but not limited to different nature of the resources, supply methods, location and climate of the region. On the contrary, parameter choices should be made according to the particular refugee camp problem context and this requires a better set of knowledge in the particular problem situation. With the systems model of a refugee camp of Chapter 4, the attributes of this particular problem situation is better understood and the parameters can be chosen accordingly. The parameters for the models are explained for a sample problem situation, but they can fit to others considering different refugee camp problem situation attributes (nature of the resources, supply methods, location and climate, etc.). The order of explanation first enables the robustness, but then, adaptability to various attributes of the situation.

6.1. Two-Stage Supply Model For A Refugee Camp

Here we present and explain the mathematical model for two-stage supply problem for a refugee camp. In this problem situation there is a previously opened and populated refugee camp that needs to be supplied with resource items. These items can be obtained via various methods of supply.

The objective is to meet the needs of a refugee camp while minimizing the monetary costs and vulnerability of the population. In the first stage, the infrastructure for the various sourcing methods of various supply items is to be built. The costs are linear, meaning that the economies of scale and scope are disregarded. In the second stage, the weather conditions are realized and the amounts of supply items to purchase or produce are decided upon. If there is a deficit in supply of a resource, then, the utility from the other resources also decreases, due to the relationships between each other as in Chapter 4. The model conveys these relationships between the resources in terms of a deficiency in one having a deprivation effect on another, systemic deprivation. To overcome the systemic deprivation, the decision on the extra resources to supply is made.

Objective function represents the sum of the monetary cost and future vulnerability of the population as a result of deprivation and systemic deprivation. Monetary cost is of the infrastructure and unit cost of a supply via different methods. The vulnerability cost can also be inferred as the future responsibility to satisfy the requirements and that the decision makers are playing against their future selves via the vulnerability. Vulnerability is then, used as a current and future cost of not supplying the demand.

The model is then simplified for an active camp. An extension for sustainability in supply is also provided.

6.1.1. Mathematical Model

Indices

i, i': 1,…I resources

j: 1,…J methods of supply

w: 1,…W scenarios for weather conditions

Parameters

IC_{ij}: Infrastructure cost for resource i via method j

SC_{ij}: Variable cost for resource i via method j

C_{ij}: Normal capacity of resource i via j

CC_{ijw}: Change in the production capacity in scenario w

Budget: Budget for the camp supply

R: Refugee population hosted

ND_i: Normal demand for resource i for an average refugee

CD_{iw}: Change in the demand for the resource i in scenario w

$Limit_i$: Minimum supply target for resource i

P_w: Probability of scenario w

$DF_{ii'}$: Deprivation factor of resource i due to the deficit of resource i'

VC_i: Vulnerability cost due to the deprivation of resource i

First Stage Decision

Y_{ij}: if infrastructure investment is made for the supply of resource i via method j for the camp

Second Stage Decisions

X_{ijw}: amount of resource i supplied by the method j in scenario w

E_{ijw}: extra amount of resource i supplied by the method j in scenario w

V_w: vulnerability of the camp in scenario w

Additional Decision

ID_{iw}: initial deprivation incurred on resource i in scenario w

Minimize

$$Z = \sum_{w}\left[P_w \times (V_w + \sum_{i,j}(IC_{ij} \times Y_{ij} + SC_{ij} \times (X_{ijw} + E_{ijw}))\right] \quad (1.1)$$

Subject to

$$\sum_{i,j}(IC_{ij} \times Y_{ij} + SC_{ij} \times (X_{ijw} + E_{ijw})) \leq \text{Budget} \qquad \forall\ w \quad (1.2)$$

$$X_{ijw} + E_{ijw} \leq C_{ij} \times CC_{ijw} \times Y_{ij} \qquad \forall\ i, j, w \quad (1.3)$$

$$\sum_{j} X_{ijw} \geq ND_i \times CD_{iw} \times Limit_i \times R \qquad \forall\ i, w \quad (1.4)$$

$$ID_{iw} \geq \sum_{i'}\left[DF_{ii'} \times (ND_i \times CD_{i'w} \times R - \sum_{j} X_{i'jw})\right] \qquad \forall\ i, i', w \quad (1.5)$$

$$ID_{iw} - \sum_{j} E_{ijw} \geq 0 \qquad \forall\ i, w \quad (1.6)$$

$$V_w \geq \sum_{i}\left[VC_i \times (ID_{im} - \sum_{j} E_{ijw})\right] \qquad \forall\ w \quad (1.7)$$

$$Y_{ij} \text{ binary} \qquad \forall\ i, j \quad (1.8)$$

$$X_{ijw}, E_{ijw}, ID_{iw}, V_w \geq 0 \qquad \forall\ i, j, w \quad (1.9)$$

The model is solved for the objective Z, sum of the monetary cost incurred and vulnerability cost. The nature of the decision variables are stated in constraints (1.8) and (1.9).

6.1.2. The Resource Supply Decisions

The resources i are assumed to be water, energy, food and healthcare; pooled in their own sub-system. For example, water covers its amount and quality in taps, baths and latrines, whereas energy is for both the usage in various needs as in heating, lighting or cooking, and its distribution. The supply methods j are either local or via outsourcing. The hard constraint for resource satisfaction aligns with UNHCR and Sphere Project minimum targets, as in Chapter 4.

The alternative assumptions for a serving point for outsourcing are

- A water reservoir or a water dam for water supply.
- A regional warehouse of the aid organizations, a food supplier or a transportation node to serve the region, such as a harbor for food supply.
- An energy plant for energy supply.

- A hospital accessible for healthcare services supply.

Then, the outsourced goods and services must be transported to the camp as

- Water through pipelines
- Food via vehicles
- Energy through power lines
- Healthcare with the transportation of the refugees to the hospital for operations, radiography and emergency cases whereas with the transportation the doctors to the camp for regular visits for basic polyclinic appointments. Laboratory testing is conducted in the hospitals, while the samples may be taken in the camp. Medical supplies can be provided in the hospital to the arrived refugees, or to be sent to the camp given the prescriptions.

The fixed cost of outsourcing represents the initial infrastructure for the transportation methods. If the camps are supplied via a single serving point for each of the resources, thus, the transportation cost is in the form of distance between the camp location and that point for that resource, as the unit cost. Otherwise, this unit cost must also include the purchasing cost.

For the local supply, the region is assumed to be suitable for rainwater harvesting, horticulture and solar energy generation. The local healthcare supply is via a medical area in the camp.

The fixed cost of local supply represents the initial infrastructure for the facilities.

- For rainwater harvesting, the collection and storage tanks as well as treatment facilities.
- For solar energy, the energy panels
- For horticulture, machinery and soil treatment
- For camp medical area, the building and the equipment

The unit cost of local supply represents the labor and material needs for these, such as doctors and pills for the healthcare.

The decision variable Y_{ij} is whether the investment on the method for the resource is made or not, and X_{ijw} is the amount of items provided via the method in the scenario w for the weather conditions. They are bounded by the budget in the constraint (1.2) due to their costs and the monetary cost portion of the objective function Z (1.1) is minimized.

The constraint (1.3) limits the amounts of items obtained with the capacity, as a function of the item type, weather conditions, method and whether the investment for the method is made or not. The constraint (1.4) requires the supply of at least the minimum targeted portion of the demand, which is affected by the climate conditions (Chapter 6.1.3).

6.1.3. Change in the Climatic Factors

As in Chapter 4, climate in terms of its temperature, precipitation and wind aspects affects the supply and demand of various resources in various ways. In our model, we show these effects based on the following assumptions:

- the region is suitable for rainwater harvesting, horticulture and solar energy generation.
- the production capacities of the outside suppliers are not affected by these changes, meaning that the outsourcing capacity and the price – a reflection of the market price – are static.

Then, the relationships are as in the Table 6.1, Climatic Effect Matrix. In the mathematical model this matrix is represented as the parameter CC_{ijw} for the capacity and CD_{iw} for the demand.

Table 6.1. The Climatic Effect Matrix

	Temperature		Precipitation	
Resource	Local Supply	Demand	Local Supply	Demand
Water	no effect	low positive	high positive	no effect
Food	high positive	no effect	high positive	no effect
Energy	high positive	low negative	high negative	no effect
Healthcare	no effect	no effect	no effect	high positive

For the region, a higher temperature

- increases the water demand slightly, since it increases the loss of water from the body through sweating.
- increases the food supply immensely, since it provides more agricultural yield.
- increases the energy supply immensely, since it represents more energy arriving to be converted into electrical energy.
- decreases the energy demand slightly, since it decreases the energy required for heating, an aspect of the water demand.

For the region, a higher amount of precipitation

- increases the water supply immensely, since rainwater harvesting is used
- increases the food supply immensely, since it provides more agricultural yield.
- decreases the energy supply immensely, since it decreases the number of sunny days.
- increases the healthcare demand immensely, since it increases the possibility of catching a cold and getting sick.

For other and multiple methods of resource supply, similar effect matrices can be generated.

The constraints related with these decisions are as follows: The constraint (1.3) gives the effect of the climatic factors on the production capacity. The constraint (1.4) includes the effect of the climatic factors on the realized demand. This realized demand is also used in constraint (1.5) for the decisions for vulnerability, which is detailed in Chapter 6.1.4.

6.1.4. Vulnerability and deprivation

Vulnerability refers to the susceptibility to hazards. In reality, as the vulnerability increases, there should be additional effort made in the next periods to compensate for the future risks. For that, we introduced vulnerability of residents in a refugee camp due to the deprivation of a resource and the effects of this deprivation on other resources: systemic deprivation. The vulnerability cost is a representation of the future state of the refugee camp. The vulnerability indicators discussed in Chapter 5 is implicitly converted into a vulnerability cost.

The resources that are not supplied have an effect on the population that cannot be disregarded just because they are not monetary. Thus, deprivation is represented as an opportunity cost in the literature, as in Holguin-Veras et al. (2013). But previously, the resource not supplied has a single deprivation effect, assuming turning back at itself. The deprivation effect matrix of our model extends this through a systems perspective. The dynamics of these relationships are detailed in Chapter 4.

Table 6.2. The Deprivation Effect Matrix

Deficient source	Affected need			
	Water	Food	Energy	Healthcare
Water	deprivation	systemic deprivation	no effect	systemic deprivation
Food	no effect	deprivation	no effect	systemic deprivation
Energy	systemic deprivation	systemic deprivation	deprivation	systemic deprivation
Healthcare	systemic deprivation	systemic deprivation	no effect	deprivation

The parameter $DF_{ii'}$, deprivation factor of resource i due to the deficit of resource i', captures these relationships in The Deprivation Effect Matrix forming these relationships:

- The main diagonal of The Deprivation Effect Matrix represents the deprivation effect of resource on itself. If there is not enough water, then, people will be dehydrated. If there is not enough food, then, the people will have hunger.
- If the water provided is not at the required amount and quality, then, food preparation and cleaning is negatively affected. This also affects the health of the refugees, as this paves the way for water-borne diseases and immune system deficiencies as well as dehydration-related health issues previously discussed in Chapter 4.
- If there is not enough food, then, the population would be undernourished – especially children. This malnourishment damages the immune system and the health of the population gets worse. Also, medical supplements may be required for the population to get the minerals and vitamins they needed.
- If there is not enough energy, then, water treatment and collecting activities may be affected and these may decrease the water quality and supply amount. Without energy the foods may not be cooked which forces the refugees to skip meals. The energy also would not be used for heating. The energy is also used to supply the healthcare equipment in the camp as simple as refrigerators for medical supplies. All of these damage the health of the refugees.
- If the healthcare provisions are not enough, then, better quality food and water will be needed to make the population less susceptible to diseases.
- There are also negative effects on the other aspects of the vulnerability. In the case of energy deficiency, the refugees may try to go look for energy sources such as firewood, which puts them in dangerous positions, as previously discussed in Chapter 4. The unequal distribution of water turns it into a power source, forming groups, damaging the camp culture. These are implicitly

included in The Deprivation Effect Matrix as a part of the deprivation effect of resource on itself.

