POLITECNICO DI MILANO
DEPARTMENT OF ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING

COMPREHENSIVE ENERGY SOLUTIONS IN HUMANITARIAN SETTLEMENTS

FROM THE ENERGY-FOOD NEXUS TO A HOLISTIC APPROACH TO ENERGY PLANNING

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Abstract

Energy plays a fundamental role in shaping the human condition: affordable, clean and safe energy services are key elements of the economic development and a leverage for the eradication of extreme poverty. The Sustainable Development Goal 7, ‘Ensure access to affordable, reliable, sustainable and modern energy for all’, specifically addresses the most relevant challenges of the global energy sector. However, this Goal is still far to be reached, especially when looking at humanitarian settings, where the extreme conditions of displaced people are exacerbated by energy shortages.

The research work presented in this doctoral thesis aims at contributing to this challenge by improving the understanding of energy in humanitarian settings, and proposing better strategies for comprehensive energy planning in critical contexts.

The analysis starts with a focus on the energy-food nexus, which can be identified as the essential entry point to recall the relevance of energy in situations of displacement. In fact, food security and nutrition are among the main pillars of the humanitarian response. The research shows that both are strongly influenced by energy access. It is found that energy for cooking has been the most addressed topic so far. However, other areas of intervention, including food preservation and sustainable power systems, constitute promising emerging sectors, and require innovative and more integrated approaches to energy systems.

Based on such considerations, a novel framework for Comprehensive Energy Solutions Planning (CESP) in rural and remote areas of the Global South is proposed, and adapted in particular for the case of humanitarian settings. In fact, despite different methodologies have been proposed for energy planning in critical contexts, the literature lacks of a comprehensive framework covering all the phases of energy interventions. The framework is applied to a case study in a refugee settlement in North Lebanon. The CESP represents a first step towards the implementation of sustainable energy systems in humanitarian settings.

However, the framework itself would not be effective without a sufficient level of awareness of humanitarian operators on the matter. For this reason, the SET4food capacity building programme is introduced as an example of capacity building action. The programme includes trainings, practical supportive tools, and an online global community of practice (ENERGYCoP) fostering networking and collaboration among different professionals and stakeholders of the humanitarian sector.

Estratto in lingua Italiana

L’energia svolge un ruolo fondamentale per il genere umano. La disponibilità di sufficiente energia a un prezzo ragionevole, prodotta in modo sostenibile, è un elemento chiave per lo sviluppo economico e costituisce una presupposto per la mitigazione della povertà estrema. Tra gli obiettivi dello sviluppo sostenibile, l’importanza del ruolo dell’energia è rimarcata dall’obiettivo numero 7, ‘Garantire l’accesso a energia sostenibile, affidabile e moderna per tutti’. Questo obiettivo infatti identifica in modo esplicito le attuali, più importanti sfide riguardo la fornitura energetica globale. Purtroppo, la strada verso il raggiungimento di questo obiettivo è ancora lunga, specialmente per quanto riguarda i contesti più critici, come quelli umanitari, ove le codizioni di vita estremamente precarie dei rifugiati sono ancor piùù esacerbate dalla cronica mancanza di energia.

Il lavoro di ricerca presentato in questa tesi di dottorato si pone come obiettivo principale quello di contribuire alla sfida di migliorare le condizioni in contesti critici tramite una migliore fornitura di energia. Per questo motivo, il lavoro mira a fornire una conoscenza più approfondita delle dinamiche che riguardano l’energia in contesti umanitari, e a proporre migliori strategie per un approccio olistico alla pianificazione energetica in tali contesti.

L’analisi inizia focalizzandosi sul legame energia-cibo, che è identificato come il legame essenziale che richiama l’importanza del ruolo dell’energia in situazioni umanitarie, in quanto la sicurezza alimentare e la nutrizione sono annoverati tra i cardini della risposta umanitaria. Il lavoro mostra come entrambi siano intrinsecamente legati al tema energetico. L’analisi permette di capire che fino ad oggi l’interesse della macchina umnaitaria si è focalizzato sul tema della cottura dei cibi, ma che, tuttavia, vi sono altri ambiti applicativi di grande interesse potenziale, quali ad esempio la conservazione del cibo e l’utilizzo di sistemi di produzione più sostenibili. L’innovazione in questi campi richiede un approccio più integrato e sistemico alla materia.

Sulla base di queste considerazioni, la ricerca approda in un secondo momento alla proposta di un framework innovativo per la pianificazione di sistemi energetici sostenibili in contesti critici, partendo dal caso di areee rurali remote, per poi adattarsi alla specificità dei contesti umanitari. Si dimostra infatti come, nonostante esistano varie linee guida alla pianificazione energetica, la letteratura manchi di un framework completo che definisca in modo semplice ed efficace le varie fasi della pianificazione, tenendo conto sia degli aspetti tecnici che di quelli non tecnologici, più legati alla dimensione umana. Il framework proposto è applicato a un caso di studio in un insediamento informale di rifugiati siriani in Libano.

Se da una parte l’applicazione a un caso reale dimostra il potenziale del framework, dall’altra è necessario riflettere sul fatto che esso rappresenti solamente uno strumento, e che, come tale, risulterebbe inutile, se non accompagnato da una adeguata campagna di sensibilizzazione del personale umnaitario. Il lavoro svolto mostra infatti come tale personale, in media, manchi di conoscenze anche di base riguardo le tematiche energetiche. Per tale motivo, il programma di capacity building portato avanti nell’ambito del progetto SET4food è presentato come un esempio efficace di sensibilizzazione e

formazione in ambito energetico. Il programma include differenti elementi, quali corsi di formazione in presenza e online, la realizzazione di manuali e strumenti pratici, e la creazione di una comunità globale in rete (ENERGYCoP), che mira a connettere virtualmente le persone impegnate nel settore in ogni parte del globo, promuovendo la collaborazione tra diversi professionisti e stakeholder del settore umanitario.

Contents

List of figures

List of tables

Notation

Main acronyms used in the text

AC	alternate current
CESP	Comprehensive Energy Solutions Planning
CO	carbon monoxide
CO2	carbon dioxide
COE	cost of energy
COOPI	COOPerazione Internazionale
GACC	Global Alliance for Clean Cookstoves
GPA	Global Plan of Action for Sustainable Energy Solutions in Situations of Displacement
DC	direct current
DCs	developing countries
DSS	decision support system
E4SD	Energy for Sustainable Development
ESMAP	Energy Sector Management Assistance Program
FAO	Food and Agriculture Organization
GHI	Global Horizontal Irradiation
GIS	Geographic Information System
GIZ	Gesellschaft für Internationale Zusammenarbeit
HH	household
HOMER®	Hybrid Optimization of Multiple Electric Renewables
IAP	indoor air pollution
IASC	Inter-Agency Standing Committee
ICS	improved cooking stove
IDP	internally displaced person
IEA	International Energy Agency
IEF	impact evaluation framework
IGA	income generation activities
IOM	International Organization for Migration
IRENA	International Renewable Energy Agency
LFA	logical framework approach
LPG	liquefied petroleum gas
M&E	monitoring and evaluation
MEI	The Moving Energy Initiative
NGO	non-governmental organization
NPC	net present cost
O&M	operation and maintenance
OCHA	Office for the Coordination of Humanitarian Affairs
PA	Practical Action
PAT	pump as turbine
pc	per capita
PM	particulate matter

RET	Renewable Energy Technology
SAFE	Safe Access to Fuel and Energy
SDG	sustainable development goal
SET4food	Sustainable Energy Technologies for food security
SHP	small hydropower
SPARK	Solar Photovoltaic Adaptable Refrigeration Kit
SPV	solar photovoltaic
SSA	Sub-Saharan Africa
SW	small wind
UN	United Nations
UNDP	The United Nations Development Programme
UNEP-DTU	UN Environment and Danish Technical University
UNFN	The United Nations Foundation
UNHCR	United Nations High Commissioner for Refugees
UNITAR	The United Nations Institute for Training and Research
USAID	United States Agency for International Development
WFP	The World Food Programme

Thesis outline

This thesis is the result of a research programme on sustainable energy solutions in humanitarian settings. The research programme has been headed by the candidate under the supervision of prof. Emanuela Colombo, including different desk studies and hands on works in the field[1]. The thesis is organized into five main chapters.

