Alma Mater Studiorum – Università di Bologna

DOTTORATO DI RICERCA IN

MECCANICA E SCIENZE AVANZATE DELL'INGEGNERIA

Ciclo XXX

Settore Concorsuale: 09/B2

Settore Scientifico Disciplinare: ING-IND/17 **-** Impianti Industriali Meccanici

Development of innovative plant design solutions, sustainable and efficient for humanitarian organizations

Presentata da: **Ing. Francesco Piana**

Coordinatore Dottorato

Prof. Ing. Marco Carricato

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Esame finale anno 2018

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Abstract

In the last decades the problem of refugees and humanitarian organizations took a great significance because of the continuous increasing number of humanitarian crises. To this day, this problem is still more current than ever, due to the last crises in Syria and in the middle eastern, with the consequently movement of thousand people, call refugees, escaping wars and battle fields and looking for somewhere better. Crises born or by natural catastrophes, also call disasters, such as earthquakes, floods, hurricanes, volcanic eruptions, tsunami, blazes, tornado, blizzard, and other geologic processes, or are caused by man such as wars, economic crises, and social disparities. After these events are arrange by the humanitarian agencies camps to gather and give relief to refugees, where people can find shelters, food and a safe place to live temporarily.

The humanitarian logistics becomes more and more important, not only as worldwide relief organizations, but also for the scientific community takes interest, especially in the last decade, on this new research field. The humanitarian camps and the whole relief supply chains in fact suffered from inefficiency and other operational and management problems. Thanks to researchers works, humanitarian agencies start a gradual improving using methods, knowledge and equipment proper of industrial context and other innovative sectors (i.e. military, etc.) never used before. The introduction of these improvements achieves the desire goals, makes the humanitarian supply chain more efficient and then more incisive during humanitarian missions.

This research project born long ago from a mutual partnership since 2012, between the Department of industrial Engineering (DIN) of Alma Mater Studiorum - University of Bologna, with the person of the Professor Alberto Regattieri and the WFP-UNHRD (World Food Programme – United Nation Humanitarian Response Depot) of Brindisi, one of the most important humanitarian agency of the United Nations. This triennial research thesis is focus on the improvements and innovations of mechanical plants usually use or to be introduce in humanitarian camps. The projects present following in this dissertation are real solutions for daily issues presents both in humanitarian logistics and developing regions in general.

In the following chapters will present three macro themes of research proper of humanitarian context and developing regions: the waste management, the problem of lack of drinkable water (will investigate both water purification and particularly the desalination) and, finally, the production of electricity by renewable resources. All the projects following present, start by a deepen scientific and technical literature review work. Studied the current state of the arts, then are studied and planned innovative solutions and/or improvements. Next a prototyping stage and the successively testing in

laboratory have been done. Results are finally present to humanitarian management to feedback and for a planning additional testing stages in the humanitarian field.

Sommario

Negli ultimi vent'anni la logistica umanitaria ha ottenuto un ruolo predominante sia dal punto di vista scientifico, sia purtroppo per essere il punto di riferimento durante le sempre più frequenti crisi umanitarie scatenate o da eventi naturali o ricongiungibili all'uomo. Col passare degli anni le più importanti agenzie umanitarie hanno perciò migliorato il loro modo di intervento agli eventi catastrofici, migliorandosi sia dal punto di vista logistico, sia per il crescente utilizzo di sistemi e impianti innovativi.

L'obiettivo di questa tesi è lo studio, lo sviluppo, l'integrazione e la successiva applicazione di soluzioni impiantistiche innovative per le agenzie umanitarie da utilizzare sia nei paesi in via di sviluppo sia nei campi umanitari in genere. I progetti presentati si propongono di risolvere problemi reali propri dei campi umanitari. Questo progetto di ricerca triennale si affianca ad un più ampio progetto di collaborazione pluriennale tra WFP-UNHRD, agenzia umanitaria delle Nazioni Unite, con il Dipartimento di Ingegneria Industriale sezione impianti, nella persona del Prof. Ing. Alberto Regattieri, volto allo studio e alla soluzione di problemi della logistica umanitaria, nato nel 2012.

Le problematiche proposte sono quindi raggruppate in tre macro-aree di ricerca, ognuna, rispettivamente, tema di ricerca annuale di questo percorso di dottorato triennale. Verranno approfonditi progetti riguardanti la gestione dei rifiuti, la potabilizzazione e la desalinizzazione di acqua ed infine la generazione di energia tramite fonte rinnovabile.

La prima macro area trattata è la gestione dei rifiuti generati sia durante le missioni umanitarie (packaging waste) sia nei campi umanitari (organic waste). Per ognuna di queste è stato analizzato e studiato il problema, sia dal punto di vista della letteratura scientifica internazionale sia dai dati raccolti presso le missioni umanitarie. Vengono quindi presentate e comparate fra loro differenti soluzioni impiantistiche. Le soluzioni più promettenti sono state prototipate per essere approfondite e testate, sia in laboratorio sia nelle reali condizioni di utilizzo. Successivamente alcuni prototipi sono stati spediti e utilizzati nei campi umanitari per essere testati.

La depurazione e la desalinizzazione dell'acqua sono il tema della seconda area di ricerca: il problema della mancanza di acqua potabile non solo affligge la maggior parte di paesi del mondo, ma anche i campi umanitari, dove l'acqua potabile rappresenta più di ogni altra cosa una fonte vitale. Ad oggi le tecnologie utilizzate, seppur efficaci, sono molto rudimentali. L'introduzione di innovativi sistemi di desalinizzazione osmotica, potrebbero rappresentare un'interessante soluzione sia per depurare acqua potabile, sia per utilizzare l'acqua salata come fonte per produrre acqua ultra-pura. In questo capitolo, dopo un'approfondita introduzione sul problema della mancanza di acqua potabile, sono state studiate

le principali tecnologie per la desalinizzazione, concentrandosi in seguito sulle tecnologie a membrane osmotiche, ad oggi le più interessanti per quest'utilizzo. Viene quindi presentata una critical review e le principali linee guida per un corretto dimensionamento per l'introduzione di queste tecnologie nei campi umanitari.

Infine l'ultimo capitolo tratta la produzione e gestione efficiente di energia elettrica tramite fonte rinnovabile. Quest'idea nasce sia da un problema operativo in contesto umanitario, ovvero dal fatto che l'energia elettrica prodotta tramite generatori a diesel in paesi remoti è molto costosa, sia perché le aree in cui solitamente sorgono i campi umanitari sono ricche di risorse naturali, quali sole e vento in abbondanza. Sfruttare queste risorse, oltre alla diminuzione di costi operativi, permetterebbe di rendere i campi umanitari più ecologici e rispettosi dell'ambiente in cui operano. In questa analisi verrà studiato e analizzato un progetto operativo, energicamente auto sostenibile tramite fonte rinnovabile, per lo stoccaggio di prodotti deperibili in campo umanitario tramite Mobile Storage Unit. Inoltre nella trattazione verrà presentato anche un modello decisionale per massimizzare la produzione di energia elettrica nei campi umanitari tramite lo sfruttamento di risorse rinnovabili, quali eolico e solare. Questo modello può essere esteso sia ai campi di nuova progettazione sia ai campi umanitari già esistenti. Il modello economico permette di capire in ambienti differenti, quale sia il giusto bilanciamento di energie rinnovabili con sistemi tradizionali di produzione quali generatori diesel.

Development of innovative plant design solutions, sustainable and efficient for humanitarian organizations

By
Francesco Piana

Submitted in fulfilment of the requirements for the Degree of
Doctor of Philosophy

University of Bologna
Doctoral School of Mechanics and Advanced Engineering Sciences

“The difference between what we do
and what we are capable of doing
would suffice to solve
most of the world’s problems”
Mahatma Gandhi

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1. Introduction

Research Framework

The research presented in this thesis has been developed following the structured framework in figure 1 presents below.

This research is a developing in the humanitarian field, to introduce innovative mechanical plants solutions in this unique sector: this research examines in depth three different sub-themes of research, born from likewise humanitarian issues, such as Waste Management, Water Purification and Desalination Systems and Renewable Energy Solutions.

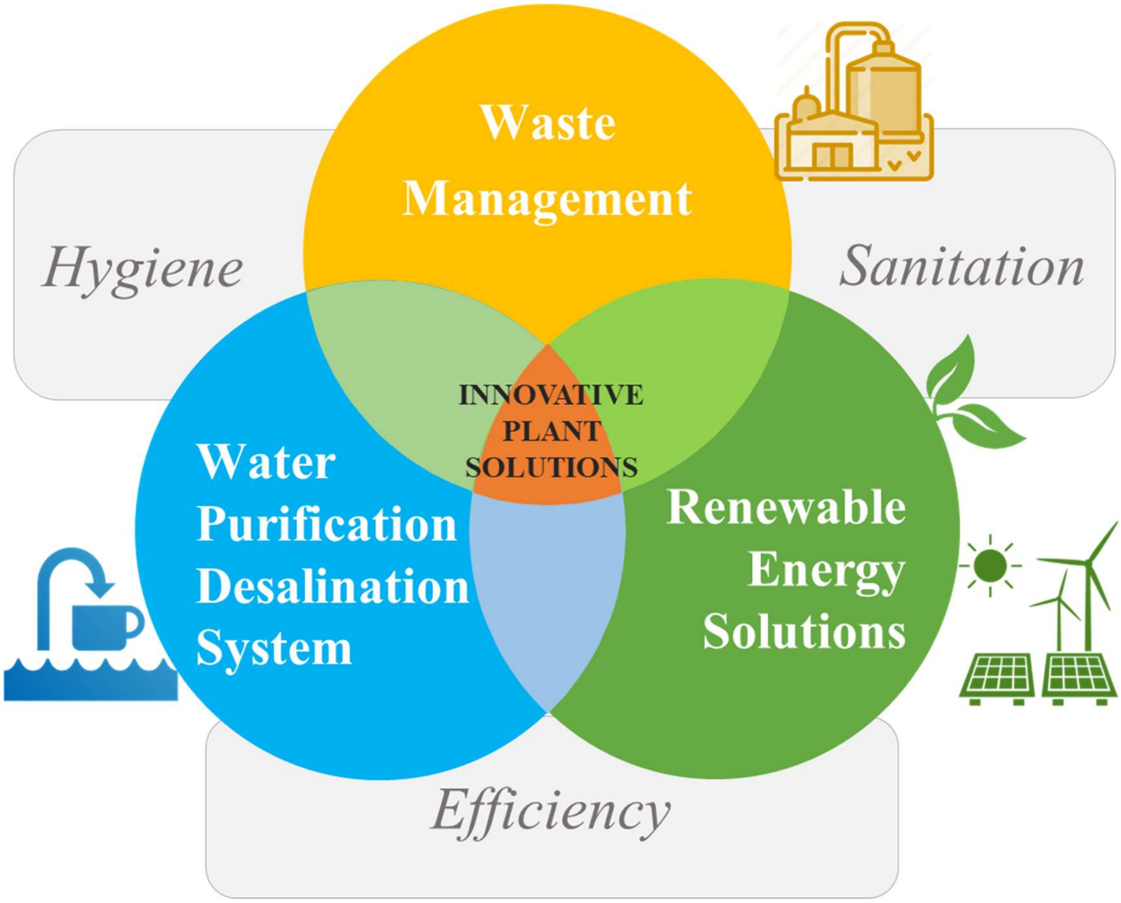

Figure 1: Research Framework

As shown in the picture above, these research themes are all connect to each other, makes this study-work an all-round developing within humanitarian sector. The waste management and the water quality are the major themes relate to sanitation and hygiene. Waste, is not scrap, but if proper used should be an important resource for people and humanitarian management, should, in fact, become the input to create a green-renewable energy to use daily.

The sun and the wind should be the paths to makes greener the humanitarian supply chains reducing the carbon-footprint of a humanitarian camp, increasing the efficiency to produce electricity in developing regions and in isolated areas.

Thesis Outline

This thesis has been developed in accordance with the research framework presented above.

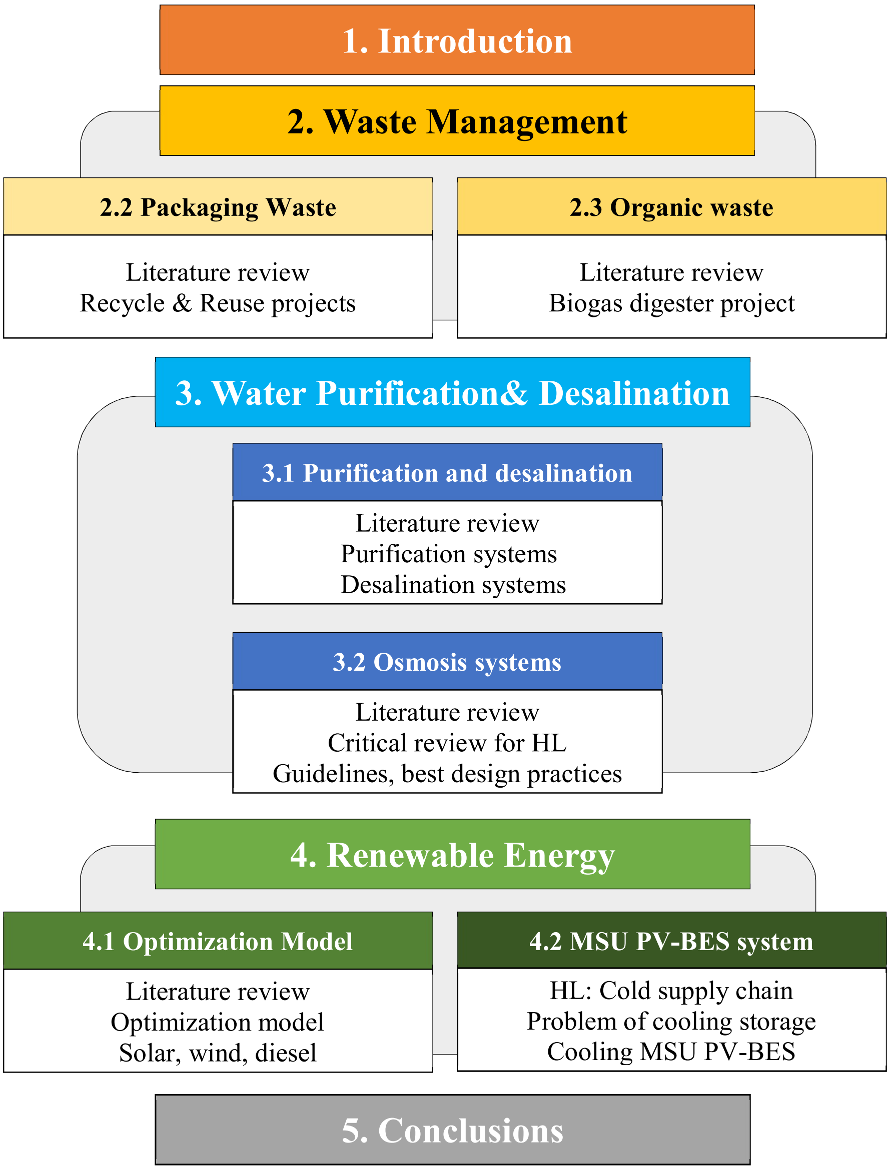

Figure 2: Thesis outline structure

This thesis starts with a brief introduction of humanitarian sector, and introducing the main issues of humanitarian sector, both in the logistics and supply chain, and on mechanical plants. Later, in this paper, this last theme will be the main one of the dissemination.

During the planning of these triennial research project we asked ourselves some main and general research questions about improvements should introduce in this field.

In the following list are cited some examples:

- Is it possible introduce in humanitarian context technologies already available in developed industry sector?

- Are these technologies affordable?
- Is it possible makes these technologies usable for unskilled persons?
- Are there some technique of recycle and reuse waste to introduce in developing regions and humanitarian camps?
- Does humanitarian context already ready for renewable energies?
- Do humanitarian camps reducing the carbon-footprint?

In the following, during the dissertation will be mention, and answer, some more specific questions of research proper of the particular field discussed.

Chapter 2 propose the first main issue of the humanitarian camps, the waste management: after a brief introduction at the problem, a brief taxonomy presents the three-main types of waste: disaster, packaging and organic waste. Following in sections 2.2 and 2.3 are study in depth packaging waste and organic waste. For each one, are presents solutions for the reuse and the recycle of these types of waste.

Chapter 3 analyzes method for water purification and desalination. After a brief introduction to water quality issue in humanitarian camps and during emergency with a particular focus on the consequences and disease of undrinkable water consumption. In the following section is presents water desalination system, an innovative technology for the purification of fresh water and for use salt water as resource. Section 3.2 propose a detailed study on desalination systems, a particular attention will give on Reverse Osmosis plants, probably the most interesting desalination systems for humanitarian sector. Finally, are presents some guidelines and a critical review on the use of these system in humanitarian logistics and refugees camps.

Chapter 4 investigate the problem of energy production, electricity in particular, in humanitarian camps from the renewable energies, solar and wind. The first section proposes an optimization model to find the best-trade-off for energy production in a humanitarian camp using both traditional diesel generators and renewable energies. The optimization starts with environmental and boundary conditions where camps will locate. This tool should become an interesting decisions and management support for humanitarian agencies, especially to planning further humanitarian missions. The next section discusses an operative problem occurs in the cold humanitarian supply chain. In the humanitarian camps is not possible stocking items in a control temperature warehouses. An innovative solution is proposed and analyzed. To make the system more flexible a PV-BES system is adopted, to produce the electricity necessary for cooling the mobile storage unit. An economical evaluation is proposed to understand the convenience of the system.

Chapter 5 presents the conclusions of this work and the further researches should be done in the future on this interesting field. The references and acknowledgments conclude the paper.

Collaboration WFP-UNHRD

Since the 2012 the Department of Industrial Engineering (DIN) of the Alma Mater Studiorum - University of Bologna, with the courtesy of the professor Alberto Regattieri, has a mutual collaboration with World Food Programme – United Nations Humanitarian Response Depot (WFP-UNHRD) of Brindisi.

The WFP is one the most important humanitarian agency of United Nations in the world, which provides food assistance to needy, hungry persons. According to the WFP, it provides food assistance to an average of 80 million people in 76 countries each year (http://it.wfp.org/).

Figure 3: WFP logo

The United Nations Humanitarian Response Depot (UNHRD), managed by WFP, is a network of six strategically located depots that procures, stores, and transports emergency supplies on behalf of the humanitarian community. It focuses on emergency preparedness and response, and enables the strategic stockpiling of relief items and equipment for its 86 Partners including UN agencies, governmental and non-governmental organizations. The depots provide a full range of comprehensive supply-chain solutions and are located in Italy, United Arab Emirates, Ghana, Panama, Malaysia and Spain. All depots are located within international airport premises and are in close proximity to sea ports and road transport hubs (http://unhrd.org/).

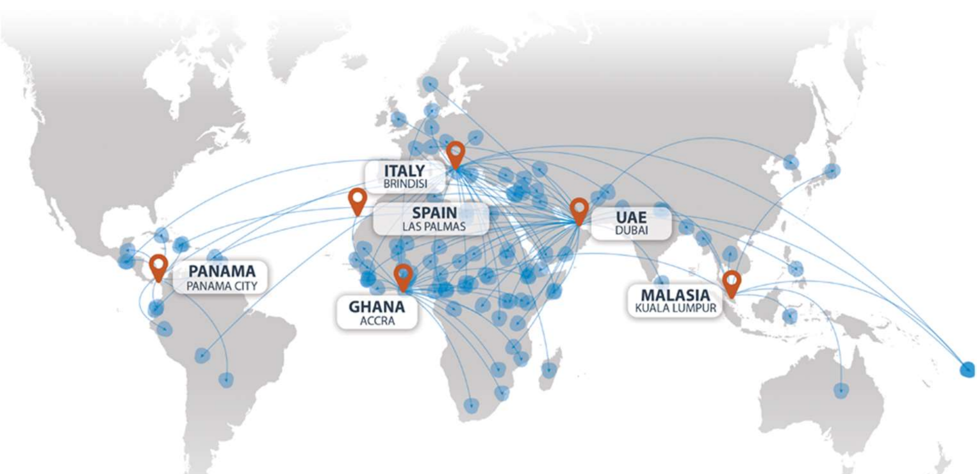

Figure 4: The six UNHRD depots in the world

DIN’s primary activities involve the development of education, methodologies and new approaches for the practice of supply chain engineering and new tools for analysis, design and management of logistics and plants processes. Usually humanitarian agencies have problems close and similar to the industrial context such as management, logistical, energy efficiency, mechanical plants, etc. ordinarily themes of projects and researches of the DIN Department.

During these years University of Bologna has been studied different problems for WFP-UNHRD on two different main fields: logistics and mechanical plants. On logistics, the most common problems are on the efficiency on the humanitarian supply chain, warehouses, items storage, innovative shipping methods and packaging. On the other side, on mechanical plants, as reported afterward in depth in this thesis, has been investigated and solved problems relate on mechanical plants usually used in humanitarian camps such as waste management plants, water purification systems and energy production plants.

Humanitarian logistic

Natural disasters, such as earthquakes, typhoons, hurricanes and floods, or manmade disasters, such as conflicts, economic crisis and social disparities, usually result in a significant forced population displacement. In the recent decades, the number of refugees in humanitarian camps has grown significantly due to the increasing number of humanitarian crises.

The main response of the international community to the increased scale of refugee movements has been that the increase of donations to humanitarian assistance. This is usually provided within the context of refugee camps where exiled populations wait for several months, sometimes several years, in the hope they will be able to return home "in dignity and security".

A refugee camp is a camp set up to assist people who need several types of relief (e.g. accommodation, water, health assistance, etc.), especially after strike of disaster (Langu, 2010). According to UNHCR (2011), humanitarian camps provide several advantages for people during the disaster, such as the protection they ensure to people, the ease in finding out how many people live there and what they need, and the ease with which some basic services can be organized (e.g. food distribution, vaccinations, etc.). Unfortunately, life in humanitarian camps is in non-permanent living solutions where vital and life-saving assistance is sometimes offered at borderline standards (Bjerregaard, 2008). Although basic needs are similar in the most of the contexts, the living conditions vary across thematic areas depending on a complex of social, economic, political and attitudinal factors (Regattieri, 2016). Construction materials, camp layout, services and infrastructures should fit to the aforementioned environmental factors (Rehfuess , 2008)(Regattieri et al. 2015)(Regattieri et al. 2015)(Regattieri et al. 2015)(Regattieri et al. 2015)(Regattieri et al. 2015)(Regattieri et al. 2015)(Regattieri et al. 2015)(Regattieri et al. 2015).

After a catastrophe in most cases, refugees are lacking in basic needs, namely clean drinkable water, food, shelters, energy and all things necessary to live in dignity (Regattieri, 2015). Primary needs are similar in the most of the contexts, despite of the living conditions of different people vary across thematic areas depending on a complex of social, economic, political and attitudinal factors. Often, append that refugees have to live in the camp for much longer than expected (Salehin et al., 2011). On the other hand, too many people living in the camp increase the risk of spreading disease, their dependence on aid from all organizations, their isolation and idleness and, finally, the surrounding environment can be degraded.

Various parties are involved in the planning, management, provision and maintenance of refugee camps, but the coordination between them is not always as good as it should be. This may be a significant obstacle in giving the best help to people living in refugee camps. Despite these disadvantages, refugee camps are vital and essential for people affected by disasters, as they often represent the last life-saving protection.

Even if, the existing literature provides multiple guidelines to follow, during the early stages of camp settlement and in extreme emergency contexts, which are characterized by urgency, poverty and insecurity, short time, few resources and only raw tools are available for the camp set up and for the everyday life. Due to the importance of this theme, was designed a complete refugee camp profile to be used by humanitarian organizations during the first phase of assessment and can help camps improvement.

The proposed profile, present in this chapter, deals with the general structure of a camp and overall with the identification of a set of key technical indicators such as surface area per person, tent area per person, water consumption per person, etc. This approach is well known in the commercial and industrial field and it is applicable to the humanitarian field because of the required speed in response to a crisis. The proposed data is collected by a rigorous study on papers existing in literature, unpublished working papers of humanitarian organizations and several interviews with managers of humanitarian organizations, agencies and government authorities.

Humanitarian camp taxonomy

Camps are usually situated on the edges of towns or cities, away from borders and war zones. In general, there should be a substantial distance between camps, which depends on a number of factors: access, proximity of the local population, water supplies, environmental considerations and land use (UNHCR, 2007). As show in the following paper, the location of a humanitarian camp is a fundamental parameter for the life within the camp: such as a temporary city a camp need resources to survive, as fuel, nourishment, water, and many different items. Usually, a camp is built as a temporary solution, giving refugees a place to live until they can safely return to normality. However, it happens sometimes that the camp becomes the permanent home of refugees for many years.

There are several essential aspects to consider when establishing a refugee camp, in particular (excluding food and nutrition that are out of scope of this work):

- main services and infrastructures;
- shelter and accommodation;
- water consumption and distribution;
- sanitation and hygiene, and in particular the waste management;

- energy consumption;

Main services and infrastructures

The general organization in terms of infrastructures of a refugee camp is a very critical aspect. An incorrect structure or service design can generate many problems, e.g. the roads are impracticable, local hospitals and health services do not function, schools are closed, food supplies do not arrive on time, markets and small establishments of refugees do not function properly because of their isolated position (Crisp, 2005), and so on.

Furthermore, the unpredictability of the disasters and the urgency in tackling them, make the camp design very difficult. A preventive reference framework can be crucial in order to avoid errors.

There are several main facilities required for a refugee camp. They are roads and firebreaks, water supply and sanitation facilities (defecation areas, latrines, waste disposal pits, ablution places), health facilities (health centers, health posts, hospitals and pharmacies), nutritional facilities (therapeutic and supplementary feeding centers), distribution sites and storage facilities (in separate locations), administrative center, reception area, other community facilities such as markets, schools, cemeteries, meeting places. Clearly, the number and configuration of these services depend on the number of people involved.

Shelter and accommodation

It is argued that a safely built environment, including adequate housing conditions, is one of the most primary human needs (Habib et al., 2006). Shelter is likely to be one of the most important determining factors in the general living conditions and is often one of the significant items of non-recurring expenditure (UNHCR, 2007).

Inadequate shelter and overcrowding are the main causes of the transmission of diseases with epidemic potential (e.g. measles, meningitis, typhus, cholera, etc.), and outbreaks of disease are more frequent and severe when the population density is high. In addition, protection against sun, rain, cold and wind is essential for the welfare of the refugees, as is the provision of a safe living space for families.

While the basic need for shelter is similar in almost all emergencies, considerations such as the kind of housing needed, the materials and design to use, who constructs the housing and how long it must last, differ significantly in each situation. Over recent years, the importance of providing safe houses that are free from physical hazards has increased (Robert Wood Johnson Foundation, 2008), but housing in refugee camps is often overcrowded and of inferior quality. Well known is the case of refugee camps in Sri Lanka that were composed of houses realized in small wooden one room huts with a corrugated iron roof (Turner et al., 2009).

The minimum shelter space recommended is 3.5 m^2 per person in warm and tropical climates (excluding cooking facilities, which are placed outside), and 4.5 to 5.5 m^2 in cold climates, including the kitchen and bathing facilities (UNHCR, 2007; 2011).

The minimum distance between shelters must be 2 meters and the maximum distance between firebreaks must be about 72 meters.

A new trend in building temporary houses is the use, whenever possible, of local materials such as wood, metal sheets, tree branches or plastic. This solution can be interesting both due to cost reduction**,** the utilization of local materials and the employment of refugees in the construction. On the other hand, it requires a very significant effort in terms of planning and coordination by humanitarian staff and volunteers. Temporary shelters made in the first stage of the emergencies are usually tends, because are lighter to shipping, easy-fast to build and adaptable at different environment.

Figure 5: UNHCR Tend in humanitarian camp[1]

[1] http://inapcache.boston.com/universal/site_graphics/blogs/bigpicture/2011part2/bp38.jpg

Water consumption and distribution

People can survive longer without food than without water. The provision of water demands immediate attention from the beginning of a refugee emergency. Water and the environment play an essential role in the spread of many communicable diseases and epidemics. Diarrhea diseases, mostly caused by poor hygiene and lack of safe water, are the major cause of unhealthiness and mortality among refugees and displaced populations. The aim of humanitarian organizations is to assure the availability of sufficient water to allow its effective distribution in the required quantities, and to ensure that it is safe to drink and easily accessible.

Minimum daily requirements of water vary in accordance with the climate and the habits of the involved population. In the chapter 3 the theme of water is present in deepened, with quantities requires for different environments and situations.

A reduction in the quantity of water available to individuals will directly affect the overall health status of the refugee population. It is essential for refugees to receive good quality water since it has a major impact on nutrition, health, and sanitation (UNHCR, 2013).

Figure 6: Two different water systems in different humanitarian camps[2]

Ideally, the supplied water should meet the quality standards defined by World Health Organization (WHO) (Médecins Sans Frontières, 1994). However, it is generally difficult or even impossible to adhere to these standards during emergencies. The main goal is to provide clean water to restrict water-borne diseases, i.e. containing the fewest pathogenic germs. The presence or absence of pathogenic organisms is the only criterion of real importance to ensure health and prevent diseases.

[2] http://www.aljazeera.com/mritems/Images/2015/5/26/3657162949f84aa4be5a430bb36aad93_6.jpg
https://www.mercycorps.org/sites/default/files/styles/slideshow/public/Good0015-20150719_Sumaya%20Agha.jpg

The bacteriological quality of untreated water should be assessed. This is based on the detection of the presence of organisms and their quantity, which are the indicators of fecal pollution, i.e. fecal coliforms, always present in large numbers in the feces of humans and other animals. This bacteriological analysis can be performed by using field-testing kits, i.e. Del Agua/Oxfam kit, which provide results within 24 hours but are expensive and require experienced or specially trained sanitation officers. Water for consumption should contain less than 10 fecal coliforms /100 ml.

Sometimes there are nearby water sources such as rivers, lakes, wells or springs. If the water source is clean (e.g. from wells or springs), it can be used without treatment, even if boiling should be the best way before drink. Water coming from rivers and lakes can be contaminated and must be treated before human consumption (Minimum requirements: immigrant connect, 2010). In a refugee camp, where so many people live close to each other, epidemics can start and spread very quickly. Cholera, a disease caused by drinking contaminated water, can kill people within a few hours if they do not get medical help. The most serious threat to the safety of a water supply system is contamination by faces. Water contaminated by human faces puts people at a high risk of cholera, dysentery, diarrhea, and intestinal worms (Practical action, 2010). This is the reason why the quality of the water is as important as the quantity. Water diseases will be analyzed longer in the chapter 3 of this thesis.

When water is not available close to the community site, it has to be transported from the well to the camp. Even if the water provided is not contaminated, its transfer between tanks, home storage, and hand touching the inside of water tanks are risk factors for contamination (Roberts et al., 2001).

Another relevant aspect concerning the water issue is that it should be readily accessible, and the water taps should be centrally located. If the water taps are far away, children might have to interrupt their schooling to collect water for their families. In addition, if the water taps are very far away, the physical burden of water collection increases immensely. For example, if a person draws water for all of their family’s needs (around 80-120 liters) from a well located 200 meters away, he/she may use up to 1/6 of his/her rationed calories for the day on this one task (UNHCR, 2007) and there is higher vulnerability to health problems.

For this reason, a strong recommendation is that there should be at least one water distribution point for every 200 to 250 refugees and placed at the maximum distance of 100-200 meters from the shelter. Unfortunately, many refugee camps do not meet this basic standard. Refugee camps in Uganda, for example, have particularly poor access to water. Only 43% of the population has access to water taps within 200 meters. In addition, there are over 450 people per water tap, far exceeding the UNHCR standard of 200 persons per water pump (Bruijn, 2009).

Sanitation and hygiene: the waste management problem

Sanitation and hygiene programs aim to ensure a safe environment and reduce the incidence of environment-related diseases. Sanitation refers to safeguarding water quality, proper disposal of human excreta, water waste, garbage and dead bodies, insect control, safe food-handling practices, and effective site drainage (UNHCR, 2007).

Waste management plays a fundamental role in the problem of sanitation and hygiene. Waste is unavoidable; if not properly managed, it may cause environmental and health problems but it can also represent a great opportunity. This is even more evident in a humanitarian crisis. The following chapter, the number 2, will discuss and presents in depth the problem of waste management relate to the sanitation and hygiene.

Energy consumption

One of the basic needs of people living in refugee camps has been translated into electricity demand (Salehin et al., 2011). In crisis conditions, local commercial electrical power is usually not available, so a centralised camp electrical supply source is necessary. Diesel engine electrical generators are normally used and positioned around the camp. Priority for electrical power should be given to security lighting, access lighting and operating water pumps around the camp. When time and funds are sufficient, electrical power can be provided to individual living shelters (Department of Air Force, 2000). Usually, electricity is installed at camp module level.

The electricity demand for a camp module can be estimated considering some fundamental factors such as lighting demand, water purification demand, cooling demand, catering and telecommunications demand.

Following is present such as an example table 1 with the main electrical needs find in a scientific literature review from humanitarian camps.

Electrical needs	Assessment of energy, water and waste reduction options for the proposed AMISOM HQ in Mogadishu, Somalia and the support base in Mombasa, Kenya (UNEP, 2010) [Data for the headquarter camp]	Assessment of energy, water and waste reduction options for the proposed AMISOM HQ in Mogadishu, Somalia and the support base in Mombasa, Kenya (UNEP, 2010) [Data for the support base camp]	Designing of an emergency energy module for relief and refugee camp situations: case study for a refugee camp in Chad-Sudan border (Salehin et al., 2011)
Lighting [kWh/day]			52.1
Lighting (external) [kWh/day]	273.0	273.0	
Lighting (internal) [kWh/day]	320.0	160.0	
Water purification [kWh/day]			63.8
Hot water [kWh/day]	497.3	248.7	
Cooling [kWh/day]	1,750.0	875.0	
Vaccine cooling [kWh/day]			18.8
Small power (accommodation) [kWh/day]	832.3	416.1	
Small power (office) [kWh/day]	536.8	273.7	
Catering [kWh/day]	42.6	21.8	
Telecommunications [kWh/day]			0.6

Table 1: Humanitarian camp electrical needs

Table 1 (Salehin et al., 2011; UNEP, 2010) shows in detail the electricity demand in a refugee camp module for different needs. However, electricity consumption should change by different places and situations. A standardization of humanitarian camps is a necessary step to improve the humanitarian efficiency and reducing the waste of energy

Lighting is provided in the communal area of refugee camps, hospitals, toilet areas, and offices. The total number of staff and area of the office have been calculated based on UNHCR standards (UNHCR, 2007). One important factor is to prevent the spread of preventable diseases through vaccination. The vaccines have to be stored in refrigerated tents that represent significant electricity consumption.

Figure 7: Night time picture of refugee camp in northwest Pakistan (Shah Mansour)[3]

Humanitarian camp taxonomy

Every humanitarian camp is different from the other one because every crisis is different and variables involved are unlimited. The number of people living in a camp depends to different factors, above all on the crisis itself. When the number of refugees in the region is hundreds of thousands, is better for the humanitarian agency establish few smaller camps with a population of no more than 20,000 people, rather than one, bigger, unique camp. Indeed, in smaller camps it is easier to manage problems such as fire, waste management, security or the spreading of disease (UNHCR, 2007). Based on the belief in global human rights and human needs, which are valid and equal all over the world, the fundamental planning approach for refugee camps is characterized by the neutrality.

To planning the standardization for refugee camp begin start from the smallest component, called "family", and then builds up a resulting modularization using larger units: such as community, block, sector and module. In the following table are present these "unit-of-measurement" proper of a humanitarian camp and the corresponding number of people (Crisp, 2005; UNHCR, 2007).

Module	Consisting of	Approximate number of persons

[3] https://muftah.org/afghanistan-increased-pressure-on-refugees-to-leave-pakistan/#.WicfGkriZPY

Family	1 family	4-6 persons
Community	16 families	80-100 persons
Block	16 communities	1,250 persons
Sector	4 blocks	5,000 persons
Camp module	4 sectors	20,000 persons

Table 2: The humanitarian camp modularization

To better define the division is possible use road and street, for example smaller tracks and non-motorised lanes separate communities and blocks from each other, while roads for motorised traffic divide the larger camp sectors and modules (Crisp, 2005).

Ideally, the recommended minimum surface area is 30 m^2 per person included the area necessary for roads, footpaths, educational facilities, sanitation, security, firebreaks, administration, water storage, distribution, markets, relief item storage and, of course, plots for shelter. Anyway, usually is difficult maintain this ratio during humanitarian crises, because is difficult estimate the actual number of refugees in the camp.

2. Waste management

Introduction to the waste problem during emergencies

Waste is an unavoidable output of life; a humanitarian camp, such as anything else community of people, during its activities produces different types of waste. Waste, if not properly managed, it may cause environmental and health problems. Indeed, if reuse or recycle, waste can also represent a great opportunity. This is even more evident during a humanitarian crisis, where waste management is a huge problem to deal with, due to the amount of waste produce firstly by catastrophes, and then by survivors. Frequently occur, even though in the last years humanitarian agencies improve camps standardization rules, humanitarian camps are more overpopulated than should be. This cause some serious management problems with the food, the water system, shelters and other accommodations in the camp. In these situation, due to the correlation between waste and sanitation, a proper organic waste management is crucial for people live in the camp.