Given $DF_{ii'}$, the model decides upon ID_{iw}, the initial deprivation incurred, based on the demand and direct supply in constraint (1.5). The model enables some of these deprivations to be overcome via additional supply, such as emergency medical aid to the camp. If the water deficit caused by drought affects healthcare, then, the model lets investments in healthcare to overcome the systemic deprivation from the water. But this additional supply, represented as E_{ijw} in the model only mitigates the systemic deprivation effective, it can be assumed to be supplied immediately after the population is hit by the deprivation of the other resources.

The constraints related with these decisions are as follows: The constraint (1.6) limits the amount of additional supply with the initial deprivation incurred, and (1.7) decides on the vulnerability for the given deprivation levels and the additional supply for all resources, representing the mitigation on the deprivation effect via this additional supply. The cost of this supply is considered in the budget constraint (1.2) and in the objective Z (1.1).

6.1.5. Model For An Active Camp

If the camp is already opened and the infrastructure has already been built for resource i* via method j*, then, this can be represented in the model by forcing the decision variable Y_{i*j*} into the value 1 in the model. The value of the infrastructure cost parameter, IC_{i*j*} should be chosen as 0, to since the cost of the infrastructure becomes a sunk cost, not a fixed cost at the moment of decision making.

6.1.6. Sustainability

The option for local and green production, as an implicit inclusion of sustainability in the model is important. In addition to that, the externalities can also be shown directly in the model, as well. For that, the transportation emission can be an objective to minimize.

Besides the monetary variable cost, we may introduce an emission cost parameter to capture the hazards caused for a unit of service, HC_{ij}. This parameter may be a combination of the transportation emissions, as well as production emissions, such as energy generation in a coal plant and solar panel. Other concerns such as toxicity, water pollution and other impacts on the ecosystems can also be represented in this parameter.

HC_{ij}: Environmental hazard per unit of resource i via method j.

A new objective Z_2 can be formulated to capture the hazardous effects of the decisions, as in (1.10). For the model run, a weighted sum model of Z and Z_2 can be suggested.

$$Z_2 = \sum_{i,j,w}\left[P_w \times (\sum_{i,j}(HC_{ij} \times (X_{ijw} + E_{ijw}))\right] \quad (1.10)$$

If desired, the hazards of the infrastructure can be represented via such parameter for the damage of the whole investment, like deforestation due to opening up agricultural land, since it is independent of the yield obtained after the trees are cut. Waste generated in the camp and waste management can also be included in the model as such a monetary and an externality cost for the resource use.

6.2. Two-Stage Location and Supply Model For Refugee Camps

Here we present and explain the mathematical model for a location and supply problem for multiple refugee camps in a region. The model is the extension of the previous Two-Stage Supply Model For A Refugee Camp. It is formed through the addition of alternative locations for the camp, to open the camps and investigate the effect of the camp location on the supply decisions. Based on the findings of Chapter 4., both the climatic and terrain conditions of the location affect the resource supply, demand and vulnerability. Also, the change in the climatic conditions throughout a period depends on the location. Vulnerability, a function of the living conditions of the refugees, depends on the climate of the location, as well.

The extensions for this model are network of multiple camps with supply flow among the camps and limit on the number of refugee camps to open. The simplification for the close proximity of each alternative camp locations is also provided.

Basic Decisions

In the first stage, at which locations camps are opened is decided upon. If a camp in location k opens, then the infrastructure for the various sourcing methods of various supply items is to be built is decided for that camp. In the second stage, the climatic conditions are realized. Based on that, the amounts of supply items to purchase or produce in each camp is decided upon. In parallel, the deprivations on resources if there is deficit of some are applied. To overcome the systemic deprivations, the decision on the extra resources is made.

6.2.1. Mathematical Model

Indices

i, i’: 1,…I resources

j: 1,…J methods of supply

k: 1,…K alternative camp sites

w: 1,…W scenarios for weather

Parameters

IO_k: Infrastructure cost for opening the camp in location k

SO_k: Shelter building cost in location k

CO_k: Available capacity for shelters in location k

IC_{ijk}: Infrastructure cost for resource i via method j in location k

SC_{ijk}: Supply cost for resource i via method j in location k

C_{ijk}: Normal capacity of resource i via j in location k

CC_{ijkw}: Change in the production capacity of resource i via j in location in scenario w in location k

Budget: Budget for the camp supply

R: Refugee population to host

ND_i: Normal demand for resource i for a refugee

CD_{ikw}: Change in the demand for the resource i in scenario w due to the location/climate characteristics of the camp location k

$Limit_i$: minimum supply target for resource i

P_w: probability of scenario w

$DF_{ii'}$: Deprivation factor of resource i due to the deficit of resource i'

VC_{ikw}: Vulnerability cost due to the deprivation of resource i in location k in scenario w

First Stage Decisions

O_k: if a camp in location k is opened

S_k: amount of population settled in camp located in k

Y_{ijk}: if infrastructure made for the supply of resource i via method j for the camp in location k

Second Stage Decisions

X_{ijkw}: amount of resource i supplied by the method j for camp located in k in time t in scenario w

E_{ijkw}: extra amount of resource i supplied by the method j for camp located in k in scenario w

V_{kw}: vulnerability of the camp located in k in scenario w

Additional Decision

ID_{ikw}: initial deprivation incurred on resource i in camp location k in scenario w

Minimize

$$Z = \sum_w P_w \times \sum_k \left[IO_k \times O_k + SO_k \times S_k + \sum_{i,j} \left(IC_{ijk} \times Y_{ijk} + SC_{ijk} \times \left(X_{ijkw} + E_{ijkw} \right) \right) + V_{kw} \right] \quad (2.1)$$

Subject to

$$\sum_{i,j,k} (IO_k \times O_k + SO_k \times S_k + IC_{ijk} \times Y_{ijk} + SC_{ijk} \times (X_{ijkw} + E_{ijkw})) \leq \text{Budget} \quad \forall\, w \quad (2.2)$$

$$X_{ijkw} + E_{ijkw} \leq C_{ijk} \times CC_{ijkw} \times Y_{ijk} \quad \forall\, i, j, k, w \quad (2.3)$$

$$\sum_j X_{ijkw} \geq ND_i \times CD_{ikw} \times Limit_i \times S_k \quad \forall\, i, k, w \quad (2.4)$$

$$ID_{ikw} \geq \sum_{i'} \left[DF_{ii'} \times (ND_i \times CD_{i'kw} \times S_k - \sum_j X_{i'jkw}) \right] \quad \forall\, i, i', k, w \quad (2.5)$$

$$ID_{ikw} - \sum_j E_{ijkw} \geq 0 \quad \forall\, i, k, w \quad (2.6)$$

$$V_{kw} \geq \sum_i \left[VC_{ik} \times (ID_{ikw} - \sum_j E_{ijkw}) \right] \quad \forall\, k, w \quad (2.7)$$

$$\sum_k S_k = R \quad (2.8)$$

$$S_k \leq CO_k \times O_k \quad \forall\, k \quad (2.9)$$

$$Y_{ijk} \leq O_k \quad \forall\, i, j, k \quad (2.10)$$

$$Y_{ijk}\ O_k, \text{binary} \quad \forall\, i, j, k \quad (2.11)$$

$$X_{ijkw}, E_{ijkw}, ID_{ikw}, V_{kw}, S_k \geq 0 \quad \forall\, i, j, k, w \quad (2.12)$$

The model is solved for the objective Z, sum of the monetary cost incurred and vulnerability cost. The nature of the decision variables are stated in constraints (2.11) and (2.12).

6.2.2. Opening the camp

The decision O_k is whether the camp is opened in alternative location k or not, and requires an investment of IO_k for various needs in reality, from the agreements on the land and preparation for the construction. The decision S_k is the number of refugees settled in the camp. In the model, all refugees that needs settlement is settled in the constraint (2.8), where the amount that is settled limited by the capacity for the particular location, CO_k, in the constraint (2.9), for the camps that are open. S_k is related with the size of the camp and the amount of shelter units to build. The unit cost of this size increase and shelter unit building is represented as SO_k. These costs for the infrastructure and shelter building are incurred in the objective Z (2.1) and constrained by the budget in (2.2).

For the remaining decisions for the supply and vulnerability, the infrastructure investment can only be made if the camp is open (2.10) and the constraints (2.2), (2.3), (2.4), (2.5), (2.6) and (2.7) is the adjustment of the base model (1.2), (1.3), (1.4), (1.5), (1.6) and (1.7) respectively; for the various alternative locations, with the addition of index k. As in the base model, the vulnerability cost is represented as a linear function in the objective Z (1.1), of the deprivation effective of the resource deficits, in constraints (2.5), (2.6) and (2.7). Since the vulnerability is a function of the conditions, it differs for each camp location.

6.2.3. Refugee Camp Network

The refugee camp, with its supply chain and transportation arcs, forms a network structure. In this particular location model, we may look at the camp in its network to improve the decisions. The current network of supply points and multiple camps require either local supply for only the particular camp, or obtaining the goods and services from a single point, explained in Chapter 6.1.2 for the base model. But the efficiency of the network can be improved with flows between the camps. Also with additional constraints can be imposed on the network.

6.2.3.1. Network of multiple camps with the supply flow among the camps

If the network enables movement of the resources of one camp to another, it can also be introduced in the model where the demand is supplied through other camps as well. The two dimensions of this decision is the infrastructure for this transportation activity and the amount to transport.

The infrastructure is required to carry the supplies from one camp location to another. Going back to the assumption on the location of the source nodes for outsourcing, it was assumed that the infrastructure is for pipelines for water from a water dam and power lines for energy from an energy generation plant. For these, the transportation between camps also requires the pipelines and the power lines. For the food and healthcare, roads for the vehicles need to be built. Thus, these are first stage decisions.

The amount of supply outsourced to carry to another camp or produced to another camp is the second stage decision. Besides the regular demand, extra demand to overcome the systemic deprivations realized can also be supplied through this way.

k, k': 1,…K

k' is an alias for k, camp site the good is obtained for.

The new first stage binary decision variable for the infrastructure between the camp sites is introduced.

$YT_{ikk'}$: if the investment for the resource i to transport from k to k' is made.

The nonnegative decision variables X_{ijkw} and E_{ijkw} change as:

$X_{ijkk'w}$: amount of resource i supplied by the method j through the camp k for camp located in k' in time t in scenario w

$E_{ijkk'w}$: extra amount of resource i supplied by the method j through the camp k for camp located in k' in time t in scenario w

As a result, these variables replace their counterparts in the constraints (2.14).

Introducing the parameters $TC_{ikk'}$ $TI_{ikk'}$

$TI_{ikk'}$: infrastructure cost for the resource i from camp located in k to k'

$TC_{ikk'}$: transportation cost of a unit of resource i from camp located in k to k'

$CT_{ikk'}$: transportation capacity of a unit of resource i from camp located in k to k'

$TI_{ikk'}$, $TC_{ikk'} = 1$ and $CT_{ikk'}$ should be an appropriately large number for all ∀k=k' for the parameter design, for the transportation within the camp. To satisfy the two-way arcs, the model can be easily adjusted for the infrastructure cost.