Chapter 1 – Introduction

This chapter introduces fundamentals on energy access. Paragraph 1.1 firstly presents an analysis of the current status of energy in development regions, showing that the relevance of the matter is confirmed by the international agenda and by the Sustainable Development Goals, including in particular Goal 7, "Ensure access to affordable, reliable, sustainable and modern energy for all", which is yet far to be reached. On a second step, the analysis focuses on energy access in humanitarian settings, evidencing that the lack of sustainable energy provision is one of the major contributors to many challenges of the humanitarian response. In particular, the relevance of the energy-food nexus is underlined in the light of the core elements of the humanitarian response. Moreover, the analysis of the "energy gap" in the humanitarian system briefly describes the main overall financial and institutional causes of the current situation.

The analysis of the current situation paves the way for the formulation of the research questions and of the objectives of the work. In this framework, the contribution of the SET4food project is outlined.

The paragraph describing the SET4food project is mainly based on the following publication:

- Barbieri J., Leonforte F., Colombo E. *Towards an holistic approach to energy access in humanitarian settings: the SET4food project from technology transfer to knowledge sharing*. Journal of International Humanitarian Action, 2018 [1].

Chapter 2 – An essential entry point: the energy-food nexus in humanitarian settings

Chapter 2 mostly focuses on "what have been done so far" concerning energy in humanitarian settings. Given the fact that energy is fundamental for food processing, preparation and preservation, as well as for safe water provision, energy for food security, and in particular for cooking, has been the most addressed topic by the humanitarian system so far. For this reason, in this chapter an in-depth analysis of current cooking technologies and practices in humanitarian is carried out, with the aim to understand their sustainability and impact. The analysis also allows to identify other emerging areas of intervention, including food preservation and sustainable power systems. An exemplificative set of innovative approaches that may improve the success, and widen the areas of energy interventions is proposed in the form of simple case studies, based on the pilots put in place in the framework of the SET4food project action. Such innovative

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[1] See Annex A for a complete list of scientific products and materials for practitioner to which the Author contributed through the research work presented in this doctoral thesis.

approaches include adoption of technologies used in other contexts, technology adaptation, and technology creation with a cooperative approach. The overall analysis brings to the conclusion that best achievements would be reached by shifting from very focused interventions (e.g., energy for cooking) to a holistic approach considering all energy uses.

This chapter is mainly based on the following publications:

- Barbieri J., Colombo E. (Eds.), *SET4Food guidelines on sustainable energy technologies for food utilization in humanitarian contexts and informal settlements*. Department of energy, Politecnico di Milano, 2015 [2];
- Barbieri J., Riva F., Colombo E. *Cooking in refugee camps and informal settlements: A review of available technologies and impacts on the socio-economic and environmental perspective*. Sustainable Energy Technologies and Assessments, 2017 [3];
- Aste N., Barbieri J., et al. *Innovative energy solutions for improving food preservation in humanitarian contexts: A case study from informal refugees settlements in Lebanon.* Sustain Energy Technol Assessments 2016. doi:10.1016/j.seta.2017.02.009 [4].

Chapter 3 – Expanding the horizon towards a holistic approach to energy

Chapter 3 expands the analysis on "how could we do better". In this chapter, the problem of ensuring the sustainability of energy interventions in critical settings is tackled by proposing an innovative comprehensive energy solutions planning (CESP) framework. The proposal is based on the awareness that very few studies in the literature deal with this specific topic with a specific focus on critical contexts, including rural areas of the Global South and humanitarian settings. Therefore, there is a clear room for contributing on the topic in order to support researchers, practitioners and policy makers with a clear identification of the different phases and actions that characterize the energy planning process from needs assessment to impact evaluation. As a first step, the general theory of CESP is introduced through a characterization of the various phases of the planning process, from needs assessment to impact evaluation. More practical indications and specific considerations follows, for the case of humanitarian settings. The CESP framework is applied to a case study in a refugee settlement in north Lebanon, where a hybrid micro-grid has been developed to power community refrigerators for food preservation and additional small appliances for basic lighting and communication.

The chapter is partially based on the following publications:

- Barbieri J., Simonet E., *Technologies for power generation in rural contexts*, in Colombo E., Bologna S., Masera D. (eds.), Renewable Energy for Unleashing Sustainable Development, Springer International Publishing, 2014 [5];
- Barbieri J., Colombo E. (Eds.), *SET4Food guidelines on sustainable energy technologies for food utilization in humanitarian contexts and informal settlements*. Department of energy, Politecnico di Milano, 2015 [2].
- Aste N., Barbieri J., et al. *Innovative energy solutions for improving food preservation in humanitarian contexts: A case study from informal refugees settlements in Lebanon.* Sustain Energy Technol Assessments 2016. doi:10.1016/j.seta.2017.02.009 [4].

Chapter 4 – Enhancing the capacity of the humanitarian system on energy

Chapter 4 completes the overall work by targeting the theme of “transferring knowledge from energy experts to humanitarian professionals”. The idea at the basis is that even the best innovation is pointless if it is not capitalized nor replicated by the humanitarian system. Therefore, the chapter describes the capacity building and knowledge sharing programme carried out under the cap of the SET4food project, including the supportive tools that were created for field practitioners, in-presence and online courses on energy in humanitarian settings, and the ENERGYCoP platform, an online global community of practice on humanitarian energy.

This chapter is mainly based on the following publication:

- Barbieri J., Leonforte F., Colombo E. *Towards an holistic approach to energy access in humanitarian settings: the SET4food project from technology transfer to knowledge sharing*. Journal of International Humanitarian Action, 2018 [1].

Chapter 5 – Results and conclusions

The main results and conclusions of the work are discussed in the last chapter. Possible future research directions are also briefly presented.

1 Introduction

Energy plays a fundamental role in shaping the human condition. The need to increase access to modern energy services for balancing the economic, social and environmental dimensions is recognized worldwide: affordable, clean and safe energy services are key elements of economic development and a leverage for the eradication of extreme poverty. The Sustainable Development Goals (SDGs), launched in September 2015 as one of the main assets of the UN Agenda 2030, are intended to introduce a new comprehensive paradigm of development. In particular, Goal 7, 'Ensure access to affordable, reliable, sustainable and modern energy for all', specifically addresses the most relevant challenges of the global energy sector. However, this Goal is still far to be reached, especially when looking at humanitarian settings, where the extreme conditions of displaced people are exacerbated by energy shortages. This chapter presents an analysis of the current situation concerning energy access in development and humanitarian settings, which constitute the framework at the basis of the research objective and rational of this work. Moreover, the Sustainable Energy Technologies for food security (SET4food) project is introduced, evidencing its role in the present research.

1.1 A global perspective on energy access

Nowadays, about 1.1 billion people do not have access to electric energy and more than 2.8 billion are still relying on traditional biomass (mostly firewood and charcoal) for their domestic needs.

The number of people without access to electricity is constantly decreasing, with more than 100 million people that gained access every year since 2012. However, this positive trend is not equally distributed all over the world. The majority of people without access to electricity are in developing countries, especially in Asia and sub-Saharan Africa (SSA).

On the one hand, Asian countries, and in particular India, have strongly improved the situation respect to few years ago, reaching 89% of electrification rate in 2016 (Figure 1.1) compared to a 67% in 2000 (Figure 1.2). Conversely, the situation in SSA is still critical, with an electrification rate of only 43% despite the huge efforts put in place [6] (Figure 1.3).