During a humanitarian crisis can be generate different types of waste, which can be classified as the follows list:

- Debris caused by catastrophes, usually called *Disaster Waste (DW)* (both natural and man-made);
- *Packaging Waste (PW)*, usually from humanitarian aid packaging (e.g. packaging of tents, kitchen set, blankets, etc.);
- *Organic Waste (OW)*, waste produced from everyday activities in refugee camps (e.g. paper, plastic, food, organic, excreta, etc.)

Quantity and types of these waste depends to different factors first of all the area where disaster occurs, type of disaster, land urbanization, etc. In relation to the disaster and its effects should necessary organize a waste management.

Reuse and recycle

As in ordinary situation the well-known hierarchical approaches to waste management is based on the 5 R's, Reduce, Reuse, Repair, Recycle and Residual management. This approach should be considered, also, in the humanitarian context. In the following sections will be present some proposal on this purpose. However, a well waste management is not easy to put in practice during a humanitarian crisis, it should start from the management to the camps until to all refugee. The community participation and commitment are decisive into the planning, design and implementation of an effective waste management system within the camps. Involving the community will assist in identifying what normal practice is, developing preferred solutions, developing public health and other matters associated with waste management.

Obviously, the requirements of men, women, young people, children, and persons with special needs and disabilities will be different in relation to the waste management. During the first stages of emergency is crucial have a consulting with the community: is important that men and women are both consulted and their needs and requirements identified. Women, for example, will largely be responsible for household and family waste management while men may be involved (paid or unpaid) as waste loaders, in waste collection roles, or in waste recycling and re-use.

In the following paragraphs will discuss in depth each type of waste presented in the list before. A particular focus will be on packaging waste and then organic waste, because literature and research projects on those two topics was poorest than for disaster waste.

2.1 Disaster Waste (DW)

Disasters can take many forms, natural, man-made or technological and their duration can last from few minutes, such as earthquakes and tsunami, to several years i.e. civil wars and radioactive contamination. Most of them create a large amount of debris and waste in relation to their nature. Debris are the larger part of waste during a catastrophe especially in urban areas.

The management of the disaster waste considers three phases (Brown et al., 2011):

- the *emergency response*, 0-72 hours after disaster, short term actions: debris management to facilitate preservation of life, provision of emergency services, removing public health and safety hazards such as unstable buildings, etc;
- the *recovery phase*, mid/long-term action: debris management as part of restoring, lifeline restoration and building demolition;
- the *rebuild phase*, mid/long term action: debris management of wastes generated from and used in re-construction.

During the recovery phase will be managed the majority of the waste generated by disaster, usually the longest phase toward full recovery, often lasting a number of years. In New Orleans, for example, after the Hurricane Katrina in 2005, this phase has lasted up to 5 years (Luther, 2008). The recovery phase can be affected by a number of factors outside the control of waste managers including police/coroner investigations which can limit site access for public and waste contractors (Ekici et al., 2009) and slow resident return (New Orleans, Hurricane Katrina) (Cook, 2009). The rebuilding phase is a much longer process and it is hard to define the “end” of this phase. According to Haas et al. (1977) the rebuilding phase duration could be in the order of 10 years or more.

The aim of waste management is to minimize risks to human life and health, reduce risks to the environment and to reuse and reutilize materials. This last aspect must be over-stressed in the future. Disaster debris must be considered as a fundamental resource to reduce the additional impact on the environment during the reconstruction phase. Traditionally, waste can be seen as a huge problem, especially organic waste because causes the spread of contagious diseases; but seen from a different perspective debris may become a resource rather than a mere waste problem. DW can be employed in many different ways: it may contain valuable materials such as concrete, steel, and timber as well as organics for composting. This value can be realized as either a source of income or as a reconstruction material, and can reduce burdens on natural resources that might otherwise be harvested for reconstruction.

Mainly, disasters generate several waste streams (Brown et al, 2011):

- Vegetative debris or green waste;
- Sediment/soil and rock;
- Household hazardous waste (refrigerant, oils, pesticides, etc.);
- Construction and demolition debris from damaged buildings and infrastructures (such as roads, pipe networks and other services);
- Industrial and toxic chemicals (including fuel products);
- Putrescible waste (such as rotting food);
- Vehicles and vessels;
- Recyclables (plastics, metals, etc.);
- Electronic and white goods;
- Human and animal corpses;

Quantity and types of waste present in an area strict by catastrophe depending on the environment in which disasters happen such as coastal or inland and urban or rural. The Federal and Emergency Management Agency (FEMA) categorizes materials according to the type of disaster.

The estimation of the quantity of debris produced by a disaster is very difficult due to the high number of parameters influencing this data (e.g. kind and intensity of disaster, type of buildings, environment (coastal/inland, urban/rural), etc.).

Large quantities of materials are usually available. On September 1999, more than 20 million m^3 of demolition waste were created as a result of the devastating Chi–Chi earthquake in Taiwan (Yang, 2009). The Hurricane Katrina created disaster debris across a 90,000-square mile (234,000 km^2) disaster area. Disaster debris totals are estimated at 1,5 million m^3 in Alabama, 33 million m^3 in Mississippi and 38 million m^3 in Louisiana (Luther, 2006).

Driftwood is a common sight along the coast after a typhoon in Taiwan, in fact after Typhoon Morakot (August 2009) the total clean-up amount of driftwood is 1.03 million tons (Doong at al., 2011). On January 17, 1995, the Hyogoken-Nambu earthquake resulted in devastating damage to the highly developed urbanized region of Kansai in Japan, and created total of 2000 million tons of debris (Hayashi and Katsumi, 1996).

In general, a huge amount of waste had certainly been generated for example by collapsed houses and dilapidated buildings. Therefore, special attention should be paid to the problem of how to assess the total amount of disaster waste scientifically and accurately, and the problem of how to collect statistics of the amount of waste caused by different building materials, thus leading to better waste reclamation. A detailed analysis on disaster waste is helpful in developing a strategy on the treatment of building waste and its use as a resource in post-disaster reconstruction activities. In literature there are some empirical statistics studies discussing structures and building waste produced in an earthquake-hit area (Hayashi and Katsumi, 1996, Xiao et al.2012). For example, based on the field damage investigation in the earthquake-hit areas, the relationship between different building structures and building waste produced is established and evaluated. Xiao et al. (2012) propose a mathematical model to forecast the amount of building waste in the earthquake-hit area considering the different structure of buildings and develop an empirical relationship between building waste and seismic intensity. However, these studies must only be considered approximate because it is almost impossible to correlate all the factors involved in a disaster due to the number of variables. In contrast to machine demolition where massive flows of construction debris are trucked into landfills, deconstruction (the hand dismantling of buildings for maximum salvage) diverts building material from the waste stream by returning it to homeowners or redirecting it back into the disaster reconstruction. In 2005, Mercy Corps (MC) responded to the disaster of hurricanes Katrina and Rita with an innovative deconstruction program aimed at human empowerment and environmental protection (Denhart, 2010). An aggressive deconstruction project at Ft. Lewis demonstrated a fully-closed loop system with 100% recovery of building material (Biocycle, 2007). The Deconstruction Institute estimates that 6000 board feet of reusable lumber goes into the average 2000 square feet (sf) home, requiring 33 mature trees taking 10 acres of planted pine. Deconstruction not only preserves the trees but also reduces the CO_2 necessary to harvest, process and transport them.

2.2 Packaging waste (PW)

The humanitarian supply chain is a significant source of packaging waste. Items shipping during an emergency or a catastrophe in a strike area are wrap, both for protection and to improve material handling, with different packaging materials just like traditional commercial items. When items arrive to the final users, refugees and persons needing, packaging materials wrapping items become waste.

Figure 8: Packaging waste in humanitarian camps[4]

In the near future, if not managed, this amount of material could become an important global sustainability issue, and for this reason, it is necessary to find worthwhile alternative solutions to the problem.

The packaging waste, if cleverly managed, particularly cardboard, pallets, wood elements, and plastics, should represent for refugees a real worthwhile resource. Just to understand the dimension Merrild et al. (2009) stated that the contribution from the reprocessing or reuse and recycling of paper waste ranged from approximately 490 to 1460 kg CO_2-eq. saved for each ton of paper waste. It can also be assumed that wood not used for virgin paper production can instead be used for energy production as a substitute for fossil fuel energy. This would result in a contribution of 1850 to 4400 kg CO_2-eq. saved for each ton of paper waste. These examples reveal the large potential environmental savings should be by the reusing and recycling of packaging waste.

On this purpose, in collaboration with the WFP-UNHRD, the researchers of DIN studied and analyzed the magnitude of the problem. A set of packing lists corresponding to supplies used in 2013, that are representative of typical shipments from various humanitarian organizations, has been studied during this project. Results were interesting and promising for the goal of the project: the overall

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[4] http://www.ben-harvey.org/UNHCR/WASH-Manual/Wiki/images/5/52/Emergency_NFI_Packaging_Waste_%28UNICEF_2010%29.png
http://www.ben-harvey.org/UNHCR/WASH-Manual/Wiki/images/c/c9/Waste_Scavenging_%28UNDP_2013%29.jpg

incidence of packaging materials is roughly 10% to 12% in mass. Figure 9 shows the average mass incidence of different main packaging materials on the above-mentioned packing lists. In the table 3 below is present the analysis of packing list with the quantities and materials shipping to staging areas.

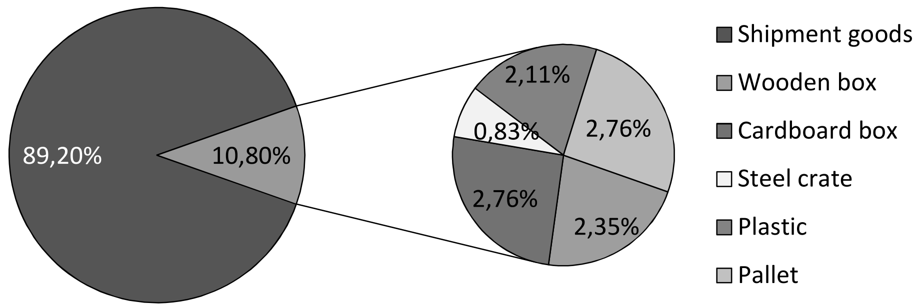


Figure 9: Average mass incidence of different main packaging materials on the packing list

	Packaging materials					
Packing list No.	Wooden box [Kg]	Cardboard box [Kg]	Steel crate [Kg]	Plastic [Kg]	Pallet [Kg]	PW/GR [%]
1	-	102	720	-	20	10.0%
2	-	-	360	-	40	4.8%
3	-	-	-	-	60	0.8%
4	2,320	592	200	1,533	1,302	19.2%
5	1,421	344	200	33	1,230	16.9%
6	-	24	120	-	-	6.9%
7	594	1,706	-	2,500	2,200	22.4%
8	-	640	-	-	-	6.5%
9	-	1,920	-	-	480	9.8%
10	200	-	-	-	-	
Total	4,535	5,328	1,600	4,066	5,332	10.8%

Table 3: Quantity and typology of transported packages

where:

PW packaging weight per packing list [Kg/packing list]

GR gross weight per packing list [Kg/packing list]

The end of packaging life is an important resource. In a refugee camp, the management of the packaging waste is, if possible, a more important issue; in fact, waste has an immediate and long-term negative effects for the people and for the environment, if not properly managed. Furthermore, the transportation of waste packaging materials also represents a waste of money for the humanitarian agencies. Today, such as in the traditional manufacturing supply chain, it is important to investigate all the practicable ways to reduce and reuse waste (Catania and La Mantia, 2004).

In this case the solution to this problem is to conceive a general strategy of utilizing various recycling techniques, and/or of recovering energy. These packaging materials should be removed from the waste stream, reprocessed and used again. In this study we will consider several available packaging materials from humanitarian logistics, and we will propose some new products manufactured using these materials reducing the environmental impact.

Figure 10: Examples of packaging waste reuse in developing countries[5]

[5] https://inhabitat.com/wp-content/blogs.dir/1/files/2017/05/Refugee-Camp-Plastic-Bottle-Homes.jpg
http://www.ben-harvey.org/UNHCR/WASH-Manual/Wiki/images/f/f4/Reuse%2C_Dadaab_Refugee_Camp_%28Jeffrys_2009%29.jpg

QR - Questions of research

Before started this study, with the mind focus on the main issue of packaging waste within areas strike by a catastrophe, we asked some research questions, with the purpose to reply them during the project.

Following the main research questions on this topic are presented:

- Is it possible reuse and recycle packaging waste within humanitarian camps?
- Is it possible create equipment useful for refugees from packaging?
- Are packaging materials useful and strong to manufacturing something?
- Which are the main tools needing refugees?

In the next sections of this chapter is presented one of the most interesting and complete (from the earlier business idea to the prototipation within the humanitarian field) project made during this research work on the packaging waste reuse: start from the goal to reuse or recycle a cardboard from a kitchen-set, and the necessity to find a solution for cooking and heating some meals in poor regions, will be developed a portable solar-cooker. This interesting equipment is able to cook and heat-up meals with mainly the sun rays reflection.

So, following are present tests and all trails to validate the idea.

In the following paragraphs will reply to all research questions present above.

The problem of cooking in humanitarian camps and developing regions

Cooking is one of the major necessities for people all over the world (Rehfuess 2006; Mwamakamba et al. 2012; Flavin & Aeck 2005). In developing countries, cooking accounts for a major share of the energy consumption, i.e. approximately 90% of the total 45% energy consumption of the worldwide domestic sector (Pohekar et al. 2005). People in developing countries usually make use of firewood and charcoal for cooking (Owen et al. 2002). High demand for these two fuels leads to environmental degradation because of supplies of dead wood are progressively exhausted and live trees are cut in uncontrolled manners (Panwar et al. 2011). The traditional method used for cooking with these fuels is the so-called *"three stone fire"* technique (Pohekar et al. 2005; Deutsche Gesellschaft für Technische Zusammenarbeit & Department of Minerals and Energy 2004). The cooking pot stands on three stones, bricks or metal pegs and it is heated by firing wood or charcoal. Such methods are highly inefficient, i.e. only the 15% of the energy released enters the water or food (Flavin & Aeck 2005). Furthermore, fire produces smoke often causing respiratory diseases, particularly to women, who are in charge of the cooking activity (Otte 2013), and their kids, who usually live with them. In areas with high population density, such as urban regions in the developing world and regions close to the humanitarian refugee camps, the lack of firewood supply is a, further, huge problem (Schwarzer & da Silva 2008). A report by the Food and Agriculture Organization (FAO) shows that, between 1990 and 2010, the global biomass stock decreased by 3.6% and the largest declines are in South America and Africa (Otte 2013).

Due to the lack and high cost of fossil and other traditional energy sources, the search for effective and cheaper alternatives is a crucial issue within the humanitarian context (Makai & Molinas 2013). Solar energy is rapidly becoming a viable alternative (Bortolini, Gamberi, Graziani, Mora, et al. 2013; Bortolini, Gamberi, Graziani, Manzini, et al. 2013) and the use of solar cookers is widely spreading to several developing countries, villages and remote areas (M. Abu-Khadera, M. Abu Hilalb, S. Abdallahc 2011). Solar cookers are also of great benefit in humanitarian camps and regions struck by catastrophes (Goswami 2005). They use sunrays to heat, cook or pasteurize foods and drinks (Saxena et al. 2011). These devices should be of low cost and easy-use, meaning that people have no difficulties in switching to such systems of cooking (Toonen 2009). Finally, solar cookers are known as environmental friendly solar systems (Mirdha & Dhariwal 2008).

Starting from this background, this research combines the problems of providing effective cooking facilities and properly managing the packaging waste (Regattieri et al. 2014). The Authors develop a portable solar cooking device from the cardboard used in packaging humanitarian supplies. The humanitarian supply chain is a significant source of packaging waste, cardboard, pallets, wood elements and plastics, which may represent a worthwhile resource from both social and environmental saving perspectives (Regattieri et al. 2015; Merrild et al. 2009). For this reason, worthwhile solutions to this problem are strongly encouraged. Focusing on packaging, by analyzing typical shipments from various humanitarian organizations, the overall incidence of packaging materials is 10% to 12% in mass.

Solar cookers

Solar cooker is a reflect device which absorb solar energy and convert it to heat focused on a spotted area where the target is located, e.g. a pot with food, water or drinks. Heat allows cooking, baking or boiling. A solar cooker is the simplest, safest and most convenient way to cook food without consuming fuel. It is further practical because of its inherent simplicity and low cost (Panwar et al. 2012).

Figure 11: Different solar cookers[6]

Cooking with solar energy is not a novel idea (Wentzel & Pouris 2007). According to Halacy and Halacy, the first scientist experimenting solar cooking was the German physicist Tschirnhausen (1651–1708) (Halacy & Halacy 1992). He used a large lens to focus the solar rays boiling water in a clay pot (Wentzel & Pouris 2007). During the following centuries, multiple experiments relating to solar cooking devices are performed (Deutsche Gesellschaft für Technische Zusammenarbeit &

[6] http://www.solarcooker-at-cantinawest.com/images/solar-oven-gosun.jpg
http://2ff8n03drmib1b12373aauek-wpengine.netdna-ssl.com/wp-content/uploads/igm/d2/octagon-cooker-600x464.jpg

Department of Minerals and Energy 2004). Increased public interest in solar cookers emerges in the ‘50s and ‘60s, when the most of the basic design variants are tested and disseminated.

The literature proposes a wide number of solar cooker configurations. Their working technology includes three major macro-categories depending on their shape (parabolic or not), the sunray path (concentrating or non-concentrating) and the heating manner (direct or indirect). Figure 12 exemplifies three basic configurations of concentrator, solar box (or solar oven) and indirect solar cooker crossing the introduced categories.

(a) *(b)* *(c)*

Figure 12:Solar cooker technologies: concentrator (a), solar box (b) and indirect solar cooker (c)

Developments and modifications are proposed from such basic configurations varying the shapes, materials and dimensions. Extensive reviews on the existing solutions are in (Sharma et al. 2009; Yettou et al. 2014; Saxena et al. 2011; Panwar et al. 2012). According to the literature, the followings are among the most developed and promising systems (Saxena et al. 2011):

- The *Indian Box Cooker* – further known as solar box cooker or solar oven, it is made of a fiber reinforced plastic or sheet metal outer case, an aluminum interior case, a double tempered glaze and a single glass mirror reflector lid (Deutsche Gesellschaft für Technische Zusammenarbeit & Department of Minerals and Energy 2004). In some applications, it includes a light bulb as a back-up heat source;
- The *Telkes Cooker* – in 1953, Dr. Maria Telkes, active on solar technologies at the Massachusetts Institute of Technology (MIT), worked on the development of a solar oven on the basis theory of solar box cooker. The goal was to improve the existing solar ovens allowing preparation of any national cuisine by individuals of any country of the world, safe enough to be used by kids, free the cook from constant stirring and not to scorching food (Kubiszewski 2006). Telkes cooker is a box cooker featuring an array of four external mirror reflectors used as thermal booster to improve the efficiency and the cooking time of the solar oven (Stanley

1993). It is a good example of solar oven mass-producible at a reasonable price to permit its widespread to poorest environment (Bowman 1979);

- The *Tabor Cooker* – during the '90s Harry Tabor, former Director of National Physical Laboratory of Israel (Anon 1958), invented the first parabolic concentrator, using an array of shaving mirrors, for the use of thermal energy from solar rays (Deutsche Gesellschaft für Technische Zusammenarbeit & Department of Minerals and Energy 2004). Tabor cooker is another key thermal resource for cooking, especially in poor countries. It is made of twelve concave glass mirrors mounted on a metal frame in a two-axis mounting. Over 500W are delivered to the target in bright sunlight conditions (Tabor 1966).

Furthermore, the oil crisis of the early '70s contributed to efforts to become less dependent on non-renewable energy sources. Growing wood and other natural energy shortages, in combination with expanding populations in China and India, encouraged research on alternative energy sources. The birth of the ULOG group in Switzerland, EG Solar in Germany and Solar Cookers International contributed significantly to the development of solar cooking systems (Wentzel & Pouris 2007). In the United States, the work of Kerr and Cole resulted in an effective solar cooker kit that is easy to build (Yettou et al. 2014) and still used today (Wentzel & Pouris 2007). It is called eco-cooker because of it is assembled from prefabricated cardboard kits (Panwar et al. 2012).

Finally, in May 2010, in Jamhuriat High School in Afghanistan, the Scheffler Community Kitchen is installed and equipped with parabolic solar cookers (Otte 2013). The interest in improving solar cooker features and efficiency is still actual and studied by several researchers (Auti et al. 2015).

In this project, major attention is paid on concentrating solar cookers (see Figure 12a). They are the simplest, compact and potentially most efficient solutions (Panwar et al. 2012). They consist of a reflector panel focusing the incident solar radiation onto the target, i.e. the cooking pot (Muthusivagami et al. 2010)(Muthusivagami et al. 2010)(Muthusivagami et al. 2010)(Muthusivagami et al. 2010)(Muthusivagami et al. 2010)(Muthusivagami et al. 2010)(Muthusivagami et al. 2010)(Muthusivagami et al. 2010)(Muthusivagami et al. 2010)(Muthusivagami et al. 2010). This approach is capable of generating high temperatures, suitable for a wide variety of applications, ranging between 150°C and 400°C, depending on the solar irradiance, the solar cooker reflector surface and the overall concentration factor (Bortolini, Gamberi & Graziani 2013).

Such solutions could have an important impact on poverty reduction in developing areas for multiple complementary reasons (Balakrishnan 2001):

- Solar cooking systems use renewable solar energy and restrict fossil fuel use for cooking and heating food (Flavin & Aeck 2005; Pohekar et al. 2005; Deutsche Gesellschaft für Technische Zusammenarbeit & Department of Minerals and Energy 2004) conserving the precious natural resources (Balakrishnan 2001). Actually, wood and coal are the primary fossil fuels used for cooking in humanitarian camps and in the developing world where nearly 3 billion people cook and boil water with firewood (Practical Action 2010; Wentzel & Pouris 2007; Vanschoenwinkel et al. 2014). Around the 80% of the expenditure on energy services by poor people is on fuel for cooking (Flavin & Aeck 2005). In Africa, women and kids spend up to four hours per day collecting wood for cooking (Wentzel & Pouris 2007; Shaw n.d.). On the contrary, solar rays are free and available through the year, especially in areas with high solar radiation, as the sun-belt area (Harmim et al. 2014; Ibrahim & El-Reidy 1995).
- Solar cookers allow to pasteurize or sterilize water in a simple and efficient manner helping to prevent dracunculiasis, diarrhea or other common diseases caused by waterborne bacteria (Green et al. 2013). The World Health Organization (WHO) estimates that diarrheal diseases kill 1.6 million people yearly, mostly kids under five years of age (Kosek et al. 2003). Today, approximately 1.1 billion people worldwide lack access to clean drinking water and use unsafe surfaces and unclean ground-water sources (Sobsey et al. 2008; Langergraber & Muellegger 2005; Elasaad et al. 2015).
- Solar cooker use reduces the problem of air pollution (Biermann et al. 1999). Solar cookers do not generate air emissions (Biermann et al. 1999). In developing areas, air pollution is caused by the low efficiency of the *"three stone fire"* used in huts and tents (Pohekar & Ramachandran 2006; Deutsche Gesellschaft für Technische Zusammenarbeit & Department of Minerals and Energy 2004; Saxena et al. 2011). Fire burning with low efficiency produces considerable toxic smoke (Otte 2013). In poorly ventilated locations, smoke in and around homes often exceeds acceptable levels for fine particles by over 100 times (M Connolly 2005). These particles, breathed by people, causes disastrous effects on health, e.g. pneumonia, chronic obstructive pulmonary diseases, lung cancer, inflammation of the airways and lungs and eye diseases (Rehfuess 2006). According to the WHO (Rehfuess 2006), 4.3 million people die every year because of their exposure to household air pollution. This phenomenon is known as *indoor air pollution* or *household air pollution* (Vanschoenwinkel et al. 2014; Bates 2007; Rehfuess 2006; Bryden et al. 2006).

Unibo cardboard solar cooker

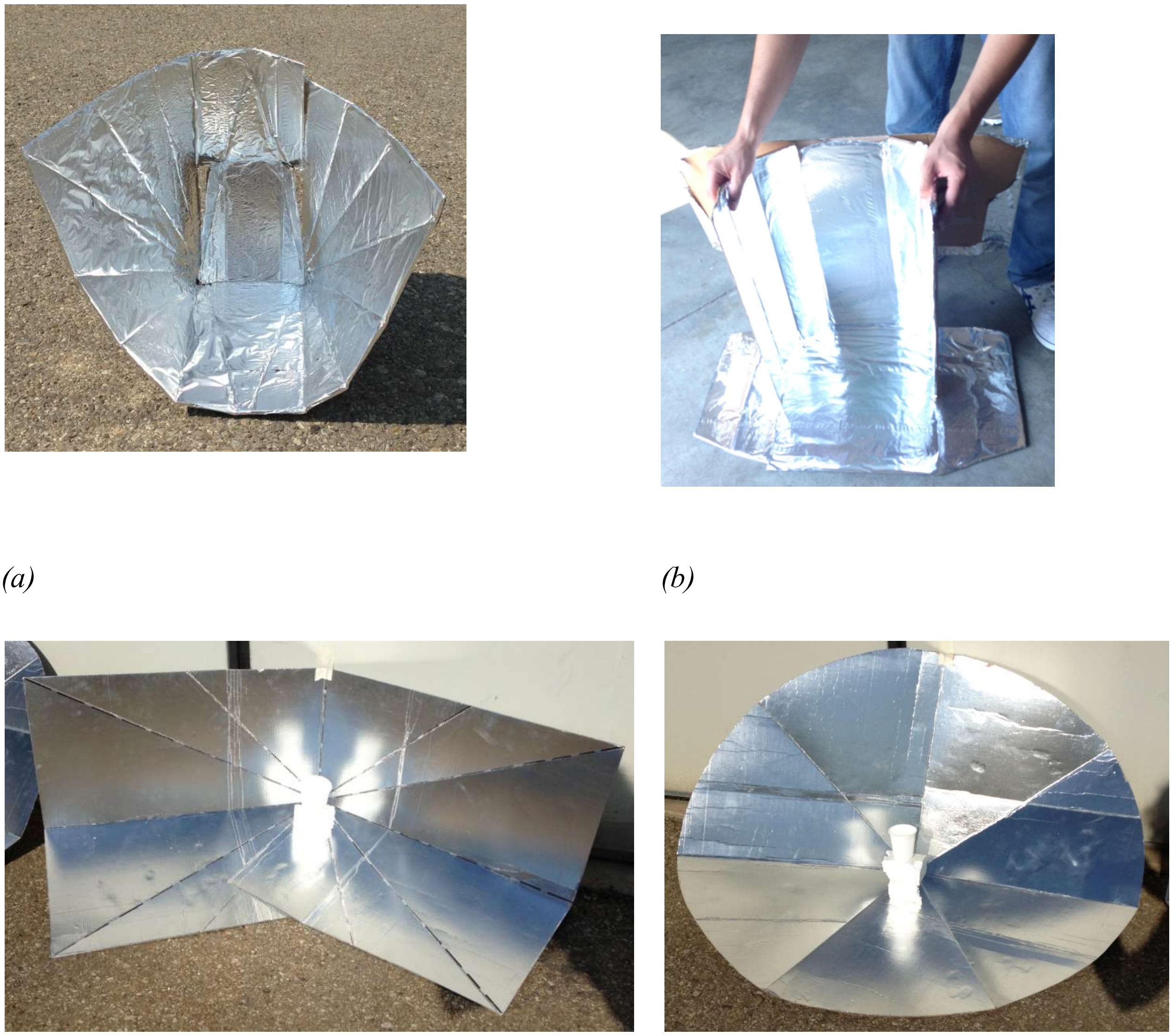
The main idea of this study is to build a concentrated solar cooker by recycling the cardboard box used for the packaging of humanitarian supplies. In particular, the *kitchen-set* box package is used, i.e. the box that contains a complete cooking set with forks, knifes and pots usually shipped to crisis areas by humanitarian organizations (Figure 13).

Figure 13:The kitchen-set box used for the prototype, courtesy of UNHRD-Lab.

Starting from the literature, a set of tentative shapes of the solar cooker are proposed. The goal is to have a simple and portable solution, easy to build, to use and to ship, obtained from the cardboard box of the *kitchen-set* after its end-of-life. After a preliminary screening, four potential ways of folding the material appear of interest. Their performances are investigated through a test session, called *elephant test* in the following, to identify the best shape joining adequate heating efficiency to easy-assemble and use. The *elephant test* outcomes are in the next section.

Elephant test made for solar cooker shape assessment

Figure 14 presents the introduced tentative four shapes to study looking for a good trade-off between heat efficiency and assembly and use complexity.



(a) (b)

(c) (d)

Figure 14:Selected shapes for elephant test, polyhedral (a), semi-cylindrical (b), bi-rectangular (c) and parabolic (d)

The *kitchen-set* box does not have any metalized surfaces to increase reflectivity. Manual bonding of an aluminum film is done. Such film is household aluminum foil for cooking with 0.016mm of thickness. It reflects up to 98% of the light and infrared heat (Saxena et al. 2011). This preliminary raw solution is acceptable for the purpose of this preliminary comparative test.

The next Figure 15 exemplifies the design and assembly procedure for the polyhedral shape, i.e. the most complex to assemble.

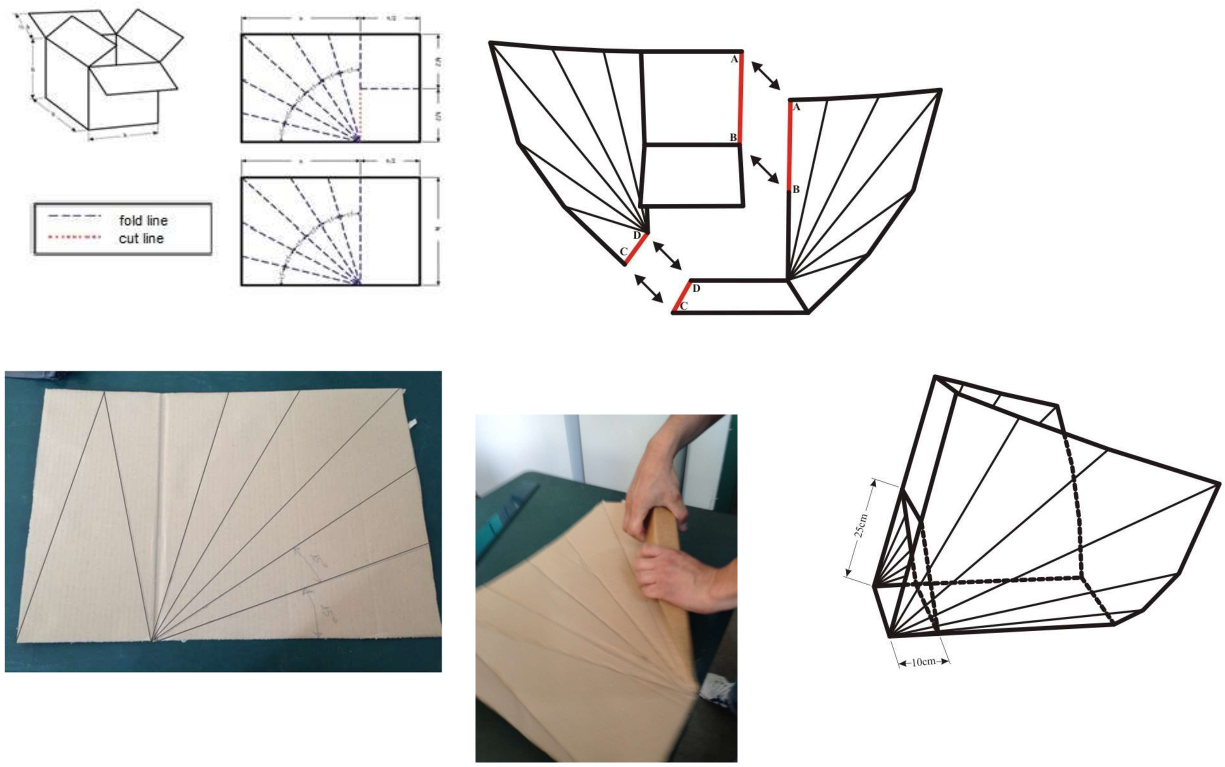


Figure 15: Assembly process of the polyhedral solar cooker.

The cube-shaped cardboard box is cut to obtain two large rectangular panels of about 300x450mm. Each panel is made up of one square face of the box and one flap. Then, six-fold lines are drawn. Each line is approximately 15° from the two packaging corners. It is further necessary to cut the "cut lines" and to stick the aluminum film onto the inner side of the two-large rectangular cardboard panels. The next phase is to fold the "fold lines" and assemble the two large rectangular panels, as shown in Figure 15. Finally, to support the device, a small piece of cardboard pushes forward the lower edge of the center square panel by a distance of roughly 10cm from the rear edge.

Given the prototypes, their heating capacity comes from the direct comparison of the temperatures reached by a pot containing 0.5 liters of water, located on the solar cooker target, when heated under the same solar irradiance conditions. The assembling and use complexity is measured qualitatively.

Different runs are done in Bologna, Italy (Latitude 44°30' North, Longitude 11°21' East, Altitude 42m a.s.l.) under comparable weather conditions in terms of solar irradiance, external temperature and time of the day. Both solar radiation and the water temperature are measured continuously (sampling time of 25s).

The adopted Delta Ohm - LP Pyra 03AC pyranometer works in the nominal range [0;2000]W/m^2 with a sensitivity of 17.09 μV/(W/m^2) - internal resistance of 37.6Ω, while the Pt100 thermocouple works in the nominal range [0;101.5]°C with a precision of 0.3%.

Figure 16 summarizes the performances of the four prototypes after one-hour run.

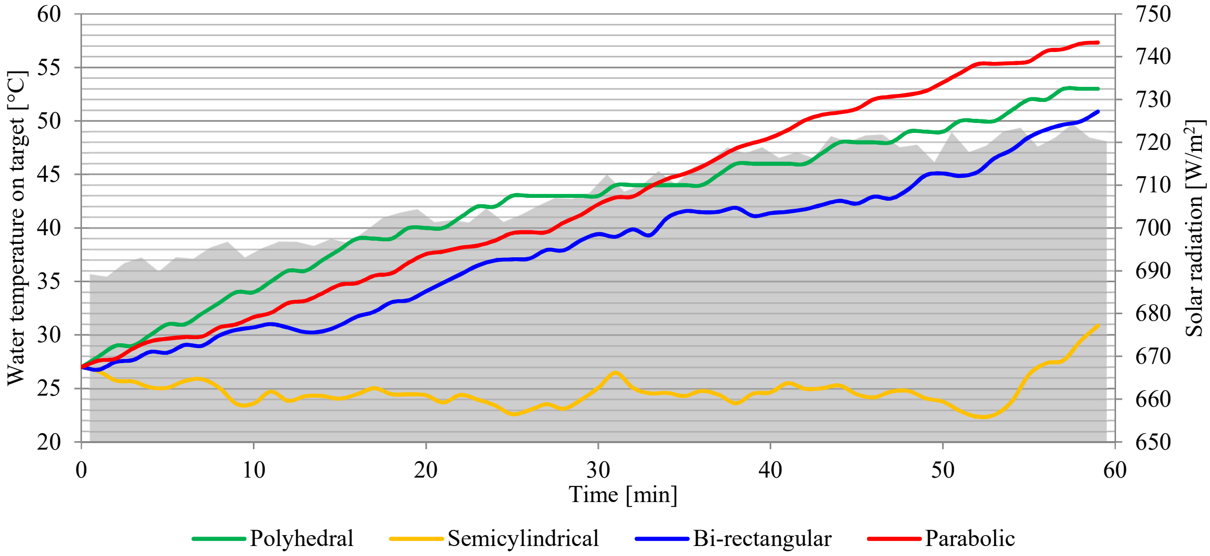


Figure 16: Elephant test results, heating performances (the solar radiation level is the shaded area).

Two out of the four shapes outperform the others. The polyhedral shape (green line) presents a rapid gradient at low temperature, i.e. below 40°C, and, then, increases slowly, while the parabolic shape (red line) has a quasi-linear trend reaching the best performance over one-hour of work, i.e. 57°C.

The following Table 4 joins such results to the second driver of analysis, i.e. the assembly and use complexity.

	Solar cookers			
	Polyhedral	Semicylindrical	Bi-rectangular	Parabolic
Heating performance	Almost high	Low	Almost low	High
Assembly and use complexity	Very complex	Quite complex	Very easy	Quite easy

Table 4: Elephant test global results

Concerning assembly and use complexity, the bi-rectangular and parabolic shapes outperform the other configurations due to the lower assembly time and higher flexibility in use, setting-up and orienting to the sunrays. From Table 1, the parabolic shape appears as the best balance between the two key drivers. Further research focuses on this shape refinement and assessing its energy efficiency through other quantitative tests.

Parabolic solar cooker experimental test

The following efficiency tests on the parabolic solar cooker use the cardboard of the *kitchen-set* metalized by an industrial process to increase reflectivity (6μm Al-lamination). After the shape assembly (Figure 17), the experimental test is a boiling water test, according to the needs within the humanitarian field.