Then, the supply constraint (2.3) turns into (2.13) and (2.14). The demand constraint (2.4) becomes (2.15).

$$\sum_{k'}(X_{ijkk'w} + E_{ijkk'w}) \leq C_{ijk} \times CC_{ijkw} \times Y_{ijk} \qquad \forall \text{ i, j, k, w} \quad (2.13)$$

$$X_{ijkk'w} + E_{ijkk'w} \leq YT_{ikk'} \times CT_{ikk'} \qquad \forall \text{ i, j, k, k', w} \quad (2.14)$$

$$\sum_{jk}(X_{ijkk'w}) \geq ND_i \times CD_{ik'w} \times Limit_i \times S_{k'} \qquad \forall \text{ i, k', w} \quad (2.15)$$

In the objective Z (2.1) and budget constraint (2.2), $\sum_{k'}(X_{ijkk'w})$ replaces X_{ijkw} and $\sum_{k'}(E_{ijkk'w})$ replaces E_{ijkw}.

For the vulnerability, $\sum_{jk}(X_{ijkk'w})$ becomes the amount supplied for the resource I in camp k' in scenario w, and $\sum_{jk}(E_{ijkk'w})$ the extra amount. The constraint (2.5) turns into (2.16) and (2.6) into (2.17). The vulnerability decision in the constraint (2.7) is also adjusted for the new decision variables, as in constraint (2.18).

$$ID_{ik'w} = \sum_{i'}\left[DF_{ii'} \times (ND_i \times CD_{i'k'w} \times S_{k'} - \sum_{jk} X_{ijkk'w})\right] \qquad \forall \text{ i, i', k, w} \quad (2.16)$$

$$ID_{ik'w} - \sum_{jk} E_{ijkk'w} \geq 0 \qquad \forall \text{ i, k, w} \quad (2.17)$$

$$V_{k'w} \geq \sum_i\left[VC_{ik'} \times (ID_{ik'w} - \sum_{jk} E_{ijkk'w})\right] \qquad \forall \text{ k', w} \quad (2.18)$$

6.2.3.2. Limit on The Number of Refugee Camp

Limits on the number of camps to open can be limited, for agglomeration purposes of the decision makers. If there is a limit in number of camps to open, then, the limit can be exerted by adding constraint (2.19) below.

$$\sum_k O_k \leq (Limit\ on\ the\ number\ of\ camps\ to\ open) \qquad (2.19)$$

6.2.4. Location proximity

If the alternative camp locations are in the same region, then, the following simplifications in the model can be applied:

- The change in the temperature and precipitation cover the whole region, meaning that the locations are similarly affected by the changes.

  Change in the production capacity of resource i through j in location k depending on scenario w, CC_{ijkw} becomes CC_{ijw} and the constraint (2.3) becomes

$$X_{ijkw} + E_{ijkw} \leq C_{ijk} \times CC_{ijw} \times Y_{ijk} \qquad \forall\ i, j, k, w \quad (2.20)$$

  Change in the demand of resource i in location k depending on conditions m, CD_{ikw} becomes CD_{iw} and the constraint (2.4) becomes (2.21). $CD_{i'w}$ also replaces $CD_{i'kw}$ in the constraint (2.5).

$$\sum_j X_{ijkw} \geq ND_i \times CD_{iw} \times Limit_i \times S_k \qquad \forall\ i, k, w \quad (2.21)$$

- The vulnerability cost may also become not a function of the location, only of the resource, under the similar conditions the locations face.

  VC_{ik} becomes VC_i and the constraint (2.7) becomes (2.22).

$$V_{kw} \geq \sum_i \left[VC_i \times \left(ID_{ikw} - \sum_j E_{ijkw} \right) \right] \qquad \forall\, k, w \qquad (2.22)$$

However, this assumption does not mean that the supply capacities, C_{ijk} are not homogeneous throughout the whole region, since the capacity differences may come from terrain configuration, land structures or altitude.

6.3. Two-Stage Multi-Period Location and Supply Model For Refugee Camps

Here we present and explain of the two-stage multi-period location and supply model for a refugee camp network. This model is for refugee camp problems where the decision makers have a long-term approach on the location decision, infrastructure investment and planning for the refugee camps for the current and incoming refugee population.

In the first stage, the decision on the location and infrastructure investment for the future under stochastic weather conditions and refugee influx distributions made for the homogeneous planning horizon. For each period, whether to open a camp in an alternative location and whether to make an infrastructural decision for a supply method for a camp that is opened are decided upon in the first stage. Then, the weather conditions and refugee population size for the periods are realized. Based on those, the allocation of the refugee population among the opened camps, amounts of supply items to purchase or produce in each camp and additional shelters to built are decided upon. In parallel, the deprivations incurs if there are resource deficits. To cope with these deprivations, the decision on the extra resources is made.

The extensions for this model are changes in the budget in time, the distribution of refugee influxes, heterogeneous periods to capture seasonality and climate change. After the refugee influx is realized, the decision makers then are able to use the previous two-stage models for every period in time.

6.3.1. Mathematical formulation of the two-stage multi-period model

Indices

i, i':	1,…I resources
j:	1,…J methods of supply
k:	1,…K alternative camp sites
t, t':	1,…T periods
s:	1,…S scenarios for refugee influx
w:	1,…W scenarios for weather conditions

Parameters

IO_k:	Infrastructure cost for opening the camp in location k
SO_k:	Shelter building cost in location k
CO_k:	Available capacity for shelters in location k
IC_{ijk}:	Infrastructure cost for resource i via method j in location k
SC_{ijk}:	Supply cost for resource i via method j in location k
C_{ijk}:	Normal capacity of resource i via j in location k
CC_{ijkw}:	Change in the production capacity of resource i via j in location in scenario w in location k
Budget:	Budget for the camp supply
R_{ts}:	Refugee population to host at time t in scenario s
ND_i:	Normal demand for resource i for a refugee
CD_{ikw}:	Change in the demand for the resource i in scenario w due to the location/climate characteristics of the camp location k
$Limit_i$:	minimum supply target for resource i
PW_w:	probability of scenario w
PS_s:	probability of scenario s
$DF_{ii'}$:	Deprivation factor of resource i due to the deficit of resource i'
VC_{ikt}:	Vulnerability cost due to the deficit of resource i in location k in time t

First Stage Decisions

O_{kt}:	if a camp in location k is opened at time t
S_{kt}:	amount of population settled in camp located in k at time t

Y_{ijkt}: if infrastructure made for the supply of resource i via method j for the camp in location k at time t

Second Stage Decisions

X_{ijktsw}: amount of resource i supplied by the method j for camp located in k in time t in scenario s and scenario w

E_{ijktsw}: extra amount of resource i supplied by the method j for camp located in k in time t in scenario s and scenario w

V_{ktsw}: vulnerability of the camp for camp located in k at time t in scenario s and in scenario w

ST_{ks}: total number of shelter units built in camp located in k if the refugee influx is according to scenario s.

Additional Decision

ID_{iktsw}: initial deprivation incurred on resource i for camp located in k at time t in scenario s and scenario w

Minimize

$$Z = \sum_{t,s,w} PW_w \times PS_s \times \sum_k \Big[IO_k \times O_{kt} + SO_k \times ST_{ks} + \sum_{i,j} \Big(IC_{ijk} \times Y_{ijkt} + SC_{ijk} \times \left(X_{ijktsw} + E_{ijktsw} \right) \Big) + V_{ktsw} \Big] \quad (3.1)$$

Subject to

$$\sum_{i,j,k,t} \Big(IO_k \times O_{kt} + SO_{kt} \times S_k + IC_{ijk} \times Y_{ijkt} + SC_{ijk} \times \left(X_{ijktsw} + E_{ijktsw} \right) \Big) \leq \text{Budget} \qquad \forall \text{ s, w} \quad (3.2)$$

$$X_{ijktsw} + E_{ijktsw} \leq C_{ijk} \times CC_{ijkw} \times \sum_{t'} Y_{ijkt'} \qquad \forall \text{ i, j, k, t, t'} \leq t, \text{ s, w} \quad (3.3)$$

$$\sum_j X_{ijktsw} \geq ND_i \times CD_{ikw} \times Limit_i \times S_{kts} \qquad \forall \text{ i, k, t, s, w} \quad (3.4)$$

$$ID_{iktsw} \geq \sum_{i'} \big[DF_{ii'} \times (ND_i \times CD_{i'kw} \times S_{kts} - \sum_j X_{i'jktsw}) \big] \qquad \forall \text{ i, i', k, t, s, w} \quad (3.5)$$

$$ID_{iktsw} - \sum_j E_{ijktsw} \geq 0 \qquad \forall \text{ i, k, t, s, w} \quad (3.6)$$

$$V_{ktms} \geq \sum_i \big[VC_{ikt} \times (ID_{iktws} - \sum_j E_{ijktws}) \big] \qquad \forall \text{ k, t, s, w} \quad (3.7)$$

$\sum_k S_{kts} = R_{ts}$	$\forall$ t, s	(3.8)
$S_{kts} \leq CO_k \times \sum_{t'} O_{kt'}$	$\forall$ k, t, t'$\leq t$	(3.9)
$Y_{ijkt} \leq \sum_{t'} O_{kt'}$	$\forall$ i, j, k, t, t'$\leq t$	(3.10)
$ST_{ks} \geq S_{kts}$	$\forall$ k, t, s	(3.11)
Y_{ijk}, O_{kt} binary	$\forall$ i, j, k	(3.12)
$X_{ijktsw}, E_{ijktsw}, ID_{iktsw}, V_{ktsw}, S_{kts} \geq 0$	$\forall$ i, j, k, t, s, w	(3.13)

The model is solved for the objective Z (3.1), sum of the monetary cost incurred and vulnerability cost. The nature of the decision variables are stated in constraints (3.12) and (3.13).

6.3.2. Time

In this model, the planning horizon is beyond one period, to reflect the fact that refugee camps are active for multiple years, as discussed in Chapter 3 for the consistency in the refugee crisis and in Chapter 4. In these periods, we observe impermanent deviation from the average climate conditions, represented in scenarios w and probabilistic changes in the refugee population to host, in scenarios s.

For each period the first stage decisions are given the capacity, whether to open a camp in an alternative location is decided. Whether to make an infrastructural decision for a supply method for a camp that is opened is dealt with in constraint (3.10). Then, during the period, the weather conditions and refugee population size is realized. Based on those, the allocation of the refugee population among the refugee camps and additional shelters to built in constraints (3.8), (3.9) and (3.10) – detailed in Chapter 6.3.3, amounts of supply items to purchase or produce with the observed capacities for each camp (3.3) and demands (3.4) and are decided upon.

As in the base model, vulnerability cost is represented in the objective Z (3.1) as a linear function of the systemic deprivation of the resource deficits, in constraints (3.5), (3.6) and (3.7), adjusted from (2.5), (2.6) and (2.7) of the Two-Stage Location and Supply Model For Refugee Camps for the periods with the addition of index t and refugee scenarios, with the addition of index s. In parallel to the regular resource allocation decision and the realized demand, the deprivations of a resource is applied in (3.5). To overcome the deprivation, the decision on the extra resources is made in (3.6). Since the vulnerability is a function of the conditions, it differs at each period.

All of the monetary costs for the infrastructure and unit supply are incurred in the objective (3.1) and constrained by the budget in (3.2).

6.3.2.1. Spending and Budget in Time

The model has the implicit assumption that the budget for the refugee settlement is set for the whole horizon, and it can be spent at any time. If the budget for the years differ, than, a periodic budget parameter should replace the Budget parameter, independent of time.

$Budget_t$: The budget for the period t

The following changes should be made in the budget constraint (3.2) to turn it into (3.14).

$$\sum_{i,j,k} \left(IO_k \times O_{kt} + SO_{kt} \times S_k + IC_{ijk} \times Y_{ijkt} + SC_{ijk} \times (X_{ijktsw} + E_{ijktsw}) \right) \leq Budget_t \qquad \forall\ t, s, w \qquad (3.14)$$

For the model, it is assumed that the inflation is 0, meaning that prices does not change in time with the changing economic conditions; and the technology is stagnant, to satisfy the same amount of yield and capacity with investments made in different times. The model can be adjusted for these if desired, by including time t in the related parameters.