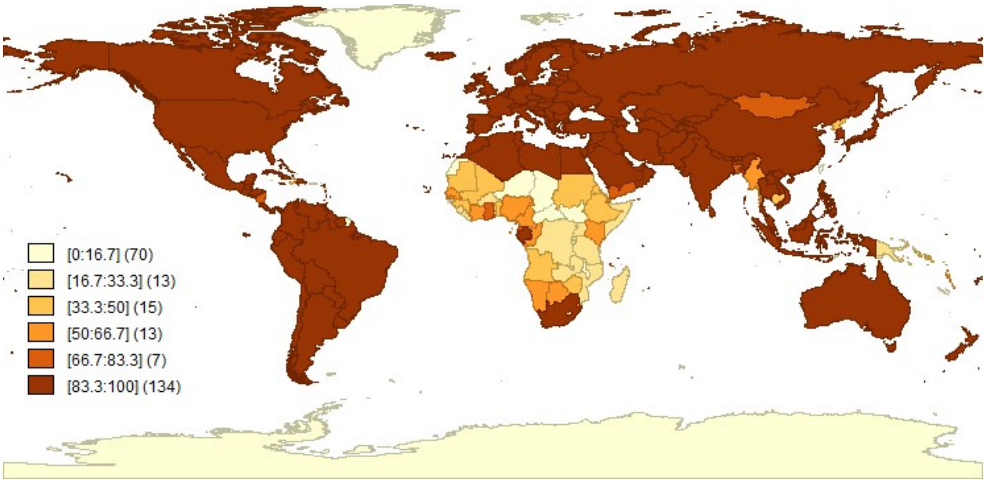

Figure 1.1 Access to electricity (% of population) – 2016. *Author's elaboration based on [7].*

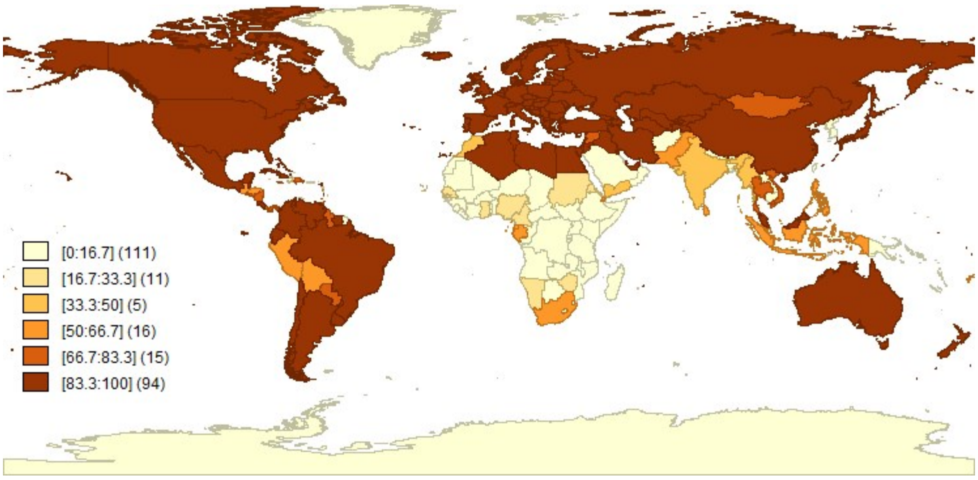

Figure 1.2 Access to electricity (% of population) – 2000. *Author's elaboration based on [7].*

Looking at modern fuels, 38% of the world population still lacks access, with the majority of such people living in developing countries. Globally, the situation has been improving since 2000, and in some countries, especially in Asia, modern fuels have reached a high level of penetration. However, the total number of people still relying on traditional biomass has not changed much in the last years [6] (Figure 1.4 and Figure 1.5).

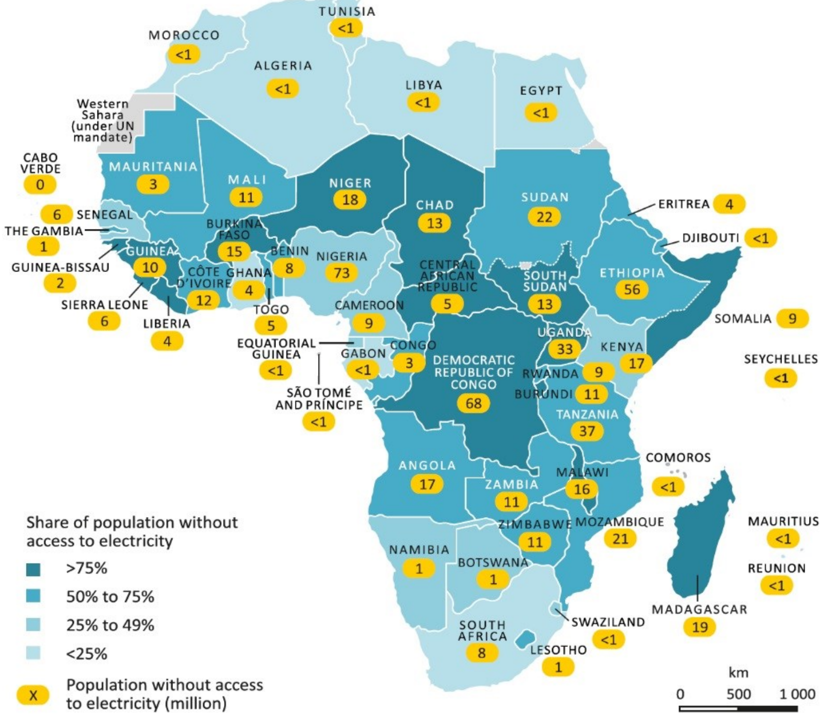

Figure 1.3 Population without access to electricity in Africa by country – 2016. *Source: [6]*.

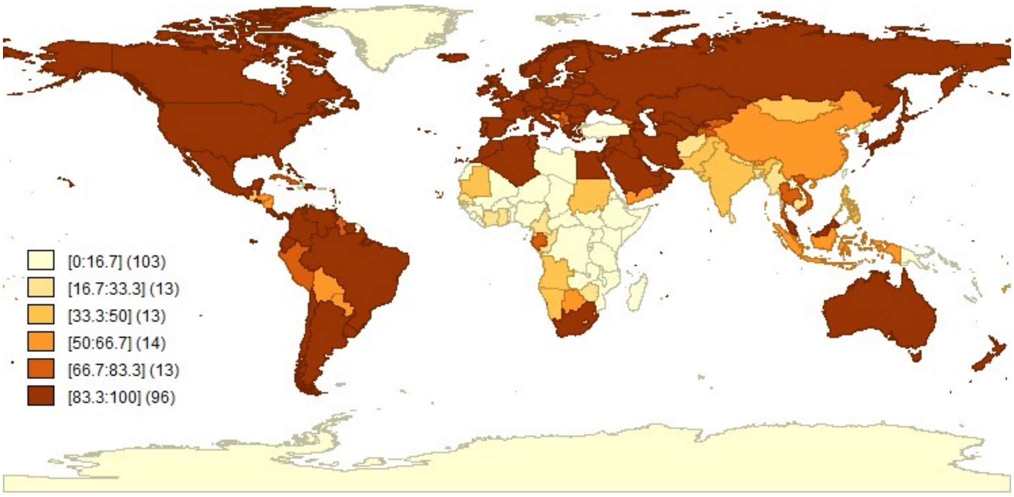

Figure 1.4 Access to clean fuels and technologies for cooking (% of population) – 2010. *Author's elaboration based on [7]*.

A focus on the African continent underlines how the situation is particularly critical in SSA, where still more than 90% of the households rely on traditional fuels in most countries (Figure 1.6).

The complexity concerning a substantial improvement of energy access is clear [8], [9]. However, the fact that in the next future a transition to sustainable energy systems will play a big role through low-carbon energy innovation is recognised worldwide.