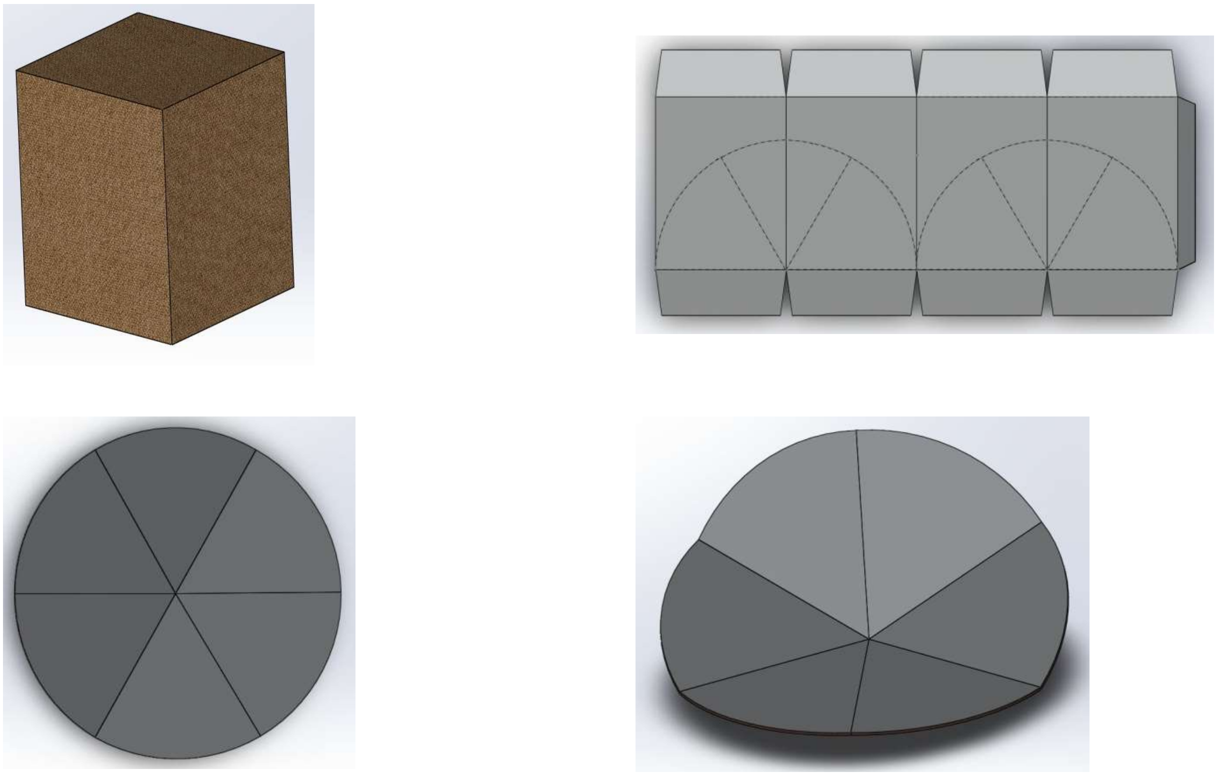
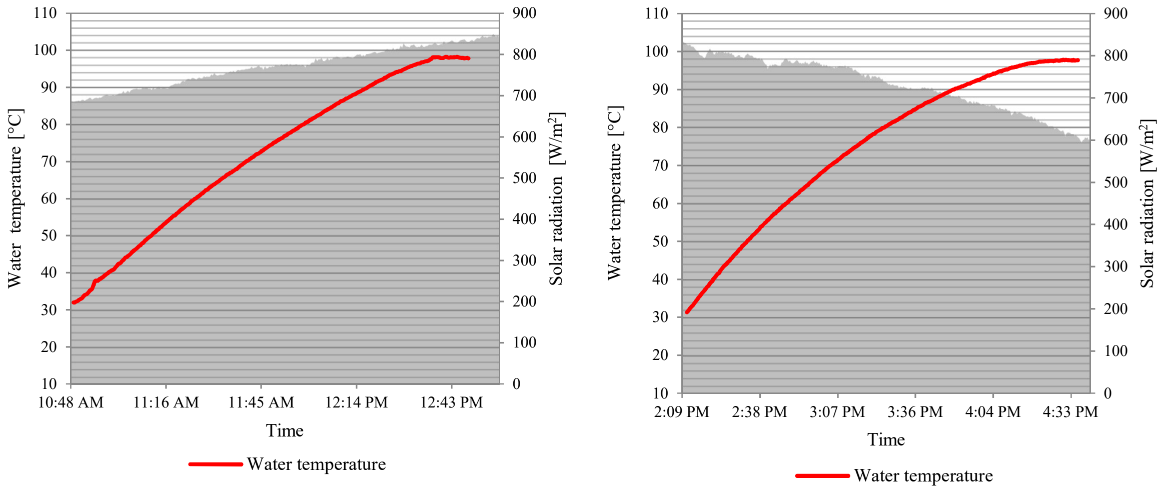


Figure 17: Parabolic solar cooker assembly from the Al-laminated kitchen-set packaging

The test is arranged in the same location as before, i.e. Bologna, Italy (Latitude 44°30' North, Longitude 11°21' East, Altitude 42m a.s.l.), using 0.5 liters of water within a closed aluminum black cylindrical pot (thickness: 2mm, diameter: 100mm, height: 150mm). According to the practice, the pot is put into a closed transparent cooking PET bag (thickness: 25.4μm) and located on the target of the parabolic solar cooker. Then, the solar cooker is correctly oriented to the sunrays and cyclically re-oriented to follow the sunbow (the optimum approach requires re-arrangement every 20 minutes). Figure 18 presents the test set.

Figure 18:Parabolic solar cooker test set

Several boiling tests are done, but for the most interesting are two, called *Test 1* and *Test 2* in the following. Such two tests simulate possible typical working conditions of the solar cooker within operative environment. *Test 1* is a morning test completed in summer from 10:48 AM to 12:48 AM. The average external temperature is of 33.1°C, the external humidity is of 52.35% and the average wind is of 12.6 km/h. *Test* 2 is an afternoon test completed in summer from 2:11 PM to 4:36 PM. The average external temperature is of 27.4°C, the external humidity is of 51.20% and the average wind is of 11.9 km/h. The next Figure 19 presents the profiles of the measured temperature of the water for the two tests together with the solar radiation level.



(a) *(b)*

Figure 19:Boiling water test results, morning Test 1 (a) and afternoon Test 2 (b), (the solar radiation level is the shaded area)

Results and discussion

The average heating-power of a solar cooker, Q, is in Equation (1) (Schwarzer & da Silva 2008; Panwar et al. 2012)

$$Q = \frac{m \cdot C_p \cdot (T_b - T_a)}{\Delta\tau} \text{ [W]} \quad (1)$$

where:

C_p	water specific heat capacity at constant pressure, equal to 4186 J/(kg·°C)
m	mass of the water [kg]
T_a	water ambient temperature [°C]
T_b	water boiling temperature [°C]
$\Delta\tau$	boiling time interval [s].

Usually, T_b is assumed equal to 95°C to avoid the uncertainty of the exact water boiling point (dependent on the exact locations). Furthermore, the overall thermal conversion efficiency, η, is the following:

$$\eta = \frac{Q}{I \cdot A} [\%] \quad (2)$$

where:

A	collector surface, equal to 0.72m^2
I	incoming average solar radiation [W/m^2]

The following Table 5 summarizes the evidences from *Test 1* and *Test 2*.

	Q [W]	I [W/m^2]	$\Delta\tau$ [s]	η [%]
Test 1	98.64	769.95	7200	17.79
Test 2	81.63	730.38	8700	15.52

Table 5: Experimental test results on parabolic solar cooker

A number of other tests under similar conditions confirm an expected efficiency in the range 14% to 18%. Such results are almost comparable to the "*three stone fire"* cooking device but they are from a renewable source and recycled cardboard. The advantages of such a system are evident.

Finally, through a reverse analysis, by using the efficiency of the solar cooker from Table 5 and the average solar radiation of a sun-belt area country, e.g. 1100 W/m^2 for the Ethiopian region, the time necessary to boil 0.5kg of water under the introduced conditions is of about 1.4 hours.

Conclusions and further research

People in developing countries make use of *"three stone fires"* for cooking using stones and local wood. Such fires are inefficient, produce smoke causing respiratory diseases and impact on the depletion of local natural resources. Moreover, in the event of humanitarian emergencies, a high quantity of aids, such as tents, blankets, kitchen sets, etc., are supplied to the areas affected by the crisis. Their packages, becoming waste after the arrival, is collected in the surroundings and openly disposed in dumping areas with immediate and long-term negative effects. Furthermore, the transportation of packaging materials that become waste immediately after their arrival represents a waste of money. Combining such issues, portable solar cookers, made from the cardboard packaging of humanitarian supplies, are of interest. This study revises the state of the art of this technology and demonstrates that a portable solar cooker from reused metalized cardboard of humanitarian aid *kitchen-set* could be an important cooking device for people living in developing countries or humanitarian camps where the lack of fossil fuels and wood is a daily problem. Laboratory tests highlight how a simple carton-made solar cooker could heat meals or boil water in a relative short time. Different shapes are tested and the parabolic configuration gives the best results with an average efficiency of about 14-18%, comparable to rough fire. The available solar radiation within regions struck by harsh crisis easily allows the use of this system.

Starting from the described experimental evidences, several prototypes are sent to humanitarian camps for direct test. Furthermore, the study of the industrial process for the effective manufacturing of a *kitchen-set* box that is easily convertible into a solar cooker with pre-printed and pre-formed fold and cut lines is a future research issue. Finally, solar cookers are not a closed solution to solve the cooking problem because of the intermittence of the solar radiation. To this purpose, the parallel study of thermal storage systems working together with the solar cookers is encouraged to enhance their range of applicability further reducing the global poverty.

Field prototyping

After these experiments, results have been presents to WFP-UNHRD management, who really appreciate the project, thus takes some prototype of solar cookers to present to partners and donors.

During the 2015 UNHRD Global partner meeting in Brindisi, where also the University of Bologna have participating, a prototype of solar cooker has been present to all UNHRD managers and partners present, and the interest on the prototype and on the packaging waste reuse project was overwhelming.

Then the UNHRD-Lab, a UNHRD section focus on testing and experiments on humanitarian items, made some encouraging test with solar cooker.

Other experiments will be doing in the real humanitarian field with some prototypes made from kitchen-set cardboard.

2.3 Organic waste (OW)

Waste management is a crucial issue in developing regions and refugee camps, where technological, economic and social difficulties and the inadequate training of the staff hamper the safe handling and processing of waste (Manga et al. 2011). If not properly managed, waste, and, especially, organic waste (OW) main subject of this paragraph, has immediate and long-term negative effects on the environment and on human health. Particularly, in overpopulated areas, organic waste management is a major theme related to human hygiene and sanitation. It contains infectious pathogens, toxic chemicals, heavy metals and, in some cases, substances that are genotoxic or radioactive (Alagöz & Kocasoy 2008; Patwary et al. 2009). Similar conditions occur after emergencies, when people are forced to live in congested humanitarian camps as refugees.

An emergency is the result of man-made or natural disasters, such as war, earthquakes, floods and typhoons (Caniato & Vaccari 2014). After a disaster, debris, materials used in the humanitarian aids (packaging waste), as shown in the previous paragraph, and organic waste from the everyday human life of high concentrations of people (e.g. faeces, urine and domestic garbage) are produced in large quantities (Garfì et al. 2009).

Waste in general and especially OW management is a major theme related to the personal hygiene, safe and health so that great deal of attention is mandatory. Sanitation and hygiene programmes aim to ensure a safe environment and to reduce incidences of environment-related diseases. Such programmes refer to safeguarding water quality, main topic of the next chapter of this thesis, proper disposal of human excreta, wastewater collection and purification, garbage disposal, dead body burying, insect control, safe food-handling practise spread and effective site drainage (UNHCR 2007).

The study present in this paragraph aims at facing the OW management both revising the topic and presenting a simple and easy-use solution for biogas micro-production system from human excreta. The system following present includes a waterless toilet connected to a simple bio-digester for biogas micro-production under anaerobic conditions. Biogas should be an important and renewable source of household energy. In parallel, the residual solid matter is a good fertilizer for agriculture.

Within emergencies or without modern and advanced systems, the collection and proper disposal of waste and OW are among the most important problems to face. Typically, the emphasis is on the raw removal of waste from the areas where people live, to avoid potential health and safety problems. After that, an integrated, intelligent and planned approach for waste management is considered (Bjerregaard & Meekings 2008). Elements of attention, recommendations and risks while tackling this issue are suggested by the literature and the current practice. Some of them are in the following list.

- Burning and incineration of waste is to be the last option. It should take place at a considerable distance from the dwellings, as it creates an environmental hazard in relation to the pollutant gases emitted into the atmosphere (Reed 2013; Baba & Smedt 2013);
- Communities have to be careful when they decide to discard harmful materials in dumps or to bury their waste. Waste is a breeding site for insect-vectors, pests, snakes and vermin that increase the likelihood of disease transmission (Harvey et al. 2011; Rouse & Reed 2011);
- Hazardous materials, such as glass and metals, which are usually buried, remain as waste hazards, particularly for children and people who usually wander around the camp and villages without wearing any type of shoes or footwear;
- Water contamination is a risk to prevent. Solid waste may carry toxic materials and pathogenic organisms into the subsoil of dumps and landfills. If landfills are not properly managed, liquid leachate contaminates ground and surface waters (Rouse & Reed 2011). The use of contaminated water is one of the main causes of diseases, such as cholera, causing serious consequences in a few hours after unsafe-water consumption (Practical Action 2010);
- The deposit of harmful materials in unsuitable areas causes air pollution due to fungi development from the waste, creating breathing difficulties and bad smells. OW disposed within deep dumps undergoes anaerobic degradation and becomes a significant source of methane. This mixture of gas, if not disperse or fired, becomes dangerous (Garfi & Bonoli 2004).

These topics and risks further stress waste management as a crucial issue in emergency contexts and poor regions for environmental, social and safety reasons (Reed 2013).

Hygiene, sanitation and water storage habits affect the health of people in developing countries and emergency areas. In the recent years, the term sanitation is used to refer to environmental conditions that affect the community health (De Bruijn 2009).

Figure 20: Pictures on sanitation in humanitarian camps [7]

It includes the means of collecting and disposing excreta and community liquid waste in hygienic manners not to endanger the health of individuals and the community as a whole (Schuler 1987). A key example is fecal-oral or diarrhea disease. Such communicable diseases are a major cause of mortality and morbidity in emergencies, where hygienic behavior has a critical influence on the transmission (M Connolly 2005). The United Nations reports that diarrhea kills approximately 2.2 million people every year and the most of the affected individuals are children under five years of age (Harvey et al. 2007). Diarrhea is the second largest killer of children under five in the world (Marshall et al. 2011). Agencies and providers working at local, national and international levels should increase their efforts in preventing and controlling the major communicable diseases and health problems by promoting large-scale and easy actions to create barriers to infection spread. In particular, they focus on the appropriate use and maintenance of sanitation facilities to prevent open defecation and burying of feces, limiting the spread of parasites, bacteria and viruses (Marshall et al. 2011), the safe disposal of feces and the improvement of personal hygiene. As example, accurate and frequent hand washing ensures that fecal contamination on hands is not transmitted via food or water (see Figure 1). Washing hands with soap reduces the risk of diarrhea by 42% to 47% (Curtis & Cairncross 2003). Keeping waterways and water sources clean is dependent on how the waste is managed. If people do use inadequate latrines, as "pit latrine" basic toilet that collects faces in a hole in the ground, or they defecate in the open, human waste seeps into groundwater, wells, rivers and the sea, causing environmental problems due to bacterial contamination (Harvey et al. 2011).

[7] http://www.ben-harvey.org/UNHCR/WASH-Manual/Wiki/images/6/6b/Child_Bathing_%28UNHCR%2C_2004%29.jpg
https://www.unicef.org/eu/images/Uganda__Photo_Essay_28.05.2015(1).jpg

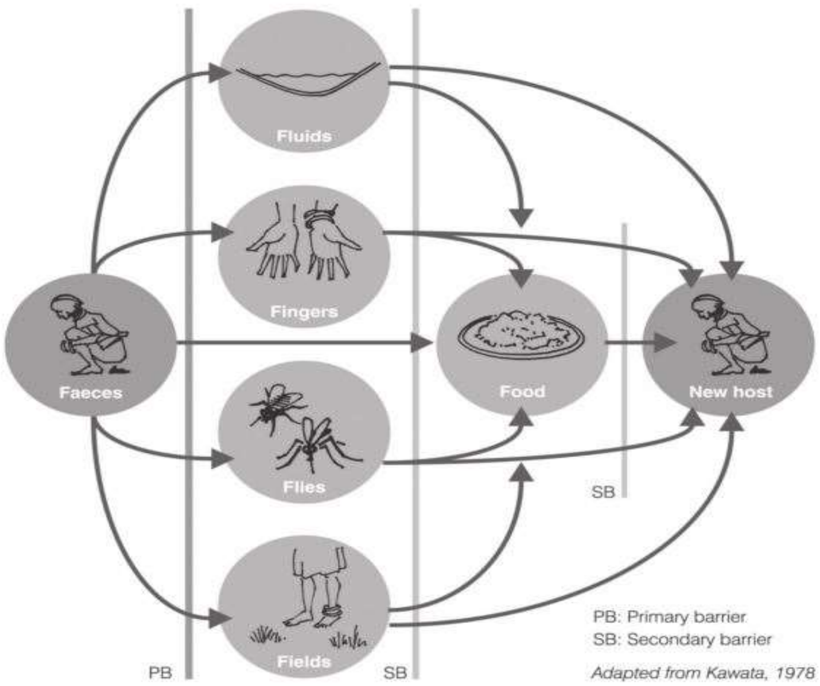


Figure 21: Fecal-oral transmission routes (Harvey et al. 2007)

Therefore, in the last years, excreta management and disposal play a crucial role in these regions. Humanitarian organizations and local authorities should pay more attention to supplying adequate training and a system for excreta disposal to create barriers against fecal contamination. Furthermore, it is well known that providing toilets does not guarantee their use (Marshall et al. 2011). Without community mobilization, participation and training, achieving a sustainable and effective sanitation and hygienic improvement is difficult.

Excreta OW represents a threat to human health from a sanitary point of view. The importance of having adequate human excreta disposal systems is well documented even if, in refugee camps, over 30% of the inhabitants do not have adequate waste disposal services or access to latrines (UNHCR 2007; Depoortere & Brown 2006). This is mainly because, during the early stages of the camp design and planning, little attention is paid to effective human excreta disposal systems (Regattieri et al. 2015). Furthermore, nowadays, approximately 2.4 billion people in rural and urban areas do not have access to adequate sanitation services (Langergraber & Muellegger 2005). In such contexts, the natural behavior of the population is to try to continue using their traditional defecation practices, wherever possible. Otherwise, people adopt 'coping mechanisms', resulting in inadequate and unsafe practices both for them and the surrounding environment (Bjerregaard & Meekings 2008).

The aim of safe excreta disposal systems is to provide and maintain the environment free from contamination risks (Sphere Project 2011). The literature and humanitarian organization manuals propose a wide range of conventional sanitation systems, ranging from septic tanks to bucket latrines, discussing their strengths and weaknesses. The acceptance factors to consider are coverage, space limitation, modularity, maintenance, socio-cultural acceptance and economic sustainability (Fenner et al. 2007). Among the most relevant issues to face are the effect on dignity and protection, especially for women, children, elderly and disabled individuals (Patel et al. 2011). Additionally, night-time use of the traditional latrines is found to be limited due to a perception of insecurity, lack of lighting, distance from tends and other unsafe conditions, particularly for woman and children (Birkeland et al. 2008). In conclusion, open defecation and raw-pit latrines remain major problems to face after a catastrophe and they are significant problems in wide areas of developing countries (Harvey et al. 2007). Furthermore, the most of the existing sanitation systems do not avoid environment contamination. The OW remains within the environment after collection without losing its polluting power. In this way, organic materials are not eliminated and they represent a steady threat for human and environmental safety with serious economic and welfare consequences.

To tackle such problems, both technological solutions and best practices are to spread, e.g. design, appropriate use and maintenance of sanitation facilities, safe disposal of faces, personal hygiene practices, access to clean water and storage water facilities, etc. Matching the introduced needs and best practices, an effective way to tackle OW management deals with the anaerobic digestion of faces and urine to micro-produce biogas, for local use, and fertilizers, as residual, for local agricultural. Biogas digesters could be an effective solution to face the sanitation problems without restricting or forcing way-of-living changes and, in parallel, avoiding the illegal market of fossil fuels. The following Section 3 presents a review of fundamentals about anaerobic digestion of OW and discusses the new idea to integrate a waterless safe toilet system to a biogas micro-production digester.

QR - Questions of research

The purpose of this research work was to find out solution to solve the organic waste: focus was in particular for organic waste produce by human in humanitarian camps, but the same technologies studied can use also in developing region in rural context.

During the literature review analysis, we asked some research questions, which I want to reply during the following paragraphs. In the successive list are present the mayor research questions on organic waste project.

- Which technologies could solve organic waste problem in developing regions?
- Is it possible reuse or recycle organic waste?
- Are biodigester feasible for developing regions?
- Is it possible build a cheap, durable and reliable biodigester for humanitarian camps?
- Is it possible produce clean-renewable-fuel from daily organic waste?

Bio digestion

Anaerobic digestion is the biological process that converts organic matter into a methane rich biogas (Kothari et al. 2014). It is a well-established technology for the treatment of the organic fraction of various waste materials (Singh & Gu 2010; Cioablã et al. 2011; Rao et al. 2010). Well documented attempts to use anaerobic digestion on biomass by human date from the mid-nineteenth century, when digesters are constructed in New Zealand and India. In 1890, a sewage sludge digester built in Exeter, UK, fueled the local street lamps (Bond & Templeton 2011). The spread of biogas technology was in the 1970s when high oil prices motivates research into alternative energy sources. In these years, fast grow of biogas use is in several Asian, Latin American and African countries (Ni & Nyns 1996; Sovacool & Drupady 2012).

Because of it is recognized among the most energy-efficient and environmentally friendly technologies for bioenergy production (Weiland 2010; Rajendran et al. 2013; Buysman 2008; Gwavuya et al. 2012; Kabir et al. 2013), anaerobic digestion of OW can mitigate the environmental and human health problems (Surendra et al. 2014) representing, at the same time, an effective OW management strategy. This is particularly true within developing countries due to the lack of other OW collection and treatment systems (Kothari et al. 2014; Surendra et al. 2014; Cheng et al. 2014; Mengistu et al. 2015; Rao et al. 2010; Cioablã et al. 2011; Guo et al. 2015).

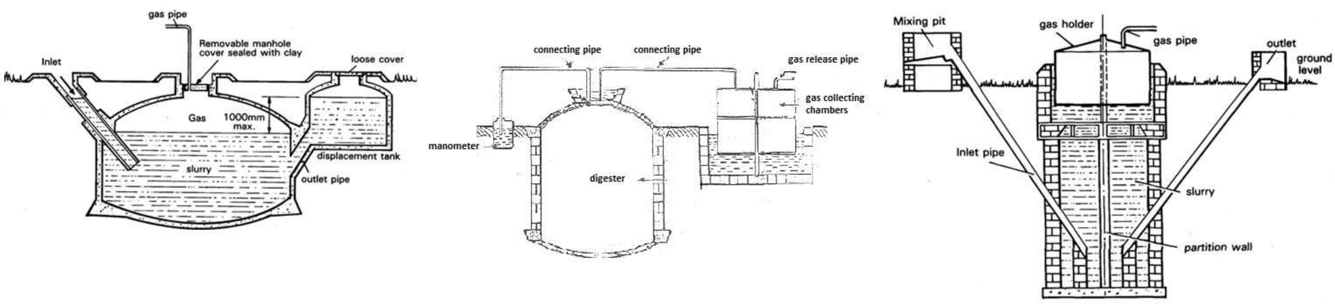
Anaerobic digestion is applied to the organic biodegradable matter in airproof reactor tanks, commonly named digesters, and it generates two main products, i.e. biogas and nutritious digestate, which is useful as a fertilizer in agriculture (Vögeli et al. 2014), containing nitrogen, phosphorous and potassium (Jatinder Singh & Singh Sooch 2004). Furthermore, anaerobic treatment minimizes the survival of pathogens within OW which is important for using the digested residue as fertilizer with no safety hazard (Weiland 2010). Finally, biogas drastically reduces air-pollutant-emissions compared to the fossil fuels (Weiland 2010; Kothari et al. 2014; Kossmann et al. 1988; Rajendran et al. 2012).

Anaerobic digestion occurs in four stages, i.e. hydrolysis, fermentation and acidification, acetogenesis and methanogenesis. Wide discussion of the bio-chemical digestion process is in (Surendra et al. 2014; Bond & Templeton 2011; Kossmann et al. 1988; Guo et al. 2015; Buysman & Mol 2013). To be effective, several factors are influent, such as temperature, pH and carbon/nitrogen (C/N) ratio. The temperature is among the most significant parameters influencing anaerobic digestion, because it not only influences the activity of enzymes and co-enzymes but also influences the methane yield and digestate quality. Particularly, biogas production becomes possible when the temperature is between 15°C and 65ºC. The methane-producing bacteria operate efficiently at temperatures between 30ºC and 40ºC (mesophilic conditions) and 50°C to 60°C (thermophilic conditions) (Vögeli et al. 2014; Bates 2007; Weiland 2010). Concerning the digestion time, it ranges from a couple of weeks to a couple of months, depending on the feedstock and the digestion temperature (Bates 2007). The acidity of the OW slurry is also important, with a desired pH between 7 and 8. With a low acid content (implying a high pH index), fermentation slows down until the bacteria produce enough acid to restore the balance. Furthermore, the optimal C/N ratio in anaerobic digesters is between 16 and 25, avoiding lower gas production due to the rapid consumption of nitrogen and toxic situations caused by ammonia accumulation (Vögeli et al. 2014). Almost all types of biomass can be used as substrates for biogas production as long as they contain carbohydrates, proteins, fats, cellulose and hemicelluloses as the main compounds (Weiland 2010). Lignified organic substances, as wood, are not suitable. The composition of the produced biogas and the overall yield depends on the feedstock type, the digestion system and the retention time (Braun 2007).

Anaerobic digester structure and layout

The structural composition of an OW digester includes, as the main component, a vessel or tank that contains the slurry. Such a tank should be hermetic and watertight to create anaerobic conditions. No strong limitations are present on the construction materials, its shape and size (Rajendran et al. 2012; Surendra et al. 2014). It must include a method of filling the slurry as well as a way of extracting the biogas. Multiple basic configurations and hybrid combinations are available, e.g. for industrial bio digester one-stage vs. two stages, dry vs. wet, batch vs. continuous, etc. (Nizami & Murphy 2010). Within development regions bio digesters are not novel solutions for OW. Government policies promote the use of household bio digester to tackle the problem of OW management (Rajendran et al. 2012; Jatinder Singh & Singh Sooch 2004; Mengistu et al. 2015). These bio digesters are simpler than industrial solutions and, commonly, they are called domestic bio digesters (Bond & Templeton 2011; Buysman & Mol 2013; Surendra et al. 2014). Domestic bio digesters are smaller than industrial bio digesters (Bond & Templeton 2011; Cheng et al. 2014; Surendra et al. 2014), they are both onsite-constructed or prefabricated (Cheng et al. 2014) with different materials, as brick, concrete, and plastics. Nowadays, their diffusion is wide, while governments and institutions are involved in subsidy schemes, planning, design, construction, operation and maintenance of such systems (Bond & Templeton 2011). Several countries in Asia, Africa, China, India, Nepal, Bangladesh, Cambodia, Vietnam, Kenya, Rwanda and Tanzania are launching massive campaigns to promote biogas technology (Kossmann et al. 1988).

The following Figure 22 shows three major types of domestic bio digesters commonly used in developing countries (Cheng et al. 2014; Rajendran et al. 2012; Mao et al. 2015; Singh & Gu 2010; Rajendran et al. 2013; Bond & Templeton 2011): the plug flow digester, also known as Chinese bio digester, sausage-bag or channel digester, the fixed-dome digester or Sri Lankan digester and the floating drum digester, also called telescopic digester or Indian digester. Even if the gas collection method and design are different, the digestion process is the same. They are designed for use with OW, animal waste and dung (Bates 2007).



(a) *(b)* *(c)*

Figure 22: Bio-digesters: plug flow digester (a), fixed-dome digester (b) and floating drum digester (c)[8]

The concept is the same in all types, they differ on constructing materials and gas collection method (Bates 2007). The plug flow digester is a polyethylene tank. At the extremity of the digester, there are the slurry inlet and outlet, while on top there is the biogas outlet. This digester is made of a single tank, easing transportation, even if its lifetime is often relatively short (Cheng et al. 2014; Buysman 2008). On the contrary, the fixed-dome digester is a non-movable, two-tank system. The slurry is generally stored in an underground vessel, protecting it from physical damage and saving space, while the produced biogas is piped to a separate chamber (Anon n.d.; Vögeli et al. 2014; Ramesh et al. 2013). Globally, the fixed-dome digester is a local autonomous plant, quite compact but with relevant repairing costs in the case of leakage (Cheng et al. 2014; Bates 2007; Munasinghe & Sanjeevani 2003). Finally, the floating drum digester is an underground digester with a moving gas holder. Biogas is collected in the top gas drum moving up and down according to the amount of the produced gas (Anon n.d.). The level of productivity is visible, immediately, but the moving drum may cause maintenance and gas-leakage problems (Cheng et al. 2014). Despite their diffusion, a common limit of such three solutions is in the building and management complexity, requiring high-value materials, human skills and economic initial investments. Furthermore, due to their dimensions, such solutions

[8] http://www.build-a-biogas-plant.com//wp-content/uploads/2014/09/Chinese_Indian_BiogasDesign.jpg
http://www.ecotippingpoints.org/our-stories/indepth/china-biogas.html

are not private, i.e. dedicate to single users, as families, but common public facilities. For this reason, acceptance difficulties are probable. To overcome these weaknesses the proposed micro-scale domestic digester, assembled from simple raw and recycled materials, becomes of interest.

OW biogas properties

Biogas is a flammable gas made of a mixture of methane (CH_4), carbon dioxide (CO_2), hydrogen (H_2) and traces of minor compounds. The composition of biogas varies on the type of feedstock and operating conditions of the digester (Surendra et al. 2014). The standard composition of biogas, coming from methanogenic bacteria working in anaerobic conditions, is in Table 6 (Karki 2009).

Compound	**Symbol**	**Mass percentage [%]**
Methane	CH_4	50-70
Carbon Dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Water Vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	*traces*

Table 6: Standard composition of biogas produced through anaerobic digestion (Karki n.d.)

Biogas burns with a clean blue flame without smoke and at a temperature higher than fire fueled by traditional resources (Charlottenburg & Rosenheim 2015). It is not toxic and its heating value is higher than kerosene, wood, charcoal and cow-dung chips (Karki 2009). Assuming a methane fraction of about 60%, under stoichiometric conditions, six liters of air combust one liter of biogas (Bond & Templeton 2011). Methane is the sole compound of biogas that contributes to the heating value (Surendra et al. 2014). Biogas is a renewable energy carrier with high potential for diverse end-use applications, e.g. cooking, lighting, heating, electricity production and as vehicle fuel (Weiland 2010; Surendra et al. 2014). Among them, the most common uses of biogas within developing countries, from small-scale digesters, are for cooking and lighting, known as two basic needs for everyday life of poor people (Regattieri et al. 2016). Concerning productivity, one ton of OW (dry weight) produces

120m^3 of biogas in industrial digesters (Charlottenburg & Rosenheim 2015) with a heating value of about 21-24MJ/m^3 (Bond & Templeton 2011). Follows that 1m^3 of biogas allows to cook up to three meals for a family of five to six people or to operate a 60-100W bulb for 6 hours (Bates 2007). Depending upon the design and operating conditions, the efficiency of biogas cook stoves in developing countries ranges from 20% to 56% (Charlottenburg & Rosenheim 2015; Itodo et al. 2007).

Unibo biodigester prototype

As introduced, this study aims to provide a domestic waterless toilet integrating an anaerobic biogas digester. The building materials have to be simple and available within humanitarian camps and poor regions, e.g. relief items. The system assembly and use must be extremely simple and of low cost. The solution is to conceive a general strategy of utilizing various recycle/reuse techniques and to produce energy tackling the barriers and risks discussed in the previous paragraph. Finally, the use and maintenance for final users, as for all prototypes developed for humanitarian camps, must be as simple as possible.

Starting from the configurations of Figure 22, the two-tank pattern is chosen, as in the fixed-dome digester, because it is simpler to build and more reliable than the other types. Two linked vessels are for OW digestion and the biogas collection and storage. Differently from the fixed-dome digester that uses masonry structures, cheaper and easy-moving tanks and jerry cans are used. They are common and immediately available devices within developing countries and humanitarian camps. Their reuse is a win-win strategy to prevent their improper disposal or burn. As example, the United Nations Humanitarian Response Depot (UNHRD) ships tanks of multiple shape and capacity, e.g. from 5 to 10,000 liters, with humanitarian aids in almost all the emergency response projects. Such tanks are collapsible and they have the same standard screwed top (diameter of 120mm). Figure 23 presents the overview of the proposed anaerobic digester waterless toilet.

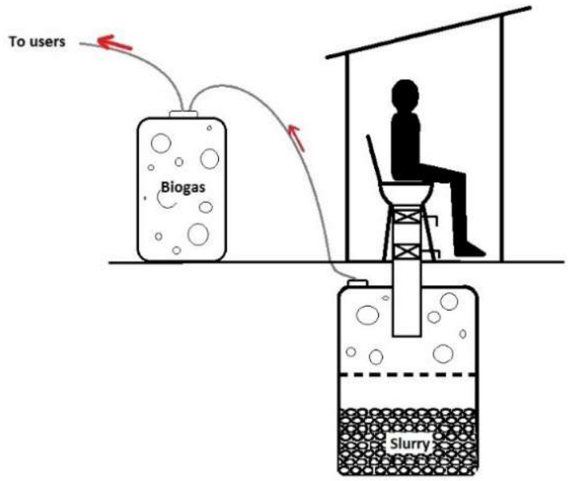


Figure 23: Overview of the proposed anaerobic digester toilet for developing regions and humanitarian camps

The slurry tank is directly connected to the toilet and a separate vessel collects the produced biogas. The top opening is a critical part of the device to prevent the biogas overflow and losses during the waste refilling. In the literature, there are many solutions matching these needs, as automatic non-return valves. Frequently, their cost does not match to the study purpose to develop cheap, simple and reproducible equipment. To solve the problem, a pipe assembled with a series of two common plastic global valves is used (see Figure 24). This mechanism permits the fill of the digester during the day by opening and closing the valves in sequence without losing biogas and minimizing the introduction of oxygen within the anaerobic chamber. It further prevents bad smells and it is compatible to the double digester installation (as toilet or as bin for waste).

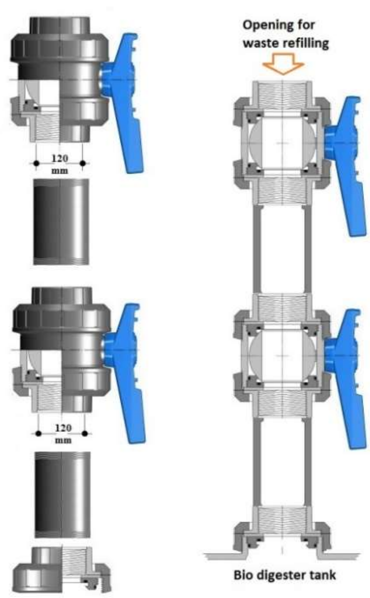


Figure 24: Digester filling pipe

The biogas collector tank can be either a common jerry can either a plastic bag for liquids. A common PVC pipe connects this tank to the digester. The tank capacity has to match to the digester productivity. As example, Haque and Haque (Haque & Haque 2006) stated that for each kilo of cow-dung, a global production of 47 liters of biogas is possible. The Khadi and Village Industries Commission (KVIC) of India estimated that the average gas production rate per kilo of cow-dung is approximately of 0.037m^3 (Haque & Haque 2006). Rajendran et al. (Rajendran et al. 2012) stated that domestic digesters should produce 0.26-0.55m^3/kg/day of biogas. Such performances depend on a mix of operative and environmental factors. If the biogas vessel is for a family of six people it should be of about 50 liters.

The last part of the system is the pipe that connects the biogas tank to the burner. It is a simple and immediately available plastic or rubber pipe fitting with the burner. To guarantee the system security, i.e. to prevent the flame from returning during the use of a burner, it is mandatory to insert a flame-breaker within the pipe.

Figure 25: The burner used during experiment

Finally, because of the bio-digester has to work under anaerobic conditions, it is recommended to use sealing paste, such as silicone or Teflon, or to use pipes and valves with a screw-end. This solution is preferable and simpler.

According to such features, a preliminary prototype of the proposed domestic anaerobic digester toilet is assembled and field-tested. Experimental evidences are discussed in the next paragraph.

Tests

This section discusses the test conditions and the results of the lab test adopting the proposed prototype. A small-scale digester is assembled to check the effectiveness of the proposed solution and to have an accurate biogas productivity analysis. A micro-gas chromatography has been done at the end of this test to define the quality of biogas product.

Figure 26 presents a picture and the schematic of the domestic anaerobic digester small-scale prototype equipped with sensors.