6.3.3. Refugee Population to Host

For this model, how the refugee crisis will evolve is unknown, but the directions may be available for the decision maker. In order to help with the decision-making, scenarios for the change in the refugee population can be made. The index s represents the scenarios.

The constraint (3.8) provides the total shelter capacity should cover for the total number of refugees in a particular camp for a particular period t., S_{kts}. S_{kts} is limited by the capacity for the particular location, CO_k, in the constraint (3.9), for the camps that are opened in that period or before. The cost of building a shelter for a unit population SO_k, incurs for the ST_{ks}, maximum amount of population settled in the camp k throughout the time the camp is opened, shown in the constraint (3.11), because the units stay even if the population depletes in time and can be reused if grows again. The budget constraint (3.2) and the objective (3.1) capture this.

The decision on where the refugee population should settle requires a different discussion. The stability in one location is beneficial, but the camp density affects the access to resources; to move the refugees if another camp is available might be a better option. In this model we do not impose a structure for one way or another but if desired, appropriate ones can be introduced.

6.3.3.1. Refugee growth in camp

In this approach, the refugees are assumed to be increasing in size without an influx to the camp, like natural birth-death process. Thus, the reflection of the camp population on the change in the demand will be represented with the probability of change in the population. Scenarios s can provide that. The values of the parameter R_{ts} - the refugee population to host - can be chosen as a function of the initial population that is settled and its growth or depletion. For example, if the rates are $\alpha(t,s)$, then, the parameter values should be chosen as $R_{ts} = R_{(t-1)s} \times \alpha(t,s)\ \forall s, t$ for an initial refugee population is equal to $R_{1s} \times \alpha(t,s)$.

6.3.3.2. Refugee influx in time

In this approach, the refugee arrival continues in time, beyond the natural birth-death process. The parameter R_{ts} - the refugee population to host – should be chosen to reflect this. If the amount of the new refugees are NR_{st} in scenario s in time t and if the growth rates are α(t,s), then, the values of R_{ts} can be chosen as $R_{ts} = R_{(t-1)s} \times \alpha(t,s) + NR_{st}$ ∀s, t.

6.3.3.3. Budget for refugee influx

If the budget also a function of the refugee influx scenarios in time, then, a periodic and probabilistic budget parameter should be defined.

$Budget_{ts}$: The budget for the period t for the refugee influx scenario s

Then, the budget constraint (3.2) turns into (3.15)

$$\sum_{i,j,k} \left(IO_k \times O_{kt} + SO_{kt} \times S_k + IC_{ijk} \times Y_{ijkt} + SC_{ijk} \times (X_{ijktsw} + E_{ijktsw}) \right) \leq Budget_{ts} \quad \forall\, t, s, w \qquad (3.15)$$

6.3.4. Heterogeneous Periods

The periods are homogeneous for their weather characteristics before the stochastic changes, as in they show the same production properties. These may capture a day in a climate such as tropical rainforest climate, where the weather conditions hold still throughout the year. But for climates that show differences in weather throughout the year, such as continental climate, the period is a year, since the model does not consider the changes in seasons.

The conditions matter not only for the capacity decisions, but also the allocation of the demand in time, because the pooling disregards the storage or the times the resource cannot be produced locally, such as solar energy generation in rainy season, or rainwater harvesting in dry and sunny season, which can happen in a year. Thus, a decision to supply with only local energy generation via solar energy, even if the energy capacity is enough for the whole year if it were to be stored, is not an applicable one, since it cannot be stored.

To capture various characteristics of a season, a new parameter CDT_{ikt} is defined as

CDT_{ikt}: Change in the demand for the resource i in camp location k due to the periodic characteristic of time t

CCT_{ijkt}: Change in the production capacity of resource i via j in location k in time t

This parameter capture the differences in seasons, as in the local agricultural yield in winter months equaling 0 but in the end of summer, the most. If a year is of α periods, and β is a positive integer, then, $CCT_{ijkt} = CCT_{ijk(t+\alpha\beta)}$ for all periods the model is defined for. The constraint (3.3) is replaced as (3.16).

$$X_{ijktsw} + E_{ijktsw} \leq C_{ijk} \times CC_{ijkw} \times CCT_{ijkt} \times \sum_{t'} Y_{ijkt'} \qquad \forall \text{ i, j, k, t, t'} \leq t, \text{ s, w} \qquad (3.16)$$

The demand for heating, for example, differs in seasons. If a year is of α periods, and β is a positive integer, then, $CDT_{ikt} = CDT_{ik(t+\alpha\beta)}$ for all periods the model is defined for. The constraints (3.4) and (3.5) are replaced with (3.17) and (3.18), respectively.

$$\sum_j X_{ijktsw} \geq ND_i \times CD_{ikw} \times CDT_{ikt} \times Limit_i \times S_{kts} \qquad \forall \text{ i, k, t, s, w} \qquad (3.17)$$

$$ID_{iktsw} \geq \sum_{i'} \left[DF_{ii'} \times (ND_i \times CD_{i'kw} \times CDT_{i'kt} \times S_{kts} - \sum_j X_{i'jktsw}) \right] \qquad \forall \text{ i, i', k, t, s, w} \qquad (3.18)$$

The weather can be randomly warmer than normal of time t in time t and cooler than normal of time t+1 in t+1. If the additional warmth in a period and cold in another result in different directions and magnitudes of effects in the supply and demand, then, those also must be defined. For demand, CD_{ikw} and CDT_{ikt}; for supply, CC_{ijkw} and CC_{ijkt} should be combined.

If desired, the change in market prices and production costs can also be exerted in the model via the variable costs.

6.3.5. Climate Change

In the previous models, the climatic factors change around the normal climate conditions and this change does not affect the factor levels in the next period. Climate change, on the other hand, exerts a direction in time on the climate conditions. To show this relationship between the climatic factors and time, CC_{ijkw}, the constraint for the change in the production capacity, and CD_{ikw}, the constraint for the change in demand needs to be updated as

CC_{ijktw}: Change in the production capacity of resource i via j is scenario w in location k in time t

CD_{iktw}: Change in the demand for the resource i in scenario w due to the location/climate characteristics of the camp location k in time t

CC_{ijktw} replaces CC_{ijkw} in he constraint for the supply decisions (3.3) and as a result, the capacity depends on both the direction of change and the climate. CD_{iktw} replaces CD_{ikw} in the constraint (3.4) and $CD_{i'ktw}$ replaces $CD_{i'kw}$ in (3.5); first dealing with the change in the demand, the second with the changed deprivation with the changed demand at the particular period under the climate change.

To capture the climate change, temperature and precipitation can be considered as significant factors, with high and low level representing increase and decrease from the climatic factor conditions of the location. For that, the scenarios w are represented as

w: warmer and wetter, warmer and dryer, cooler and wetter, cooler and dryer

The effects of changes in the climate conditions, in scenarios w on supply capacities and demand are either monotonically non-increasing or non-decreasing, meaning that the direction is the same and the magnitude of the effects of m on supply capacities and demand – if there is – increases in time. For supply capacity, for example, $|CC_{ijktw}| \geq |CC_{ijk(t-1)w}|$ for any resource i via method j in camp location k.

6.4. Computational Experiments

The computational experiments for the mathematical programming models are designed and instances are generated for the particular models in order to show the decisions they make, their behavior under various conditions and their validity. The values of the stochastic solution are obtained for the probabilistic complexity sources introduced.

Artificial data is generated for the experiments, due to three main reasons. First, artificial data is satisfactory for experiments for validation purposes. Second, real data is not available for the purposes of these refugee camp models. Third, data collection for refugee camp operations is a subject beyond the scope of this thesis.
The instances are generated via appropriate normal distributions for each parameter type for each model they are for. The instances are solved by IBM ILOG Cplex 12.4.0.1 on a 3.60 GHz server and 8Gb RAM. All instances are solved within a second.

6.4.1. Computational Experiments for Two-Stage Supply Model For A Refugee Camp

Two-Stage Supply Model For A Refugee Camp that is explained in Chapter 6.1 is important for three reasons: the technical complexity through the interactions between the resource item deficits, the probabilistic complexity through weather conditions and the purposive complexity through the vulnerability cost. To show the effect of these properties of the model, a simple experiment setting is chosen to observe the model performance in different objectives.

The resources i are water (W), food (F), energy (E) and healthcare (H) whereas the methods of supply j are local (L) and outsourcing (O). The weather scenarios, w are of 4 scenarios of equal probability. They are colder and dryer than normal (CD), colder and wetter than normal (CW), hotter and dryer than normal (HD) and hotter and wetter than normal (HW).

6.4.1.1. Change in the supply and demand due to the climatic factors

The mathematical model formulation for the changes in the parameters based on climatic factors is explained in Chapter 6.1.3. Those are the effect of climate on the local supply and on the demand, where the effects under the location condition assumption is shown in the Table 6.1. For the demand we chose a 10% change if there is an effect. There is a differentiation in the magnitude of effects on the production capacity, to represent that we chose a 10% change in high effects and 5% for low for local production capacity, resulting in the demand amounts per unit resource as in Table 6.3 and 6.4.

Table 6.3. The effects of climatic scenarios on demand, CD_{iw}

	Climate Scenarios				
Resource	CD	CW	HD	HW	Average Condition
Water	0.95	0.95	1.05	1.05	1.0
Energy	1.05	1.05	0.95	0.95	1.0
Food	1.00	1.00	1.00	1.00	1.0
Healthcare	0.90	1.10	0.90	1.10	1.0

Table 6.4. The effects of climatic scenarios on local supply, CC_{ijw} for j=1, local.

	Climate Scenarios				
Resource	CD	CW	HD	HW	Average Effect
Water	0.90	1.10	0.90	1.10	1.00
Energy	0.99	0.81	1.21	0.99	1.00
Food	0.81	0.99	0.99	1.21	1.00
Healthcare	1.00	1.00	1.00	1.00	1.00

The factor chosen for the experiment is the existence of climatic probability, for which the Level 1 is the expected value of the demand and supply capacity and Level 2 is the stochastic problem. For the value of the stochastic solution, the solution of the deterministic model is found for the investment decisions. In level 2, the two-stage model is solved for the decisions made by the deterministic model and the solutions are compared.

6.4.1.2. Resource Relationships and Deprivation

This factor setting is to show the difference in the decisions made when the relationships between the deficit of one resource with the performance of the other. The following levels in the Table 6.5 are chosen for the The Deprivation Effect Matrices for Experiments is formed according to the Chapter 6.1.4's Table 6.2.

In the Level 1 there is only deprivation effect of resource on itself whereas in Level 2 there are systemic deprivation effects joining. The systemic deprivation enables the model to form relationships between the resources. Without the vulnerability, the model does not have an incentive to supply more than the demand limited by the hard supply constraint (1.4).

Table 6.5. The Deprivation Effect Matrices for Experiments

Deficient source		Affected need			
		Water	Food	Energy	Healthcare
Level 1	Water	1	0	0	0
	Food	0	1	0	0
	Energy	0	0	1	0
	Healthcare	0	0	0	1
Level 2	Water	1	1	0	1
	Food	0	1	0	1
	Energy	1	1	1	1
	Healthcare	1	1	0	1

6.4.1.3. Experiment Results

The experiment is designed for 3 factors, first two being "the climatic effects" and "resource relationships and vulnerability" as in 6.4.1.1 and 6.4.1.2, respectively. The third one is the budget, either having a low or a high level. The factor setting can be observed in Table 6.6.

Table 6.6. The control array for the two-stage supply model experiments

Climatic Factors	Deprivation and Vulnerability	Budget
Level 1: expected climatic factors Level 2: probabilistic climatic factors	Level 1: Only deprivation (no systemic deprivation) Level 2: Deprivation and Systemic Deprivation	Level 1: low Level 2: high
1	1	1
1	1	2
1	2	1
1	2	2
2	1	1
2	1	2
2	2	1
2	2	2

In the comparisons, $Limit_i$ is chosen as 0.9 to reflect standards discussed in Chapter 4 for all i. This generated instance is used for the experiments. The vulnerability cost VC_i is chosen as 1.2 for all resources. The population to host, R is chosen as 1. The instance can be observed in Table 6.7.