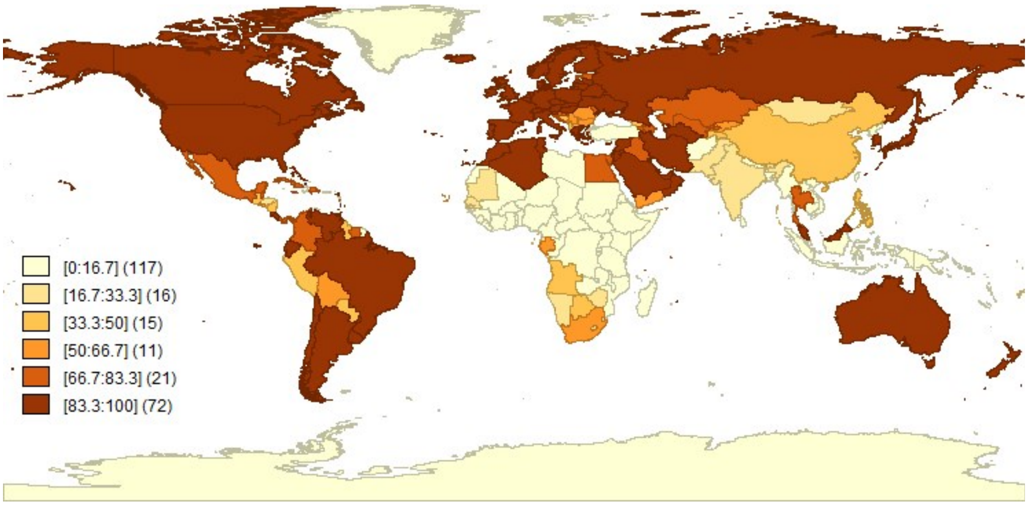

Figure 1.5 Access to clean fuels and technologies for cooking (% of population) – 2000. *Author's elaboration based on [7].*

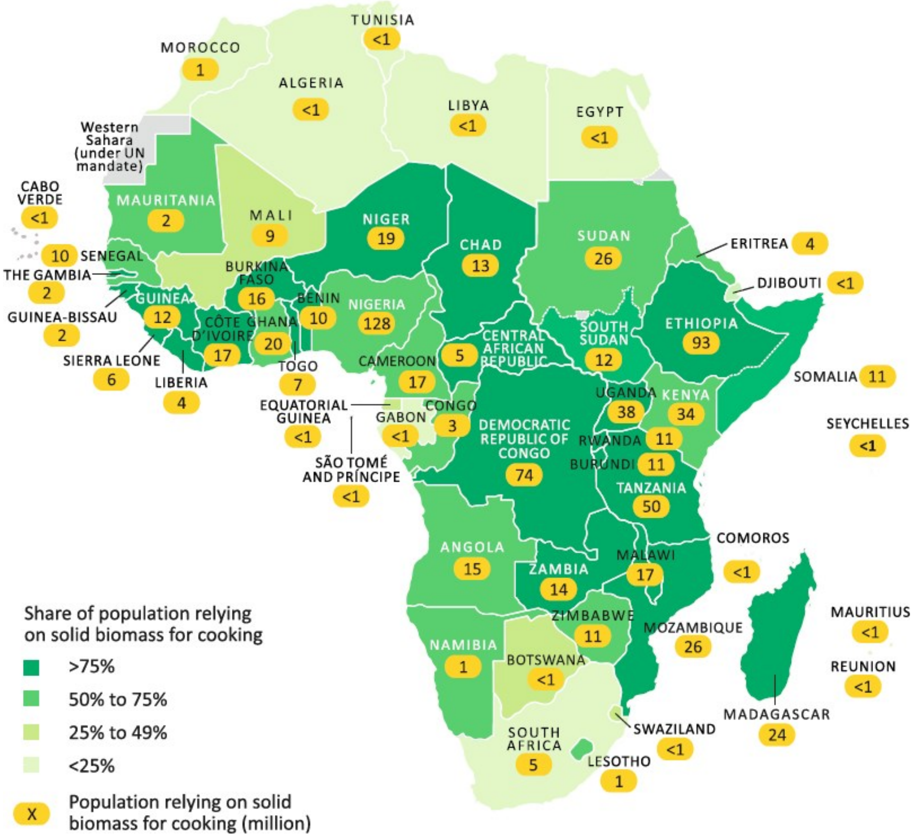

Figure 1.6 Population without access to electricity in Africa by country – 2016. *Source: [6].*

The year 2012 has represented a pivotal year (International Year for Sustainable Energy for all) engaged by the international community in the shift of the development paradigm and the agenda for the following decades. SDGs, launched in September 2015 as one of the main asset of the UN Agenda 2030, are intended to introduce a new comprehensive paradigm of development, where the essential principle is the integration of environmental, social, and economic concerns into all aspects of decision-making, directed to the future to preserve the social and cultural diversity and excellence.

Goal 7, 'Ensure access to affordable, reliable, sustainable and modern energy for all' specifically addresses changes in the global energy sector, by defining the following targets to be achieved by 2030 [10]:

- ensure universal access to affordable, reliable and modern energy services
- increase substantially the share of renewable energy in the global energy mix
- double the global rate of improvement in energy efficiency
- enhance international cooperation to facilitate access to clean energy research and technology
- expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries.

This confirms that universal access to modern energy services is needed for balancing the economic, social and environmental dimensions of sustainable choices. Affordable energy services are key elements of economic development and for the eradication of extreme poverty. Sustainable energy is essential to ensure the socio-economic development, and other key issues such as people's quality of life, global security (natural resources and materials, food, water), and environmental protection [11]–[13].

More in details, on the one hand energy is essential for water purification and sanitation, to support access to healthcare and agriculture, to ensure effectiveness of educational programs and to provide access to information and communication [9].

On the other hand, inefficient and pollutant energy conversion systems are a threat for people and the environment. Today more than 2.8 million deaths (more than those due to malaria) are attributed to the effect of breathing smoke from poorly-combusted biomass devices [6], [14]. Moreover, in developing regions depending on traditional biomass, women and children are generally responsible for fuel collection, which represents a time consuming and exhausting activity. This practice has relevant consequence on the social asset: women are prevented from practicing other activities such as artisanal jobs and, even more important for the future of the nation, children are prevented from attending with regularity school and from allocating the proper time to home learning. An energy mix that is strongly unbalanced towards the use of traditional and non-commercial biomass, also often leads to heavy consequences on the environment, including: deforestation and degradation of woodlands due to unsustainable biomass exploitation; increased rates of land erosion, flooding, and desertification; decline in ground water availability; damage of natural heritages and augmented threats to wildlife conservation [3], [15]–[19].

1.1.1 Energy access in humanitarian settings

The lack of access to energy is particularly critical in humanitarian settings, where its linkages with other issues are even more evident and essential.

Compared to overall energy consumptions and related challenges at global level, in absolute terms energy consumptions and needs in humanitarian settings only represent a small fraction. However, the relevance of the issue of energy access in emergency and post-emergency situations, and protracted crises, is constantly raising, due to both the increasing awareness of the international community on the fundamental role of energy for effective humanitarian response, and the increasing trends in the number of displaced people in the world.

According to the Office for the Coordination of Humanitarian Affairs (OCHA), in 2018 about 135 million people will be in need for humanitarian assistance to survive [20]. This estimate represents the highest value since Second World War, and has been constantly rising in the last period. The number of forcibly displaced people has grown from 33.9 million in 1997 to 59.5 million in 2014, and raised up to 65.6 million in 2016. The number has been substantially increasing in particular during the last years [21].

Access to energy in emergency and humanitarian settings is absolutely fundamental for many purposes, and in particular to face five key challenges: "protection, relations between hosts and displaced people, environmental problems, household energy-related natural resource restrictions and livelihood-related challenges" [3], [22]. In fact, energy is also related to health, education, and even income generating opportunities. For example, the use of contaminated water and poor food storage conditions can both cause a loss of nutritive properties and health problems.

More in details, energy scarcity in humanitarian settings is often directly linked to the followings [22], [23]:

- insufficient means for food preparation, and in particular for cooking, with negative effects on health and nutrition;
- water scarcity and utilization of contaminated water, with (again) negative effects on health and nutrition;
- food deterioration due to poor storage conditions, which cause a loss of nutritive properties and health problems;
- indoor air pollution due to the use of three-stone fires and other non-improved cooking solutions, which causes health diseases and respiratory illnesses, and puts great pressure on local deforestation;
- huge consumption of firewood, which has a negative impact on the surrounding environment and leads to social problems (mainly for women and children);
- negative impacts on security and protection: "(...) there are several protection risks related to the fulfilment of household energy needs: among the others, those associated to sexual and gender-based violence. Harassments are particularly common when women collect firewood outside the camps" [22];
- negative impacts on education: "(...) women and girls are usually the ones in charge of wood collection and, therefore, they are disproportionately affected by this issue, as wood collection is highly time-consuming, that limits their time available for education" [22].