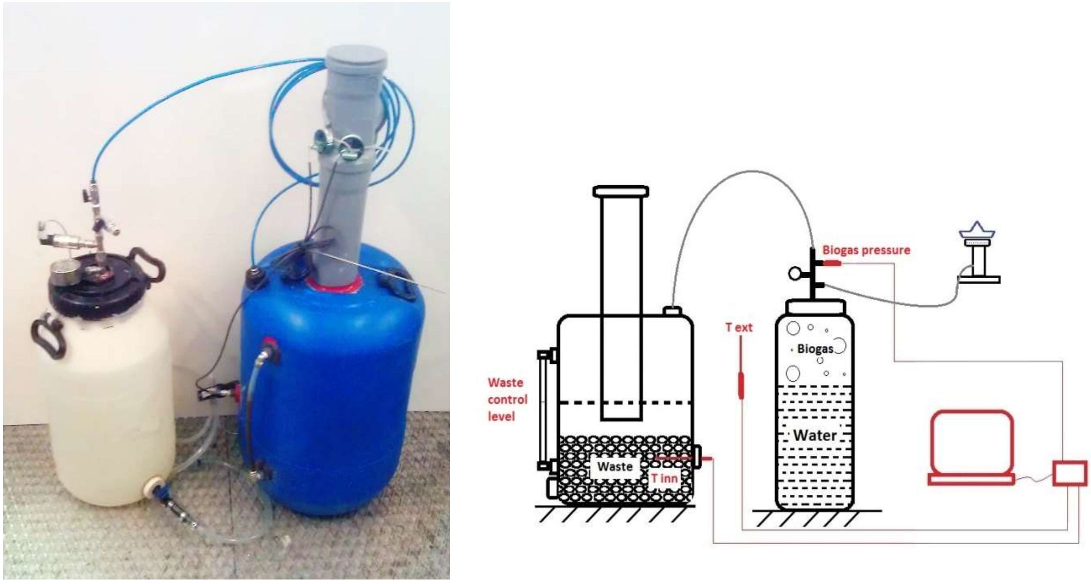


Figure 26: Domestic anaerobic digester small-scale prototype, picture and schematic

The digester (blue jerry can) has an available capacity of 6.9 liters, while the biogas vessel (white vessel) available capacity is of 0.6 liters. Pipes for biogas flow are 6mm diameter pneumatic pipes, 800mm long, equipped with pneumatic connection valves.

Data collection is through a customized real-time interface developed in Labview^{TM} Integrated Development Environment (IDE).

To maintain the temperature and relative humidity within controlled ranges, a climate-room chamber is used as the test environment. The air set point is of 35°C and the relative humidity is 25% according to typical features of common developing countries.

The trend of the temperature inside the digester and of the pressure inside the biogas vessel are tracked (sampling frequency of 0.1Hz) through a Pt-100 (accuracy ±0.3%) and a 0÷10bar membrane pressure sensor (accuracy ±0.5%).

Finally, the used slurry is a mix of 3kg of human faces, 1.9kg of urine and 0.9kg of raw water, simulating the real context of 1-day living conditions of a 5-people family. Such quantities follow the results of Haque and Haque (Haque & Haque 2006). The authors explain how the mix of both faces and urine leads to an increase of the biogas production up to 30%, compared to the use of sole water as the liquid part of the slurry. They suggest an optimal slurry composition of 50%:35%:15% (faces, urine and water). In the case of water scarcity, the use of urine as the sole liquid part with a ratio of 50%:50% is satisfactory, except for the C/N ratio to balance with a small quantity of green grass, ash or hay.

Given the small-scale prototype under the introduced test conditions and slurry composition a preliminary 1-month long test is done. The productivity analysis result, together with a chromatographic analysis of the produced biogas, are in the next Section.

Results

Figure 27 shows the trend of the biogas pressure inside the vessel during the test together with the slurry temperature.

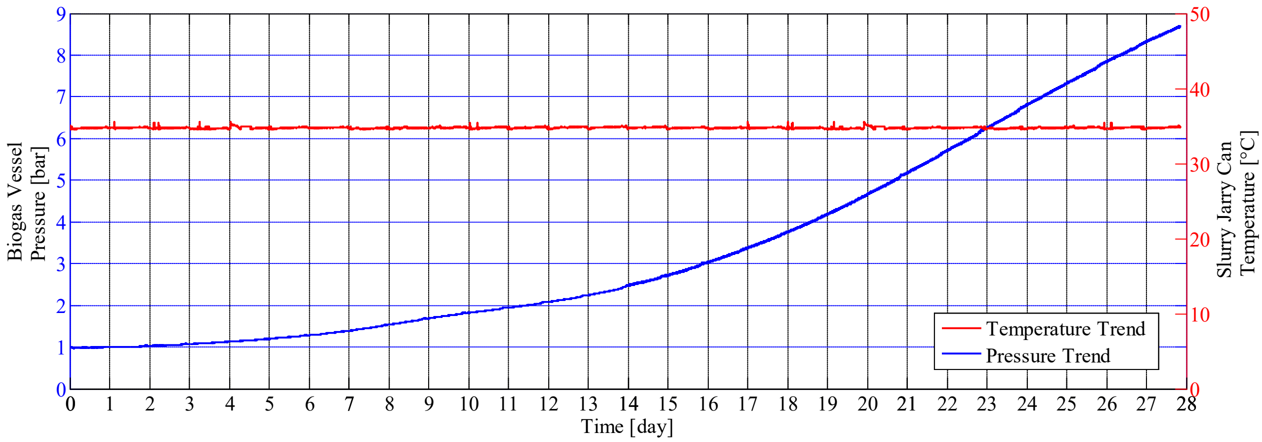


Figure 27: Trend of the biogas pressure inside the vessel during the lab test

After a five-days little increase, the pressure rises significantly reaching a value of 8.7bar at the end of the test. On the contrary, the slurry temperature remains approximately constant at about 34.5°C and the average slurry pH is 7.3, within the optimal range for anaerobic digestion. According to Halley et al. (Halley & Averous 2014), assuming the produced biogas as an ideal gas, the production rate comes from the ideal gas law:

$$n = \frac{P \cdot V}{R \cdot T}$$

where P is the pressure, V is the volume occupied by the biogas, i.e. the vessel volume, the pipe and the top of the slurry tank, R is the universal gas constant, T is the biogas temperature and n is the number of produced biogas moles. Using the equation above, it follows $n = 0.581$mol over a 1-month long test.

To convert such a value into mass and to assess the quality of the produced biogas, a chromatographic analysis is necessary. Adopting the micro-gas chromatography Soprane© software by SRA Instruments the results of Table 28 follow.

Compound	Mass fraction [%]
CH_4 - Methane	74.69
CO_2 - Carbon dioxide	15.30
H_2 – Hydrogen	10.01
Other gases	*traces*

Table 7: Composition of biogas

The overall quality of the produced biogas is higher than the current standard of Table 7 due to the higher fraction of methane. Such a result comes from the optimal mix of slurry and the fully controlled anaerobic digestion environment. Further tests to optimize the biogas quality varying the slurry composition are among the next future developments.

Weighting the compound molar masses by their fractions, the produced biogas molar mass is of 18.883g/mol, so that the total produced biogas after 30 days of digestion is of 10.972g, equal to 3.657g per kg of dry slurry. Finally, under normal temperature and pressure conditions, the volume of the produced biogas is of 0.132Nm^3, equal to 0.044Nm^3/kg of dry slurry. Such a value is lower than the industrial digester productivities but matches with domestic needs, i.e. micro-generation, and has the strong advance of a raw and simple bio-digesting system used to get it (Regattieri et al. 2016).

The proposed results are from a first full lab-test and require refinements and further validation, e.g. longer digestion time, slurry composition optimization and environmental condition change. Nevertheless, they are promising for the development of domestic micro-generation of biogas through OW anaerobic digestion within emerging and humanitarian contexts.

Conclusion and further research

People living in developing countries and humanitarian camps do not have standardized waste management systems and often neglect the negative effect of uncontrolled organic waste (OW) on their health and on the environment. OW is a significant problem and creates severe risks for people everyday life. If buried, it becomes a serious problem causing water pollution, bad odours and the diffusion of flies, insects and worms. Furthermore, polluted aquifers carry lethal diseases, such as chronic diarrhoea, killing, approximately, 2.2 million people per year.

This study revises the waste and OW management and sanitation hot topic for developing countries and within humanitarian crises. It also presents a domestic anaerobic digester toilet for OW management and valorization to obtain biogas and solid fertilizer, as residual. The system is a win-win solution to both safely dispose OW and to produce heat for domestic uses. The proposed system is for rural destinations with no access to advanced materials and technologies. Simple and durable materials are preferred. Bio-digesters in poor regions and humanitarian camps are a practical and useful solution for the toilet problem requiring minor changes on the people habits. The assembly and preliminary lab-tests on a prototype of the bio-digester assess the effectiveness of the idea and of the chosen system layout leading to recommendations for improvements and further analyses on the system productivity. The key obtained results are of 0.044Nm^3 of biogas per kg of dry slurry with a 74.69% mass fraction of methane within the biogas mix.

Future research deals with the system operative test in humanitarian camps and rural regions to measure its social acceptance and the real potential for people living under emergencies together with standardization of the system layout and the definition of operative guidelines to maximize the quality and quantity of the produced biogas.

3. Water purification and desalination

Introduction to the water scarcity

Water for creatures is life. People, animals and plants all need water to live and to grow (). People need water as surely as they need oxygen: without it life could not exist (Conant 2005). Water scarcity, which is the lack of sufficient available water to meet needs, is a problem that affects every continent and around 2.8 billion people (Watkins 2006; UNICEF 2008). Water is not only a scarce resource, but it might be undrinkable because of the presence of man-made and organic pollutants. Since the mid-1990s there has been a proliferation of international conferences dealing with water, along with a proliferation of high-level international partnerships.

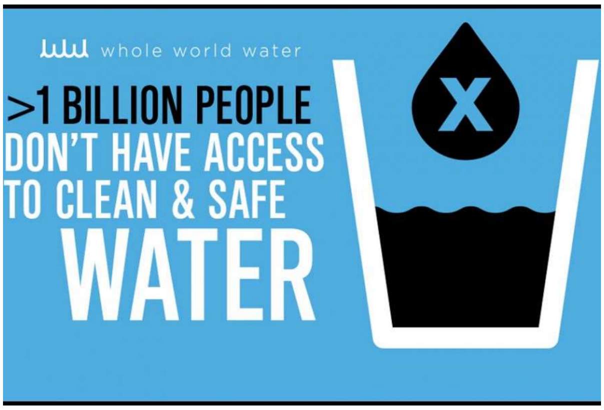


Figure 28: Advertising on water scarcity in developing regions[9]

Meanwhile, there are 23 UN agencies dealing with water and sanitation (Watkins 2006), i.e. Unicef, UNHCR, FAO, WHO, etc [10]. Such programs refer to safeguarding water quality, disposal and use, proper disposal of human excreta, wastewater collection and purification, garbage disposal, dead body burying, insect control, safe food-handling practice spread and effective site drainage.

Clean water and sanitation would save the lives of countless children, support progress in education and liberate people from the illnesses that keep them in poverty (Watkins 2006). This problem become enormous in emergency situations, where water, food and generally resources are more scarce than usual, and people are forced to live for surviving in congested area as humanitarian camps.

[9] https://www.treadright.org/sites/default/files/styles/large/public/worldwaterday.jpg?itok=zHo4GDc7
[10] http://www.unwater.org/

Lack of drinkable water

Overcoming the crisis in water and sanitation is one of the great human development challenges of the early 21st century. Water, the stuff of life and a basic human right, is at the heart of a daily crisis faced by countless millions of the world's most vulnerable people. A crisis that threatens life and destroys livelihoods on a devastating scale. This crisis claims more lives through disease than any war claims through guns. It also reinforces the obscene inequalities in life chances that divide rich and poor nations in an increasingly prosperous and interconnected world and that divide people within countries on the basis of wealth, gender and other markers for disadvantage (Watkins, 2006).

The problem of water scarcity affects each continent and consists in three different major aspects:

- water stress;
- water shortage or deficits;
- water crisis

Water stress is a recent concept, it is the difficult to obtaining sources of fresh water or the impossibility (physical or economical) to reach the resources of fresh water such as aquifers, groundwater, etc. This situation may result in further depletion and deterioration of available water resources in term of quantity (aquifer over-exploitation, dry rivers, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc .). Water shortages is the lack of drinkable water, caused by different reasons such as climate change, water pollution and water overuse. In many parts of the world is not only a problem catch water in nature, although catch drinkable and safe water. Rivers and lake, in fact, suffer by man-made pollutants from farming, agriculture, companies, and organic pollutant from latent waste management. Particularly, in overpopulated areas, these themes are related to human hygiene, sanitation and water quality. Today, nearly 1 billion people all around the world don't have access to it (). Clean, safe drinking water is scarce.

Finally, water crisis, the worst, is the lack of sufficient available potable, unpolluted water to meet needs in a region due to environmental aspects, such as in the sub-Saharan African regions or in other desert areas.

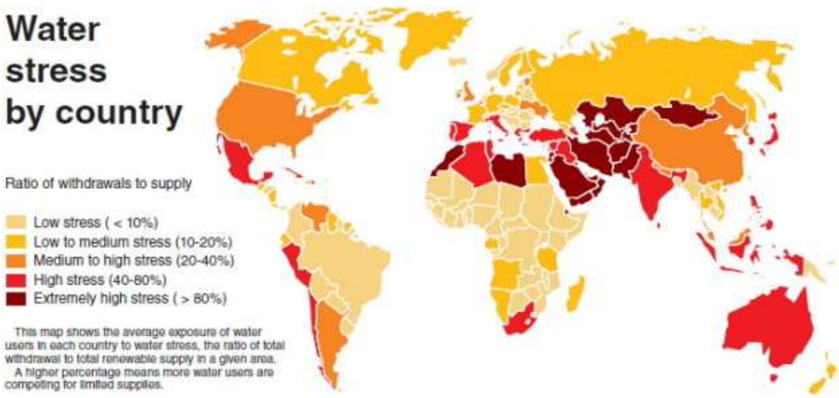


Figure 29: Worldwide water stress status by country

Disease related water

In poor regions water, should be undrinkable and especially carrier of many disease (Conant 2005): diarrhea, dysentery cholera, typhoid fever, etc. are caused by many kinds of germs carried by human waste, unsafe water, flies and insects and also by food. This is due to pathogens and micro-organism, in particular bacteria, viruses and parasites, cause a water microbiological contamination, and then disease in humans. Water contaminated with pathogens is the second biggest killer of children around the world: more than 4,500 children die every day from pathogens that cause diarrhea. As well, almost half of all people in developing countries are sick at any given time from illnesses that are caused by poor drinking water and lack of proper sanitation.

Figure 30: Most common disease related water

Disease caused by water are usually classified, not by pathogens, but by the Bradley classification, based on transmission routes in the environment, in which water-related disease could be:

- water-borne: ingestion of contaminated water

- water-washed: inadequate use of water for domestic and personal hygiene
- water-based: infections caused by parasitic pathogens found in aquatic host organism
- water-related: caused by insect vectors which either breed in water or bite near water

Water-borne disease, most interesting for the topic of the research because one of the major problem in humanitarian camps and developing regions, are disease cause by the ingestion of water contaminated by human or animal faces or urine containing pathogens.

The worst water-borne disease is undisputable diarrheal. Approximately 4 billion cases of diarrhea each year cause at least 1.8 million deaths, 90% are children under the age of five, mostly in developing countries. These deaths represent approximately 4% of all deaths, and 18% of under-five child deaths in developing countries. The World Health Organization (WHO) estimates that 88% of diarrheal diseases is caused by unsafe water, inadequate sanitation and poor hygiene. Water, sanitation, and hygiene interventions reduce diarrheal disease on average by between one-quarter and one-half. The most common causes of severe diarrheal disease are rotaviruses, photogenic E. coli, protozoan parasites, etc. Shigella and Vibrio cholera, two diarrheal pathogens, are particularly infectious and can cause severe epidemics.

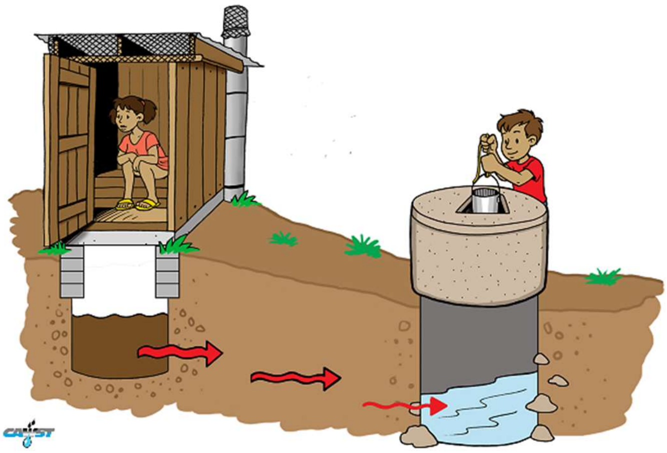


Figure 31: Contamination of groundwater

In the following list are present some non-diarrheal water-borne diseases from a chapter of a Unicef Handbook (UNICEF, 2008):

- Typhoid fever (not to be confused with typhus fever, caused by body lice) is caused by ingestion of Salmonella typhi bacteria in food or water, and affects about 17 million people each year, causing some 600,000 deaths. Infection causes a sudden high fever, nausea, severe headache, and loss of appetite. It is sometimes accompanied by constipation or diarrhea.

- Hepatitis, or liver inflammation, is caused by viral infection. Symptoms include yellowing of the skin and eyes (jaundice), dark urine, fatigue, nausea and vomiting. Two forms of the disease, hepatitis A and E, are primarily caused by ingestion of faecally contaminated drinking water. Hepatitis A causes about 1.5 million infections each year (mostly in children), and can occur in epidemics. Hepatitis E is less common than hepatitis A, and occurs mainly in epidemics caused by monsoon rains, heavy flooding, contamination of well water, or massive uptake of untreated sewage into city water treatment plants. No specific treatment exists for hepatitis A or E, but most (>98%) patients recover completely. Hepatitis can have more serious effects on older or immunocompromised people, and pregnant women are particularly vulnerable to hepatitis E, with approximately 20% mortality rates. Hepatitis B, C and D are not considered water-borne diseases, as they are transmitted by contact with body fluids.
- Polio is a highly infectious viral disease that mainly affects children under 5. Most infected people show no symptoms, but severe cases cause irreversible paralysis. As a result of a concerted initiative – the Global Polio Eradication Project – reported cases have declined by over 99% since 1988, from estimated more than 350,000 cases to 1,919 reported cases in 2002. Still, polio can easily spread among unimmunized populations, and in 2003 polio was still endemic in Afghanistan, parts of India, and Pakistan in Asia; and Egypt, Niger, northern Nigeria and Somalia in Africa. Since poliovirus is primarily transmitted through the fecal-oral route, safe water and sanitation interventions can help reduce risk, but the top priority is to ensure high immunization coverage of infants and children.
- Legionellosis may also be considered a water-borne disease, but infection occurs through inhalation of water droplets containing Legionella bacteria. Severe infection leads to Legionnaire's disease, characterized by pneumonia and 5-15% mortality rates. More mild infections cause Pontiac fever, which usually requires no treatment. Legionella prefer warm environments (>36°C) and can survive in the environment in association with bacteria or protozoan hosts. Legionella can grow in water storage tanks, boilers, or pipes in distribution systems. Outbreaks of Legionnaire's disease are fairly rare.
- Leptospirosis is a bacterial disease caused by ingestion or bodily contact with water contaminated with the urine of infected animals, especially rats. Symptoms include a high fever, headache, vomiting, chills and aches. If not treated, the disease can cause serious damage to internal organs. The disease is difficult to diagnose and is often overlooked, but may be important, especially following flooding.

For drink unsafe water should be purified before use, with proper treatment including filtration, disinfection and depuration or at least boiling: these methods should produce pathogen-free water. Boiling, for example, kills viruses and bacteria present in water causes of water-related diseases. However, a proper filtration is necessary to ensure the quality of water in terms of taste and turbidity.

The problem of water in humanitarian camps

The water supply is a huge problem in humanitarian camps, both because these camps are overpopulated and usually areas where they are established do not have natural resources available for all refugees (Regattieri et al. 2015). A water supply is an essential requirement for people. Provide to daily request of fresh, clean and drinkable water in humanitarian camps is an arduous vital mission for humanitarian agency. A water supply and a correct waste management system are the major themes related to sanitation. Sanitation and hygiene programs aim to ensure a safe environment and to reduce incidences of environment-related diseases. Water and sanitation are critical determinants for survival especially in the initial stages of a disaster relief. Furthermore, people need clean water and sanitation to maintain their dignity.

The right to water and sanitation is inextricably related to other human rights, including the right to health, the right to housing and the right to adequate food. As such, it is part of the guarantees essential for human survival.

Figure 32: Pictures of real humanitarian camps water systems[11]

The aim of humanitarian organizations is to assure the availability of enough water to allow its effective distribution in the required quantities, and to ensure that it is safe to drink and easily accessible. In extreme emergency situations, there may not be sufficient water available to meet basic needs and in these cases, supplying a minimum level of safe drinking-water for survival is of critical importance. Providing water is never free: water needs to be collected, stored, treated and distributed. Providing too much water is a waste of money (WHO n.d.). On the other hand, insufficient water and the consumption of contaminated water are usually the first and main causes of ill health to affect

[11] http://www.centreculturelsyrien.org/wp-content/uploads/2015/11/94066scr.jpg
https://i.pinimg.com/originals/31/0e/28/310e28f09edf3e92871df401c9745217.jpg

displaced populations during and after a disaster. Determining how much is needed is one of the first steps in providing that supply (Gorchev & Ozolins 2011).

Understand the requirements of each situations is not a simple task because it is conditioned by different factors, such as where nutritional standards have not been met, the urgency to improve the standard of water and sanitation is greater as people's vulnerability to disease will have significantly increased. The same applies to populations where HIV and AIDS prevalence is high or where there is a large proportion of older people and persons with disabilities.

Furthermore, another complication, is people use water for a wide variety of activities and do not always have predictable needs. In some cultures, for example, the need to wash sanitary towels or to wash hands and feet before prayer may be perceived to be more important than other water uses. Is fundamental talk to people and understand their priorities.

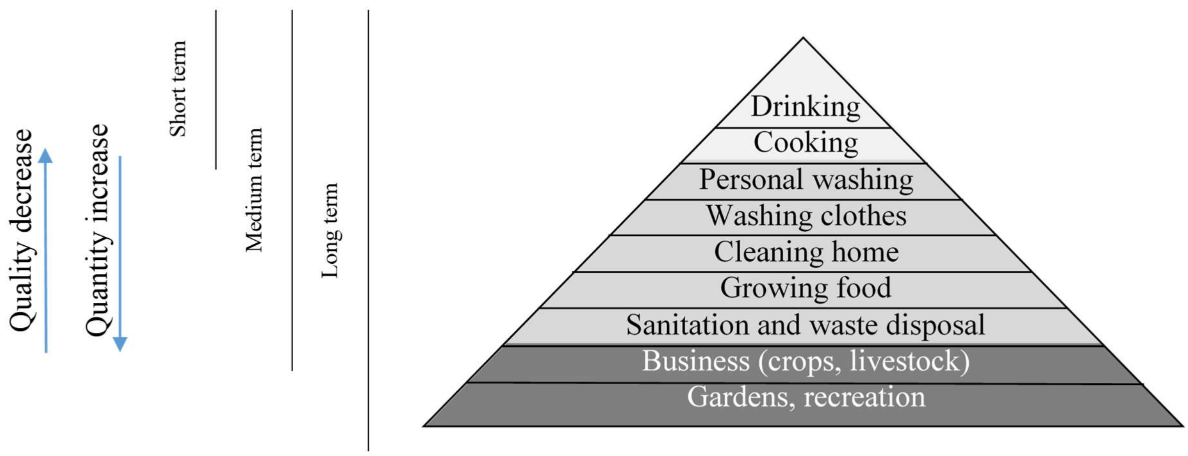


Figure 33: Water requirements in Maslow's hierarchy of needs

The figure 34 above, demonstrates with the Maslow's hierarchy of needs, some water requirements generally are more important than other. The picture shows how needs of people be divided in three macro categories, in the short-term for survival, in the medium-term for maintaining, and in the long-term for lasting solution. As demand for water increases, generally the quality required for each use can be reduced. Water for cleaning a floor does not have to be of the same quality as drinking-water and water for growing subsistence crops can be of a lower quality still. Despite of the difficult to quantify the water requirements in different situations and environments, as explained above, due to the multitude of variables condition in the study, some humanitarian organizations and researchers try to put on paper water requirements in humanitarian context. In the table below XX, are presents some of these researches, by The Sphere project, UNHCR and WHO. Moreover, to compare these quantities was added also the US military water requirements. Is interesting notice how being different the total amount of water necessary between the refugees and the militaries.

		The Sphere Project (2011)	UNHCR (1992)	WHO	US Army requirement (2008)
		PERSONAL INTAKE			
Drinking and food	Sedentary life, Temperate environment Physically active Increased temperature	2.5-3	n.d.	2.5 adult male (70kg) 2.2 adult female (58kg) 3-4 average 1 child (10kg) 0.75 child (5kg) 4.5 adult male (70kg) 4.5 Average 4.5 adult female (58kg)	6.5 Average for temperate climate
Cooking needs		2-6	n.d	2-3	7,5
Hygiene practices		3-6	n.d	6-7	6.5
Total basic water needs		**7.5-15**	**7**	**11-14**	**20,5**
Minimum refugee camp allocation			15-20	15-20	
		CAMP SERVICE			
Health centers	per outpatient per inpatient	5 40-60	5 40-60	5 l 40-60	
Hospital (with laundry facilities)			220-300	220-300	
Schools		3	2	2	
Feeding center			20-30	20-30	
Camp administrator			5	5	
Staff accommodation			30	30	
Mosques				5	
		LIVESTOCK AND AGRICULTURE			
Vegetable gardens				3-6 l/m^2	
Cattle, horses, mules				20-30 l/head	
Goats, sheep, pigs				10-20 l/head	
Chickens				10-20 l/100	

Table 8: Refugees water intake compare to military water intake

Humanitarian camp water supply system

As wrote before, the place where a humanitarian camp is placed, should be fundamental for the sake of refugees. If possible, the humanitarian agency usually builds camps close to environmental resources and in strategic logistic points to ensure the humanitarian supply chain for relief. One of the most important guideline for the camp choice is the presence of fresh water supply such as rivers, lakes and aquifer, to use such as water reserve for the camp. The camp proximity to fresh water supplies is one of the most important parameter for the camp locating.

Sometimes appended that is difficult find an area close to a fresh water resources, or appended also humanitarian camp is built in an area with a scarcity of surface fresh water. In these cases, is necessary find aquifers to use like water supply. Sometimes build and digging springs and wells is the only option available for humanitarian organizations to have a water resources in the camp. Only if this option is not possible is necessary set-up a supply chain to provide fresh drinkable water in the camp.

Figure 34: Well digging in an Asian camp

A system made by water mechanical pumps, carry the water into the camp. The number and the dimension of pumps depend by the water flow necessary in the camp, and obviously as discuss in the paragraphs above, by the number of people live in the camp. Water usually is storage in huge collapsible tanks, used as a water buffer, such as the picture below. Depending from environment conditions and for the duration of the humanitarian mission water tank should be different as shape, materials and dimensions. Sometimes in some humanitarian camps is possible find also plastic, rigid water tanks, but these are more difficult to install and to ship.

Figure 35: Collapsible water tank used in humanitarian camps

Before the storage water pass through a filtration system: a mechanical filtration system is used, made with a multi-layer filtration. The most used filters are made by sand layer and charcoal layer. This filtration system is not capable to hold all the substances present in the water, but is a good such as pre-filtration system, as explained in depth in the following paragraphs.

Water storage usually is chlorinated to kill viruses and bacteria presents. Chlorine not only disinfect water, but also all the water system, such as tanks, pipes and taps.

With smaller pumps water is spread to all the camp by water taps place in different parts. In the following picture there is a water taps system used in WFP-UNHRD humanitarian camps.

Figure 36: Water taps system used in humanitarian camps in UNHRD bases in Brindisi

Figure 37: The same water taps in a humanitarian camp in South Sudan[12]

The water system present above is the most used in humanitarian camp, such as WFP, UNHRD, UNICEF, etc. all over the world: it is strong, simple and reliable, such request by humanitarian organization plants. This is very helpful because ensure a good fresh water flow, clearly depends by the water quantity in the spring used. But the quality of the water product depends by the quality of the spring: the filter is not able to remove all particles and substances present in the water especially the finest. But if use simultaneously with a improved filtration system, produce ultrapure water, should ensure both water to drink and cooking and a lower quality water for people cleaning and hygiene.

To improve the water supply system, is possible introduce in humanitarian camps innovative filtration technologies, ensure the final quality of treated water to use with the traditional filtration system. As shown in the previous paragraphs, different quality of water should use for different purposes. The introduction of water desalination systems in humanitarian logistic should enhance the camps location choose. Salt water is much more presents than fresh water. Produce drinkable water from undrinkable salty water should revolutionize the water supply within humanitarian camps. Furthermore, water treated by these plants is much more safety than fresh water treated with sand-charcoal filters.

The integration of these plants in humanitarian sector, moreover, will increases water source available for producing drinkable water, as well as the overall fresh water quality, improving widely life condition of poor refugees in humanitarian camps.

[12] https://www.mercycorps.org/sites/default/files/southsudan-201612-dnahr8407-2.%20Medium%20Resolution.jpg

Water filtration system in humanitarian camps

Today in WFP-UNHRD (World Food Programme – UN Human Response Depot) humanitarian camps are used cheap, simple and reliable water filtrations system, to clean fresh water for refugees. Water is used by families for all household needs, from drinking and cooking to personal hygiene. Some pumps take water intake from natural fresh water supply near camps, filtering through some multi-stage filters explain in depth below and then storage in the camp. These systems are very far to be the best solution for producing drinkable water for people usually jet unhealthy and affect by different contagious disease. The quality of the treated water, in fact, in terms of color, turbidity, and presence of pathogens, depends to the quality of the intake spring water. In addition, with these plants is not possible use sea water or just salty water as a water resource, because they cannot remove salt ions, so is necessary camps be close to some fresh water supply. Anyway, each water filtration system should produce up to 4 m^3 of water per day, depending on the spring water presence in the camp site, sufficient to satisfy the community needs.

These water purification systems are composed by some water pumps, pipes, filtration system (the number depends to water purification system dimension), some storage tanks and taps. Tap are used to fill small tanks provided to each family for household water needs.

The filtration system, core of these plants, is made by multi-layer filters (Sphere Project 2011) (Figure 39), made with sand, activated carbon and other mechanical filters: the sand layer offers a mechanical filtration, removing part of gross impurities like turbidity and odors. Secondly, the water passes through a charcoal carbon filter, which reduces organics concentration and oxidant by chemical adsorption. Pores in carbon are a natural filter system able to remove particle until 50 μm.

Figure 38: Example of multi-layer sand, carchoal filtration system[13]

After filtration, water is stored in some tank and chlorinate. Chlorine is required to disinfect water and water supply (pipes and tanks), as it kills bacteria and microbes, and makes water ready to use (Ersel 2015).

13 http://www.omegagroup.gr/omega/portals/0/Images/%CE%95%CF%80%CE%B5%CE%BE%CE%B5%CF%81%CE%B3%CE%B1%CF%83%CE%B9%CE%B1_%CE%BD%CE%B5%CF%81%CE%BF%CF%85/Multimedia-filter.png

QR – Questions of research

In this chapter the objective of the research was to understand if the newer, innovative filtration systems used in industry to desalinate water should use also in humanitarian logistic to improve the water filtration system.

These systems can produce drinkable water from dirty, mud fresh water and also from sea salt water; the quality of the water products is the finest ever. These solutions will immensely increase the quality of drinkable water products, but especially increase the springs of water available for humanitarian needs. Sea salty water is most common than fresh water. Use the sea salt water such as water supply should enlarge the possibility to humanitarian agency both during the selection of the camp locations and during the humanitarian mission too.

However, before introduce these technologies in humanitarian field, is necessary understand if these systems are already ready to use in a difficult and severe environment such as humanitarian is. Furthermore, is necessary understand if these systems meet the utilizing features of humanitarian standard conditions, i.e. reliability, maintainability, user-friendly, costs-efficient etc.

The research questions ask during the research are:

- Is possible already use desalination system in humanitarian camps?
- Are them affordable for humanitarian agencies?
- Do desalination systems meet humanitarian standard conditions, i.e. reliability, maintainability, user-friendly, etc. yet?
- Are Osmosis processes the best trade-off such as desalination system for humanitarian camps?

3.2 Desalination processes

Desalination is a natural process for the production of drinkable fresh water from sea salt water. Sea water contains different types of dissolved substances, from mineral salts (sodium, potassium, magnesium, etc) to organic substances like bacteria, viruses, etc. Most common sea water components are shown in the table below (Table 9).

Ions	**Average values** $\frac{g}{Kg\ Water}$	%	**Actual values** $\frac{g}{Kg\ Water}$	%
Chlorine, CL	18,971	55,29	18,9799	55,04
Sulphate, $SO_4{}^{=}$	2,639	7,69	2,6486	7,68
Carbonate, $CO_3{}^{=}$	0,071	0,21	-	-
Bicarbonate, $HCO_3{}^{-}$	-	-	0,1397	0,41
Bromine, Br^{-}	0,065	0,19	0,0646	0,19
Fluorine, F^{-}	-	-	0,0013	0
Boric Acid, H_3BO_3	-	-	0,0260	0,07
Sodium, Na^{+}	10,497	30,59	10,5561	30,61
Magnesium, Mg^{+}	1,278	3,72	1,2720	3,69
Calcium, Ca^{++}	0,411	1,20	0,4001	1,16
Strontium, Sr^{++}	0,411	1,20	0,0133	0,04
Potassium, K^{+}	0,379	1,10	0,3800	1,10
Total	34,311	100,11	34,4816	99,99

Table 9: The main components of sea salt water

Sea water salinity range is from 18-20‰ (black sea) to most salinity oceans 75‰. Water salinity inlet into the plant is one of the most important parameter to decide plant characteristics (i.e. number of desalination stages, plant sizing, types of membranes, etc).

Process of desalination consists in removing dissolved salt and other macro-substances from the water. There are different processes for make this separation: filter salty water by nonporous membrane holding salt micro molecules, separate liquid from salt by freezing water or by an evaporation/condensation process. These different industrial processes for remove salt from water and all of them are inspired by natural processes. For example: solar desalination creates humidity heating the sea surface that will become rain; sea water freezing in poles is another method to separate water (in the form of ice) from salt; osmosis in membrane cells is a natural filtration for different salinity liquids by the use of a microporous membrane.

There are many classifications for desalination processes: generally, desalination processes can be categorized into two major types: phase-change/thermal and membrane process separation. Some of the phase-change processes include multi-stage flash, multiple effect boiling, vapor compression, freezing, humidification/dehumidification and solar stills. Membrane based processes include reverse osmosis (RO), forward osmosis (FO), membrane distillation (MD) and electrodialysis (ED) (Charcosset 2009).

Today leanings on desalination processes is to combining of different processes to maximize the efficiency, reducing operative costs and so the final cost of water product. As explained in these following paragraphs, is possible to combine more processes together to obtain a more energy efficient plant (Charcosset 2009).

People and researchers during years have developed and improved all of these methods to produce fresh water building prototypes and then complex plants to use sea water as fresh water resource. Desalination is not a free-cost process because to remove salt from sea water is a complex activity, which requires a huge quantity of thermal and electrical energy. In the last decade, the increase of desalination capacity is caused primarily not only by increases in water demand but also by the significant reduction in desalination cost as a result of significant technological advances that result in making desalinated water cost-competitive with other water sources (Ghaffour et al. 2013).

Nowadays, methods for water desalination are:

- Physical: distillation, water freezing (Rahman et al. 2007), reverse, forward and pressure retarded osmosis (Elasaad et al. 2015)(Prante et al. 2014) (Cath et al. 2013);
- Chemical: ion-exchange (IX) (Jason et al. 2006), absorbing (Sapre et al. 2013), water precipitation;
- Electrical: electrodialysis (ED) (Valero & Arbós 2009).