Table 6.7. Parameters for Instance 1

	IC_{ij}		SC_{ij}		C_{ij}		
Resource	L	O	L	O	L	O	ND_i
W	1.14	0.99	0.59	1.39	1.89	1.85	1.39
E	1.2	0.82	0.51	0.81	2.15	1.75	1.65
F	1.29	1.06	0.82	0.92	1.95	1.6	1.45
H	0.54	1.24	1.23	1.05	1.2	1.49	0.70

The factor levels for the budget are chosen as 7.5 for low level and 7.6 for high level, as these factors show visible diversity in model performance without sacrificing the model solution, where lower values make the model infeasible and higher does not change the decisions made. The selected decisions are given in the tables 6.8 and 6.9. In Table 6.8, decision on which supply method to use for the resources and how much of the demand is not supplied is shown.

Table 6.8. Selected decisions for Instance 1

Control Array			Y_{ij}				Unsatisfied demand (in percentage)								
							CD			CW			HC	HW	
			W	E	F	H	E	F	H	E	F	H	F	F	H
1	1	1	L	O	O	O	4		0.6	4	0.5	10			9.9
1	1	2	L	O	O	O	4			4					
1	2	1	L	O	O	O	4	0.5		4	10	1		10	0.3
1	2	2	L	O	O	O	4			4					
2	1	1	L	O	O	O	4		0.6	4	0.5	10			9.9
2	1	2	L	L	O	O						3.2			2
2	2	1	L	L	O	O		4.1			10	4.3	2.9	10	3.2
2	2	2	L	L	O	O					3.3			2.1	

Table 6.9 Monetary cost incurred and vulnerability for Instance 1

Control Array			Monetary Cost in Scenario w				Vulnerability in Scenario w			
			CD	CW	HD	HW	CD	CW	HD	HW
1	1	1	7.500	7.500	7.499	7.500	0.068	0.175		0.106
1	1	2	7.505	7.598	7.499	7.592	0.062	0.062		
1	2	1	7.500	7.500	7.499	7.500	0.262	0.513		0.244
1	2	2	7.505	7.598	7.499	7.592	0.250	0.250		
2	1	1	7.500	7.500	7.499	7.500	0.068	0.175	0.000	0.106
2	1	2	7.536	7.600	7.526	7.600		0.034		0.022
2	2	1	7.500	7.500	7.500	7.500	0.095	0.372	0.067	0.335
2	2	2	7.536	7.600	7.526	7.600		0.078		0.058

In Table 6.8, it can be observed that inclusion of system complexity – Level 2 for the "resource relationship and vulnerability" factor – forces the model to supply more of the initial demand to avoid negative effects on the other resources affected in terms of the systemic deprivation and vulnerability. The stochastic model level gives a different first stage decision set than the expected value model level for "the climatic effects" factor for 75% of the instances. The budget available for the decision may also affect the first-stage decisions, as in the experiment runs for Level 1 for climatic effects and Level 2 for resource relationship and vulnerability. For the objectives Z and its components the Total Monetary Cost Incurred and Total Vulnerability Cost the optimal solution values are given in the Table 6.10.

Table 6.10. The values of the objective for Instance 1

Control Array			Total Monetary Cost	Total Vulnerability Cost	Z
1	1	1	7.500	0.087	7.587
1	1	2	7.549	0.031	7.611
1	2	1	7.500	0.255	7.755
1	2	2	7.549	0.125	7.674
2	1	1	7.500	0.087	7.587
2	1	2	7.566	0.014	7.580
2	2	1	7.500	0.217	7.717
2	2	2	7.566	0.034	7.5995

The value of the stochastic solution for this instance set is calculated as the difference between the objective function values of the stochastic and deterministic model solutions for every "deprivation and vulnerability" and "budget" factor level pair in Table 6.11. The average percentage value of the stochastic solution is 0.467.

Table 6.11. The values of the stochastic solution

Deprivation and Vulnerability	Budget	Value of the stochastic solution	Value of the stochastic solution (in percentage)
1	1	0	0
1	2	0.031	0.407
2	1	0.038	0.490
2	2	0.075	0.971

6.4.2. Experiment for the Two-Stage Location and Supply Model For Refugee Camps

The experiment for the Two-Stage Location and Supply Model For Refugee Camps is made for 3 additional camp location alternatives on the setting of the previous model. The aim is to show model validity. Their fixed and variable costs for resources and the normal capacities are as in the Table 6.13 and in Table 6.12 camp opening and shelter building costs and camp capacities for population is introduced.

Table 6.12 Camp Opening Parameters for Instance 2

k	IO_k	SO_k	C_k
1	3.68	1.95	2.27
2	3.99	2.30	2.29
3	3.71	2.14	2.5
4	3.83	1.81	1.81

Table 6.13 Parameters for Instance 2

Alternative Location	Resource	IC_{ijk}		VC_{ijk}		C_{ijk}		
		L	O	L	O	L	O	ND_i
1	W	1.14	0.99	0.59	1.39	1.89	1.85	1.39
	E	1.2	0.82	0.51	0.81	2.15	1.75	1.65
	F	1.29	1.06	0.82	0.92	1.95	1.6	1.45
	H	0.54	1.24	1.23	1.05	1.2	1.49	0.70
2	W	0.79	1.39	1.44	1.31	1.54	1.69	
	E	1.22	1.23	0.61	1.26	1.73	1.56	
	F	0.83	1.12	1.3	1.49	1.45	1.51	
	H	1.05	1.31	1.11	1.32	1.85	1.11	
3	W	0.65	0.63	0.79	1.06	1.83	1.59	
	E	1.49	0.86	1.47	0.68	1.25	1.74	
	F	1.43	0.92	1.07	0.93	1.71	1.89	
	H	0.6	1.39	0.54	0.75	1.72	1.35	
4	W	1.45	0.92	0.8	0.65	1.15	1.36	
	E	1.14	0.93	0.72	1.44	1.33	1.82	
	F	1.04	1.48	0.64	0.59	1.83	1.63	
	H	1.34	0.78	1.41	0.93	1.86	1.04	

Parameters for the climatic probability are handled as in Table 6.3 and 6.4, as the effect of this probability on the model decisions is already shown. The systemic deprivation and vulnerability is handled as in Level 2 of the Table 6.5, as the effect of the systemic deprivation on the model decisions is already shown. The supply limit, $Limit_i$ and vulnerability cost, VC_{ik} are chosen as 0.9 and 1.2 for all i, respectively. The population to host, R is chosen as 1. The budget is chosen as 53 for the first run, and 52.6 for the second, to observe its effect. For both runs, the model decides to open one refugee camp in location 3. The selected decisions for the optimal solutions are in the Table 6.14. Model behaves as prescribed.

Table 6.14. Selected decisions for the optimal solutions of two-stage location models for Instance 2

					Unsatisfied demand (in percentage)									
Run	$Y_{ijk=3}$				CD		CW			HD		HW		
	W	E	F	H	W	F	W	F	H	W	F	W	F	H
1	1	2	2	1										
2	1	2	2	1	5.2	10	10	10	2.5	6.6	10	10	10	4.0

6.4.3. Experiment for the Two-Stage Multi-Period Location and Supply Model For Refugee Camps

This model brings temporal changes into the model setting, for the refugee camps are used and planned for a long time. To observe the model performance without making the analysis complex, we chose to have 4 periods. Two sources of probability are first, the climatic conditions, and then, the refugee arrivals. The difference the stochastic approach makes for the climatic conditions and importance of the system behavior sustained with the systemic deprivation approach are already shown, thus, they will be handled as in the previous models.

Two set of refugee influx scenarios, s are generated for this model for the amount of refugees to host, R_{ts}; both are of 3 scenarios, in Table 6.15. They differ only for $R_{t=4,s=3}$. They are denoted as Level 1 and Level 2 for “refugee influx scenario”. The expected values are found to compare the stochastic model with the deterministic. For the “refugee stochasticity” factor Level 1 is the deterministic model’s first stage and Level 2 is the stochastic solution.

For the value of the stochastic solution, the solution of the deterministic model is found for which camp or camps to open and which infrastructure investments to make. The two-stage model is again infeasible for the investments. Only the decision on which camp to open can be handled with the stochastic model, for that a different set of infrastructure decisions have to be made.

The Budget parameter is chosen large enough for many more periods of camp activities; the constraint (3.2) is not a binding constraint. For Level 1 for refugee influx scenario, the deterministic model opens the camp in Location 3 at time 1 and Location 1 at time 3, where the selected decisions made are in the Table 6.16; and the deterministic, in location 3 at time 1. However, the deterministic model decisions are infeasible for the refugee influx realized and the changes in the demand accordingly in the stochastic model. As the result, we do not have a solution that satisfies the supply limit constraints.

Table 6.15. Parameters for Instance 3

Refugee Influx Scenario	Time	Refugee Population Scenario 1	2	3	Expected population
Level 1	1	0.8	1.01	1.07	0.96
	2	1.15	1.12	1.45	1.24
	3	1.58	1.28	1.82	1.56
	4	2.14	1.65	3.56	2.45
Level 2	1	0.8	1.01	1.07	0.96
	2	1.15	1.12	1.45	1.24
	3	1.58	1.28	1.82	1.56
	4	2.14	1.65	2.54	2.11

For Level 2 the stochastic model opens the camps in locations 3 at time 1 and 4 at time 3 and the deterministic one in location 1 at time 4 and location 3 at time 1. The deterministic model decisions for the camp opening times and infrastructures made are not infeasible for the refugee influx realized of the scenarios and the changes in the demand accordingly in the stochastic model. But if only the decisions for which camp is opened is used in the stochastic model, the deterministic solution is feasible for the realized scenarios, and it differs from the stochastic model solution for infrastructure investment and in the resource allocation decisions. The selected meaningful decisions of the optimal solutions are in the Table 6.16.

Table 6.16. The Selected Decisions For Instance 3 Optimal Solutions

Control Array		O_{kt}		Y_{ijkt}			
Refugee Influx Scenario	Refugee Stochasticity	k	t	W	E	F	H
1	1	1	3	1	2	2	2
		3	1	1	2	2	1
1	2	3	1	Infeasible			
2	1	3	1	1 & 2	2	2	1
		4	3	1 & 2	1 & 2	1 & 2	1 & 2
2	2	1	4	1	2	2	2
		3	1	1	2	2	1
2	2	1	1	1 & 2	1 & 2	1 & 2	1 & 2
		3	1	1 & 2	1 & 2	2	1

CHAPTER 7

CONCLUSION

In this thesis we first present the extent of the current global refugee crisis at hand in the context of the temporal, spatial and demographic distribution of the world refugees in order to understand the size of the current problematic situation. Based on the trends in time – the refugees do not go back to their home countries or they are not provided with long-term stable solutions – we observe that the problem will not be contained as it is but it will get larger. We propose the climate change as an important factor for the direction the refugee crisis takes and we discuss that direction before we face its impact.

We explain the dynamics of a planetary heat balance and how factors react to a change in their systems to project how the systems will react to a systemic change: the climate change. The tolerance of the species to the climate change is expected to be very low due to two main reasons. One, the species exist today did not adapt to the particular changes coming with the global phenomenon in the past. Two, they did not face such a speed of the change in their surroundings before. Thus, the climate change will have a massive effect on the natural habitat and flora of the region. Besides the weather extremities and rise of water levels, there will be resource scarcities. We estimated the effects of these on the environment and populations – whether they already suffer from conflict and resource scarcity, or are assumed to be stable. We expect mass migrations and the research effort on problems that govern refugee situations; especially their settlement should prepare us for the future size and scope of the issue.