Clearly, even if all the previously mentioned criticalities are claimed to be relevant, in humanitarian settings, food-related challenges are among the most concerning and impellent. Actually, food security is one of the core elements of humanitarian response: the humanitarian system is organized in eleven clusters, including food security and nutrition. Moreover, food security and nutrition also represent one of the most important issues addressed by the Sphere Handbook, the reference publication on the minimum standards in humanitarian response [24].

According to the Office for the Coordination of Humanitarian Affairs (OCHA): "Energy insecurity may also drive food insecurity. Without access to a predictable energy supply, communities that are not food insecure may become so, and those who are already food-insecure may become even more vulnerable. There can be no food security for communities without reliable access to a fuel source for heating and cooking" [25].

Food security can be split in four main pillars: (i) the physical availability of food, (ii) the economical and physical access to food, (iii) the utilization of food and related resources, (iv) the stability of food supply over time [26]. Humanitarian actors have usually tried to address them mainly focusing on the first, second and fourth pillars, while food utilization is often neglected [27]. However, food utilization represents a key dimension of food security. In particular, the way food is prepared has an important impact on nutrition and health, and is directly related to the means of cooking, in terms of available fuels and cooking systems.

Ignoring the means between food and energy may lead to important effects. In Niger, for example, humanitarian actors were used to distribute food that had to be prepared using boiling water. However, boiling water on traditional devices generally requires a huge amount of traditional biomass, and takes time. As a consequence, it was found that food rations were often consumed dry (limiting the nutritional value) or prepared using non-boiled water (raising the risk of infections) [27]. Furthermore, access to cooking energy in humanitarian settings is also among the causes of other challenges, such as protection, relations between displaced people and hosting communities, environmental damage, overexploitation of natural resources, etc. [22]. In many cases, when traditional biomass is the only source of fuel, women and children are forced cover long distances to collect firewood and to carry heavy loads back to the camps. Such tasks expose them to the risk of physical or sexual attacks and physical injuries, etc. Women and children are also often affected by asthma, pneumonia, or other respiratory diseases, due to the smoke produced by inefficient cooking systems [18], [28], [29]. In addition to this, refugees can sell or exchange a portion of their food rations in order to procure the firewood needed to cook the remaining food. Cooking systems are related to environmental impact as well: intensive firewood collection is a cause of deforestation or degradation of green areas, with permanent damage to the local environment [18], [30].

As already pointed out, the general relevance of access to energy in many aspects of people’s life and human promotion has been pointed out in the framework of the global challenges of the last decades. In fact, the interest on the energy challenge and the link with sustainability has progressively increased, as energy has started to be considered as a key means to provide several services essential for local development [8].

However, despite their extreme vulnerability and exposure to energy poverty, displaced people are not yet directly mentioned among the beneficiaries of the SDG 7, and are generally not part of governmental plans to improve energy access. Actually, the importance of access to energy in emergency and pot-emergency situations only started to be explicitly pointed out in the last few years. The Safe Access to Fuel and Energy (SAFE) working group was the first initiative, established in 2007, to focus the attention on energy needs of crisis-affected populations, in particular refugees and IDPs (SAFE, 2015). After that, some organizations started to get aware of this aspects and to publish some reports on the topic [30]–[32].

However, few organizations have already developed or are in the process of developing SAFE strategies, such as UNHCR, WFP, and FAO.

The Moving Energy Initiative (MEI) is the first international partnership specifically focusing on the multifaceted role of energy for displaced people, stressing the attention on the need to develop an alternative way of dealing with camps and change the common perception about them. "The current state of sustainable energy provision for displaced population: an analysis" reviewed camp situations, and highlighted that "despite numerous energy access initiatives over the years, the vast majority of displaced people still rely on traditional biomass and kerosene for cooking and lighting respectively", and "significant quantities of energy are also needed to power camp operations" [33].

Figure 1.7 Main cooking fuel – 2018. *Source: [34].*

In fact, according to the most recent data, more than 80% of displaced people only have minimal access to energy.

Looking at thermal energy, cooking is by far the most important and relevant activity in humanitarian contexts.

Figure 1.7 gives evidence on the fact that in regions where refugees are mostly concentrated (SSA, Southern and South-East Asia), traditional biomass (firewood and charcoal) is the primary energy source.

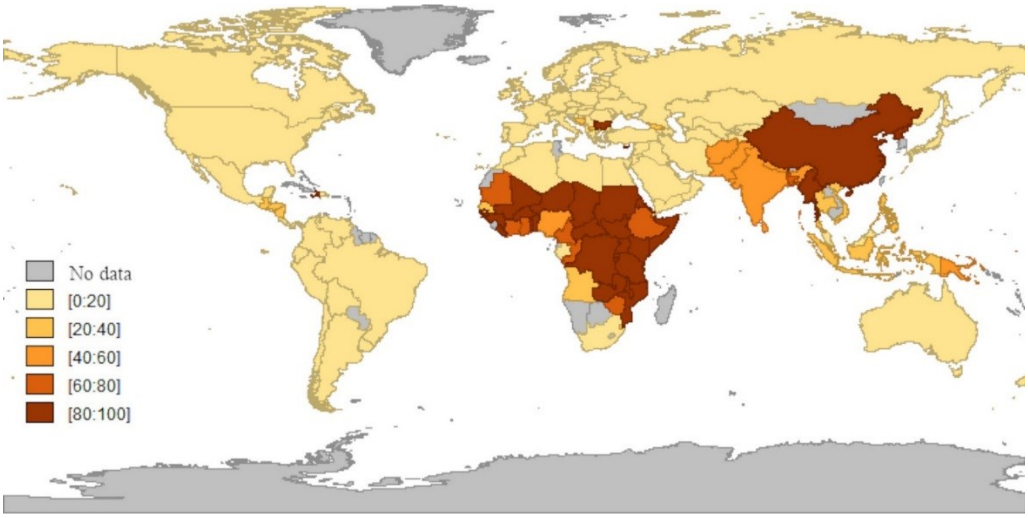

Figure 1.8 Share of displaced people relying on traditional biomass (%) – 2018. *Author's elaboration based on [34].*

Figure 1.8 shows the share of displaced people relying on traditional biomass: in most countries in SSA and Southern and Eastern Asia more than 80-90% of people do not have any access to modern fuels. Respect to the general figures as regards modern fuel access globally, the situation of displaced people is exacerbated in most countries, especially in South Asia and Central America, but even in other regions such as the Balkans, where local population usually do not rely on low-quality fuels.

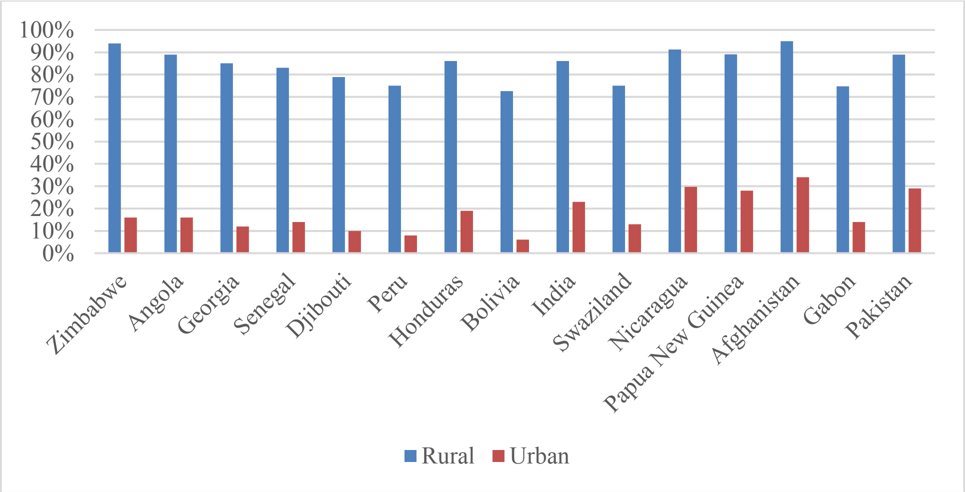

Figure 1.9 Share of displaced people relying on traditional biomass: worst 15 countries for rural/urban divide – 2018. *Author's elaboration based on [34].*

In several cases, the analysis of data on cooking fuels show extreme urban-rural divide (Figure 1.9). In particular, more than 85% of displaced people living in refugee camps located out of rural areas heavily depend on traditional biomass.