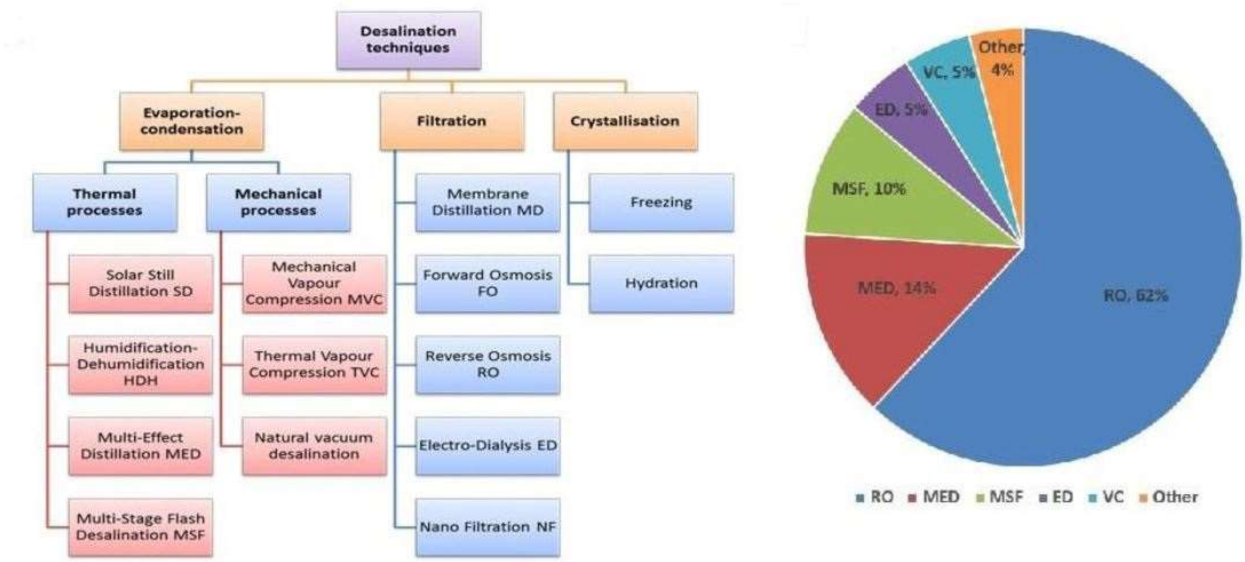


Figure 39: Desalination techniqes and them use in the world (A.Alkaisi et al, 2017)

As cited in the list above, most influence studies on desalination come from US researchers, in particular the most influence professors and researchers in this topic are: from MIT laboratories since 2011, Professor Dubowsky and his team proposed different innovations for smart RO plants. Professor Menachem Elimelech from Yale, for about a decade, is studying FO and other nonporous desalination processes. As cited below, Professor Achilli is studying osmosis processes, in particular PRO such as RO/FO energy recovery systems since 2010. However due to the importance and the vastness of this topic research, in worldwide many scientist, both from academics and industries, study the desalination processes.

In fact, this study will be important not only in a humanitarian and social context, but will also crucial in many sectors as aerospace missions, in electronics, in water waste treatments, and so on. Ultrapure water is beginning a fundamental input of many activities, furthermore even more activities working with liquids become zero-water-waste. This meaning desalinations processes, nowadays, the finest filtration ever, will become even more used technologies filtration.

Technologies available

Distillation

Distillation is a low-pressure process based on water evaporation (Wang et al. 2016). This process consists in increasing the temperature of water in a sort of boiler, up to its boiling temperature, to obtain fresh condensed water without salt. This process requires huge amount of thermal energy for boiling water, e.g. solar thermal energy or waste stream energy from industrial processes (Khayet 2013). There are different types of water distillation techniques, as Multi-Stadium Flash (MSF), Multi-effect distillation (MED) and vapor-compression desalination (VCD). MSF (Al-Hengari et al. n.d.) is one of the oldest desalination techniques for sea water. Other methods differ for plan complexity, working temperature operation and efficiency.

Electrodialysis

Electrodialysis (ED) (Ho & Li 2014) uses salt ions charges to desalinate solution through the electric potential difference given by two electrodes. An anion exchange membrane and cation exchange membrane are placed within these electrodes. Positive and negative salt ions are attracted by their opposite charge electrode and filtrated by the nonporous membrane. Electrodialysis is the higher recovery process for desalination (M. Reig et al. 2016).

Osmosis

Osmosis is a natural permeation of solvent from two solutions with different salt gradient, across a nonporous membrane (Greenlee et al. 2009). Naturally, water with low salt concentration pass through the membrane for dilute salt water until the salty equilibrium is reached.

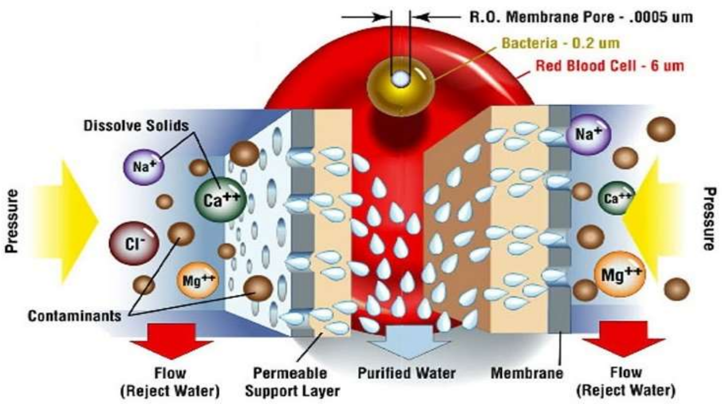


Figure 40: Working principles of osmosis membrane and pores dimension[14]

[14] https://crystalwaterperth.com.au/wp-content/uploads/2015/04/ro-mmembrane-pore.jpg

This process is called Forward Osmosis (FO) (Achilli, Cath, Marchand, et al. 2009). The application of a force (pressure) from the salty side produces a contrary flow, and water with high gradient passes through the membrane. Salt molecules cannot pass through nonporous membrane holes, so the desalination filtration takes place. The pressure applied to obtain Reverse Osmosis (RO) is directly proportional to water salt gradient. The following Figure 1 shows all possible situations for nonporous membrane filtration: feed fresh water and draw solution (high salt gradient) are separated by nonporous membrane (Sobana & Panda 2011).

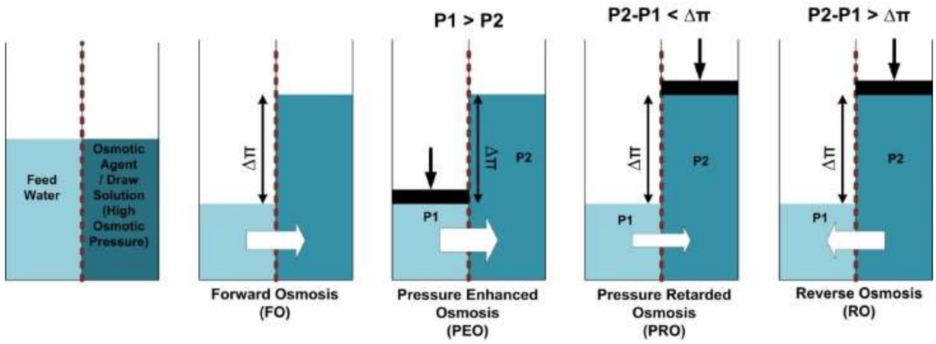


Figure 41: Processes available with nonporosus membrane[15]

Naturally feed water passes through the membrane diluting the draw solution (FO). Pressure Enhanced Osmosis (PEO) is obtained by the application of a force on the feed side. On the other hand, the application of a force lower than the osmotic pressure (Δπ) on the draw solution produces the Pressure Retarded Osmosis (PRO). Finally, Reverse Osmosis (RO) is the application of a force higher than the osmotic pressure on the draw solution. Moreover, Osmosis processes are appreciated, as different options for the integration of different types of recovery energy systems in the plant are possible (Evenden 2015). For example, Achilli et al. from several years have been studying chemical energy recovery systems using the salt gradient difference (PRO) (Achilli, Cath & Childress 2009; Achilli & Childress 2010; Achilli et al. 2013) combined with Pressure-Exchanger (PX) as mechanical recovery. Dubowsky and his research team (Bilton et al. 2011; Elasaad et al. 2015) instead are more focused on an energy recovery system with pelton-turbine and electordyalisis systems aspretreatment of the RO plant. These combinations and energy recovery solutions make osmosis the most efficient process among desalination processes.

[15] http://ifoa.llobe.com/wp-content/uploads/2014/03/Osmotic_Processes_Diagram-1024x377.jpg

Nonporous membrane

For water filtration are available many types of nonporous membrane, different by pores size (Geise et al. 2014). The following Table 43 summarizes the most common membrane from gross filtration to most fine osmosis filtration (Table 10).

Technologies	Pores size
Filtration	+10 µm
Microfiltration (MF)	0.1 µm
Ultrafiltration (UF)	0.01 µm
Nanofiltration (NF)	0.001 µm
Reverse Osmosis (RO Forward Osmosis (FO)	0.0001 µm

Table 10: Nonporosus technologies pore size

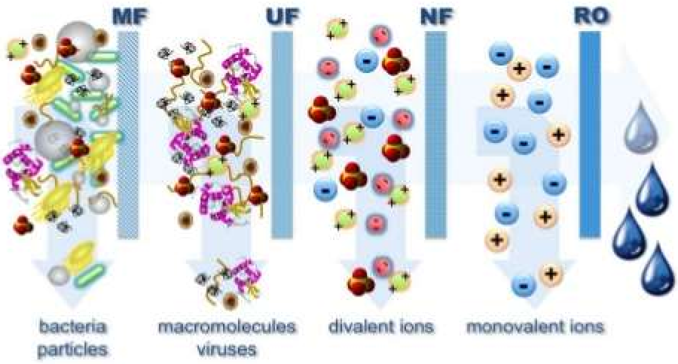


Figure 42: Pressure-driven Membrane Processes

These polymer thin film membranes are used for different type of physical membrane filtration processes. These membranes differ for pore-size dimension, which are from 0.1 to 0.001 µm. They are more fine than traditional mechanic filter, but rougher than Osmosis filtration. Their use is preferred to separate microorganism, suspended particles, suspended solids, and concentrating macromolecular in chemistry, pharmaceutical, water treatment and electronic industries. These membranes are commonly adopted in osmosis plants as water pre-treatment for reducing particles and to create fooling in osmosis pressure vessel. In particular, this solution increases efficiency and availability of osmosis membranes.

Osmosis is the finest water filtration technique available. The use of a semipermeable membrane allows to filter everything dissolved in water, as sea salt and smaller particles usually contained in water, up to a dimension of 0.0001 µm. Such process requires energy and enough pressure to exceed the osmosis pressure. Actual energy limit for desalinate sea water (35 mg/l of dissolved salt) by reverse osmosis processes is about 1 kWh/m3 for pure water produced. As aforementioned before, there are several benefits in the adoption of osmosis technologies for humanitarian logistics. The next Section 2 deeply explains pros and cons of the use of osmosis plants in remoted area characterized by lack of water.

Reverse Osmosis plant layout

In this paragraph will presents and deepened the reverse osmosis plant for water desalination. This kind of plant is one of the most common due to its layout simplicity: in fact, a basic reverse osmosis plant consists only in osmosis membranes and a high-pressure pump. Then some addition components are fundamental for the proper work of the system. In the following picture is present a basic layout of reverse osmosis plant.

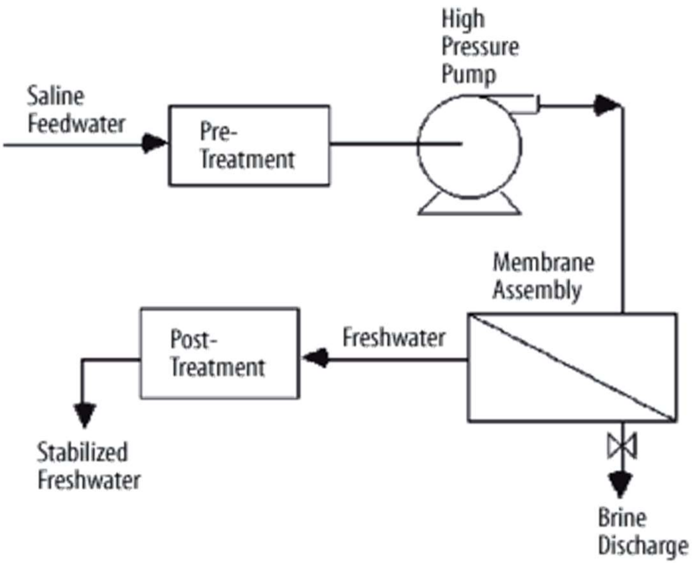


Figure 43: Reverse osmosis basic plant layout[16]

From the basic layout is add a pre and post treatments.

[16] http://www.danapointwater.com/uploads/5/2/3/1/52316257/3543952_orig.gif

Nomenclature	Explanation
Feed water	It is the sea salt water input in desalination water plants
Retentate or concentrate	It is the waste water from a desalination plant, it is full of salt removed from feed salt water. It has a high-grade concentration of dissolved salts
Permeate	It is the pure water coming from a desalination plant. Is the final output of the system
Salt Rejection (%)	This parameter is usually given by a percentage. Is the quantity of salt cannot pass thought the osmosis membrane. Its complement to one is the salt passage (%)

Table 11: Osmosis desalination nomenclature

Sea salt water is the input of the system: it passes thought the pre-treatment system. Usually this pre-filtration is used to remove the gross substances present in the water. Sometimes in particular desalination plants are made by fine membrane system such as microfiltration, ultrafiltration and also nanofiltration. These are usually use to retain mayor parts of substances in the water to prevent the fooling in osmosis membrane. Today, there are several pre-filtration systems made and choose in relation to intake salt water characteristics and for different plant purposes. After the pre-treatment salt water should increase its pressure by one or more high-pressure pumps. The number, them sizing and plant setup depending from the whole desalination plant characteristics. Pressure to become osmosis filtration depends from salt water by the following equation.

$$\pi V = n\ R\ T$$

Where

π is the water osmotic pressure

V the volume of the water

T water temperature

n the number of moles in the salt water

R is a constant

By this equation is clear how osmotic pressure is directly proportional with the salinity of intake water. To make osmosis filtration with sea salt water as water intake the pressure range is from 50 to 70 bars.

Then there is the core of the plant, the osmotic membranes: membranes are thin film polymeric membrane wrapped around in a cylindric-spiral-wound shape. Feed water is filtered tangential of the membrane, as present in the following picture.

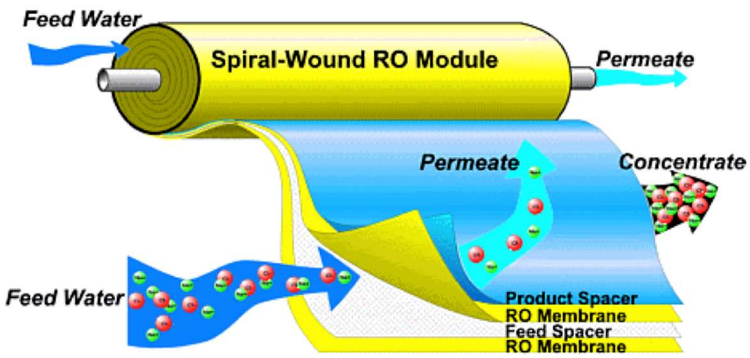


Figure 44: osmosis membrane

Membranes have different sizing depending in the length and diameter. Choose depending from water salinity, the types of desalination desire and especially by the quantity of water (flow and pressure) to treat. Osmotic membranes have to be placed in a pressure vessel, it is a particular cylindrical container able to resist at the high pressure of the water. In a pressure vessel should stay one or more membranes (usually from 1 to a maximum of 6), depending from the layout and desalination characteristics. Pressure vessel has in its extremity water pipes connections to linking with other parts of the system as shown in the following picture.

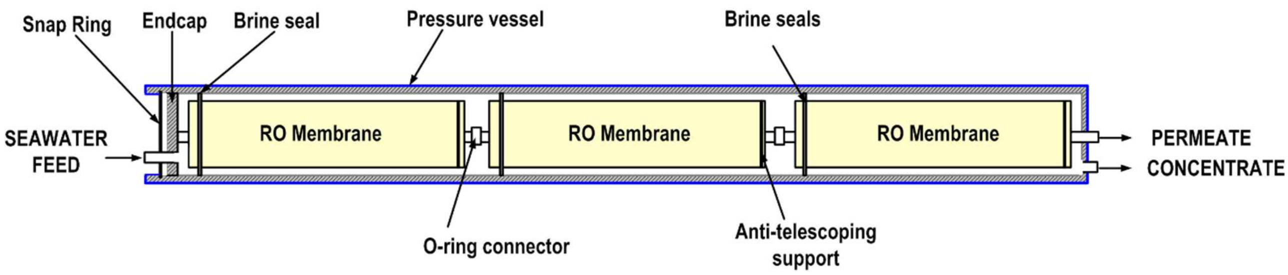


Figure 45: Inside setup of pressure vessel with RO membranes

Pressure vessels layout should different in relation to filtration, water capacity and plant characteristics: membranes and pressure vessels too should in fact, put in series, parallels or in a mixed configuration. The configuration change in relation to the grade of desalination obtained. To obtained a higher level of recovery is possible, for example have more stages thought osmosis membrane. In the following picture are presents two different osmosis layouts, the one stage and the two (or multiple stages)..

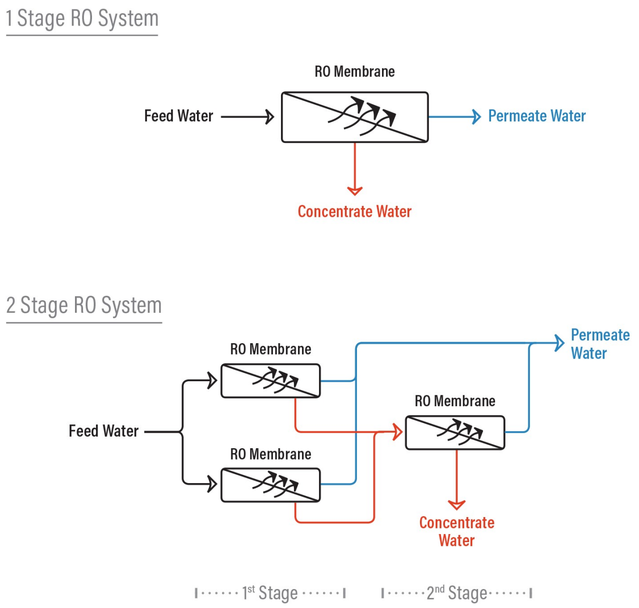


Figure 46: Single stage and multiple stage RO system[17]

The single stage RO system is the basic reverse osmosis system, where the feed water passes as one stream and the outputs, after the filtration, are a permeate and a concentrate streams

Instead of the two or multiple-stages the concentrate stream from the first stage is the input of the second stage. This method ensures a better recovery from the system.

Another layout is give by the number of passages thought the membranes, such presents in the following picture.

[17] https://puretecwater.com/reverse-osmosis/what-is-reverse-osmosis

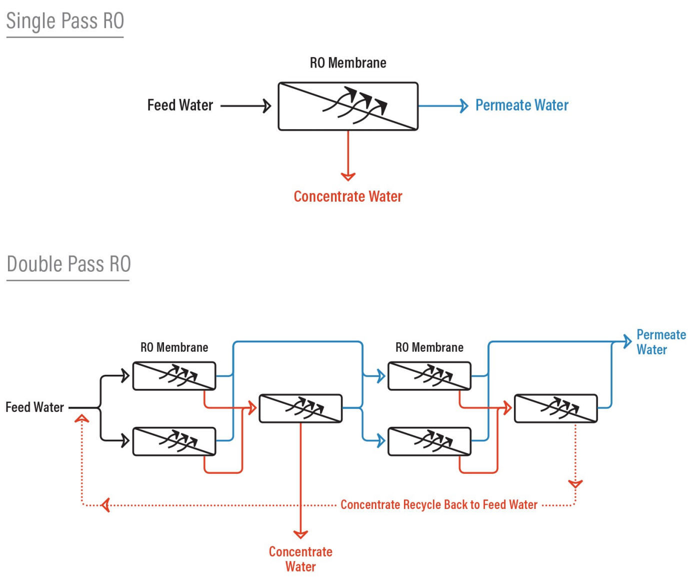


Figure 47: Single pass and multiple pass RO layout

As in the following picture, the first is the basic RO layout, with one pressure vessel at all, also called a single pass RO system. The bottom picture instead is a double passes RO system. The difference is in the second the permeate of the first pass, come in the second, become the feed water to the second pass. The quality of permeate water is much higher than the single pass, because this water is passed through two different osmosis membranes.

After pressure vessels the permeate, desalinated water, pass through the last part of the system that is the post-treatment system, usually is a remineralization system and acidity (ph) adjustment. To some applications such as application for produce drinkable water is necessary the ph adjustment, to meet the potable water specifications, and the remineralization, just to meet the right balance of minerals dissolve in drinkable water.

Fouling and scaling

A huge issue of this desalination plants is given by the fouling and the scaling. These phenomes are intrinsic of these plant, and causes by them main characteristic, the finest filtration. All substances dissolved in the water are removed by osmosis membranes. But cause the water pressure and the quantity of substances reject the membranes during them working become dirty and started lost them efficiency. Fouling occurs when dissolved salts accumulate on the membrane surface, plugging the membrane. Usually this phenomenon appended in the front end of RO systems. A method to eliminate, albeit partially, the fouling in the membranes is a clean and washing by a water-reverseflush. After few washing membrane dirt by fouling should be change. A consequence of membranes fouling is the increase of osmosis pressure to obtain the desalination, and a lower permeate flow.

Instead scaling occurs when inorganic compounds exceed their solubility limits and precipitate on the membrane surface as scale. In this case the consequence are worse than before, because there is a higher salt passage through the membrane, a low permeate flow and quality.

These factors are the main cause of the water pre-treatment improvements in desalination plants. If dissolved substances and gross substances (solids, algae, oils, microorganisms, organic molecules, etc) are removed before the osmosis membranes, then the pressure of osmosis decrease and consequentially membranes life increase, because less disposed at fouling. This is why, especially in the last decade, researchers are more focus on methods to remove waste before osmosis. Especially since osmosis membrane are more expensive than pre-treatment filtrations, so is better prevent fouling and scaling than change all system membranes.

Figure 48: Osmosis membrane with evident fouling problem[18]

Many studies analyzed the consequence of fouling in RO membranes and the whole system plant. For instance, as present in Karabelas et al (Karabelas, A.J., 2017) paper on energy consumption in RO desalination processes, for the seawater desalination case considered here, a 10% increase of feed pressure Pf due to fouling (not uncommon in RO plants) has a significant effect, leading to an increase of specific energy consumption (SEC) greater than 0.2 kWh/m^3. The direct and indirect effects due to fouling may be more important compared to energy consumption components SEC_R and SEC_P. Indeed, an increase of the effective membrane resistance due to fouling can cause a substantial increase of SEC_f and of SEC_{CP}, which lead to increased feed pressure (required for constant recovery

[18] https://www.membraneprocess.com/s/cc_images/cache_48214975.jpg?t=1440172985

processes) and in turn to an increase of energy losses primarily due to pressure-equipment inefficiencies SEC_{inef}.

Where:

SEC_R specific energy consumption due to friction losses in spiral wound membrane module retentate channel

SEC_P specific energy consumption due to friction losses in spiral wound membrane module permetate channel

SEC_f specific energy consumption due to membrane filtration

SEC_{CP} specific energy consumption due to concentration polarization

SEC_{inef} specific energy consumption due to non-ideal pump

Energy recovery systems

Even though today, reverse osmosis systems are probably the most efficient desalination systems are anyway energy intensive processes. The basic system should use from 3 to 6 kW of electricity for each cubic meter of pure water product (kW/m^3 pure water). Anyway, an interesting pro of these desalination systems are the ease to install one or more energy recovery systems. The number and types depend by the complexity to obtain with of the final plant.

Compared to available desalination processes, RO is considered the most energy-efficient technology. However, it is still considered that RO energy consumption should be reduced. Specific Energy Consumption (SEC) reduction has monopolized the focus of technological innovation and research in this sector. The energy costs in seawater reverse osmosis (SWRO) plants may reach 50% of the final costs of the produced water. Consequently, reducing the energy consumption has been intensively investigated to decrease the energy cost of RO systems (K.Touati, et al.,2017).

Energy research in desalination processes has contributed to lowering the water treatment energy footprint. In relation to reverse osmosis (RO) processes, the energy footprint would have dropped from approximately 20 kWh/m^3 in the 1970's to a value of less than 2 kWh/m^3 nowadays (A. Blanco, et al., 2017). Several factors have contributed to these achievements: membranes development, pump and motor efficiency improvements, the use of variable speed drives and especially the implementation of energy recovery devices such as hydraulic turbines or pressure exchangers to harness wasted throttling valve energy.

As mention above energy recovery system should be divide in two main families: mechanical devices and chemical devices. The first family is bigger, probably because are simpler systems and cheaper than the second, and consist of Pelton turbines, hydraulic turbines, pressure-exchangers, etc. Instead in the second family the most know method is the Pressure Retarded Osmosis (PRO). Usually in RO plants these systems are combined together to take an advantage by different pros of the systems. On the other and if the energy recovery systems allow to reduce specific energy consumption of these plants, the complexity and the cost of these systems makes the initial investment more expensive.

Mechanical energy recovery systems are based on the recovery of the kinetic energy in the concentrated flow of water, output from pressure vessels. As opposed to the permeate stream water, loss pressure (and so, energy) passes through membranes, the concentrated stream has a much higher pressure. So, this output stream full of pressure (about 40-50 bar) is use to produce energy by the use of recovery systems.

Mechanical energy recovery device (ERD) uses this stream of water to product energy: there are two different way to produce energy or use a mechanical device which exchanges directly the kinetic energy such as pressure-exchangers or turbochargers, or a mechanical device which produces by an alternator electricity to feed high pressure pumps. These second energy recovery devices are made with hydraulic turbines such as Pelton turbines.

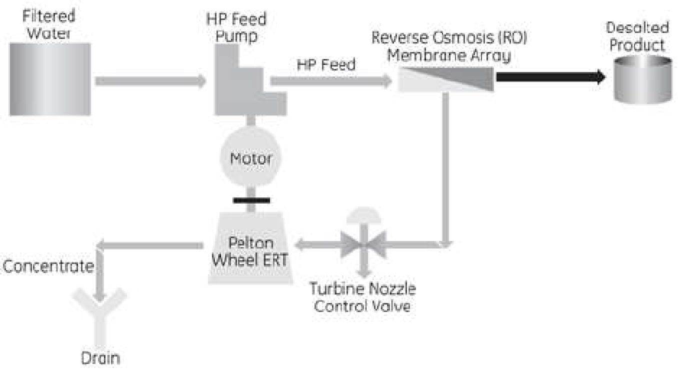


Figure 49: RO system with pelton turbine such as turbocharges energy recovery system

Pressure-exchanger (PX) are the most interesting energy recovery devices for osmosis desalination system, both for them flexibility in use and for them simplicity. They are devices which exchange the pressure of the concentrate stream to the feed side. With this device the high-pressure pump, the device which use the most important part of energy in the whole system, will work less, because pressure is increase with PX too. Pressure-exchanger nominal recovery hydraulic factors are from 45% and 80%.

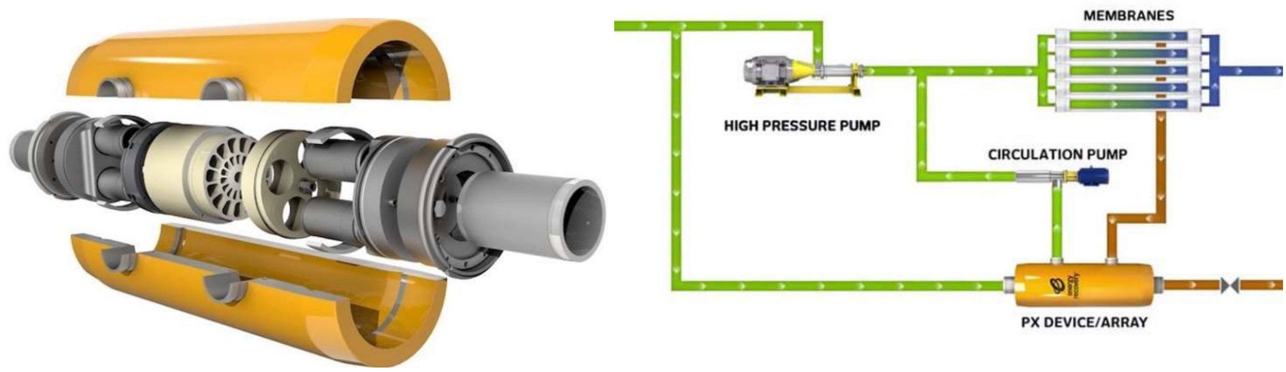
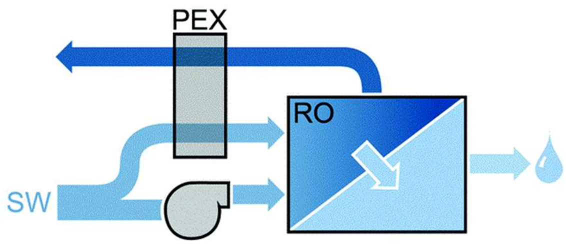


Figure 50: Pressure-exchanger; RO layout with PX for energy recovery[19]

Pressure retarded osmosis (PRO), instead use the chemical of high-gradient salinity of concentrate stream. Salinity gradient energy, which is released when two solutions with different concentrations are mixed, is considered to be a promising source of sustainable energy. Pressure Retarded Osmosis

[19] https://desalinationbiz.s3.amazonaws.com/products/images/full_4017.jpg?v=26/04/2017%2018:32:00
https://media.licdn.com/mpr/mpr/AAEAAQAAAAAAAAZHAAAAJDk3NTliNWFmLTlmMWItNDNkYi04M2EzLWI5NDg5ZGI5OTcwOQ.jpg

has been one of the most widely investigated processes. In a PRO process, a semi-permeable membrane is used to separate a low concentration stream (feed solution) and a high concentration stream (draw solution) to. If a hydraulic pressure lower than the osmotic pressure difference between the feed and draw solutions is applied on the draw solution side, the water permeates across the membrane from the feed solution to the draw solution. Then, the volume of the draw solution is expanded. The diluted draw solution is partially depressurized through a hydro-turbine to generate electricity (K.Touati, et al.,2017).



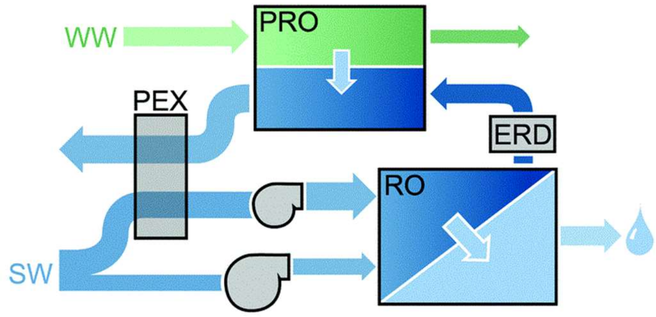


Figure 51: Conventional RO-PX left, and RO-PRO-PX on the right[20]

As shown in the above pictures usually pressure retarded osmosis plant is use in combination with one or more pressure-exchangers, depending on the complexity of the system. This combination will give more energy recovery than the single device. However, is difficult give the recovery ratio for these complex systems because depend by different characteristics of the systems too.

[20]http://pubs.rsc.org/services/images/RSCpubs.ePlatform.Service.FreeContent.ImageService.svc/ImageService/Articleimage/2016/EE/c5ee02985f/c5ee02985f-f8_hi-res.gif

RO plant setup for humanitarian camps

To improve current water management in humanitarian field, an interesting solution is integrating the use of osmosis plants simultaneously with above illustrated water purification plants.

Reverse osmotic plants are more expensive than traditional purification system, and they have a smaller flow rate. However, they use both salty water and spring water, ensuring a production of ultrapure water without pathogens and other substances bigger than the membrane pores. So, this water is suitable to satisfy primary people needs for survive, as drinking and cooking such presents in the following paragraphs and in the Maslow hierarchy of needs. The use of safe water for cooking and drinking ensures people’s health and improves the quality life of refugees, especially in crucial moments such as the first stage of catastrophes. Furthermore, this ultra-pure water should be use also in the camp hospitals and for nurseries.

All secondary needs, such as personal and clothing washing, growing vegetables, etc. may be satisfied with water purified by traditional sand/carbon purification systems. An ultrapure quality drinkable water is not necessary for cleaning activities, as bathing or laundry, or gardening and livestock breeding within the camps.

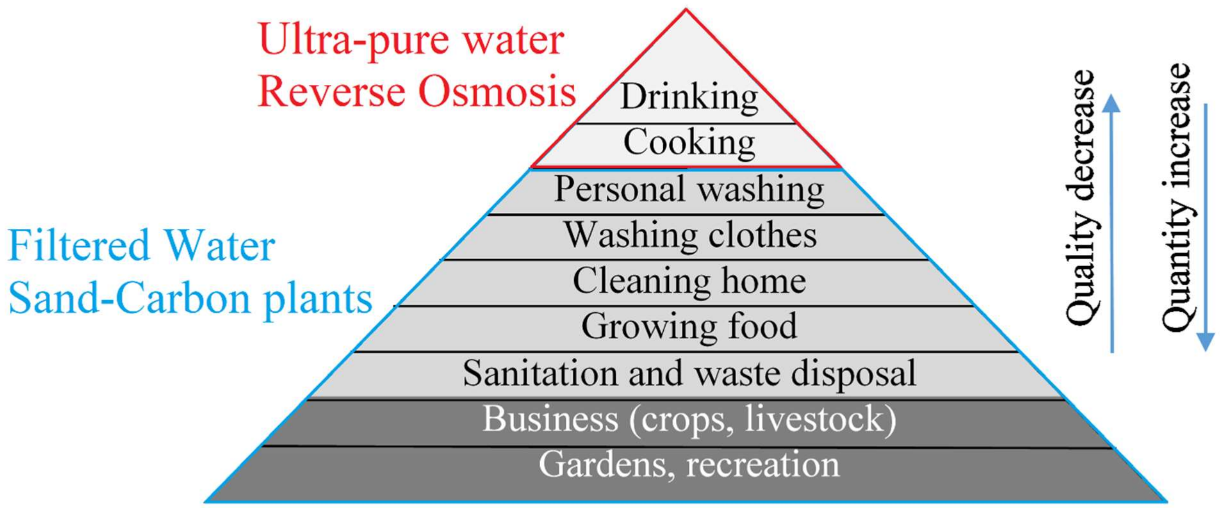


Figure 52: Water production on Maslow hierarchy of needs

Like other infrastructures and equipment of the camp, the water system should design and sized for a community module, such as described in the chapter 1 in the humanitarian camp taxonomy, which represents the unit module in the humanitarian field. As above mentioned in paragraph on water requirements, humanitarian organization studies on human water needs (Regattieri et al. 2015), the minimum vital allocation for each person is about 7 liters per day. This amount of water is used for drinking and cooking, which are the main human needs. Each community needs an osmotic plant that makes 1m^3 of ultrapure water per day.

There are several design alternatives for an integrated community water system with both traditional water plant and reverse osmosis plant, some of them, the most interesting are present in the following list:

- Osmosis plants working in parallel with a traditional filtration system. This solution requires a proper pre-treatment for osmosis plant to reduce the fooling in osmosis membrane
- Traditional carbon/sand filter systems using as pre-treatment for osmosis plant. Plants work in series and a tank after traditional filtration system is used both as a buffer for osmosis and for water supply for refugees.

The osmosis system consists of a pre-treatment system (different mechanical water filtrations), high pressure pumps (up to 70 bar), osmosis membranes with pressure vessels (number and design depends to membrane parameters and plan use), nozzle valve, water tank and energy recovery system.

Different camp and environment characteristics should prefer a solution rather than the other one. If the fresh water is abundant in the area is preferable use the second solution than the first one: the membrane fouling and scaling is a well-known problem for osmosis systems. This solution permit to use the traditional sand-carbon filter of fresh water such as a pre-treatment of osmosis plant. Such describe before more are the pretreatment systems better is for the osmotic membranes timelife.

After the osmosis treatment, chlorinate water may be adopted to reduce the possibility of bacterial contamination during the storage. The chlorine is use also for disinfect all the water system, as tanks and pipes.

Critical review

Certainly, reverse osmosis desalination systems are the future of water purification and water desalination plants, but today there are some issue that compromise them introduction in humanitarian sector, even though them will improve different aspects, as the ultra-pure quality of product water, the possibility to use all different springs such as water supply, even those the salty, before impossible to use.

Following are analyzed and present the most important issues of reverse osmosis desalination system, the most critical.

The maintenance

As presents in the paragraph on the fooling and scaling, the dirty of osmosis membranes compromise the whole plant efficiency and reduce also the plant efficacy to produce ultra-pure water. This one probably is the most important cons in these plants. High fooling and scaling meaning in many production arrests to change components dirty and worn out. Osmosis plant maintenance, not only is expensive, membranes are the core part of the system and are not cheap, but also requires a specialized maintenance team to work on it. This point introduces the second issue of osmotic plants.

Specialist staff

A continuous red line throughout all this thesis was the focus on improve system usable also in developing contest, by people without knowledge on plants and mechanics, simplicity and user friendly were the first goals of all projects. Even if, in the basic setup reverse-osmosis plants are very simple, them application in a real outside field to produce continuous water is not. It requires person with a high knowledge on these plants, mechanics and on them setup. To maintain the costs and the complexity of the plants lower is necessary a team of specialist staff to use the plat, to setting up for the daily production, and for the continuous maintenance necessary.

Otherwise is necessary a complete computer control system, with probes and sensors able to continuously setting all the system parts in relation to the environment and inputs changing. But this control system is very expensive due to the numerous of probes and sensors necessary.

Plant complexity

To obtain the best from these reverse osmosis plants are necessary some adjustment from the basic setup. As analyzed in the previous paragraphs to makes these plants affordable such as operative cost of energy is necessary a recovery energy system, choice on this are multiple and vary in relation to use conditions, the parameters of the plant and the final cost of the plant. A plant with two energy recovery system will have lover operative costs but the initial investment is higher.