With the aim motivated by the previous observations, we build the system model of a refugee camp. The camp consists of multiple stakeholders: the refugees, humanitarian aid organizations, hosting governments and neighboring population as such; they have different functions in the camp system. We show how the environmental factors, mainly the location and climate of the camp affects the main constructs and resources of the camp – the shelters, water, energy food and healthcare. The refugee camp is a complex system of various subsystems where each subsystem attains a high technical complexity itself due to the openness and the size of the inputs coming beyond their boundaries. Within the scope of the supply and demand mechanisms, each are explained inside a larger system of a refugee camp and their interconnectedness with the other components. How human factors are impacted from those harder constructs revealed themselves in the cases of resource shortages. Through those, a refugee camp with a high level of technical, stochastic and purposive complexity becomes visible.

Following those, we turn into the methodology of a refugee camp problem formulation in order to understand how to aid the policy makers in the best possible way and how to utilize the research effort the most efficiently while doing so. With the understanding of the refugee camp complexity, we offer guidance on the size of the problem modeled and how probabilistic occurrences and time can be handled in the model in order to capture enough of this complexity for a good model for a refugee camp.

Based on the methodology we propose, we build mathematical models for a refugee camp. In those models we capture the system behavior of resource supply, effect of the location and climate on the camp resource allocation and location decisions in both static and temporal context. We introduce the probabilistic nature of the refugee arrivals to the camp planning decisions. The system complexity and vulnerability aspects motivate the model to supply more than the minimum requirements governed. In the solutions, we show that the probabilistic structures and planning horizon significantly changes the decisions made for the camp.

The value of a model comes from the understanding of the system it is modeled after. Efforts for this understanding, starting with the data collection are very limited for the refugee camp situations. The resolution of both the system model and the mathematical can be increased further for every unique refugee problem situation. A larger variety of models to capture the system in a higher resolution are needed. For water, for example, the quality, collection effort, treatment, distribution in the camp and the after use treatment may be explored together. The effects of the resource subsystems, in that manner, could be differentiated for the components of these subsystems. The network structure for those subsystems, within the camp and beyond the camp boundaries, needs research effort. Models with less pooling of supply and demand in time enables a decision making process sensible for storage efforts and momentary shortages, as those can be missed with large time units. The performance measures, especially the vulnerability can be improved with a more detailed analysis and data collection. In general, a broader variety of problem situations, applicable to the current global refugee crisis or the projected future situation need to be observed and modeled.

REFERENCES

Aburto-Medina, A., Shahsavari, E., Khudur, L. S., Brown, S., & Ball, A. S. (2020). A Review of Dry Sanitation Systems. *Sustainability*, *12*(14), 5812. https://doi.org/10.3390/su12145812

Accorsi, R., Cholette, S., Manzini, R., Pini, C., & Penazzi, S. (2016). The land-network problem: Ecosystem Carbon Balance in planning sustainable agro-food supply chains. *Journal of Cleaner Production*, *112*, 158–171. https://doi.org/10.1016/j.jclepro.2015.06.082

Afghanistan emergency. UNHCR. (n.d.). Retrieved November 24, 2021, from https://www.unhcr.org/afghanistan-emergency.html

Afghanistan News. Refugee Soccer iCal. (n.d.). Retrieved January 14, 2022, from https://refugeesoccer.org/bridges/afghanistan-news/

Akodjenou, A., & Okoth-Obbo, G. (2009). *Guidance on the Use of Standardized Specific Needs Codes* . UNHCR.

Albadra, D., Vellei, M., Coley, D., & Hart, J. (2017). Thermal comfort in desert refugee camps: An interdisciplinary approach. *Building and Environment*, *124*, 460–477. https://doi.org/10.1016/j.buildenv.2017.08.016

Ali, S. I., Ali, S. S., & Fesselet, J.-F. (2015). Effectiveness of emergency water treatment practices in refugee camps in South Sudan. *Bulletin of the World Health Organization*, *93*(8), 550–558. https://doi.org/10.2471/blt.14.147645

Allaoui, H., Guo, Y., Choudhary, A., & Bloemhof, J. (2018). Sustainable agro-food supply chain design using two-stage hybrid multi-objective decision-making approach. *Computers & Operations Research*, *89*, 369–384. https://doi.org/10.1016/j.cor.2016.10.012

Arslan, O., Kumcu, G. Ç., Kara, B. Y., & Laporte, G. (2021). The location and location-routing problem for the Refugee Camp Network Design. *Transportation Research Part B: Methodological*, *143*, 201–220. https://doi.org/10.1016/j.trb.2020.11.010

Barojas-Payán, E., Sánchez-Partida, D., Martínez-Flores, J. L., & Gibaja-Romero, D. E. (2019). Mathematical Model for Locating a Pre-Positioned Warehouse and for Calculating Inventory Levels. *Journal of Disaster Research*, *14*(4), 649–666. https://doi.org/10.20965/jdr.2019.p0649

Belayneh, Z., & Mekuriaw, B. (2019). Knowledge and menstrual hygiene practice among adolescent school girls in southern Ethiopia: A cross-sectional study. *BMC Public Health*, *19*(1). https://doi.org/10.1186/s12889-019-7973-9

Bhutta, Z. A., Das, J. K., Rizvi, A., Gaffey, M. F., Walker, N., Horton, S., Webb, P., Lartey, A., & Black, R. E. (2013). Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? *The Lancet*, *382*(9890), 452–477. https://doi.org/10.1016/s0140-6736(13)60996-4

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., Ezzati, M., Grantham-McGregor, S., Katz, J., Martorell, R., & Uauy, R. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet*, *382*(9890), 427–451. https://doi.org/10.1016/s0140-6736(13)60937-x

Boshuijzen-van Burken, C., Gore, R., Dignum, F., Royakkers, L., Wozny, P., & Shults, F. L. R. (2020). Agent-based modelling of values: The case of value sensitive design for Refugee Logistics. *Journal of Artificial Societies and Social Simulation*, *23*(4). https://doi.org/10.18564/jasss.4411

Brown, H., Giordano, N., Maughan, C., & Wadeson, A. (2019). (rep.). *Vulnerability Assessment Framework Population Study 2019*. UNHCR and International Labor Organization.

Burns, F., & Brenna, R. (2021, June 23). *Medical volunteering in Moria refugee camp: Humanitarian medicine*. worldextrememedicine.com. Retrieved November 27, 2021, from https://worldextrememedicine.com/blog/2021/02/medical-volunteering-in-moria-refugee-camp/

Camacho-Vallejo, J.-F., González-Rodríguez, E., Almaguer, F.-J., & González-Ramírez, R. G. (2015). A bi-level optimization model for aid distribution after the occurrence of a disaster. *Journal of Cleaner Production*, *105*, 134–145. https://doi.org/10.1016/j.jclepro.2014.09.069

Chkam, H. (2016). Aid and the perpetuation of refugee camps: The case of Dadaab in Kenya 1991–2011. *Refugee Survey Quarterly*, *35*(2), 79–97. https://doi.org/10.1093/rsq/hdw005

Claudia, L., & Susanne, E. (2020). Empowering refugees and asylum seekers in the Italian agriculture sector by linking social cooperative entrepreneurship and social work practices. *International Journal of Social Welfare*. https://doi.org/10.1111/ijsw.12450

Cocking, C., Flessa, S., & Reinelt, G. (2012). Improving access to health facilities in Nouna district, Burkina Faso. *Socio-Economic Planning Sciences*, *46*(2), 164–172. https://doi.org/10.1016/j.seps.2011.12.004

Copping, A., Kuchai, N., Hattam, L., Paszkiewicz, N., Albadra, D., Shepherd, P., Sahin Burat, E., & Coley, D. (2021). Understanding material and supplier networks in the construction of disaster-relief shelters: The feasibility of using social network analysis as a decision-making tool. *Journal of Humanitarian Logistics and Supply Chain Management*, *12*(1), 78–105. https://doi.org/10.1108/jhlscm-01-2020-0007

Cronin, A. A., Shrestha, D., Cornier, N., Abdalla, F., Ezard, N., & Aramburu, C. (2007). A review of water and sanitation provision in refugee camps in association with Selected Health and Nutrition Indicators – the need for integrated service provision. *Journal of Water and Health*, *6*(1), 1–13. https://doi.org/10.2166/wh.2007.019

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards*. *Social Science Quarterly*, *84*(2), 242–261. https://doi.org/10.1111/1540-6237.8402002

Daellenbach, H. G., McNickle, D. C., & Dye, S. (2012). *Management science: Decision making through systems thinking* (2nd ed.). Palgrave Macmillan.

Dehydration. (2019, September 19). Retrieved December 13, 2020, from https://www.mayoclinic.org/diseases-conditions/dehydration/symptoms-causes/syc-20354086

Denekos, S. N., Koutsoukis, N.-S., Fakiolas, E. T., Konstantopoulos, I., & Rachaniotis, N. P. (2021). Siting refugee camps in mainland Greece using geographic information systems-based multi-criteria decision-making. *Journal of Humanitarian Logistics and Supply Chain Management*, *11*(3), 457–480. https://doi.org/10.1108/jhlscm-02-2020-0009

Doorenbos, J., & Pruitt, W. O. (1996). *Crop water requirements*. FAO Food and Agriculture Organization of The United Nations.

Duran, S., Gutierrez, M. A., & Keskinocak, P. (2011). Pre-positioning of emergency items for Care International. *Interfaces*, *41*(3), 223–237. https://doi.org/10.1287/inte.1100.0526

Dyg, P. M., Christensen, S., & Peterson, C. J. (2019). Community gardens and wellbeing amongst vulnerable populations: a thematic review. *Health Promotion International*, *35*(4), 790–803. https://doi.org/10.1093/heapro/daz067

Engidaw, M. T., Wassie, M. M., & Teferra, A. S. (2018). Anemia and associated factors among adolescent girls living In AW-BARRE refugee camp, Somali regional state, Southeast Ethiopia. *PLOS ONE*, *13*(10). https://doi.org/10.1371/journal.pone.0205381

Eroğlu, D. I., Pamukçu, D., Szczyrba, L., & Zhang, Y. (2020). (working paper). *Analyzing and Contextualizing Social Vulnerability to Natural Disasters in Puerto Rico* . Retrieved from https://par.nsf.gov/servlets/purl/10171048.

Feindouno , S., & Goujon , M. (n.d.). (working paper). *Human Assets Index retrospective series: 2016 update*. fondation pour les études et recherches sur le développement international.

Ferreira, G. O., Arruda, E. F., & Marujo, L. G. (2018). Inventory management of perishable items in long-term humanitarian operations using Markov Decision Processes. *International Journal of Disaster Risk Reduction*, *31*, 460–469. https://doi.org/10.1016/j.ijdrr.2018.05.010

Food and Agricultural Organization of United Nations. (2017, April). *Counting the cost: Agriculture in Syria after six years of crisis*. Retrieved June 23, 2021, from http://www.fao.org/emergencies/resources/documents/resources-detail/en/c/878213/

Foster, G. L., & Rohling, E. J. (2013). Relationship between sea level and climate forcing by co2on geological timescales. *Proceedings of the National Academy of Sciences*, *110*(4), 1209–1214. https://doi.org/10.1073/pnas.1216073110

Fuso Nerini, F., Valentini, F., Modi, A., Upadhyay, G., Abeysekera, M., Salehin, S., & Appleyard, E. (2015). The energy and Water Emergency Module; a Containerized solution for meeting the energy and water needs in PROTRACTED Displacement situations. *Energy Conversion and Management*, *93*, 205–214. https://doi.org/10.1016/j.enconman.2015.01.019

Gil, J. C., & McNeil, S. (2015). Supply chain outsourcing in response to manmade and natural disasters in Colombia, a humanitarian logistics perspective. *Procedia Engineering*, *107*, 110–121. https://doi.org/10.1016/j.proeng.2015.06.064

Gossler, T., Wakolbinger, T., & Burkart, C. (2020). Outsourcing in humanitarian logistics – status quo and future directions. *International Journal of Physical Distribution & Logistics Management*, *50*(4), 403–438. https://doi.org/10.1108/ijpdlm-12-2018-0400

Gunning, R. (2014). (publication). *The Current State of Sustainable Energy Provision for Displaced Populations: An Analysis*. London: The Royal Institute of International Affairs Chatham House.