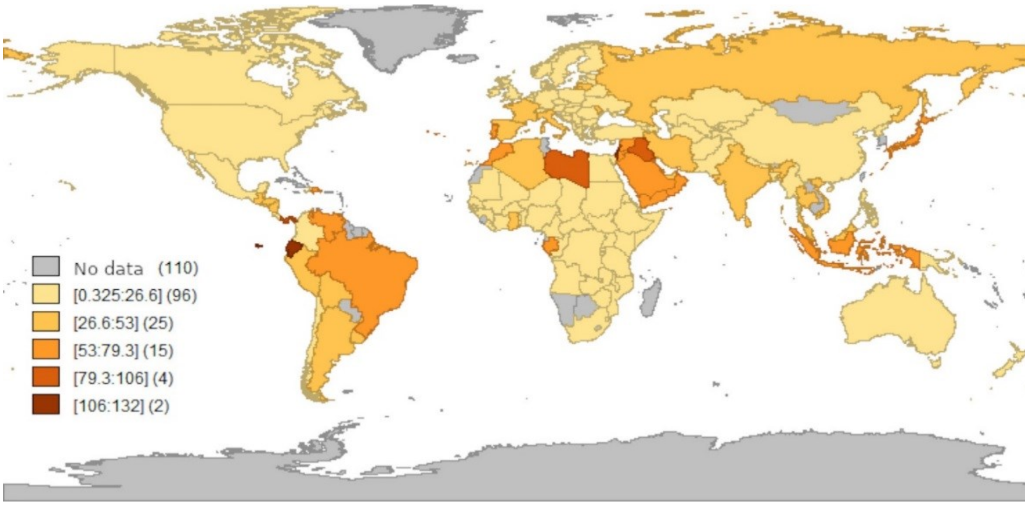

Figure 1.10 Average expenditure of displaced people for cooking (USD/pc/year) – 2018. *Author's elaboration based on [34].*

The average expenditure for cooking (Figure 1.10) varies from a few dollars up to about 130 dollars per year per capita. Such expenditure may seem quite low. However, it is worth noting that most displaced people live with an average income of a few dollars per day. To give some examples: the average income in Goudoubo refugee camp in Burkina Faso was found to be less than 400USD/pc/year, to be compared with 20 USD/pc/year spent for cooking. Similarly, the average income in Dadaab is less than

210 USD/pc/year, while the average expenditure of displaced people for cooking in Kenya is 18 USD/pc/year [35], [36]. Similar findings have been reported also in other independent studies, such as for the case of Tanzania, where the fuel expenditures can exceed 50% of households income [37].

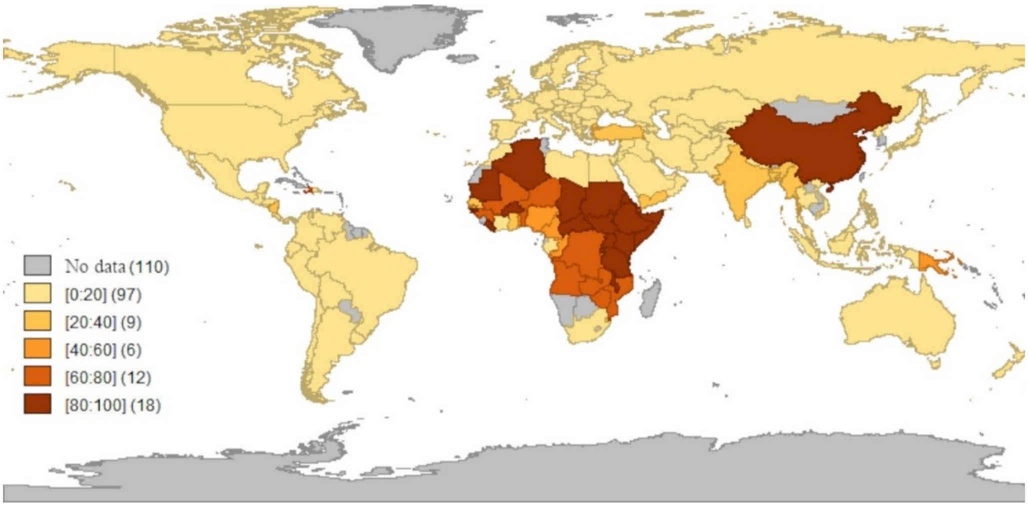

Figure 1.11 Share of displaced people without access to the grid (%) – 2018. *Author's elaboration based on [34].*

The situation as regards access to the electric grid is apparently slightly less serious (Figure 1.11). However, it is worth noting that having access to the grid does not necessarily means that electricity provision is neither affordable nor reliable. On average, displaced people only have access to electricity for less than 4 h a day, and 96.9% of people living in refugee camps are not connected to the grid [38]. In fact, even in the cases where the connection is available, the national electric service is frequently unreliable.

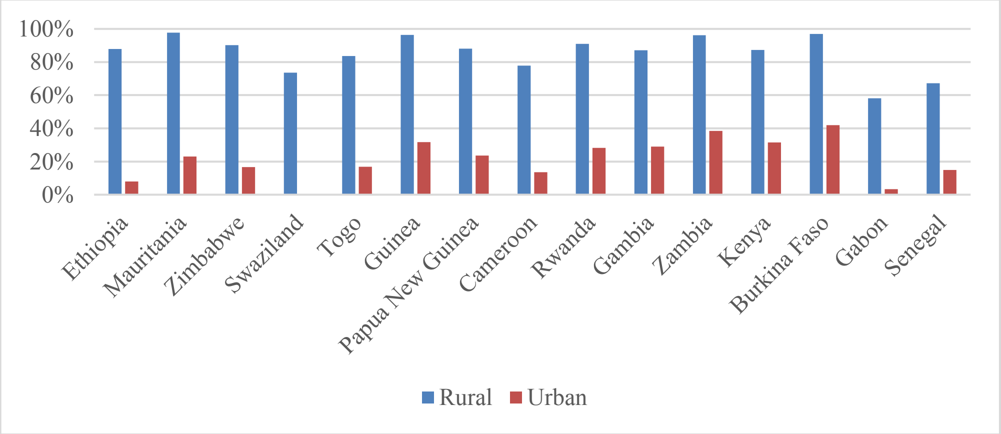

Figure 1.12 Share of displaced people without access to the grid: worst 15 countries for rural/urban divide – 2018. *Author's elaboration based on [34].*

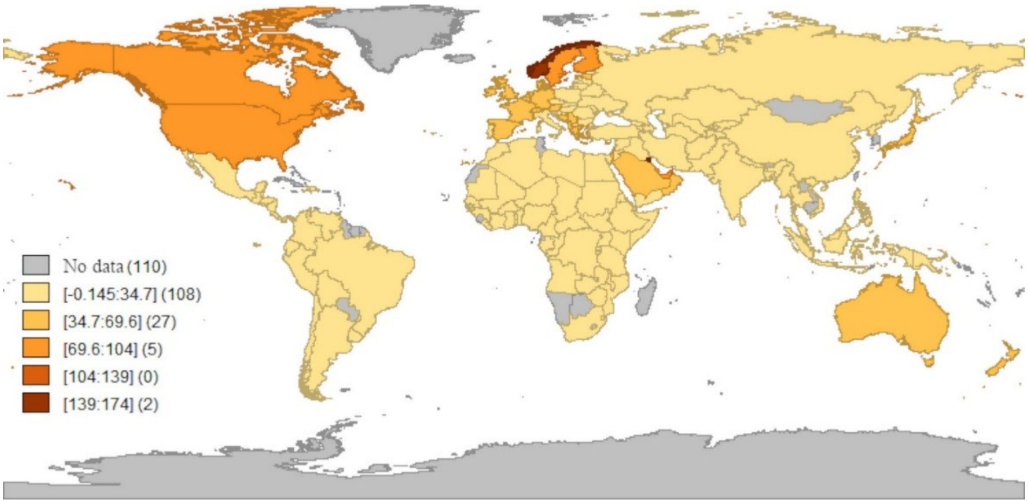

Figure 1.13 Average expenditure of displaced people for lighting (USD/pc/year) – 2018.
Author’s elaboration based on [34].