To reduce the fooling and the scaling in the osmosis membranes is require a particular pretreatment system to reduce the presence of the waste in the last part of the finest filtration. Pre-treatment system vary in relation at them effectiveness and the costs. There are today many different technologies available, from the simplest paper filters to nonporous filters such as micro and nano filtration systems. Increasing the quality of pretreatment system not only increase the initial investment of the plant, but increase, even if less than changing frequently osmotic membranes, operative cost due to the frequent changing of filter of pretreatment.

Conclusions and Further research

Further research on this topic will focus on the reverse-osmosis desalination plant design and sizing, in relation to the production of pure water. Sizing these plants on humanitarian camps size standard unit module should offer a modular plant to humanitarian organization. This solution is appreciated in humanitarian context because it offers more flexibility in different missions. Make a desalination plant usable in different environments and with different waters (salinity, turbidity, etc) is not simple as well as these plants work with several variables change with different waters in input. Furthermore, a wide study on an energy recovery system and PV-BES is necessary to offer the best trade-off for energy recovery and guarantee the best plant efficiency as possible.

Plant design will follow humanitarian specifics on plant availability, simplicity to use and maintenance. These specifications make this project more complicate as just is: water desalination plants appear simple as principles, however, in spite of the small scale (few cubic meters of water products daily) requires complicate equipment (probes, sensors, control unit, etc), knowledge to use and daily maintenance.

Reach make prototypes as describe above, not only should increase the human standard of living in humanitarian camps, but represents a great research innovation too. This solution should have an important impact also in reverse innovation market, where innovations born for developing regions and only successively for first world.

Desalination should be a trend to produce water in the next decades, in addition membrane solution, today, should be the most efficiency methods. A promising theoretical and research results are coming from graphene as new nonporous membrane desalination materials. Today several studies are on this important topic (Aghigh et al. 2015) (Khaled et al. 2015) (Tiwari et al. 2014).

4. Energy production

Introduction

Nowadays, more than in other historical ages, energy for people is life, as well as oxygen is essential for living things. By now, also in developing regions energy, especial electricity, is a fundamental resource for life. Energy not only is important for people for live, but becomes a crucial asset for the world development, the progress of people and them nations too. Electricity promote economic growth and employment opportunities, and support the provision of social services such as education and healthcare that lead to sustainable human development. Nowadays, poverty is defined as low attainment of social condition, for example, education, health, and nutrition in addition to economic deprivation. One way to cope with this multi- dimensional aspects of poverty is to promote opportunity (World Bank, 2001), and one of the opportunities is access to modern energy such as electricity (Kanagawa & Nakata 2008). As global development agendas are increasingly recognizing energy access and energy poverty as essential issues for society, it is important to address them in the context of two other significant socio-ecological issues of our time: energy security and environmental sustainability (Panos et al. 2016).

Links between energy (electricity use) and other components of poverty:

Health

- Reduce exposure to hazardous pollutants
- Enables vaccination and medicine storage by a refrigerator

Education

- Reduce drudgery and allows children to expand their opportunity
- Lighting appliances to study in the night time
- Narrows the digital divide through ICTs

Income

- Mechanization in industry
- Enterprise development

Environment

- Reduction in use of wood such as fuel
- Use of renewable energy

Education is widely recognized as one of the most essential components for poverty reduction, especially the primary education is usually the highest return to investment.

Energy shortage or even the lack of energy, especially after a catastrophe or during a humanitarian crisis, should be one of the causes of many deaths, because today everything is made consuming energy. Just like urban context, in humanitarian camps electricity is a basic energy: with electricity is possible lighting during the night, heating when weather is cold, pumping and depurating water, cooking meals and boiling water and others different things necessary for live in dignity. in developing regions energy is a theme related and close to the depletion of natural resources, as explained in depth in the chapter 2.3, because people usually used trees and timber like as the main fossil fuel resource or to produce charcoal for cooking, heating and for household uses.

The access to electricity as the main energy resource in the last years is increasing in Asia and south America, even if many parts of these countries are not covered by an efficient and available electricity grid. Africa still remains behind, especially the Sub-Saharan part of the country. More than 95% of the population without the access to electricity are in these above countries. Anyway, still approximately 2 out of 10 people in the world still live without access to electricity. The International Energy Agency (IEA) defines 1.67 million people worldwide did not have access to electricity in 2010. So, the UN "Sustainable Energy to All – SE4All" initiative aims at eradicating this electricity access deficit by 2030. Access to electricity is essential to overcome poverty, promote economic growth and employment opportunities and support the provision of social services such as education and healthcare that lead to sustainable human development.

The new Millennium Development Goals (MDGs) of 2015 proposes among the eight international development goals, a target on this purpose: the goal number 7 "Ensure Environmental sustainability". Following a brief summary of this goal is presents:

Goal 7—Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All[21]

The sustainable development goals (SDGs) proposed by the Open Working Group of the General Assembly of the United Nations recognize the importance of the natural environment and its resources to human well-being. As a whole, it is definitely a worthy charter for the twenty-first century, as it addresses the diverse challenges that we face as a global community. SDG 7 - to "Ensure access to affordable, reliable, sustainable and modern energy for all" - is a challenge confronting every country, that touches everyone. To understand the necessity of meeting this goal, and what is required to do so, we should unpack the statement of the goal itself. The four dimensions of SDG 7 are affordability, reliability, sustainability and modernity. These different dimensions are not mutually exclusive. They overlap, and in some cases even entail each other.

[…]

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[21] https://unchronicle.un.org/article/goal-7-ensure-access-affordable-reliable-sustainable-and-modern-energy-all

On the other hand, people living in places without ready stocks of fossil fuels may rely on more primitive methods of combustion, such as wood fibers or perhaps even animal dungs. Indeed, this is the condition that prevailed for the vast majority of humankind throughout its history, and continues to be the condition for many parts of the developing world. For instance, approximately 2.7 billion people (about 40 per cent of the world's population) now rely on traditional biomass fuels for cooking. Such low-quality fuels can be a major source of indoor air pollution. Even with the expansion of energy accessibility and economic development, the annual death toll from indoor air pollution will still be over 1.5 million people—a higher rate than that from both malaria and tuberculosis.

Today in the developed world there are several methods to product electricity with renewable energies, from burning fuel and converting its chemical energy, to use the natural kinetic energy of winds or waves or by the combinations of different technologies. Anyway, not all these technologies are appropriate to use in rural areas or in grave conditions. Among the possible renewable sources in developing regions, the solar energy should be the primary importance for availability, diffusion and potential impact especially within the sun-belt-area (i.e. all the Sub-Saharan part of Africa).

The most difficult thing is not how product electricity, but how to choose the best and the most efficient way to produce electricity in a specific area. In fact, environment and boundary conditions plays a fundamental role in the way to produce electric energy, and some ways should be more expensive than other depending from the specific area. From a strategic point of view, the choose of technology or the technologies to produce electricity is fundamental for the sake and the economy of the community, both for an urban developing context and for a humanitarian camp. So is crucial during the first stages of the emergency the planning of the technologies fit with a given environment.

Furthermore, for humanitarian agencies management as well as for private companies, energy costs are a huge strategic lever and play a fundamental role during a humanitarian mission. Decrease energy costs, (by making the energy production more efficient than in past years and/or find innovative, cheaper solution to product electricity) will be meaning release resource to improve humanitarian context. In addition, last but not the least, producing energy efficiently means be more environmental friendly and will decrease the energy footprint of the humanitarian organizations and the whole humanitarian supply chain.

In this chapter is presents the problem of the energy production within humanitarian context and in severe and poor environments such as developing regions by the use of renewable energies, theme of my third doctoral year. In particular in the first paragraph of this chapter, the number 4.1, will presents, study and analyze the developing of an optimization model for the energy production. This is a decision maker tool to use to find the best trade-off for the electricity production in a humanitarian camp or in whichever urban context. In this section will presents the model framework, the analytic model with all equations, variables and parameters used, and finally the economic model used to evaluate the different energy product options.

The second part of the chapter presents and confirmed by a hands-on humanitarian project, how renewable energies, in particular photovoltaic, should be useful and helpful for the humanitarian context. In fact, in this paragraph, the 4.2, is present the MSU (is the acronym used in the humanitarian field meaning the Mobile Storage Unit) project. This is a project made in collaboration with the UNHRD-Lab team of Brindisi, with the aim to solve a lack in the cold-humanitarian-supply-chain: in the humanitarian camps is not possible stock perishable items due to the lack of a cooling (or temperature control) storage system. This is a serious problem especially in hot/warm environment, where medicines and food if storage in tents deteriorate in just few days. In this section is present a solution of this logistics/plant problem, with a complete economic analysis of the investment on renewable energies. In particular for this case is used a combination between photovoltaic panels and batteries such as energy storage system.

4.1 Optimization model of renewable energy consumption of a humanitarian camp

Catastrophes are unpredictable. After a disaster strikes an area the humanitarian agency, in charge by area government to take care of refugees, begin the humanitarian mission. One of the first, and most important step of the mission, is the humanitarian response planning: it has different levels strategical, and operative. During this step have been taken all the most important decisions about the mission, i.e. dimensions and location of the camp, methods and quantity to supply items, mechanical plants to use for satisfied the request in the camp, and so on.

As analyzed and presents in this chapter the selection of the methods to produce energy in the humanitarian camps is fundamental for the agency. Energy represents the bigger operative cost in the humanitarian camp organization, so all strategic decisions take on this path are fundamental for the agency. Choosing the best mix of energy production is one of the most important step on the humanitarian camp efficiency. Renewable energies are a truly resource for them.

In the last years, humanitarian camps started to open up at new electricity generation plants, in particular them introduce renewable energy such as electricity production. Renewable energy such as photovoltaic panels and wind turbines should be an interesting option for humanitarian agency because them used natural resources in an environment to produce free and green electricity.

As presents in the following paragraph energy for humanitarian organizations is expensive and inefficient because use mainly diesel generators to produce electricity. Diesel generators are reliable, simply to install, easy to use and suitable to ship, plants but require lot of diesel fuel to work. Often, humanitarian camps are far to urban context and so is necessary have a continuous fuel supply chain to ensure the daily working of generators. Usually append fuel shipping, made by tanker trucks, are rob and stole by criminals and pirates. To tackle this problem humanitarian agencies, have to employ a security teams to ensure all fuel shipping arrive at the camps. Both for losses and for the security fuel costs increase and humanitarian missions become expensive.

To solve, even if in part (diesel generators have to use such as energy back-up, in case of failures or peak-energy-demand), the problem, humanitarian agencies should improve methods to products electricity, by taking an advantage of the natural resources. A method should be use renewable energy such as sun and wind, to use as production in relation to different environments where humanitarian camps are placed.

Following, in this chapter is presents an optimization model, used as decision-making tool to establish, before starting the humanitarian mission, the right balance and the best trade off of energy-production in a specific environment: in relation to windy and sunlit of an area, where a humanitarian camp have to placed, the model will give the best trade-off of energy production.

With this tool the humanitarian agency should decide how to produce electricity, with witch renewable energy and should have a cost-quantification of the whole energy production in the mission.

The tool output will be the power of each energy production systems:

wind turbines (W), photovoltaic panels (PV), battery energy storage system (BES) and diesel generator (G).

The model working for minimizing the total cost of energy for a humanitarian camp, using the environmental data (windily, temperature and irradiation) such as input.

QR - Questions of research

In this project the goal was to understand and demonstrate how renewable energies are important for humanitarian camps and for producing easily electricity in remote area of the world.

With the design of this model is possible have an economical comparison of different electricity production methods. The output of the model will be the sizing of the best-trade-off for producing electricity methods (photovoltaic panels, wind turbines, batteries storage system and diesel generators) in a given area.

During this dissertation I want to reply to some research questions we asked during this project as report in the following list:

- Are renewable energies affordable for humanitarian agencies?
- Is it possible makes a decision model gives as output the best trade-off for the energy production?
- How much the use of renewable energies be of use in humanitarian context?

Model framework

In the following picture is present the framework of the energy production system model. The electricity in the camp should produce using the most environmental-friendly energy available, so firstly using renewable energy, then using the battery energy storage system, and ultimately just if nothing else is available by the diesel generators. As show in the picture electricity is product mostly by photovoltaic panels and wind turbines. If the camp load of electricity is less than the product by renewable sources, the energy surplus is used to charging batteries storage system. This power storage is used when the load exceeds the power product by renewable system, such as in the night or during less sunny and less windy days. Only if the renewable system and battery storage are not able to satisfied the whole load, then the diesel generators are used such as back-up.

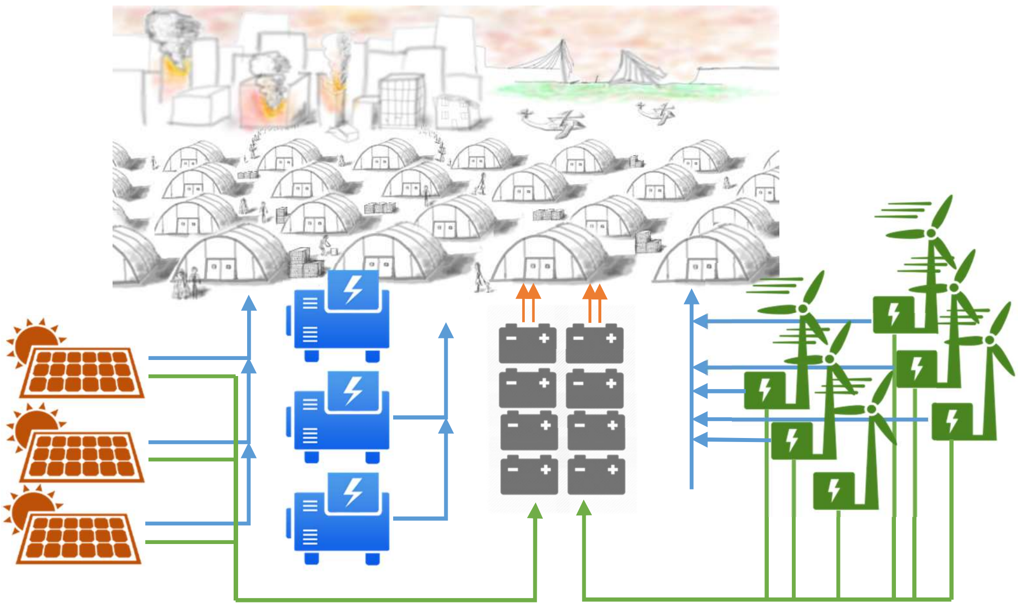


Figure 53: Renewable energy system working principles

The energy system hourly balance is given by the following equation

$$E_{h,j}^{PV} + F_{h,j}^{W} + F_{h,j}^{G} + F_{h,j}^{BES,Out} = F_{h,j}^{BES,In} + E_{h,j} + F_{h,j}^{Lost}$$

Where with the parameter $E_{h,j}^{Lost}$ is meaning energy should be lost in the system by inefficiency.

Following is presents the analytic model use to find the best trade off of energy production.

$$LCOE = \frac{C^{PV} + C^{I,PV} \cdot X^{PV} + C^{BES} \cdot X^{BES} + C^{I,BES} + C^{W} \cdot P^{W} + \sum_{j=1}^{N} C_j \cdot \frac{(1+g)^{j-1}}{(1+OCC)^j}}{\sum_{j=1}^{N} \sum_{h=1}^{H} E_{h,j} \cdot \frac{(1+g)^{j-1}}{(1+OCC)^j}}$$

Constrains

$$\min LCOE$$

Minimize the Levelized Cost of Energy of the humanitarian camp in relation to the environmental and boundary conditions where camp is placed, choosing the best tradeoff for the energy production between solar, battery storage, wind and diesel generator

$$C_j = \left(C^{O\&M,PV} + \alpha_j \cdot C^{I,PV}\right) \cdot X^{PV} + \beta_j \cdot C^{I,BES} + \gamma_j \cdot C^{BES} \cdot X^{BES} + C^{O\&M,N} \cdot P^{W} + \sum_{h=1}^{H}\left(C^{O\&M,G} \cdot T_{hj}^{G} + C_j^{fuel} \cdot F_{hj}^{G}\right) \qquad \forall j$$

$$H_{hj} \cdot \frac{X^{PV}}{H_{ref}} \cdot \eta_{hj}^{PV} \cdot \eta^{I,PV} + F_{h,j}^{w} + F_{hj}^{G} + F_{hj}^{BES.Out} = F_{hj}^{BES,In} + E_{hj} + F_{hj}^{Lost} \qquad \forall h,j$$

$$\eta_{hj}^{PV} = \eta_{module} \cdot \eta_{pc} \cdot \eta_{temp,h,j} \cdot \eta^{I,PV} \cdot (1 - (j-1) \cdot \eta_d) \qquad \forall h,j$$

$$\eta_{temp,h,j} = \left\{1 - \tau \cdot \left(T_{c,h,j} - T_{c,ref}\right)\right\} \qquad \forall h,j$$

$$T_{c,h,j} = T_{a,h,j} + \left[\frac{NOCT-20}{800}\right] \cdot H_{h,j} \qquad \forall h,j$$

$$SOC_{11} = (1 - DOD) \cdot X^{BES}$$

$$SOC_{hj} = SOC_{h-1,j} + F_{hj}^{BES,In} \cdot \eta^{BES} \cdot \eta^{I,BES} - F_{hj}^{BES,Out} / (\eta^{BES} \cdot \eta^{I,BES}) \qquad \forall h > 1, j$$

$$SOC_{1j} = SOC_{H,j-1} + F_{1j}^{BES,In} \cdot \eta^{BES} \cdot \eta^{I,BES} - F_{1j}^{BES,Out} / (\eta^{BES} \cdot \eta^{I,BES}) \qquad \forall j > 1$$

$$(1 - DOD) \cdot X^{BES} \leq SOC_{hj} \leq X^{BES} \qquad \forall h,j$$

$$F_{11}^{BES,In} \cdot \eta^{BES} \cdot \eta^{I,BES} \leq X^{BES} - SOC_{11}$$

$$F_{h,j}^{BES,In} \leq \sigma_{h,j} \cdot M \qquad \forall h,j$$

$$F_{h,j}^{BES,Out} \leq (1 - \sigma_{h,j}) \cdot M \qquad \forall h,j$$

$$\sigma_{1,1} = 1$$

$$T_{hj}^{G} \geq \frac{F_{hj}^{G}}{P^{G}} \qquad \forall h,j$$

$$F_{h,j}^{G} \leq P_{G} \qquad \forall h,j$$

$$F_{h,j}^{w} = \left(v_{h,j} - v_{in}\right) \cdot \frac{P^{w}}{v_{nom} - v_{in}} \qquad \forall h, j$$

$$P^{w} \geq 0 \qquad \forall j$$

$$T_{hj}^{G};\ \sigma_{h,j}^{IN};\ \ \sigma_{h,j}^{OUT}\ \text{ binary} \qquad \forall h, j$$

$$X^{PV}, X^{BES}, C_{j},\ F_{hj}^{G}, F_{hj}^{W},\ F_{hj}^{BES,In}, F_{hj}^{BES,Out}, F_{hj}^{Lost}, SOC_{hj} \geq 0 \qquad \forall h, j$$

The following notations are used in equations and in the presents model

Indices

$j = 1, \dots, N$	system lifetime years
$h = 1, \dots, H$	hours per year

Variables

X^{PV}	PV system rated power [kWp]
X^{BES}	BES capacity [kWh]
$F^{W}_{h,j}$	energy flow from wind turbine at hour *h* of year *j*[kWh]
$F^{BES,Out}_{hj}$	energy flow from BES at hour *h* of year *j* [kWh]
$F^{BES,In}_{hj}$	energy flow to BES at hour *h* of year *j* [kWh]
F^{G}_{hj}	energy flow from fossil fuel generator at hour *h* of year *j* [kWh]
F^{Lost}_{hj}	energy flow lost at hour *h* of year *j* due to overproduction [kWh]
SOC_{hj}	BES state-of-charge at hour *h* of year *j* [kWh]
T^{G}_{hj} (auxiliary variable)	1 if the generator is on at hour *h* of year *j*, 0 otherwise
C_j	operative net cost for year *j* [€]
P^{W}	wind turbine system rated power [kW]

$$v^{*}_{h,j} = \begin{cases} v^{in} & v_{h,j} \leq v^{in} \quad o \quad v_{h,j} \geq v^{off} \\ v_{h,j} & v^{in} < v_{h,j} < v^{nom} \\ v^{nom} & v^{nom} \leq v_{h,j} < v^{off} \end{cases}$$

Parameters

Economics

C^{PV}	PV unitary cost [€/kWp]
$C^{I,PV}$	inverter unitary cost (PV node) [€/kWp]
$C^{O\&M,PV}$	O&M PV cost [€/kWp]
C^{BES}	BES unitary cost [€/kWh]
$C^{I,BES}$	bidirectional inverter cost [€]
C^{W}	unitary cost of wind turbine [€/kW]
$C_i^{O\&M,W}$	*i-th* wind turbine O&M wind cost [%]
C_j^{fuel}	fossil fuel cost at year *j* [€/kWh]
$C^{O\&M,G}$	O&M fossil fuel generator cost [€/h]
g	inflation rate [%]
OCC	opportunity cost of capital [%]

Technical

α_j	PV inverter replacements [binary]
β_j	bidirectional inverter replacements [binary]
γ_j	BES replacements [binary]
δ_j	wind inverter replacements [binary]
η_{hj}^{PV}	PV overall efficiency at hour *h* of year *j* [%]
η^{BES}	BES charge/discharge efficiency [%]
$\eta^{I,PV}$	PV inverter efficiency [%]
$\eta_i^{I,W}$	*i-th* wind inverter efficiency [%]
$\eta^{I,BES}$	bidirectional inverter efficiency [%]
η_{module}	PV module conversion efficiency [%]
η_{pc}	PV system power conditioning efficiency [%]

$\eta_{temp,h,j}$	PV system temperature efficiency factor for hour h [%]
η_d	PV module conversion efficiency [%]
τ	temperature coefficient of solar cell efficiency [1/˚C]
$T_{a,h,j}$	Ambient temperature for hour h [˚C]
$T_{c,h,j}$	PV cell temperature for hour h [˚C]
$T_{c,ref}$	PV cell reference temperature [˚C]
NOCT	Normal operating cell temperature [˚C]
DOD	BES depth of discharge [%]
H_{ref}	yearly module reference in-plane irradiance [kW/m^2]
P^G	fossil fuel generator size [kW]

Environmental

H_{hj}	total in-plane irradiation at hour *h* of year *j* [kWh/m^2]

Load

E_{hj}	energy demand at hour *h* of year *j* [kWh]

Analytic model

Following are presents each parts of the energetic model and are analyzed all equations use in the model and presents in the framework above.

Photovoltaic system

Hourly energy product by PV system is define by the following equation

$$E_{h,j}^{PV} = H_{h,j}\, A\, \eta_{h,j}^{PV}$$

Energy product is directly depending by sun irradiation $H_{h,j}$ on the module and the area A of the module. The energy product is decrease by the efficiency of the panel, proper term of each panel. The above equation is necessary for sizing of PV energy system, especially if use in the following shape:

$$A = \frac{X^{PV}}{\eta^{module} \cdot H^{ref}}$$

Where H^{ref} meaning the irradiation in the reference condition of 1,000 W/m^2.

Photovoltaic system efficiency η_{hj}^{PV} is given for all system lifetime (years j, and hours h) by:

$$\eta_{hj}^{PV} = \eta_{module} \cdot \eta_{pc} \cdot \eta_{temp,h,j} \cdot \eta^{I,PV} \cdot (1 - (j-1) \cdot \eta_d)$$

Where the total efficiency is the product of the module efficiency η_{module}, the system power conditioning efficiency η_{pc}, the temperature efficiency of the panels $\eta_{temp,h,j}$, for each years and hours, the photovoltaic inverter efficiency $\eta^{I,PV}$ and the module conversion efficiency η_d.

Where the temperature efficiency of the panels is given by

$$\eta_{temp,h,j} = \{1 - \tau \cdot (T_{c,h,j} - T_{c,ref})\}$$

In which the photovoltaic cell actual temperature is relate to cell reference temperature (usually is take 25°C). The result is increase with the temperature coefficient of solar cell efficiency τ, given as the power percentage variation for each Celsius degree, and is a parameter given by manufacture. The one’s complement of this value is the temperature efficiency of the panels at a certain day in a certain time.

The actual cell temperature used in the equation above, is given by

$$T_{c,h,j} = T_{a,h,j} + \left[\frac{NOCT - 20}{800}\right] \cdot H_{h,j}$$

Where to calculate the temperature of the panel is used the ambient temperature where panel works, $T_{a,h,j}$, at the same time of the same day, increase with the second parameter calculate with the normal operating cell temperature, $NOCT$ and the total in-plane irradiation in the same time H_{hj}. The NOCT is a parameter give by PV panels manufacturer: it is the average temperature of a photovoltaic cell with a solar irradiation of 800 W/m^2, an environmental temperature of 20°C and a wind speed of 1 m/s.

The energy given by the solar panels is

$$E_{h,j}^{PV} = X^{PV} \frac{H_{h,j}}{H^{ref}} \eta^e (1 - \tau \left(\left(T_{h,j}^a + \left[\frac{NOCT - 20}{800} \right] \cdot H_{h,j} \right) - T^{c,ref} \right)) \, \eta^{inv} (1 - (j-1)\eta^d)$$

BES system

For the battery energy storage system different equations are involved to define the working principles.

One of the most important parameters of batteries in the rated capacity, also called the battery size. From this parameter is possible know the battery hours of working, when used. This is possible by the following equation:

$$AH = (X^{BES} \cdot \eta^{BES} \cdot \eta^{I,BES} \cdot DOD) / \, E_{h,j}^a$$

As shown in the following project, batteries have some issue with temperature. Usually batteries performances increase with the increasing of temperature, but at the same time high temperature speed up the get older of the batteries. Furthermore, the batteries capacity decrease of a 1% for each degree under the 20°C. These meaning the storage of batteries in an energy production plant should be at a temperature of 20-25°C. Anyway, in this model batteries temperature does not condition the results, so this term in this step of research will not concerns.

Another important parameter for the batteries is the state of the charge or SOC. A parameter proper to the status of charge of each battery, instead of the depth of discharge, DOD that is the complement of SOC. SOC give the energy storage actually (day/year) in the battery. For a proper use of the batteries the status should stay between the maximum capacity of the batteries and the minimum depth of discharge given by DOD. Otherwise, below, batteries operation is damage.

The batteries status the first day of them work should be between the minimum and the maximum state of charge. This is given by the first equation used, where the state of charge at day 1 of the year 1 (SOC_{11}) should be as follow

$$SOC_{11} = (1 - DOD) \cdot X^{BES}$$

Where DOD is the batteries percentage depth of discharge. In the first hour of the first working day the energy flow from batteries should be zero value by equation $F_{11}^{BES,Out} = 0$.

Batteries could not at the same time charging and discharging, to analyze this circumstance is use a binary variable $\sigma_{h,j}$, positive if batteries are charging, negative otherwise.

$$F_{h,j}^{BES,In} \leq \sigma_{h,j} M$$

$$F_{h,j}^{BES,Out} \leq (1 - \sigma_{h,j}) M$$

Where the parameter M is usually use in modelling and is a parameter with a high value.

Diesel generators

The diesel generators system working is defined by the following equations

$$T_{hj}^{G} \geq \frac{F_{hj}^{G}}{P^{G}}$$

and

$$F_{h,j}^{G} \leq P_{G}$$

The first equation is used for understand when the generator is working in a particular day of the year. The second one is used to define the maximum energy generator can produce. Clearly the generator electricity product $F_{h,j}^{G}$ should be at least as the power size of the generator P_{G}.

Wind turbines

Wind turbines are electricity generators works by the blow of the wind. They use energy kinetic of the air transform by an alternator into electricity. To work and to produce energy is require a minimum wind speed of 3-5 m/s usually called cut-in speed. If wind increase, consequentially the energy product will increase too, until the nominal speed, which is the target speed where the turbine generates the whole target-power, usually at 12-14 m/s of wind speed. The power remains constant till the reach of the cut-off speed at 20-25 m/s. This is the maximum speed which the wind turbines work, over this limit the turbine will stop by the break system for the safety shake.

The power diagram of wind turbines is presents in the picture below

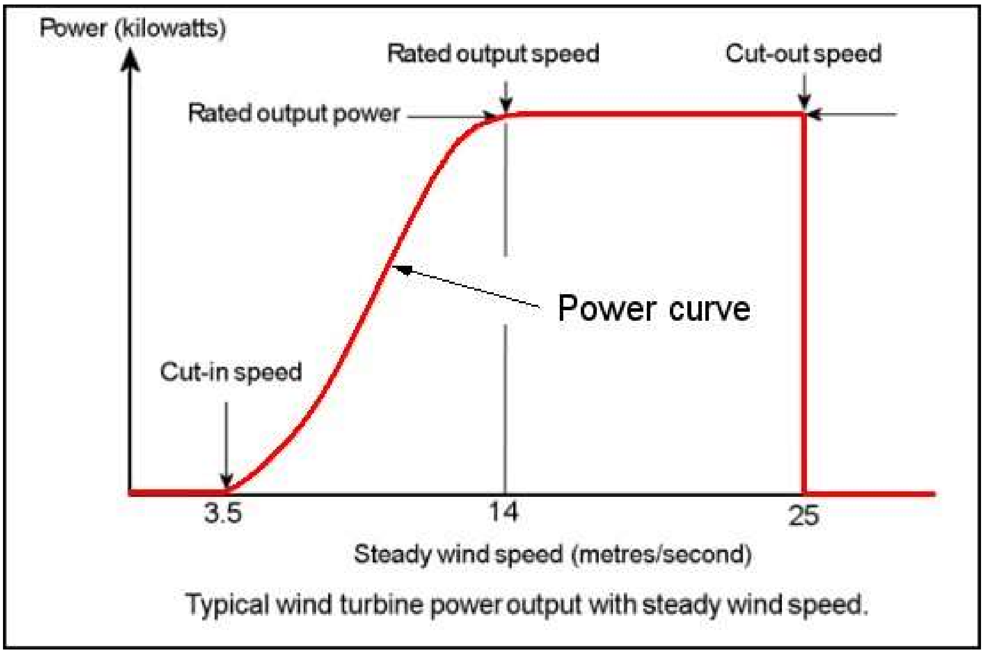


Figure 54: Generic wind turbine power curve[22]

To determine the electricity production by the wind turbines is necessary us a trick for using the actual wind speed in a linear analytic model like this one. In particular, is possible modify the wind speed in the place, using the Weibull function as follow.

The Weibull distribution is

$$f(x) = \alpha\beta x^{\beta-1}e^{-\alpha x^{\beta}}$$

Where α is the scale parameter and β is the shape parameter.

The wind speed to use in the model is given by the following relation

$$v_{h,j}^{*} = \begin{cases} v^{in} & v_{h,j} \leq v^{in} \quad o \quad v_{h,j} \geq v^{off} \\ v_{h,j} & v^{in} < v_{h,j} < v^{nom} \\ v^{nom} & v^{nom} \leq v_{h,j} < v^{off} \end{cases}$$

Where

v^{in} is the cut-in speed, 4 m/s

v^{nom} is the nominal speed, 14 m/s

v^{off} the cut-off speed, 25 m/s

22 http://www.wind-power-program.com/popups/Typical%20power%20output%20(550%20x%20363).jpg

$v_{h,j}$ is the actual speed

$v_{h,j}^{*}$ modified speed

With this trick is possible use a linear equation connecting the wind turbines energetic flow and the speed of the wind. If the turbines speed if less than cut-in speed, and more than cut-off speed, then energy is zero. Between cut-in and nominal speed, energy and speed are linear linked. From nominal speed and cut-off energy product is maximum.

$$F_{h,j}^{W} = \left(v_{h,j}^{*} - v^{in}\right) \cdot P^{W} / v^{nom} - v^{in}$$

Economical model

The economical evaluation of the hybrid plant is doing by the LCOE, the levelized cost of energy. It is a parameter use in energy models to compare the costs of different methods to product electricity by the use of renewable energies. Starting from incomes R_j and costs C_j of a plant, this parameter permits to understand what is the cheapest method to produce electricity.

$$\sum_{j=1}^{N} \frac{R_j}{(1+OCC)^j} = \sum_{j=1}^{N} \frac{LCOE \cdot (1+g)^{j-1} E_j}{(1+OCC)^j} = C_0 + \sum_{j=1}^{N} \frac{C_j \cdot (1+g)^{j-1}}{(1+OCC)^j}$$

By this equation is possible calculate the LCOE such as the ratio between the sum of the plant costs and the yearly production, each using the decreasing by inflation.

$$LCOE = \frac{C_o + \sum_{j=1}^{N} C_j \cdot \frac{(1+g)^{j-1}}{(1+OCC)^j}}{\sum_{j=1}^{N} \sum_{h=1}^{H} E_{h,j} \cdot \frac{(1+g)^{j-1}}{(1+OCC)^j}}$$

C_o is the starting plant investment: it includes the cost of PV panels, batteries, inverters and wind turbines. The costs of diesel generators are not including in this equation because they are jet used in humanitarian camps.

Instead of, the costs of PV panels and the inverter are function of photovoltaic power, as well as batteries cost is function of batteries capacity and the cost of wind turbines is function of them power. The bidirectional inverter has a constant cost.

$$C_o = C^{PV} + C^{I,PV} \cdot X^{PV} + C^{BES} \cdot X^{BES} + C^{I,BES} + C^{W} \cdot P^{W}$$

The yearly costs of the whole energy plant include also the maintenance of each plants and sometimes the cost of replacement, i.e. batteries usually are replaced after 7 years of work, as well as bidirectional inverter replaced after 9 years.

For the diesel generators costs are for the fuel and for the maintenance, each depending from hours of working.

Following is present the equation using to determine the whole costs of the plant.

$$C_j = \left(C^{O\&M,PV} + \alpha_j \cdot C^{I,PV}\right) \cdot X^{PV} + \beta_j \cdot C^{I,BES} + \gamma_j \cdot C^{BES} \cdot X^{BES} + C^{O\&M,N} \cdot P^{W} + \sum_{h=1}^{H} \left(C^{O\&M,G} \cdot T_{hj}^{G} + C_j^{fuel} \cdot F_{hj}^{G}\right)$$

This equation calculates the yearly total cost of energy system used in relation to the size and dimensions of the different systems used i.e. installed battery capacity power. The equation is the sum of respectively different costs of: PV system, BES, Wind and diesel Generators.

In particular for PV system $C^{O\&M,PV}$ are the operative and of maintenance costs; $C^{I,PV}$ is the cost for PV inverter and α_j is the binary variable used for PV inverter replacement. Finally, the X^{PV} is the PV system rated power installed in the camp.

For the Battery Energy Storage system, the total cost is calculated as the sum of two main factors:

$C^{I,BES}$ the cost of Bi-directional inverter necessary to use with battery, and β_j the binary variable used for BES bi-directional inverter replacement, plus the C^{BES} unitary cost of battery system, γ_j the binary variable for BES replacements, and X^{BES} the BES system rated power.

The cost for wind turbines is given by the operative and maintenance costs $C^{O\&M,N}$, and the wind turbine system rated power P^{W}.

A different approach is used with the costs of diesel generators, because they use fuel to product electricity: so, the total cost is given by the sum of operative and of maintenance costs $C^{O\&M,G}$, and the cost of fuel used C_j^{fuel}. These costs are present when the generators are working. h is the variable use to quantify the working hours for the generators.

Results

In this chapter is present an optimization model, both technical and economical, to sizing a hybrid-off grid system for the production of electricity in a humanitarian camp, by the use of renewable energy such as wind and sun, and a battery system to storage energy exceed product. Furthermore, the system working also with diesel generator such as back-up of energy.

The model permit to have as output the sizing of wind generators system, photovoltaic panels and inverters, and the batteries energy storage system. Input of the model are all data and parameters of the environment where the camp will be placed. The model will give the mix of systems to electricity production that will be minimizing the levelized cost of energy (LCOE). In different environments results of production plants should be different because with different environment conditions, i.e. irradiation and windy, the model will balance differently the sizing of the electricity production.

This model should become an important decision-making tool for humanitarian agencies, because guide the best choice for the electricity production before the humanitarian mission start. So, the agency could decide how manage the operations, which equipment and hardware needs, for obtain the best balance of energy product within the camp. Furthermore, renewable energies ensure the electricity production also when the fuel supply chain does not work or fail cause theft.

Moreover, with wind and sun renewable production, humanitarian camps decrease them carbon-footprint, become more environment friendly than before.

Further research

Renewable energies are surely the further method for the energy production, in particular for the electricity production. Humanitarian agencies become to understand how these energies could be important both for environment and the economy of an agency. Renewable energies permit to simplify the fuel procurements in the humanitarian camps, reducing the number of fuel-shipping, the costs of the supply chain and the costs for losses. This is an important strategic point because costs by energy production in a humanitarian camp are the higher among all operative costs for the whole mission.

A decision-make model is an important strategic support tool for humanitarian agencies because permit to set-up better the humanitarian missions before them begin. With the sizing of all energetic systems for the humanitarian camp is possible organize in advance the supply chain for the mission.

A further research will be the model testing with the actual energy consumptions of different humanitarian camps, and see how plants sizing and costs change with different environment scenarios. Another interesting study to do should be evaluate how carbon-footprint of a humanitarian camp change with renewable energies and with the whole energy production made by diesel generators.