Hansen, J., Sato, M., Russell, G., & Kharecha, P. (2013). Climate sensitivity, sea level and atmospheric carbon dioxide. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *371*(2001). https://doi.org/10.1098/rsta.2012.0294

Heaslip, G., Sharif, A. M., & Althonayan, A. (2012). Employing a systems-based perspective to the identification of inter-relationships within humanitarian logistics. *International Journal of Production Economics*, *139*(2), 377–392. https://doi.org/10.1016/j.ijpe.2012.05.022

Holguín-Veras, J., Amaya-Leal, J., Cantillo, V., Wassenhove, L. N. V., Aros-Vera, F., & Jaller, M. (2016). Econometric estimation of deprivation cost functions: A contingent valuation experiment. *Journal of Operations Management*, *45*(1), 44–56. https://doi.org/10.1016/j.jom.2016.05.008

International Federation of Red Cross and Red Crescent Societies. (2013). (publication). *Nutrition Guidelines*. Geneva.

International Organization for Migration. (2019). (rep.). *Glossary on Migration, International Migration Law n. 34*. Retrieved from https://publications.iom.int/system/files/pdf/iml_34_glossary.pdf.

International Rescue Committee . (2016). (rep.). *Vulnerability Assessment of Syrian Refugee Men in Lebanon: Investigating protection gaps, needs and responses relevant to single and working Syrian refugee men in Lebanon*.

Ivgin, M. (2013). The decision-making models for relief asset management and interaction with disaster mitigation. *International Journal of Disaster Risk Reduction*, *5*, 107–116. https://doi.org/10.1016/j.ijdrr.2013.08.005

Jaafar, H., Ahmad, F., Holtmeier, L., & King-Okumu, C. (2019). Refugees, water balance, and water stress: Lessons learned from Lebanon. *Ambio*, *49*(6), 1179–1193. https://doi.org/10.1007/s13280-019-01272-0

Jahre, M., & Jensen, L. M. (2010). Coordination in humanitarian logistics through clusters. *International Journal of Physical Distribution & Logistics Management*, *40*(8/9), 657–674. https://doi.org/10.1108/09600031011079319

Jahre, M., Kembro, J., Adjahossou, A., & Altay, N. (2018). Approaches to the design of Refugee Camps. *Journal of Humanitarian Logistics and Supply Chain Management*, *8*(3), 323–345. https://doi.org/10.1108/jhlscm-07-2017-0034

Jahre, M., Kembro, J., Rezvanian, T., Ergun, O., Håpnes, S. J., & Berling, P. (2016). Integrating supply chains for emergencies and ongoing operations in UNHCR. *Journal of Operations Management*, *45*(1), 57–72. https://doi.org/10.1016/j.jom.2016.05.009

Jansen, B. J. (2019). *Kakuma refugee camp: humanitarian urbanism in kenya's accidental city*. Zed Books Ltd.

Jemal, Y., Haidar, J., & Kogi Makau, W. (2016). The magnitude and determinants of anemia among refugee preschool children From the Kebribeyah refugee camp, Somali region, Ethiopia. *South African Journal of Clinical Nutrition*, *30*(1), 1–6. https://doi.org/10.1080/16070658.2017.1237446

Jonkman, J., Barbosa-Póvoa, A. P., & Bloemhof, J. M. (2019). Integrating harvesting decisions in the design of agro-food Supply Chains. *European Journal of Operational Research*, *276*(1), 247–258. https://doi.org/10.1016/j.ejor.2018.12.024

Kamau, E., Kibuku, P., & Kinyuru, J. (2021). Introducing cricket farming as a food security and livelihood strategy in Humanitarian settings: Experience from Kakuma refugee Camp, Kenya. *International Journal of Tropical Insect Science*. https://doi.org/10.1007/s42690-021-00550-3

Karsu, O., Kara, B. Y., & Selvi, B. (2019). The refugee camp management: a general framework and a unifying decision-making model. *Journal of Humanitarian Logistics and Supply Chain Management*, *9*(2), 131–150. https://doi.org/10.1108/jhlscm-01-2018-0007

Kau, A. L., Ahern, P. P., Griffin, N. W., Goodman, A. L., & Gordon, J. I. (2011). Human nutrition, the gut microbiome and the immune system. *Nature*, *474*(7351), 327–336. https://doi.org/10.1038/nature10213

Kosonen, H., Kim, A., Gough, H., Mikola, A., & Vahala, R. (2018). A Comparative Study on Rapid Wastewater Treatment Response to Refugee Crises. *Global Challenges*, *3*(1), 1800039. https://doi.org/10.1002/gch2.201800039

Kovács, G., Matopoulos, A., & Hayes, O. (2010). A community-based approach to supply chain design. *International Journal of Logistics Research and Applications*, *13*(5), 411–422. https://doi.org/10.1080/13675567.2010.511609

Lehne, J., Blyth, W., Lahn, G., Bazilian, M., & Grafham, O. (2016). Energy services for refugees and displaced people. *Energy Strategy Reviews*, *13-14*, 134–146. https://doi.org/10.1016/j.esr.2016.08.008

Lisiecki, L. E., & Raymo, M. E. (2005). A Pliocene-Pleistocene stack of 57 Globally Distributed Benthic Δ18O Records. *Paleoceanography*, *20*(1). https://doi.org/10.1029/2004pa001071

Macea, L. F., Amaya, J., Cantillo, V., & Holguín-Veras, J. (2018). Evaluating economic impacts of water deprivation in humanitarian relief distribution using stated choice experiments. *International Journal of Disaster Risk Reduction*, *28*, 427–438. https://doi.org/10.1016/j.ijdrr.2018.03.029

Malik, S., Bano, H., Rather, R. A., & Bhat, S. A. (2018). Cloud seeding; its prospects and concerns in the modern world -A Review. *International Journal of Pure & Applied Bioscience*, *6*(5), 791–796. https://doi.org/10.18782/2320-7051.6824

Manirambona, E., Uwizeyimana, T., Uwiringiyimana, E., & Reddy, H. (2021). Impact of the COVID-19 pandemic on the food rations of refugees in Rwanda. *International Journal for Equity in Health*, *20*(1). https://doi.org/10.1186/s12939-021-01450-1

Mejia, A., Bhattacharya, M., & Miraglia, J. (2020). Community Gardening as a Way to Build Cross-Cultural Community Resilience in Intersectionally Diverse Gardeners: Community-Based Participatory Research and Campus-Community-Partnered Proposal. *JMIR Research Protocols*, *9*(10). https://doi.org/10.2196/21218

Miller, K., Browning, J., Schmelz, W. J., Kopp, R., Mountain, G., & Wright, J. (2020). Cenozoic sea-level and cryospheric evolution from deep-sea geochemical and Continental Margin Records. https://doi.org/10.5194/egusphere-egu2020-10017

Millican, J., Perkins, C., & Adam-Bradford, A. (2018). Gardening in Displacement: The Benefits of Cultivating in Crisis. *Journal of Refugee Studies*, *32*(3), 351–371. https://doi.org/10.1093/jrs/fey033

Mollah, A. K., Sadhukhan, S., Das, P., & Anis, M. Z. (2018). A cost optimization model and solutions for shelter allocation and relief distribution in flood scenario. *International Journal of Disaster Risk Reduction*, *31*, 1187–1198. https://doi.org/10.1016/j.ijdrr.2017.11.018

Moria migrant camp fire: Four Afghans sentenced to 10 years in jail. (2021, June 12). *BBC News Europe*. Retrieved October 29, 2021, from https://www.bbc.com/news/world-europe-57441291.

Moshtari, M., Altay, N., Heikkilä, J., & Gonçalves, P. (2021). Procurement in humanitarian organizations: Body of knowledge and practitioner's challenges. *International Journal of Production Economics*, *233*, 108017. https://doi.org/10.1016/j.ijpe.2020.108017

Munshi, J. (2018). Uncertainty in empirical climate sensitivity estimates 1850-2017. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3117385

OECD & WHO . (2003). Catchment Characterisation and Source Water Quality. In *Assessing microbial safety of drinking water: Improving approaches and methods*. Retrieved November 21, 2021, from https://www.who.int/water_sanitation_health/dwq/9241546301full.pdf.

OECD & WHO. (2003). Treatment Efficiency. In *Assessing microbial safety of drinking water: Improving approaches and methods*. Retrieved November 21, 2021, from https://www.who.int/water_sanitation_health/dwq/9241546301full.pdf.

OECD & WHO. (2003). *Assessing microbial safety of drinking water: Improving approaches and methods* (Ser. Guidelines for Drinking Water Quality). Retrieved January 7, 2022, from https://www.who.int/water_sanitation_health/dwq/9241546301full.pdf.

Olivius, E. (2014). Displacing Equality? Women's Participation and Humanitarian Aid Effectiveness in Refugee Camps. *Refugee Survey Quarterly*, *33*(3), 93–117. https://doi.org/10.1093/rsq/hdu009

Oloruntoba, R., & Banomyong, R. (2018). Humanitarian Logistics Research for the care of refugees and internally displaced persons. *Journal of Humanitarian Logistics and Supply Chain Management*, *8*(3), 282–294. https://doi.org/10.1108/jhlscm-02-2018-0015

Orgut, I. S., Ivy, J., & Uzsoy, R. (2017). Modeling for the equitable and effective distribution of food donations under stochastic receiving capacities. *IISE Transactions*, *49*(6), 567–578. https://doi.org/10.1080/24725854.2017.1300358

Pape, U., Beltramo, T., Appler, F., Fix, J., Nimoh, F., Ríos Rivera, L. A., Fontep, E. R., Schmieding, F., & Delius, A. (2021). (rep.). *Kakuma Camp Results from the 2019 Kakuma Socioeconomic Survey* (Vol. Volume B, Ser. Understanding the Socioeconomic Conditions of Refugees in Kenya. , pp. 14–15). UNHCR & World Bank Group.

Pascucci, E. (2021). More logistics, less aid: Humanitarian-business partnerships and Sustainability in the refugee camp. *World Development*, *142*, 105424. https://doi.org/10.1016/j.worlddev.2021.105424

Pelek, D. (2018). Syrian Refugees as Seasonal Migrant Workers: Re-Construction of Unequal Power Relations in Turkish Agriculture. *Journal of Refugee Studies*, *32*(4), 605–629. https://doi.org/10.1093/jrs/fey050

Population figures, Venezuela (Bolvarian Republic of). (n.d.). Retrieved August 18, 2021, from https://www.unhcr.org/refugee-statistics/download/?url=d6UK32.

Practical Action Publishing. (2018). *The sphere handbook: Humanitarian charter and minimum standards in disaster response* (4th ed.). Retrieved from https://spherestandards.org/wp-content/uploads/Sphere-Handbook-2018-EN.pdf.