Also in the case of electricity access, the rural-urban divide is extremely evident in most cases (Figure 1.12).

In conclusion, Figure 1.13 shows the average annual expenditure per capita for the case of lighting. Compared to cooking, the expenditures are in general less important, but far from being negligible.

The "Heat, Light and Power for Refugees: Saving Lives, Reducing Costs" report published by MEI – the first global overview of the state of energy use among forcibly displaced people - confirms that the current energy use by displaced people is unsustainable, and children and women are the most exposed to the consequences of such situation. "Improving access to cleaner and more modern energy solutions would reduce costs, cut emissions and save lives", and also host countries may significantly benefit from an energy shift [39].

If energy consumptions and related expenses are characterized by huge regional variation (as demonstrated in the previous analysis), as a broad worldwide average, a family of displaced people spends more than 200 USD/year for energy provision, which sums to a global expenditure of more than 3.2 billion USD/year. In 2014, displaced people used around 3.5 million tons of oil equivalent, mostly from traditional biomass resources. An estimated 13 million tons of CO_2 are associated to such consumptions every year, which also evidences an incredibly high carbon intensity of energy production in humanitarian settings, considering the very poor quantity and quality of energy produced.

1.1.2 The “energy gap” in the humanitarian system

The findings described in the previous paragraph show that current energy practices in humanitarian settings are clearly unsustainable, since they generate depletion of natural resources and pollution, negative impacts on people health and security, social inequity, huge costs, and potential social conflicts for both people in need and the hosting communities. "The provision of sustainable energy can reduce the negative impacts of the current strategies, offer opportunities for improved lives and economic progress, and reduce costs and environmental impacts. The good news is that appropriate sustainable energy solutions and delivering ways, are constantly evolving with technologies, and "there are opportunities for the private sector to deliver these sustainable energy options effectively" [33]. Thus, the provision of appropriate energy services could contribute substantially to increase opportunities for refugees and Internally Displaced Persons (IDPs), and help them to conduct a more productive and active life [40]. For example, the utilization of more efficient technologies, even if still basic, such as improved stoves and solar lanterns "could save 323 million USD a year in fuel costs in return for a one-time capital investment of 335 million USD for the equipment" [39].

Barriers to this energy shift are not only technological, but also institutional, operational and political, and "a severe shortage of energy expertise in the humanitarian system and no systematic approach to planning for and managing energy provision" are among the key elements [39]. Moreover, interventions should focus on energy as a service, in a holistic way, which substantially differs from the usual approach of the humanitarian system, generally based on the distribution of products or goods. This makes the challenge more complex, and requires capacities and expertise different than the common ones.

Considering the problem under the perspective of the humanitarian system, the main gaps of the humanitarian response related to energy, according to the literature [40], [41] include technical and non-technical drivers:

- lack of robustly-designed delivery models;
- lack of knowledge and confidence in systems other than traditional ones (such as diesel generators);
- lack of experience with proven renewable energy systems;
- lack of technical expertise in the design, installation and maintenance of the systems;
- lack of knowledge for effective need assessment;
- insufficient level of involvement and training of beneficiaries;
- lack of coordination among the stakeholders at all levels (international, national and local);
- resistance in overcoming the traditional vision of the emergency-development dichotomy, especially as regards funding constraints;
- lack of sufficient data to deploy effective market systems.

In a survey carried out in 2016 in the framework of the SET4food project, staff working in headquarters and in the field with different humanitarian organizations and academia (COOPI, FAO, GIZ, GACC, IOM, ILF, Mercy Corps, Project GAIA, SNV, UNHCR, WFP, ISF-Mi, Politecnico di Milano, Pan-African Institute for Development) where asked which kind of internal resources or capabilities where most hard to find within the community of humanitarian players regarding the energy field.

Figure 1.14 shows the results of the survey: fundraising, identification of appropriate energy technologies or fuels, advocacy, lessons learned, monitoring & evaluation and impact analysis, needs assessment and analysis were indicated among the most critical elements.

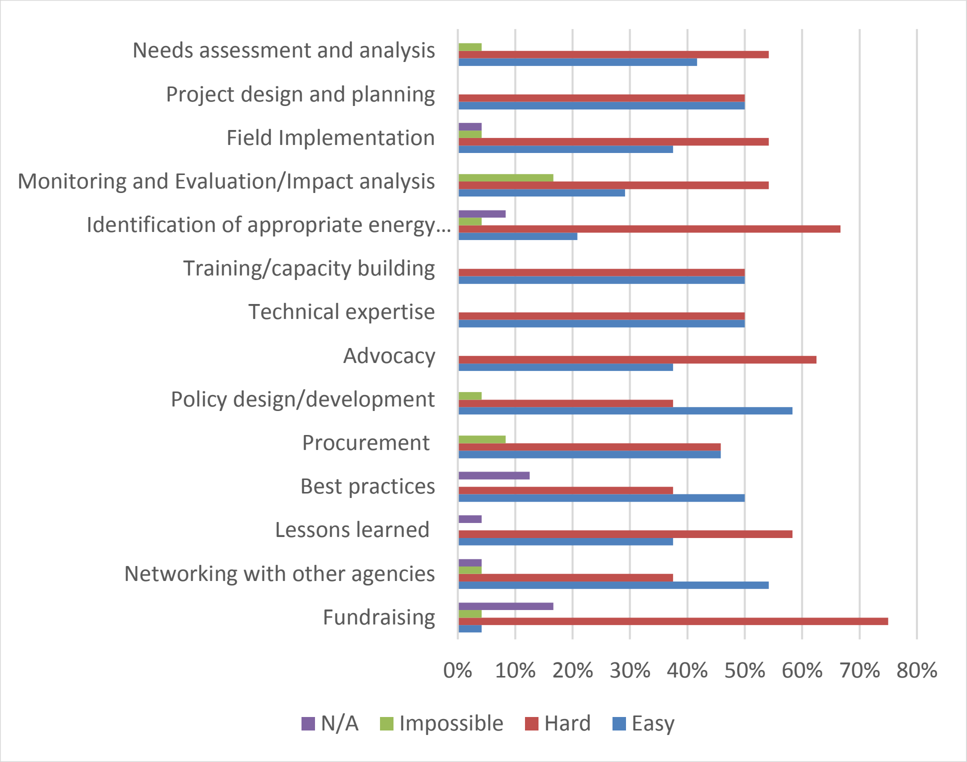

Figure 1.14 Hardness to find resources regarding different scopes of action. *Author's elaboration of SET4food data.*

The fact that energy actually misses of a home or a shared framework in the humanitarian system is probably among the main causes of the weakness of the humanitarian response on energy. The overall humanitarian system is in fact organized in global clusters, with the aim of providing better coordination, and avoid gaps and duplication in assistance. However, none of the 11 clusters (camp coordination and camp management; early recovery; education; emergency telecommunications; food security; health; logistics; nutrition; protection; shelter; and water, sanitation, and hygiene) in the system globally managed by the UN Office for the Coordination of Humanitarian Affairs (OCHA), is appointed as a responsible for energy, and there are no shared guidelines for energy-related issues. Therefore, energy interventions are based on the initiative of individual organizations that often lack of sufficient capacity and expertise in the field, and energy-related funding is not necessarily considered in humanitarian response. This "energy gap" in the humanitarian system also brings to further negative consequences: on the one hand, the scattered nature of interventions and the lack of structured indicators on energy costs, emissions, etc. brings to a lack of data and evidence-based knowledge regarding energy access in humanitarian settings. On the other hand, the short-term funding mechanism typical of the humanitarian system is also applied for funding energy interventions, since there is no specific strategy for this particular sector. This fact drastically limits the opportunities of developing efficient and reliable solutions, that would instead require more extended terms for funds and implementation periods [42]–[44].