4.2 Mobile storage unit with PV-BES system

Humanitarian cold storage supply chain

During the emergencies a humanitarian agency is able to supply to the strict area different types of resources needs to help refugees. Usually, agencies such as WFP-UNHRD, that are the first agencies who can supply in the strict area, ship tents, water tanks, kitchen sets, and other aids useful to people to survive in the first instant after the catastrophe. Humanitarian agencies usually ship materials from their Hubs to strict areas by plane or by ship. If the strict area is close to an airport, then the supply chain is short, and by vehicles, such as trucks or vans, should supply items from airport to the camps. Instead if there is not an available airport close to the camps is necessary made an intermediate or some intermediate warehouses. The transport to the airport to warehouses and to the camps is made by trucks and vans. For a standard shipping made by tents, prefabricates and so on the length of the humanitarian supply chain is not an issue. It is, instead, for different items, in particular perishable items such as medicines, drugs and food. During the first stages of the catastrophe a big number of perishable items are supply into the strict area, to assist refugees and survivors of disaster. In spite of this needs humanitarian agencies have not the right equipment and vehicles to ship and storage well perishable items. The main problem, especially in warm area, is the cold storage in humanitarian camps. In fact, until nowadays humanitarian agencies used tends such as warehouse.

This project, made with UNHRD-LAB, has been started from the gap of the cold supply chain in humanitarian camps, and presents an off-grid solution for a cooling storage module (temperature control) using photovoltaic and battery system to supply electric energy. Following is present a thermal simulation of the system and economic analysis to underline how should be efficient and affordable the system for humanitarian agencies.

This project was so appreciated by WFP-UNHRD management, that four of these systems were installed in 2016 and 2017 in Mogadiscio in Somalia.

Mobile Storage Unit

The mobile storage unit in the humanitarian field slang is a tent designate for the storage of many items. There are different types, differ by dimensions and materials. The most common in WFP-UNHRD camps is the HALL NG1 “W. Giertsen Hallsystem AS” tent.

This tent has an aluminum frame and a PVC covering tarp. It weighs about 1,600 Kg and lengths of 10x24 meters, as shown in the pictures below.

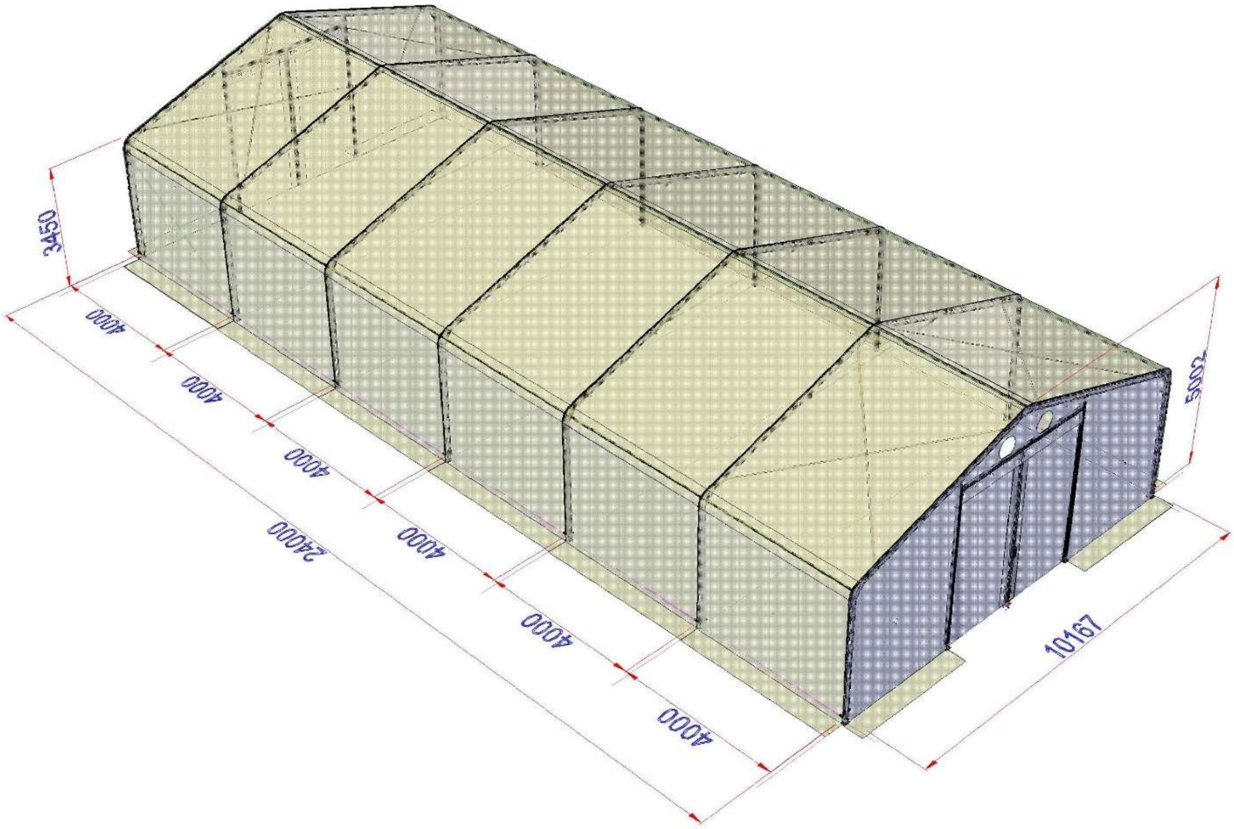


Figure 55: Giersten tent

Figure 56: Pictures of Giersten Tent in Brindisi

This tent is very useful during emergencies because it is a waterproof and weather-resistance storage. It is big and handy to use with forklift, with two big doors in the short sides.

However, especially in warm/hot climates is not suitable to storage perishable items such as medicines, drugs and food. This is due to the PVC covering tarp, reproduce the green-house-effect within the tent: during the hottest days the temperature inside the tent is warm as soon as outside.

During 2013 in the UNHRD base in Brindisi, the Unibo team has been conduct several tests with temperature/humidity control system in the Giertsen tent. Tests was made for proving that this tent is not suitable to storage food or other perishable items cause the high temperature in hot climate.

Giertsen tent tests

Test as conduct as follow.

The system used: kit Poseidon 2250 by HW group[23]

Sensors used:

- Two temperature/humidity probes
- One temperature probe

All the temperature probes have an accuracy level of about ±0.8°C, while the humidity sensors have and accuracy of about ±5%.

Two of them have been located inside the MSU while the third one has been placed outside the MSU to measure the environmental temperature and humidity, assumed as benchmark.

The adopted sensors and their features are as follows:

- IN-3m-T/IN-3m-RH: 3 meters wire long temperature + humidity integrated sensor placed inside the MSU close to the product storage location;
- IN-10m-T: 10 meters wire long temperature sensor placed on top of the MSU to detect the most critic conditions;
- OUT-3m-T/OUT-3m-RH: 3 meters long temperature + humidity sensor placed outside the MSU to measure the environmental conditions (benched mark).

The following show the trends of the temperature and relative humidity registered in Brindisi from July 17th to July 24th, 2013.

[23] https://www.hw-group.com

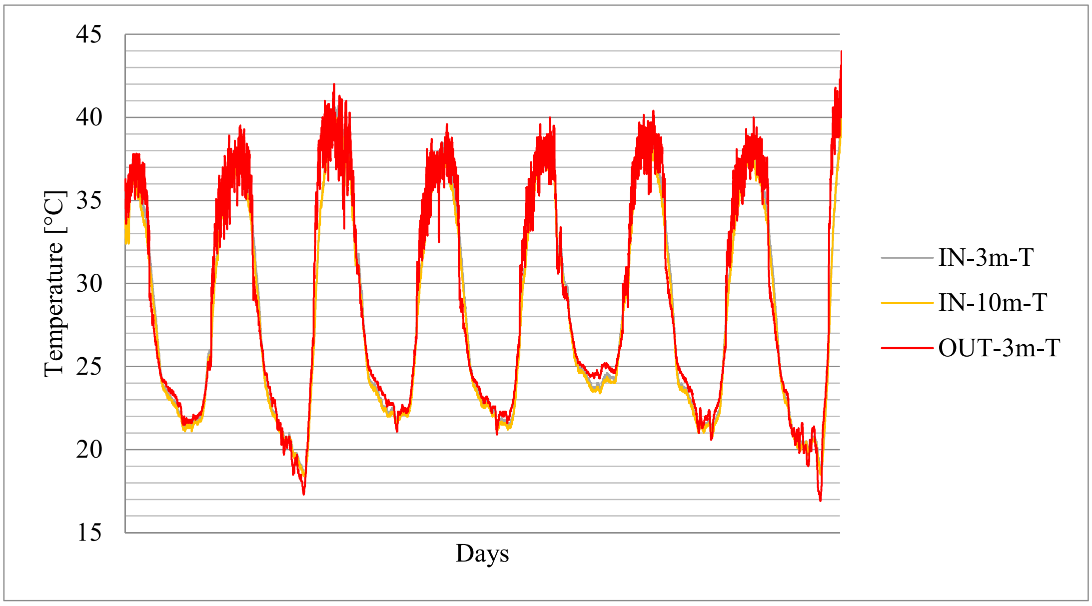


Figure 57: Graph of temperature trend

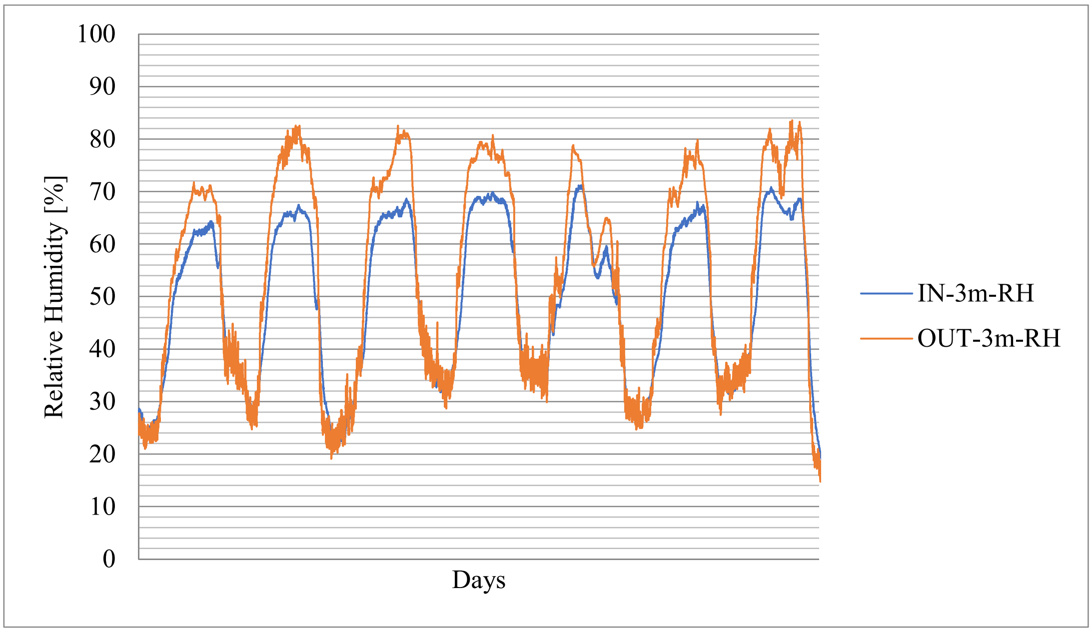


Figure 58: Graph of humidity trend

The two trial-campaigns made highlight that both temperature and humidity are critic variables for the MSU operative conditions.

These tests prove also Giertsen tent is not suitable for the stocking in warm regions of perishable items.

QR – Question of research

The goal of this study was to solve the problem of the lack of control temperature storage warehouses in humanitarian camps. The purpose of this research was to find a cost-effective solution satisfied the strict requirements of humanitarian agencies. Furthermore, find a solution which use clean renewable energy was preferred.

During the dissertation of this work I would reply to some questions we asked before start the project:

- Which are the preferable solutions for MSU instead of a tent?
- Is it possible develop a MSU with cooling system?
- Is it possible use solar energy to make a stand-alone MSU?
- Is a PV-BES system convenient for humanitarian camp?

Unibo Cooling PV-BES MSU project

As appended in the preceding project this project has to starts from something just present in humanitarian supply chain. In this project the most interesting thing for our purposes was the container modular prefabricate accommodation unit, using in humanitarian fields as office, accommodations, hospitals, dormitory, etc. as shown in the picture below.

Figure 59: Modular prefabricated accommodation unit[24]

Dimensions are:

- Length: 5.6 m
- Width: 2.3 m
- External height: 2.67m
- Internal height: 2,4 m
- Area: 12m^2

The frame is composed by aluminum and steel elements with aluminum and polyurethane walls and roof as well. In particular:

- Walls are made by a 50mm width steel/polyurethane (PUR) panel. Steel plates have a 0.4 mm width.
- Roof has a 50mm width steel/polyurethane (PUR) panel (Steel plates have a 0.4 mm width) with a 38 mm width steel covering on top.

[24] http://unhrd.org/e-catalogue/product/B38713305

- The floor is made by a 30mm width plastic panels with an aluminum frame in the border

To become a cooling storage unit the module needs some structural adjustment: first of all is necessary remove all windows and change the main door with a main front door in the short-side of the module. As shown in pictures below there are two different solutions useful for the main door.

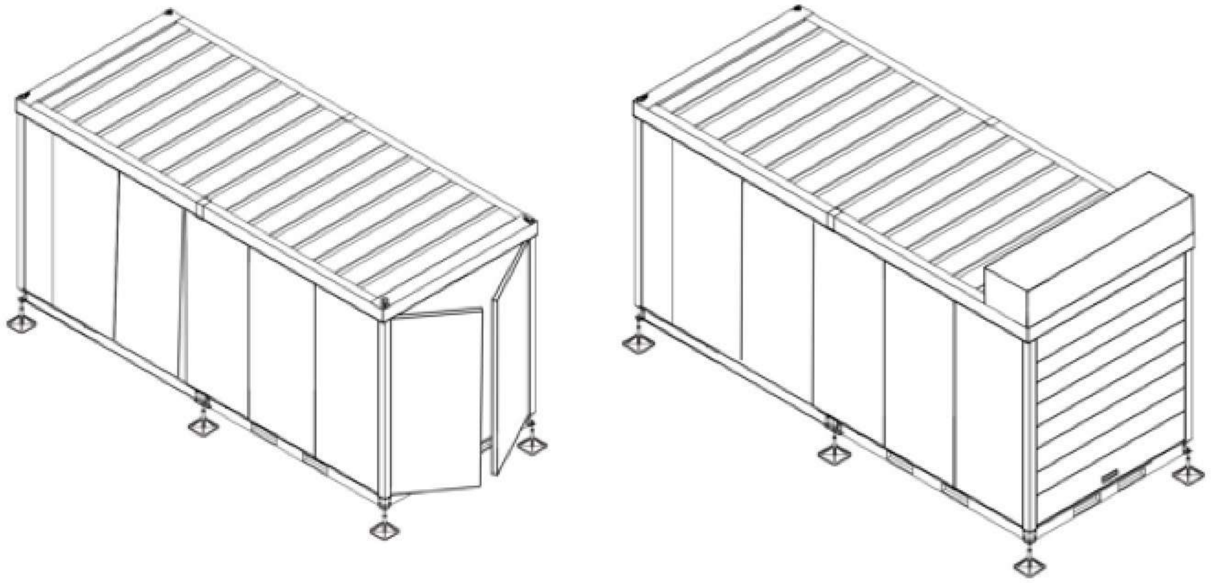


Figure 60: MSU main door

Windows are useless and are cause of thermal dissipation. For the door instead was useful the front door to fill up the module with the forklift truck.

Additionally, a floor reinforce was necessary to use the module as warehouse. Each pallet weight about 1,000 kg, and the actual floor has a payload of 250 kg/m^2. Reinforcing the frame of the floor with steel instead of aluminum permit to increase the floor payload until the maximum pallet capacity of the module.

Thermal analysis

Made the structural modification, the second step of this project was the study of sizing of the cooling system necessary to turn the prefab a control temperature module. To define the size of cooling system is to determine the refrigeration load (Q) of the module into the working field. To make this analysis is to know the environmental condition where the module will be work, in particular the temperature and irradiation during the years. Unfortunately, we don't know the real working field where the module will be used. So, we decide to use as module working condition in the areas stroked by a catastrophe during the last two years, analyzing at the end different environment working conditions. In particular environments chosen for the study were:

Abidjan, Cote d'Ivoire; Nairobi, Kenya; Teheran, Iran; Jakarta, Indonesia; Brindisi, Italy; Riyadh, Saudi Arabia; and finally, in the desert of Kuwait.

For each of these places we collect daily average temperatures and daily average irradiations during the worst yearly conditions (take in the hottest and sunniest months). Irradiations was take for the cardinal compass points for a vertical plane and for a horizontal plane. With these data is possible calculate thermal conduction and solar heating the module.

In the following list are equations used during the refrigeration load calculation:

Thermal flux into walls, ceiling and floor by conduction (W)

$$Q_{cond} = \sum_{i=0}^{n} U\, A_i(T_i - T_e)$$

Where:

U overall heat transfer coefficient $(^{W}/_{m^2\,°C})$

A Outside surface area of the section

$\Delta T = (T_i - T_e)$ Temperature difference between the outside air and the air inside the refrigerated space

The solar heating effect (W) is calculated on each wall in relation to the orientation in the cardinal compass points by:

$$Q_{sol} = F_{sh}\, A_{sol}\, I_{sol}$$

and

$$A_{sol} = \alpha_{sol}\, U\, R_{surf}\, A$$

Where:

Q_{sol} solar heating effect on a wall

F_{sh} shadow reduction factor [0;1]

I_{sol} solar irradiance $(^{W}/_{m^2})$

A_{sol} effective collection solar area (m^2)

α_{sol} solar absorption factor of opaque component [0;1]

U overall heat transfer coefficient $(^{W}/_{m^2\ °C})$

R_{surf} eternal thermal surface resistance of opaque component

A opaque component area (m^2)

Following is present such as an example a calculation of these parameters for Abidjan, Cote d'Ivoire. For each place has been doing the same calculation, presents in the following summary.

Month	**I_h** (W/m^2 day)	**I₍₉₀₎** (W/m^2 day)	**I_{hd}** (W/m^2)	**I_{(90)d}** (W/m^2)	***TD*** (°C)
Jan	6430	4640	536	350.8	27,5
Feb	6540	3500	545	264.2	29
Mar	6580	2260	548	200	28,5
Apr	5900	799	492	79.1	28,5
May	6000	776	500	80.6	28
Jun	5610	789	468	87.5	26,5
Jul	5390	840	449	90	25,5
Aug	5750	868	479	100	24,5
Sep	6150	1340	513	135	25,5
Oct	6160	2880	513	204.2	26,5
Nov	5950	3950	496	280.8	28
Dec	6080	4720	507	325.8	27,5
Year	72'540	27'362			

Table 12: Example of yearly average irradiation and temperature

Where:

I_h Monthly irradiation on horizontal plane

$I_{(90)}$ Monthly irradiation on plane at angle: 90degree

I_{hd} Daily irradiation on horizontal plane

$I_{(90)d}$ Daily irradiation on plane at angle: 90degree

TD Average daily temperature

In red is highlight the month with the higher irradiation in the years. The cooling sizing calculation will be doing on these data, because the worst conditions for the system.

	Horizontal plane	**East wall**	**South wall**	**West wall**	**North wall**
Time	I_{hd}	$I_{(90)d}$	$I_{(90)d}$	$I_{(90)d}$	$I_{(90)d}$
06:22	53	191	31	18	18
06:37	98	321	50	27	27
06:52	150	433	70	35	35
07:07	209	522	89	42	42
07:22	270	593	108	49	49
07:37	334	646	125	55	55
07:52	398	684	141	60	60
08:07	461	708	156	65	65
08:22	523	720	171	69	69
08:37	583	722	184	73	73
08:52	641	714	196	76	76
09:07	695	697	206	78	78
09:22	746	673	216	80	80
09:37	793	642	225	81	81
09:52	837	606	233	82	82
10:07	875	564	240	83	83
10:22	910	517	245	84	84
10:37	939	467	251	84	84
10:52	964	413	255	84	84
11:07	984	357	258	85	85
11:22	999	298	260	85	85
11:37	1010	238	262	85	85
11:52	1010	177	263	85	85
12:07	1010	85	263	177	85
12:22	1010	85	262	238	85
12:37	999	85	260	298	85
12:52	984	85	258	357	85
13:07	964	84	255	413	84
13:22	939	84	251	467	84
13:37	910	84	245	517	84
13:52	875	83	240	564	83
14:07	837	82	233	606	82
14:22	793	81	225	642	81
14:37	746	80	216	673	80
14:52	695	78	206	697	78
15:07	641	76	196	714	76
15:22	583	73	184	722	73
15:37	523	69	171	720	69
15:52	461	65	156	708	65
16:07	398	60	141	684	60
16:22	334	55	125	646	55
16:37	270	49	108	593	49
16:52	209	42	89	522	42

17:07	150	35	70	433	35
17:22	98	27	50	321	27
17:37	53	18	31	191	18
17:52	20	8	12	64	8
	616	**286**	**180**	**287**	**66**

Table 13: Example of daily solar irradiation

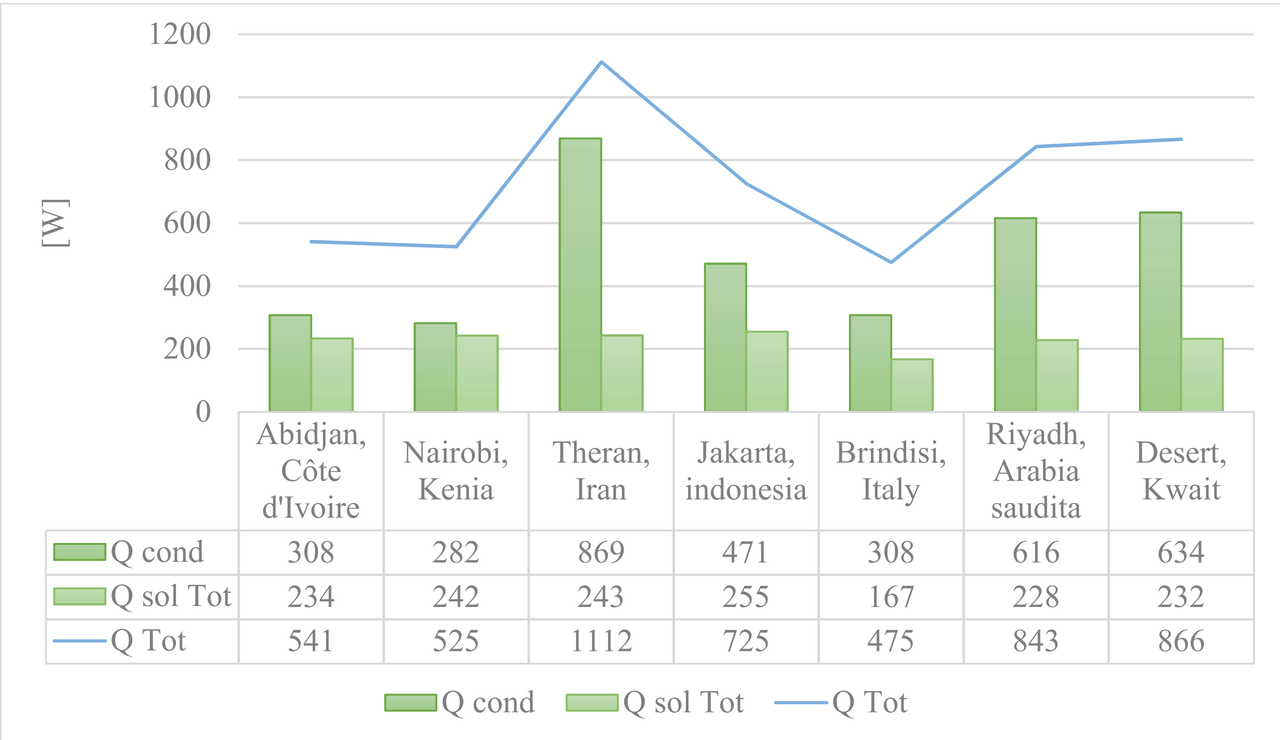
Following the results of thermal flux (W) in the module by conduction and solar irradiance using the equations present above.

$\boldsymbol{Q_{cond}}$	$Q_{sol\,h}$	$Q_{sol\,east}$	$Q_{sol\,south}$	$Q_{sol\,west}$	$Q_{sol\,north}$	$\boldsymbol{Q_{sol\,Tot}}$	$\boldsymbol{Q_{TOT}}$
308	99,0	32,8	50,3	33,0	18,5	233,6	**542 (W)**

Table 14: Termal flux incoming in the module by the sun rays

Results are coming with an inner temperature in the module of 20°C.

In the following graph and table, a summary of the results for the others environments chosen.



	Abidjan, Côte d'Ivoire	Nairobi, Kenia	Theran, Iran	Jakarta, indonesia	Brindisi, Italy	Riyadh, Arabia saudita	Desert, Kwait
Q cond	308	282	869	471	308	616	634
Q sol Tot	234	242	243	255	167	228	232
Q Tot	541	525	1112	725	475	843	866

Table 15: Total thermal flux incoming into the module in different environments choosen for this study

The total thermal flux is the same amount of cooling power that is necessary to ensure and maintain the choose inner temperature, i.e. 20°C, in the module during the whole day.

The total energy load requests by cooling system and other equipment, such as control, illumination and communications, into MSU is almost unvaried and stable during the year. Also, the temperature range between day and night is not influential, because infrequently external temperature drop-off under 20°C. Therefore, energy load should take constant during the year and the night and day. Using an increase-security factor the energy load should be 1,5 kWh.

Cooling system

The cooling system choose, was an air-air cooling system made for humanitarian organization modules. The size choose was a 1260Wh electric and 3350Wh cooling.

To put in place the cooling system was necessary make a wall into the module. The wall was a support for the cooling system and separate the module area in two different sites: a small one, is to install the electric cabin and other electric equipment, the other main side is the stocking area for the pallets. As show in the picture below, the electric side is just a small cabin 50cm long.

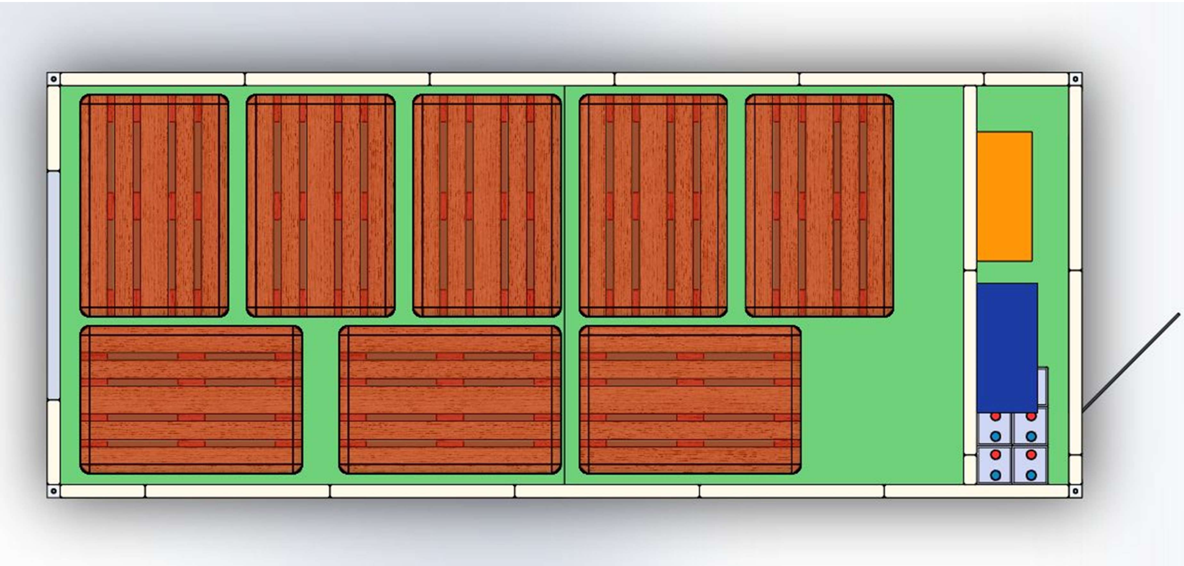


Figure 61: Module map with electric cabin

After is made a thermal flow simulator with SolidWorks to analyze how cooling air flows into the module fill with the pallets. In the following pictures the thermal simulation.

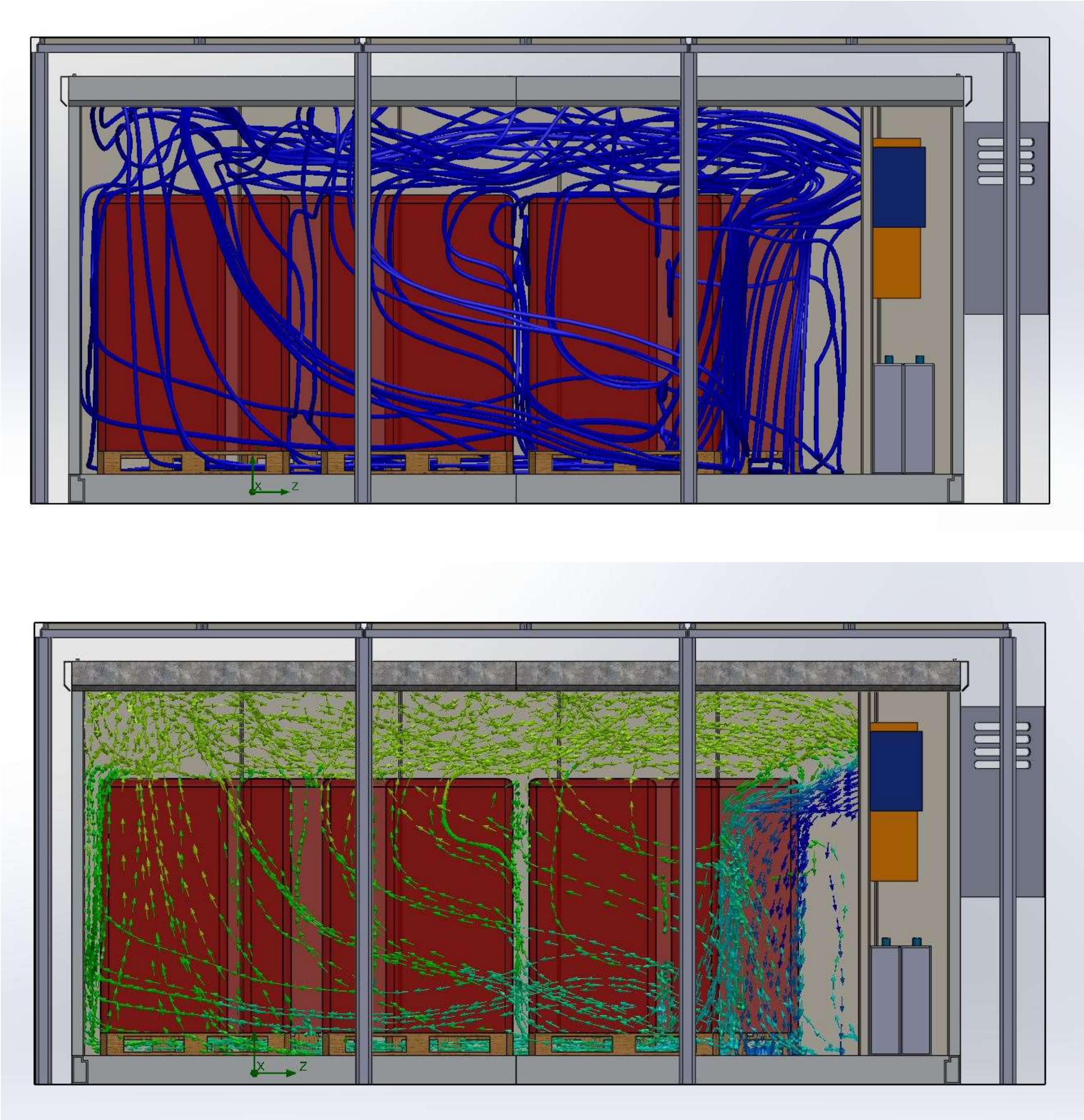


Figure 62: Thermal simulation by Solidworks Flow Simulator

In spite of the presence of the pallets, air in the simulation seem flows adequately for the cooling.

PV-BES System

As shown in the solar heating equation to reduce the sun irradiance heating is possible cover the module with a covering, making a shadow barrier. For this purpose, and to make the whole module energy stand-alone, was design a structure to support some photovoltaic (PV) panels. In addition to make shadow for the module, PV panels are useful to generate electric energy from the sun.

Moreover, to storage the energy during the night or during less sun irradiance time was decide to install a battery energy storage (BES) system into the electric cabin. Anyway, to ensure the electricity demand is also prearrange a connection with diesel generator.

The architecture of the electric generation system is explained in the figure below.

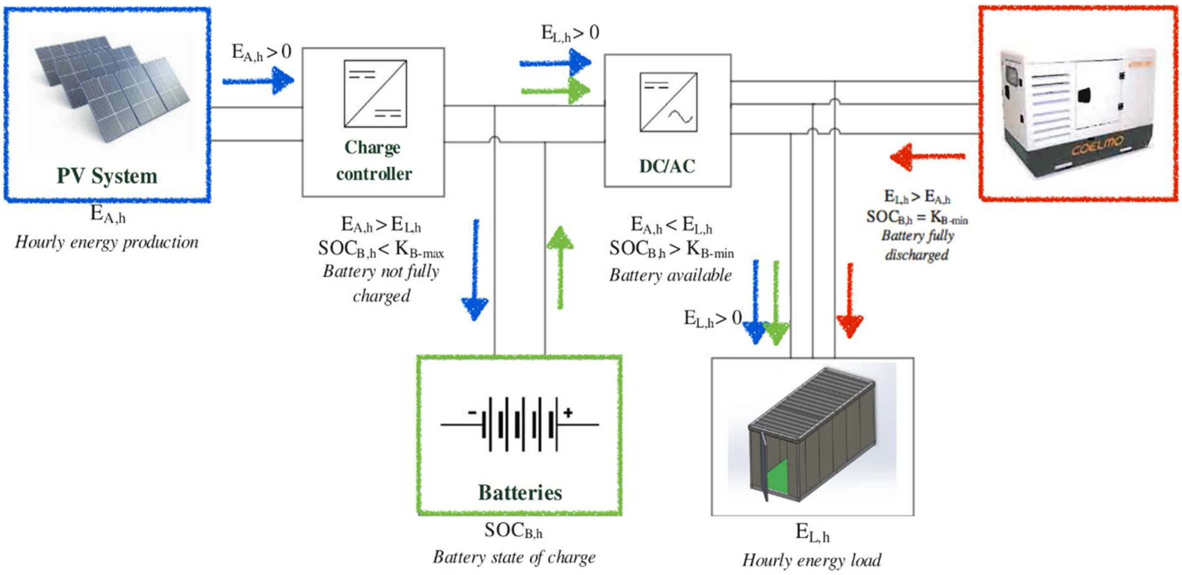


Figure 63: Module energy production framework

PV system generate electricity by the sun rays during the day. The charge controller is a device necessary to protect batteries during the charging, it avoid the electricity overload during the charging. If batteries are fully charged, electricity product by PV system pass through inverter DC/AC and flows to the user, in this case to the cooling system. If the electricity product by PV system and BES system is not sufficient to satisfy the user demand is possible use the diesel generator such as energy back-up (Bianchini et al. 2015).

The BES physical constrains are define in the following equation, for each working hour, h. (Bortolini, Gamberi, Graziani, et al. 2014)

$$K_B^{min} \leq SOC_{B,h} \leq K_B^{MAX}$$

Where:

$SOC_{B,h}$ is the hourly state of charge, that cannot exceed the maximum batteries capacity K_B^{MAX}, but it has to be higher than the minimum capacity K_B^{min}

$$K_B^{min} = (1 - DOD)K_B^{MAX}$$

Where:

DOD is the maximum allowable depth of discharge (Ismail et al. 2013).

As told before, the system aims to satisfy the cooling load thanks to the PV plant production and the energy store in the BES system. The diesel generator is used in case of the PV-BES system is not able to fully supply the required hourly energy demand.

The hourly energy balance is:

$$E_{L,h} = E_{P,h} + E_{B,h} + E_{G,h}$$

The PV system is used to satisfied the load energy demand, while if present an energy surplus it will flows to the BES system, until the battery fully charged. Exceeding energy will be dissipated by the PV inverter.

During the night-time and in the case of low irradiance BES system supply energy until the $SOC_{B,h}$ decrease to its minimum level. In this case diesel generator will supply the cooling load, even if during the night the cooling system should works less due to the decrease of external temperature.

Following is presents the analytic model of the system.