Pérez-Galarce, F., Canales, L. J., Vergara, C., & Candia-Véjar, A. (2017). An optimization model for the location of disaster refuges. *Socio-Economic Planning Sciences*, *59*, 56–66. https://doi.org/10.1016/j.seps.2016.12.001

Rabta, B., Wankmüller, C., & Reiner, G. (2018). A drone fleet model for last-mile distribution in disaster relief operations. *International Journal of Disaster Risk Reduction*, *28*, 107–112. https://doi.org/10.1016/j.ijdrr.2018.02.020

Reed, B. (2011). (tech.). *Technical options for excreta disposal in emergencies* (Ser. Technical notes on drinking-water, sanitation and hygiene in emergencies). Geneva: WEDC & WHO. Retrieved November 21, 2021, from https://www.who.int/water_sanitation_health/publications/2011/tn14_tech_options_excreta_en.pdf.

Refugees in Kenya tap global freelance job markets online. (2019, May 9). Retrieved April 25, 2021, from https://www.intracen.org/layouts/2coltemplate.aspx?pageid=47244640256&id=47244676563

Registered Syrian Refugees By Date. (2021, August 5). Retrieved August 18, 2021, from https://data2.unhcr.org/en/situations/syria/location/113.

Schmitz, F. (2020, August 20). Europe's largest refugee camp braces for Covid-19 outbreak. *DW*. Retrieved June 22, 2021, from https://www.dw.com/en/europes-largest-refugee-camp-braces-for-covid-19-outbreak/a-54640747.

Schweitzer, R. W., Harvey, B., & Burt, M. (2020). Using innovative smart water management technologies to monitor water provision to refugees. *Water International*, *45*(6), 651–659. https://doi.org/10.1080/02508060.2020.1786309

Seifert, L., Kunz, N., & Gold, S. (2018). Humanitarian Supply Chain Management responding to refugees: A literature review. *Journal of Humanitarian Logistics and Supply Chain Management*. https://doi.org/10.1108/jhlscm-07-2017-0029

Shah, S., Padhani, Z. A., Als, D., Munyuzangabo, M., Gaffey, M. F., Ahmed, W., Siddiqui, F. J., Meteke, S., Kamali, M., Jain, R. P., Radhakrishnan, A., Ataullahjan, A., Das, J. K., & Bhutta, Z. A. (2021). Delivering nutrition interventions to women and children in conflict settings: A systematic review. *BMJ Global Health*, *6*(4). https://doi.org/10.1136/bmjgh-2020-004897

Sherman, I. W. (2007). In *Twelve diseases that changed our world* (pp. 45–70). ASM Press.

Silove, D., Ventevogel, P., & Rees, S. (2017). The contemporary refugee crisis: An overview of mental health challenges. *World Psychiatry*, *16*(2), 130–139. https://doi.org/10.1002/wps.20438

Singh, N. S., Ataullahjan, A., Ndiaye, K., Das, J. K., Wise, P. H., Altare, C., Ahmed, Z., Sami, S., Akik, C., Tappis, H., Mirzazada, S., Garcés-Palacio, I. C., Ghattas, H., Langer, A., Waldman, R. J., Spiegel, P., Bhutta, Z. A., Blanchet, K., Bhutta, Z., … Wise, P. (2021). Delivering health interventions to women, children, and adolescents in conflict settings: what have we learned from ten country case studies? *The Lancet*, *397*(10273), 533–542. https://doi.org/10.1016/s0140-6736(21)00132-x

Smadi, H., Theeb, N. A., & Bawa'Neh, H. (2018). Logistics system for drinking water distribution in post disaster humanitarian relief, Al-Za'atari camp. *Journal of Humanitarian Logistics and Supply Chain Management*, *8*(4), 477–496. https://doi.org/10.1108/jhlscm-12-2017-0072

Sodhi, M. M. S. (2016). Natural disasters, the economy and population vulnerability as a vicious cycle with exogenous hazards. *Journal of Operations Management*, *45*(1), 101–113. https://doi.org/10.1016/j.jom.2016.05.010

Stauffer, J. M., Pedraza-Martinez, A. J., & Wassenhove, L. N. V. (2015). Temporary Hubs for the Global Vehicle Supply Chain in Humanitarian Operations. *Production and Operations Management*, *25*(2), 192–209. https://doi.org/10.1111/poms.12427

Strunk, C., & Richardson, M. (2017). Cultivating belonging: refugees, urban gardens, and placemaking in the Midwest, U.S.A. *Social & Cultural Geography*, *20*(6), 826–848. https://doi.org/10.1080/14649365.2017.1386323

Taghikhah, F., Voinov, A., Shukla, N., Filatova, T., & Anufriev, M. (2021). Integrated modeling of extended agro-food Supply Chains: A systems approach. *European Journal of Operational Research*, *288*(3), 852–868. https://doi.org/10.1016/j.ejor.2020.06.036

Tatham, P., Loy, J., & Peretti, U. (2015). Three dimensional printing – a key tool for the humanitarian logistician? *Journal of Humanitarian Logistics and Supply Chain Management*, *5*(2), 188–208. https://doi.org/10.1108/jhlscm-01-2014-0006

Thelwell, K. (2019, September 8). *Improving menstrual hygiene for refugees*. Retrieved October 31, 2021, from https://borgenproject.org/menstrual-hygiene-for-refugees/

Trestrail, J., Paul, J., & Maloni, M. (2009). Improving bid pricing for Humanitarian Logistics. *International Journal of Physical Distribution & Logistics Management*, *39*(5), 428–441. https://doi.org/10.1108/09600030910973751

Turner, S. (2015). What Is a Refugee Camp? Explorations of the Limits and Effects of the Camp. *Journal of Refugee Studies*, *29*(2), 139–148. https://doi.org/10.1093/jrs/fev024

U.S. Department of State US Embassy of Damascus. (2010). (rep.). *Syria (09/08/10)*. Retrieved June 23, 2021, from https://2009-2017.state.gov/outofdate/bgn/syria/158703.htm.

UNDP. (2020). (rep.). *Human Development Report 2020. The next frontier: Human development and the Anthropocene*. Retrieved from https://hdr.undp.org/sites/default/files/hdr2020.pdf.

UNHCR and IDC. (2016). (rep.). *Vulnerability Screening Tool. Identifying and addressing vulnerability: a tool for asylum and migration systems*.

UNHCR EXCOM . (2009). *Conclusion on Protracted Refugee Situations No. 109 (Lxi) - 2009*.

UNHCR Refugee Population Statistics Database. (2021, June 18). Retrieved June 27, 2021, from https://www.unhcr.org/refugee-statistics/.

UNHCR refugee wash indicators and targets (UNHCR WASH, 2020). (2015, December 17). Retrieved November 21, 2021, from https://wash.unhcr.org/download/wash-indicators-and-targets/

UNHCR WASH. (n.d.). (rep.). *WASH and COVID 19 field practices*. Retrieved June 22, 2021, from https://reporting.unhcr.org/sites/default/files/WASH%20Emerging%20Practices%20COVID-19_v5.pdf.

UNHCR. (2011). (rep.). *Global Trends 2010: 60 Years and Still Counting*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/country/4dfa11499/unhcr-global-trends-2010.html?query=global%20trends.

UNHCR. (2012). (rep.). *Global Trends 2011: A Year of Crises*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/country/4fd6f87f9/unhcr-global-trends-2011.html?query=global%20trends.

UNHCR. (2013). (rep.). *Global Trends 2012: Displacement, The New 21st Century Challenge*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/country/51bacb0f9/unhcr-global-trends-2012.html?query=global%20trends.

UNHCR. (2014). (rep.). *Global Trends 2013: War's Human Cost*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/country/5399a14f9/unhcr-global-trends-2013.html?query=global%20trends.

UNHCR. (2015). (rep.). *Global Trends: Forced Displacement in 2014, World at War*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/country/556725e69/unhcr-global-trends-2014.html?query=global%20trends.

UNHCR. (2016). (rep.). *Global Trends: Forced Displacement in 2015*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/unhcrstats/576408cd7/unhcr-global-trends-2015.html?query=global%20trends.

UNHCR. (2017). (rep.). *Global Trends: Forced Displacement in 2016*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/unhcrstats/5943e8a34/global-trends-forced-displacement-2016.html?query=global%20trends.

UNHCR. (2017). (rep.). *How Night-time Street Lighting Affects Refugee Communities*. Retrieved October 29, 2021, from https://www.unhcr.org/5b3cb5bb7.pdf.

UNHCR. (2018). (rep.). *Global Trends: Forced Displacement in 2017*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/unhcrstats/5b27be547/unhcr-global-trends-2017.html?query=global%20trends.

UNHCR. (2019). (rep.). *Global Trends: Forced Displacement in 2018*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/unhcrstats/5d08d7ee7/unhcr-global-trends-2018.html?query=global%20trends.

UNHCR. (2020). (rep.). *Global Trends: Forced Displacement in 2019*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/unhcrstats/5ee200e37/unhcr-global-trends-2019.html?query=global%20trends.

UNHCR. (2021). (rep.). *Global Trends: Forced Displacement in 2020*. Retrieved June 27, 2021, from https://www.unhcr.org/statistics/unhcrstats/60b638e37/global-trends-forced-displacement-2020.html?query=global%20trends.

UNHCR. (2022, January 14). *Operational Data Portal*. Situation Syria Regional Refugee Response. Retrieved February 3, 2022, from https://data2.unhcr.org/en/situations/syria/location/113

UNICEF. (n.d.). (rep.). *Measuring the Determinants of Childhood Vulnerability Synthesis Report*. United Nations Children’s Fund (UNICEF) New York.

United Nations Turkey . (2015). (publication). *United Nations Development Cooperation Strategy Turkey 2016-2020*. Retrieved from https://turkey.un.org/sites/default/files/2020-02/UNDCS-FInal-_2016_-1-3_1.pdf.

Vulnerability. (n.d.). Retrieved February 20, 2021, from https://www.undrr.org/terminology/vulnerability

Wang, X., Wang, X., Liang, L., Yue, X., & Wassenhove, L. N. V. (2017). Estimation of Deprivation Level Functions using a Numerical Rating Scale. *Production and Operations Management*, *26*(11), 2137–2150. https://doi.org/10.1111/poms.12760

Wanzira, H., Muyinda, R., Lochoro, P., Putoto, G., Segafredo, G., Wamani, H., & Lazzerini, M. (2018). Quality of care for children with acute malnutrition at health center level in UGANDA: A cross sectional study in West Nile region during the refugee crisis. *BMC Health Services Research*, *18*(1). https://doi.org/10.1186/s12913-018-3366-5

Washington, K., Brown, H., Santacroce, M., & Tyler, A. (2015). (rep.). *Vulnerability Assessment Framework Baseline Survey*. UNHCR.

WFP. (2021, June 18). *Refugees worldwide face rising hunger due to funding gaps amidst Covid-19: World Food Programme*. UN World Food Programme. Retrieved November 27, 2021, from https://www.wfp.org/news/refugees-worldwide-face-rising-hunger-due-funding-gaps-amidst-covid-19

What is a refugee camp? definition and statistics. UN Refugee Agency. (n.d.). Retrieved January 1, 2022, from https://www.unrefugees.org/refugee-facts/camps/

Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (2004). *At risk: natural hazards, people's vulnerability and disasters* (2nd ed.). Routledge.

World Health Organization. (2020). (tech.). *Drinking-water household practices: collection, storage, treatment and handling*. Retrieved November 21, 2021, from https://www.who.int/docs/default-source/wash-documents/sanitary-inspection-packages/2-tfs-household-practices-d.pdf?sfvrsn=565324f8_4.

Zhang, L., Tian, J., Fung, R. Y. K., & Dang, C. (2019). Materials procurement and reserves policies for Humanitarian Logistics with recycling and replenishment mechanisms. *Computers & Industrial Engineering*, *127*, 709–721. https://doi.org/10.1016/j.cie.2018.11.013

Çankaya, E., Ekici, A., & Özener, O. Ö. (2018). Humanitarian relief supplies distribution: an application of inventory routing problem. *Annals of Operations Research*, *283*(1-2), 119–141. https://doi.org/10.1007/s10479-018-2781-7