PV analytic model

Energy supply by PV system is given by (Bortolini, Gamberi, Graziani, Manzini, et al. 2013)

$$E_{P,h} = H_{I,h} A_P \mu_{PV,h}$$

Where

$$A_P = P_0/(\mu_{module} H_{I,h})$$

P_0 is a refers to the standard test condition, i.e. 1 kW/m^2, solar spectrum of AM 1.5 and module temperature of 25°C

$H_{I,h}$ is assumed equal to 1 kW/m^2

In this project PV system was not only an energy supply system, but was made also like a shadow barrier. So, the total area of the system was calculated on the need to cover all the roof of the module. The above equation become:

$$P_0 = A_P\, \mu_{module}\, H_{I,h}$$

Where A_P , area (m^2) of PV panels is given by the area of the roof module and an increase factor. The overall PV system is given by

$$\mu_{PV,h} = \mu_{module}\, \mu_e\, \mu_{temp,h}\, \mu_{inv}\, [1 - (j - 1)\mu_d]$$

As wrote in literature, PV module efficiency decrease linearly with the temperature respect to the reference condition of 25°C as define in the following equation.

$$\mu_{temp,h} = 1 - \beta\, (T_{c,h} - T_{c,ref})$$

Where

$$T_{c,h} = T_{P,h} + \left[\frac{NOCT - 20}{800}\right] H_{I,h}$$

Where both $NOCT$ and β depend to PV manufacturer specifications (Bortolini, Gamberi & Graziani 2014).

BES system analytic model

BES system capacity is given by nominal capacity K_B and the number of autonomy hours AH.

$$AH = (K_B\, \mu_{binv}\, \mu_{dch} DOD)/E_{L,a}$$

AH is the number of hours that the fully charged BES system is able to supply the energy demand considering the average hourly load $E_{L,a}$.

The charging process is given by

$$SOC_{B,h} = \max\{SOC_{B,h-1}(1 - \sigma) - \left(E_{A,h} - E_{L,h}\right) \mu_{binv}\, \mu_{ch}; K_B^{max}\}$$

The discharging process is given by

$$SOC_{B,h} = \min\{SOC_{B,h-1}(1 - \sigma) - \left(E_{L,h} - E_{L,h}\right)/(\,\mu_{binv}\, \mu_{dch}); K_B^{min}\}$$

In these last equations the initial BES system state of charge is

$$SOC_{B,h} = K_B^{min}$$

PV panels:

Dimensions 1325 x 992 x 40 mm, Weight 15kg

Nominal power 200 Wp, Nominal voltage 24,30V

12 units

Batteries:

Dimensions 212 x 193 x 690 mm, Weight 66 kg

Nominal voltage 2V, Capacity 1000 Ah

5 units with series connection

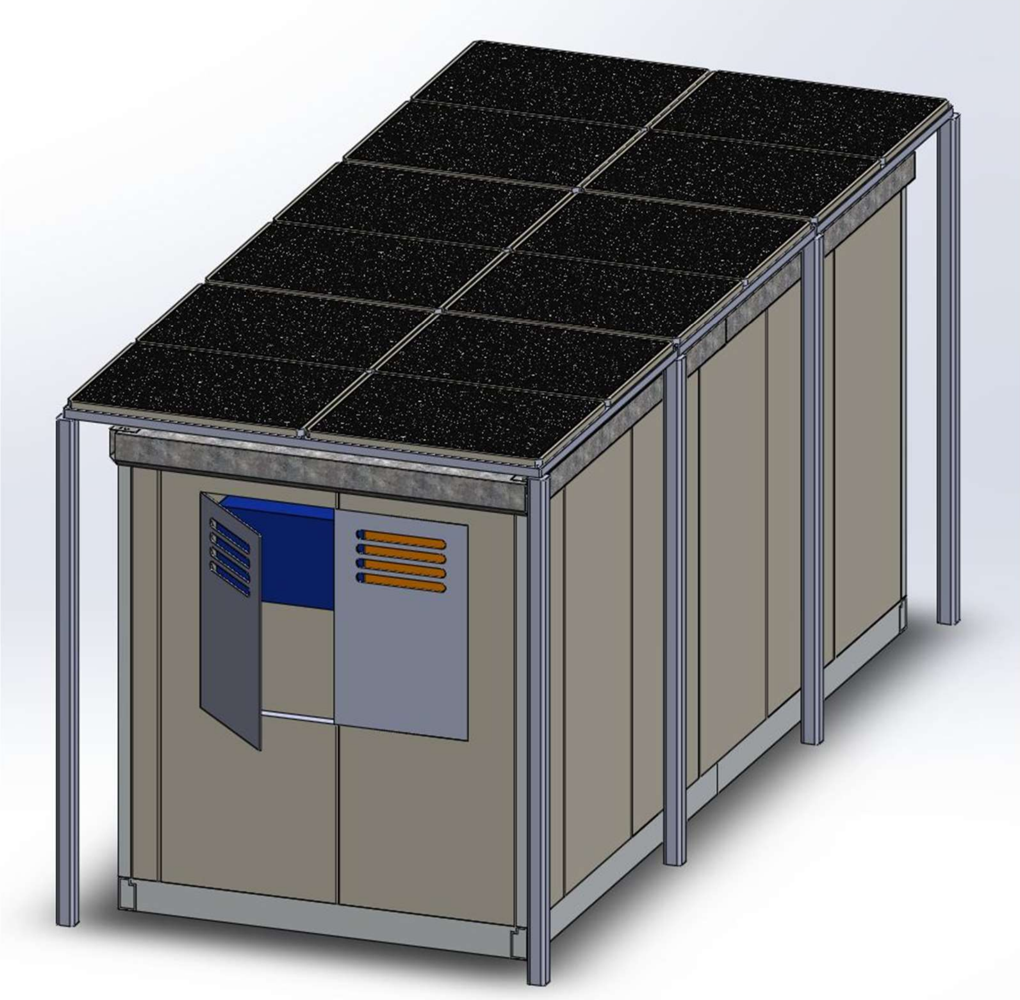
PV System		**BES System**		**Diesel Generator**		**Economic and Environmental parameters**		**Electric conversion devices**	
C^{OM}_{j}	0,01 (P_0) for j=1,..,n	C^B	150 €/kWh	C_f	1,12 €/l	$E_{L,h}$	1,5 kWh	C_{inv}	$0{,}0325(P_0)^2+196{,}25$ $(P_0)+350{,}92$€
P_0	10-14 kWp	C^B_j	150 €/kWh For j=6,12,18 years	C_m	0.6€/h	$H_{I,h}$	6,2 kW/mq	C^c_j	C_{inv} For j=10,20 years
C^{PV}	$2539{,}9\ P_0^{-0{,}253}$	DOD	0,8	P_g	5 kVA	g	0,03	C^I_j	C_{inv} For j=10,20 years
H_{ir}	1 kW/m^2	AH	5 hours			OCC	0,05	η_{inv}	0,92
n	20 years	V_b	24 V					η_{pc}	0,95
NOCT	45°C	σ	0,00583% (0,14%/day)					E_L	8100 kWh
$T_{c,ref}$	25° C	η_{ch}	0,895					$E_{L,a}$	1,5 kWh
η_d	0,005	η_{dch}	0,895					$E_{L,h}$	1,5 kWh
η_{module}	0,14	K_B	9.11 kWh					C_{cd}	4,38 €/A
β	0,005/°C								

Table 16: Values and range adopt and calculate in this project

Nomenclature used in the above equations

A_a	PV panels area (m^2)
AH	BES autonomy hours (h)
C_B	BES system unitary cost (€/kWh)
C_{cd}	control device cost (€)
C_{inv}	PV inverter cost (€)
C^I_j	PV-BES system inverter cost for year j (€)
c_m	generator hourly maintenance cost (€)
c_f	generator fuel cost (€/l)
DOD	BES system depth of discharge (%)
e_G	Diesel generator unitary system energy cost (€/kWh)
E_L	Total energy demand for the reference year (kWh)
$E_{L,a}$	Average hourly energy load (kWh)
$E_{L,h}$	Energy load for hour h (kWh)
f_G	Generator fuel consumption for year (kg/kWh)
g	inflation rate (%)
$H_{I,h}$	Total irradiation for hour h (kWh/m^2)
$H_{I,r}$	Yearly module reference irradiance (kWh/m^2), equal to 1 kWh/m^2
K_B	BES system nominal capacity (kWh)
K_B^{min}	BES system minimal capacity (kWh)
K_B^{max}	BES system maximum capacity (kWh)
LCOE	levelized cost of electricity (€/kWh)
n	system lifetime (years)
NOCT	normal operating cell temperature (°C)
OCC	opportunity cost of capital (%)
$SOC_{B,h}$	BES system state of charge for hour h (kWh)
$T_{c,h}$	PV cell temperature for hour h (°C)
$T_{c,ref}$	PV cell reference temperature (°C)
V_b	BES system voltage (V)
β	Temperature coefficiente of solar cell efficiency (1/°C)
σ	BES system hourly self-discarge rate (%)
ρ_f	Fuel density (kg/l)
μ_{ch}	BES system charging efficiency (%)
μ_d	PV module annual degradation ratio (%)
μ_{dch}	BES system discharging efficiency (%)

μ_e	PV electrical efficiency (%)
μ_{inv}	PV inverter efficiency (%)
μ_{module}	PV module conversion efficiency (%)
$\mu_{PV,h}$	PV system overall efficiency for hour h (%)
$\mu_{temp,h}$	PV system temperature efficiency factor for hour h (%)
h	index for hours
j	index for years



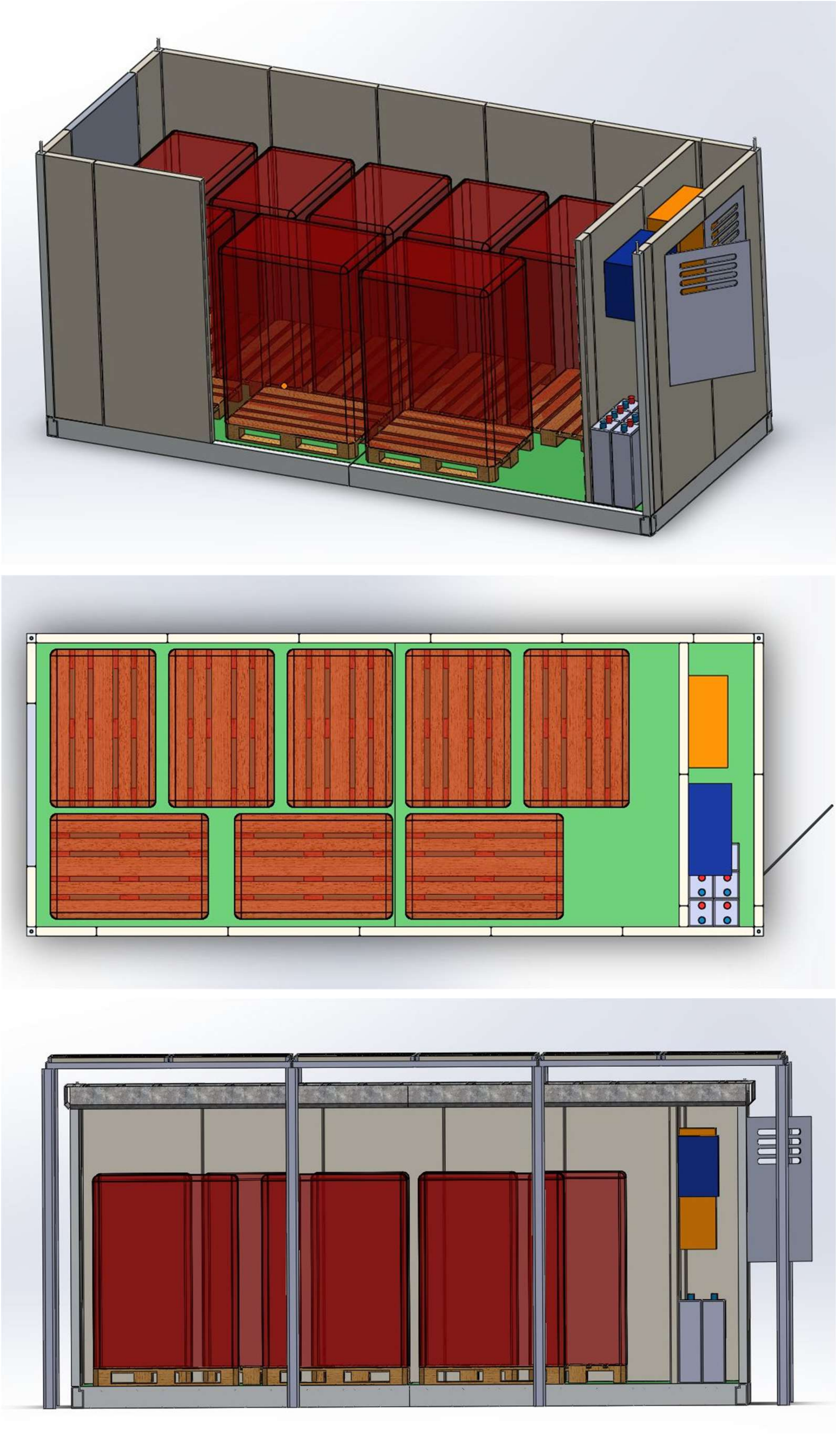


Figure 64: Final design of PV-BES MSU

Life time and cost analysis

An economic analysis was necessary to complete the analysis on the convenience of using solar energy in humanitarian camp instead of electricity made by traditional diesel generator. So, following will present a comparison between a cooling MSU with a PV-BES system such as energy supply and cooling MSU with a traditional diesel generator to makes electricity.

To make economic assessment of the system was used LCOE and then, was calculated the breakeven point of the system.

LCOE (Levelized Cost of Energy) is an index use during economic feasibility of system based on renewable energy sources (Hernandez-Moro et. Al, 2013). The LCOE is the unitary cost of the electricity produce and permit the economic comparison of different power generation technologies.

The LCOE is calculate as follow:

$$\sum_{j=1}^{n} \frac{R_j}{(1+OCC)^J} = \sum_{j=1}^{n} \frac{LCOE\,(1+g)^{j-1}E_j}{(1+OCC)^j} = C_0 + \sum_{j=1}^{n} \frac{C_j(1+g)^{j-1}}{(1+OCC)^j}$$

And

$$LCOE = \left(C_0 + \sum_{j=1}^{n} \frac{C_j(1+g)^{j-1}}{(1+OCC)^j}\right) \Bigg/ \sum_{j=1}^{n} \frac{E_L(1+g)^{j-1}}{(1+OCC)^j}$$

Where the costs of hybrid system are

$$C_0 = C_{PV}(P_0) + C_{inv}(P_0) + C_B K_B + C_{cd}$$

With this above equation is possible calculate the total costs of the PV-BES system, including contribute of PV module, inverter (both proportional to the rate power of the system P_0), batteries (proportional to battery capacity K_B) and control system.

Furthermore, is necessary adding to above equation the costs of diesel generator using as back-up. These costs are the fuel consumption C_j^{Gf} and maintenance operations C_j^{Gm}.

$$C_0 = C_{PV}(P_0) + C_{inv}(P_0) + C_B K_B + C_{cd} + C_j^{Gf} + C_j^{Gm}$$

The LCOE pf a traditional diesel generator can be evaluated by the simplified following equation considering just fuel and maintenance costs:

$$e_G = \frac{c_f f_G}{\rho_f} + \frac{(c_m 8760)}{E_L}$$

The hybrid system lifetime will be 20 years. Batteries will be replaced every 6 years of working, so after 6, 12 and 18 years. Battery replacement as shown in the following diagram (figure XX) will generate a cost increasing of the hybrid system.

Before presents results of economic analysis is necessary make a presupposition on fuel cost in developing regions and in areas strike by catastrophes. In fact, analyzing fuel costs during WFP missions is possible highlight as real cost of fuel for a humanitarian agency is too far as actual pump-fuel costs. This is due to the increase of fuel costs for humanitarian agency for its security: the fuel caravans usually used to transport fuel into humanitarian camps are generally assault on the road by pirates and bandits. So humanitarian agencies arrange security squad to safeguard fuel supply chain. This produce a high increase of fuel costs for humanitarian camps. An analysis of fuel costs conduct in WFP-UNHRD missions in Africa underline as fuel cost for liter for the agency is ten-time higher than actual pumps-fuel-cost.

To make the comparison as close as possible to the actual, we decide to use parametric costs of fuel: the comparison with PV-BES LCOE will starting from the lowest pump-fuel-cost in Africa, and raising double, triple, etc. This analysis permit to understand what is the limit of fuel costs where diesel generator is more affordable than PV-BES system. Upper than limit the hybrid solution will be advantageous than traditional.

Following is present the diagram comparison between life-time PV-BES LCOE and yearly diesel generator costs. These will be constant during the years because in the analysis is not considered the cost of generator and the consecutive amortization. In fact, diesel generators are usually use in humanitarian camps for energy supply, so should be use for different loads. In the analysis is so considered just the costs of fuel and maintenance of generators.

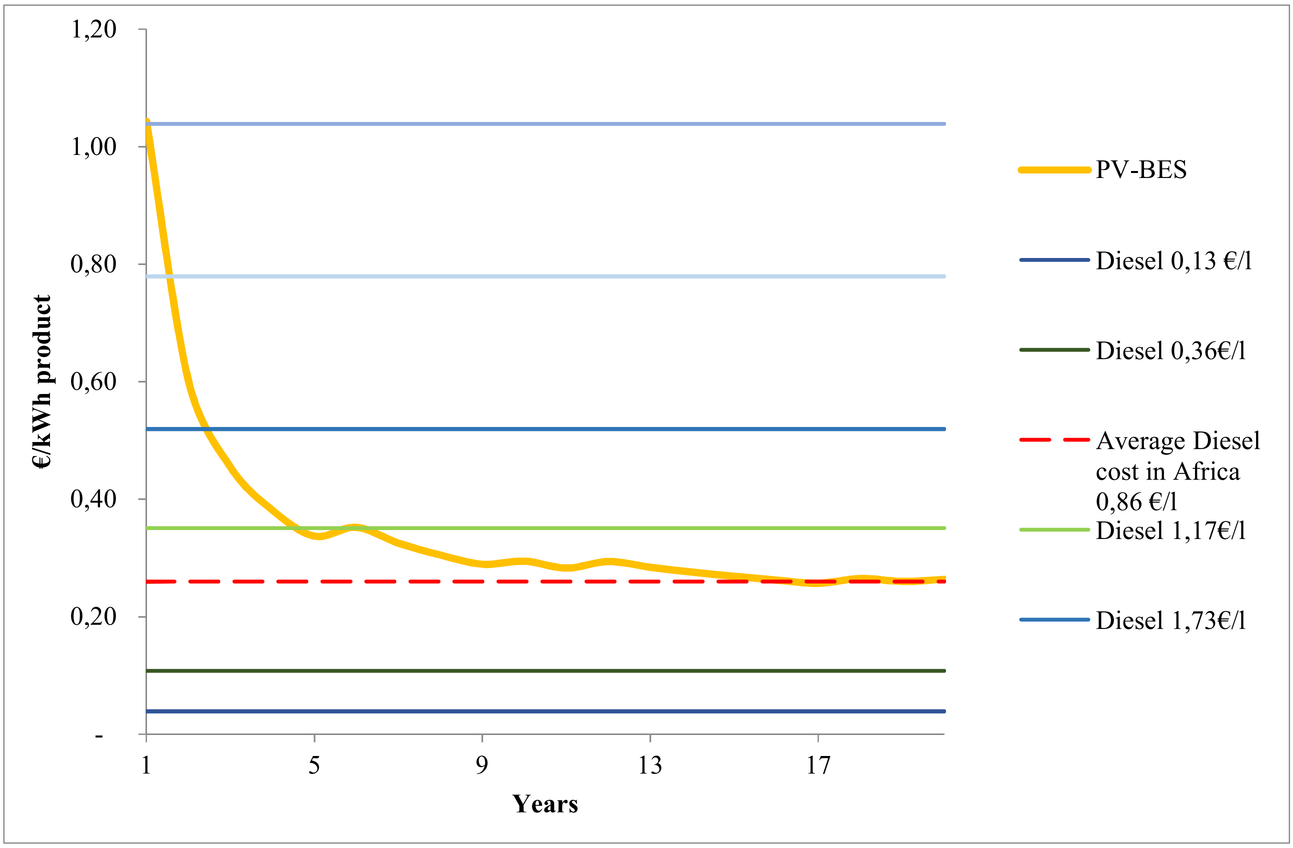


Figure 65: LCOE for PV-BES sytem and diesel generator

As shown in the diagram above the PV-BES system should be convenient if the diesel cost is superior of the average diesel cost in Africa.

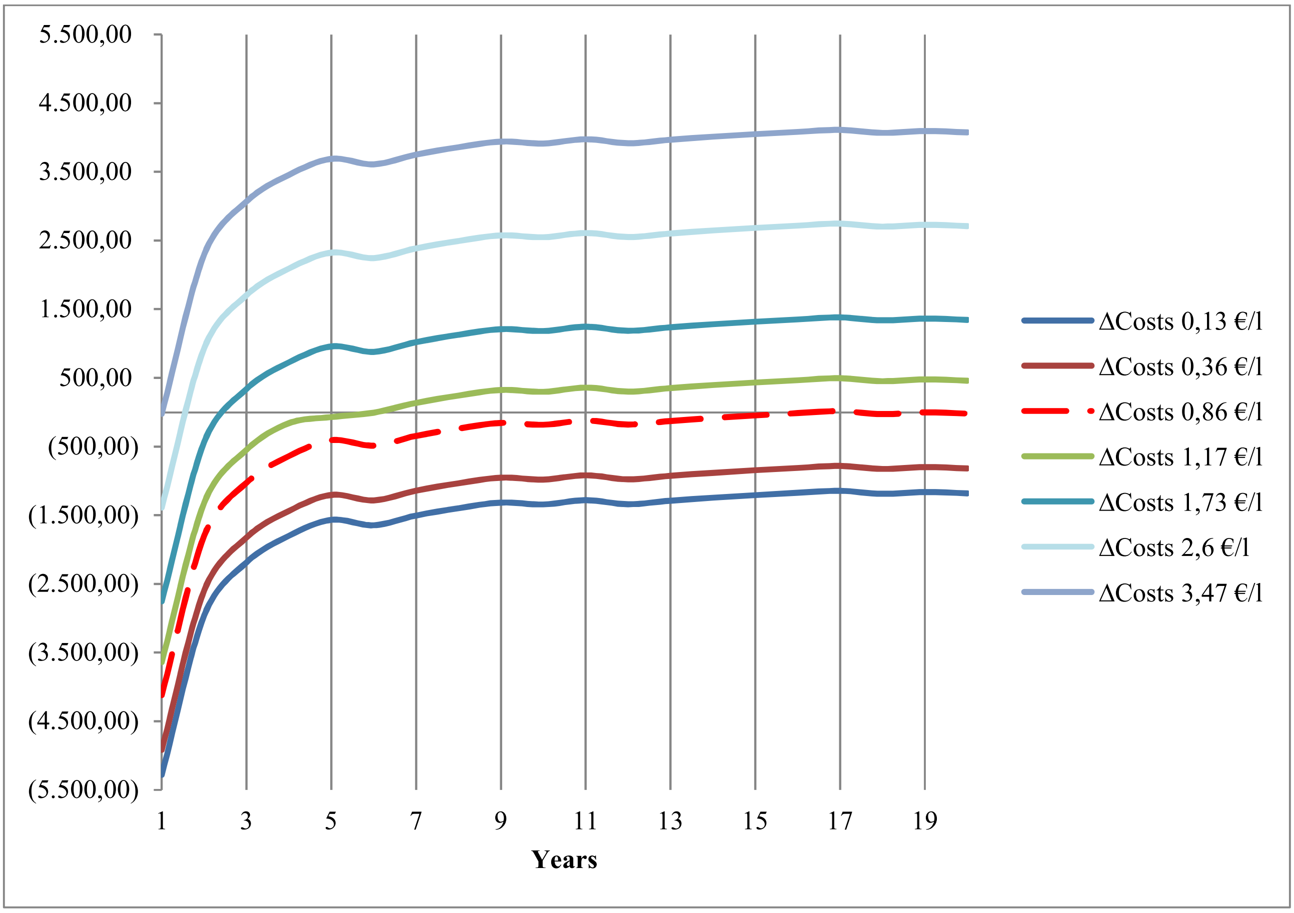


Figure 66:Return on investment in relation to cost of fuel

In this diagram it is highlight the changing of cash flows in relation to the cost of fuel.

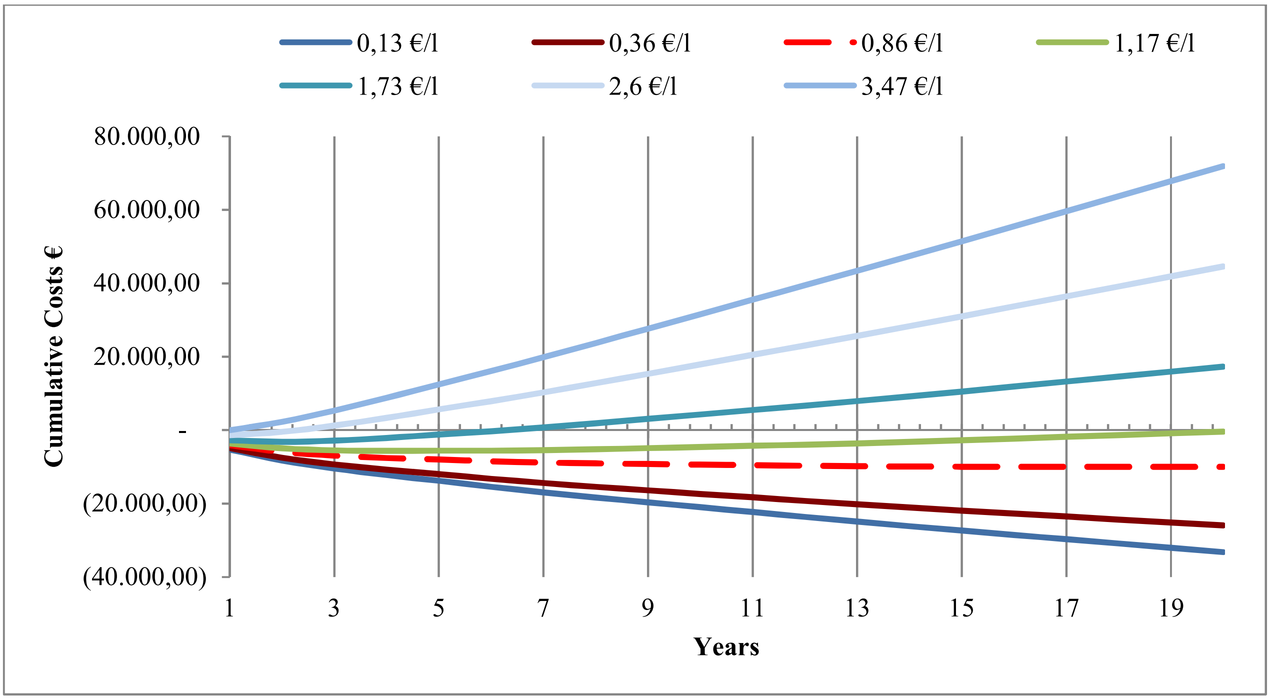


Figure 67: Breakeven point in relation to cost of fuel

The diagram presents the breakeven points of the system in relation to fuel-cost. As shown the breakeven of the investment is given with the fuel cost of 1.17 €/l, but at the end of the system life. With the cost of fuel of 1.73€ for each liter the breakeven is after 7 years.

During a WFP-UNHRD mission in Congo the fuel cost was about 12€/l (instead of a cost of fuel from the pump of 1,12€/l): this, clearly, was a limit situation, but in this and other similar cases the convenience of PV-BES system is guarantee.

Results

This project underline as renewable energies are already a reality also in the humanitarian camps. A cooling mobile storage unit, developed with an off-grid PV-BES system to product electric energy from the sun is more convenient than a diesel generator as energy supply.

5. Conclusions

Conclusion and further researches

The purpose of this thesis is to presents some studies related to the humanitarian sector, in particular on the theme of the mechanical plants using in the humanitarian logistic. Three main section are analyzed, studied in the scientific literature and, then, discuss. Waste management, water desalination and purification and energy production are large themes and embrace a large number of sub-topics (i.e. water desalination plants). The results of all the projects presents are in accordance with the all strict humanitarian requirements, such as design simplicity, user-friendly use, ease maintenance, structural strength, recycle & reuse of materials, etc.

The first chapter presents the whole study on the waste, and then the waste management in humanitarian camps and in developing regions. To analyzed in deep all aspect of the problem the waste management is divide in three macro-topics: disaster waste (DW), packaging waste (PW) and organic waste (OW). For the interesting of the themes, and for a direct repercussion of these research in the humanitarian field, are studied and analyzed in depth organic and packaging waste. The theme of disaster waste was not deepened because is a waste characteristic of just some catastrophes, (i.e. catastrophes strike in urban areas), and it has not a direct link with the humanitarian sector during an emergency. On the other hand, on the packaging waste management for the first time in this sector is studied the possibility to reuse and recycle materials generate from the packaging from humanitarian supplies. In particular is present the solar cooker, an efficient method to recycling cardboard to made something useful for refugees. So, by the study of available materials, needs of refugees in different environments have been design and made some prototypes: for example, folding the cardboard of the kitchen set supplied by humanitarian agencies, is possible obtain a portable solar cooker, which is possible heat-up and cooking meals just with the sun rays reflection. Many other minor equipment was made on these specifications. Prototypes after a laboratory testing for them characterization have been presents to humanitarian agencies management for a preliminary field tests in the camps. Solar cooker is the most interesting prototypes for its simplicity, but at the same time for its usefulness.

In the next paragraph, the Organic Waste topic is present. The focus is especially on the fraction generates daily by humans, that is a huge issue both for people and for environment sake due to the high presence of pathogens inside. To tackle this problem affects most of developing countries and humanitarian camps, has been studied a natural solution called organic digestion. This phenomenon been in laboratory in particular container or bio-digesters, that are a well-known technology able to kills all the waste pathogens. Stocking the waste in these devices is possible kick-off the anaerobic digestion of organic waste made by anaerobic bacteria naturally presents in the waste. This digestion consists in the degradation of the waste in a sort of slurry, the bacteria consumption also produces as output a mixture of gases, which the main is methane. This output is also called biogas. This device is so use both for digestate organic waste and for the free production of the biogas, household use as fuel (for cooking, heating, lighting, etc.). After the characterization of the process by few laboratories tests a prototype made with all components already present within the humanitarian supplies is made and then testing. Tests are doing for demonstrate the quality of the biogas product and for analyzed the quantity of the fuel-ratio-production.

Results are promising, especially because are obtain just from a waste dangerous for people and for the environment. The projects present in this chapter are a smart way to recycle and reuse waste otherwise problem for the society and humanitarian organizations management.

The second chapter of this thesis talks about the lack of drinkable fresh water on the earth's crust. This, probably, is one of the most crucial worldwide problem. Furthermore, the future population forecasts are not encouraging due to the sudden worldwide population growth on 2050. The quantity of fresh drinkable water will be not sufficient for the whole population, especially because climate changes are reducing the last reserves of ice in the poles. The global community, researchers and scientists should find affordable solutions for obtain fresh water from sea salt water, the hugest water resource in the globe. Unfortunately, divides water from dissolved salts is not easy and not stingy. Due to the vastness of the theme in this chapter a deepen critical review on desalination processes is presents. Some paragraphs are used to study and analyze membrane and osmosis desalination processes, especially the reverse osmosis (RO), probably today, the most interesting, wide using and promising method for desalination. Humanitarian camps, such as most of urban areas in developing regions, suffer the lack of drinkable water. In the field there are just raw methods and plants to purify fresh water, but is not possible use the sea salt water like water resource. Introducing desalination technology in the humanitarian context should be a great improvement, both for agencies and for refugees the final users of purified fresh water. As told before, RO plants probably are the most interesting option today for the small-scale desalination. But, after a deepen critical review and analysis, presents in the chapter 3, some important drawbacks conflicting with most of the humanitarian requirements cited before, makes these plants useless today in humanitarian camps for them complexity. Further research improvement on this field should be done for makes these plants usable also in poor regions and by unskilled people. To reduce the impact of energy and electricity during the desalination working, renewable energies should be an interesting combination with these plants. Some important improvements have to do on the complete control system of these desalinations plants: these are difficult to setup and complicate to the continually and the daily use, there are several parameters to setting in relation to the water intake and the conditions of plant components (i.e. membrane fouling). An integrate control unit should be the solution to use these plants also in developing regions and in humanitarian camps, to permit its use also for unskilled people. This can be a captivating research field for a further improvement of these desalination plants.

The third, and last chapter of this thesis, presents another crucial theme for our global future, the energy production by the use of the sun and the wind, the renewable energies.

The sun rays and the wind blows are, such as all renewable technologies, fundamental resources for humanity to produce electricity. Today the electricity for live is surely important as the primary needs for all people all over the world. There are different methods and several equipment to produce electricity, but the goal of this study was find the cheaper and the most environmental friendly in certain conditions. In humanitarian camps and in developing regions during humanitarian emergencies the wider used method to produce electricity is by using diesel generators, because the oil fuels are usually cheap in these areas. Anyway, analyses conduct on costs of humanitarian mission, highlight how fuels are one of the soaring cost for agencies. So an alternative methods to produce electricity was indispensable for the efficiency of humanitarian mission. The answer of this need is given by renewable energies such as photovoltaic panels, wind turbine and batteries combinate in parallel, for the night-time backup, with diesel generator. This solution offers also a most environmental friendly way to produce electricity for humanitarian camps. By the use of natural resourcing presents in the environment, decrease significantly the carbon footprint and the air-pollution of the camps.

On this purpose in the first paragraph of the chapter, an optimization model to assist humanitarian management and decision makers is studied and present. Before starting a humanitarian mission is almost impossible determine with accuracy the cheapest methods to producing electricity in a certain area. With this tool is possible find the best trade-off for the energy production: starting from environmental conditions and data is possible find the best mix of renewable technologies for produce electricity. Is also possible setup the camp energy production in relation to energy power request in a camp during the different hours of the day. By the comparison of the final energy producing costs is also possible determine which is the best method to produce energy in a given environment.

The second, and last paragraph of the chapter, present the lack in a temperature control storage system in the humanitarian aid. The problem consists in the absence of a cold storage in the last miles, and in the humanitarian camps. The MSU, the acronym uses in the humanitarian field to call mobile storage unit, are mobile warehouses largely use by organization for the storage of different items in the refugee camps, from maintenance equipment, to perishable items such as food or medicine. Unfortunately, these warehouses are not design, and are not able to storage food and other perishable items in warm/hot conditions. Today none solutions use to solve this problem permit a real temperature control or a cooling storage. Analyzed and studied data of the problem, an innovative and environment friendly solution for the cooling storage system is present and discuss.

The first step was change completely the type of storage unit, form a plastic tent to an insulating prefab building, this changing was necessary because tents was not able to ensure the adequate insulation needed, additionally plastic tents foster the green-house effect inside. Then are analyzed inner temperatures in the different environments during the daytime and the nighttime. On these data an air cooling system is sizing and design for maintain constantly the desire temperature of the storage unit. The next step was the design of an energy production system by photovoltaic panels and battery storage system, makes the entire system energy self-sufficient and eco-friendly. Thermodynamic analyses conclude the project and the MSU re-design. The new MSU-PV BES storages are actually building in different humanitarian area in the Somalia for a field tests. This was a typical example of how many improvements can be done in the humanitarian context, starting from actual problems in the field.

The humanitarian context is probably an unusual field for the scientific research. Dynamics, standards, requirements, and working methods are actually unique. Anyway, although many improvements integrate by the organizations in the last decade, is still a fruitful world for the scientific researchers. Introducing in this background methods, knowledge and equipment usually adopt in different contexts is a win-win approach for both: humanitarian agencies can improve the efficiency and the efficacy of the camps, and the whole supply chain with direct benefits for refugees. On the other hand, these innovations should be an interesting opportunity in the reverse-innovation-market where business ideas are used and developed in developing regions, then, just in a second step in the developed world.

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Acknowledgments

Thanks to the guys of WFP-UNHRD in Brindisi, was a pleasure work with them and can give our support and our contribution for a humanitarian agency such this one, both for a researcher point of view and for ethical. Know that your work should be important and can help also just for a moment life of unlucky people is something indescribable and give us the energy to do always the best. Thanks to my humanitarian mate Pietro, adventures pass in these years are memorable. Thanks to Stefano, Walid, Nicolas and all amazing people working in WFP bases.

Thanks to Professor Andrea Achilli, Professor Kerri Hickenbottom, Eng Galen O'Toole and all the guys meet during work in the amazing experience Environmental Resources Engineering in Humboldt State University in California, USA. Thanks for sharing with me their researches, competence, time and experiences.

I want to thank the Industrial Mechanical Plants research group of the Department of Industrial Engineering - Alma Mater Studiorum University of Bologna. In particular thanks to Professor Arrigo Pareschi, Professor Emilio Ferrari, Professor Riccardo Manzini, Professor Mauro Gamberi, and Professor Cristina Mora for their precious support during my Ph.D. studies.

A particular thanks to my Ph.D. supervisor, Prof. Alberto Regattieri, I'm really grateful to work with you during these years. You guided and stimulated me during this challenging work and you encouraged me during difficult moments such as a friend. Thanks for everything.

Thanks to my foolish and fantastic colleagues, Marco Bortolini, Alessandro Graziani, Riccardo Accorsi, Lucia Botti, Francesco Gabriele Galizia, Giulia Baruffaldi, Francesco Pilati, Andrea Casto and all the guys with I shared time and work during these amazing years, thanks you all!

And finally, last but not the least, thank you Federica, my best. Thanks to my family, my rock. Thanks to my friends, my amusement.