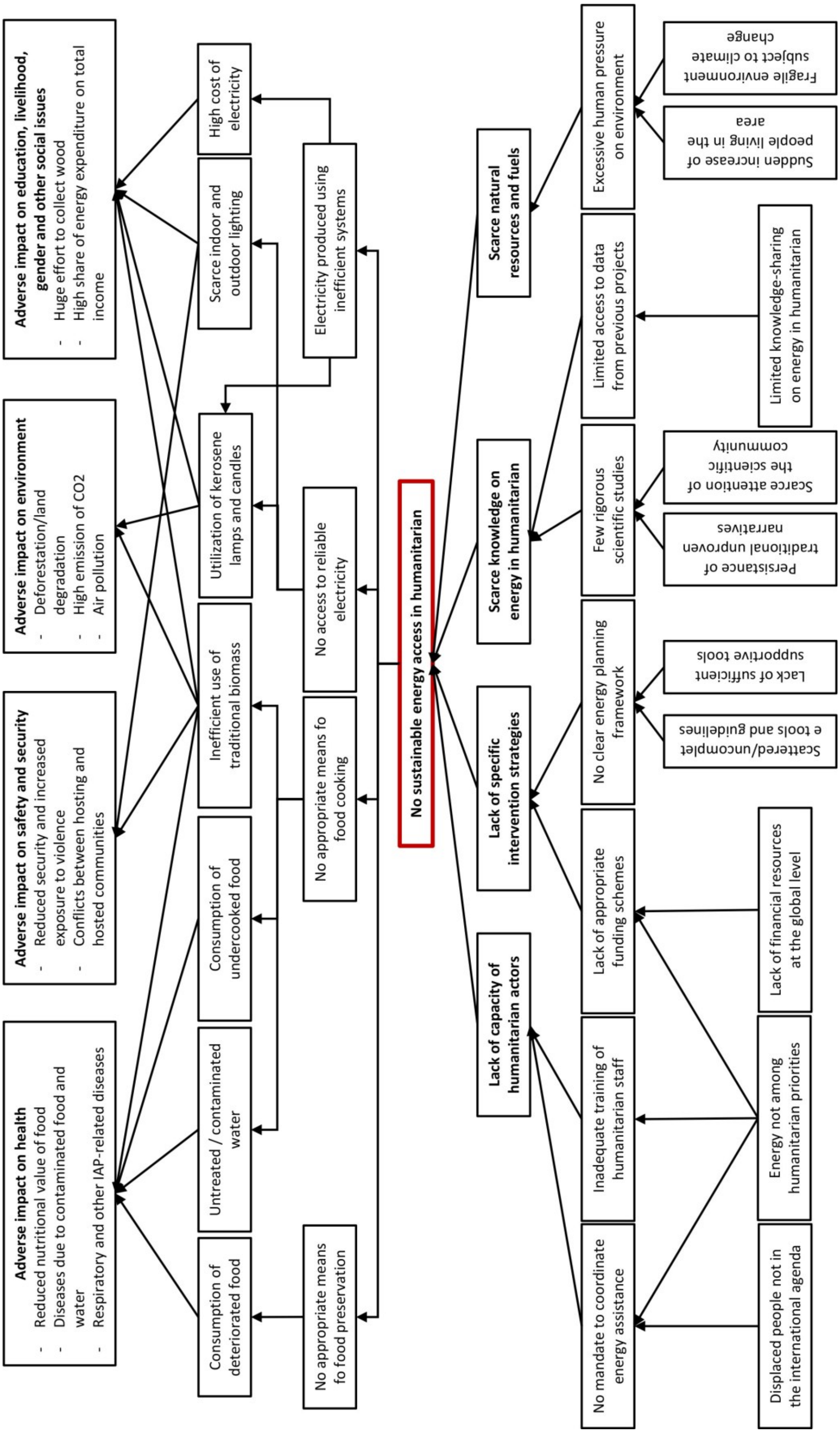

Figure 1.15 A graphical problem tree on energy access in humanitarian settings. *Author's elaboration.*

The analysis presented so far can be effectively outlined and summarized by introducing the problem tree of Figure 1.15. The problem tree provides a possible reading of the overall problem, allowing to better highlighting the overall cause-effect relationships of the energy access situation in humanitarian settings. In particular, (i) the lack of capacity of humanitarian actors on energy, (ii) the lack of specific intervention strategies, (iii) the scarce knowledge of the dynamics of energy in humanitarian, and (iv) the scarcity of resources that typically characterize humanitarian settings, are identified as the four grassroots causes of the actual situation. Each of such causes is in turn due to many other sub-causes. For example, the main sub-causes concurring to the lack of capacity of humanitarian actors include the absence of an institutional mandate to coordinate energy assistance and the inadequate training of humanitarian staff, both depending from other factors such as the missed opportunity to include energy among the priorities of the humanitarian response.

The current unsustainable situation in terms of energy access has many consequences that can be classified into the following main ones: (i) absence of appropriate means for food preservation and (ii) for food cooking, and (iii) no access to reliable electricity services or (iv) access to electricity services provided in unsustainable ways. Such four main consequences can be furthermore split into more specific ones, which allows identifying the interconnections with some of the main pillars of humanitarian interventions, including health (and nutrition); safety and security; education, livelihood and other social issues; environment.

1.2 Research objectives and methodology

As introduced in the previous sections, energy access in humanitarian settings is an emerging issue, which has not received much attention from the research community so far. On the other hand, the importance of energy access in humanitarian settings is nowadays arising, as far as the awareness of the central role of energy in humanitarian contexts makes its way in the international community.

Therefore, the main objective of this work is to study the problem of energy access in humanitarian settings, in order to explore the current main criticalities, challenges, and opportunities, and to contribute with a set of actions and tools to promote better energy interventions in such contexts.

The main objective of the work can be decomposed into three ones that are more specific:

(i) Analysis of the energy-food nexus in humanitarian

This objective is mainly focused on understanding what have been done so far. In fact, the role of energy on food security, and in particular cooking, is the main element that has been traditionally targeted by the humanitarian response till now. Therefore, the energy-food link both (i) represents the obvious and essential entry point for any analysis of energy in humanitarian, and (ii) represents the only case for which a sufficient bulk of scientific and grey literature is available to understand current practices and their impacts on the socio-economic and environmental dimensions.

(ii) Definition of an innovative comprehensive framework for sustainable energy planning in critical contexts.

This second objective focuses on how things could be done better in the future. The literature lacks of a well-defined energy planning framework in critical contexts, including, in particular, rural areas of developing countries and humanitarian settings. This fact is frequently referred as one of the major reasons at the basis of the failure of many energy projects in this kind of contexts. Facing this issue may represent a good way to expand the horizon of energy interventions from very specific needs to a holistic approach that allows identifying the overall dynamics of energy systems.

(iii) Proposal for a first set of tools and actions to enhance the overall capacity of the humanitarian system on energy.

This third objective looks at reversing into practical opportunities all the identified challenges not only in terms of technology development, innovation or adaptation, but also in terms of decision-making, sensitization, and training of humanitarian actors. In other words, it targets the need of transferring a whole bulk of knowledge from energy experts to humanitarian professionals.

The first objective is based on the evidence that there is a lack of scientific rigorous studies on energy in humanitarian, which brings to the following research question: (i) how are food and energy exactly linked in humanitarian settings? And is it possible to understand which has been the impact of energy systems, and in particular cooking systems, in such contexts? To answer such question, a comprehensive and systematic review of the literature is carried out, in order to identify the main challenges related to current practices. Moreover, pilot field experiences are added, to suggest examples of possible innovative approaches to the problem that may complement successful ones already in place.

The findings from this first step bring to an increased awareness that energy provision is hardly sustainable if a holistic approach to the problem is missing. Consequently, a second fundamental question arises: (ii) can we define a comprehensive framework for energy planning in critical contexts, also suitable for humanitarian settings? A possible answer to such question, provided through the integration of different methods and disciplines, paves the way to the achievement of the second objective. A case study is introduced as an example of application of the framework to a real project in Lebanon.

However, in practical terms, even the definition of a holistic framework to energy planning is worthless, if the overall system that is responsible for projects' implementation keeps ignoring the importance that energy plays in the humanitarian response. Therefore, the third objective originates from the awareness that a successful pathway towards sustainable energy in humanitarian cannot ignore the importance of transferring the knowledge acquired through research actions to humanitarian practitioners.

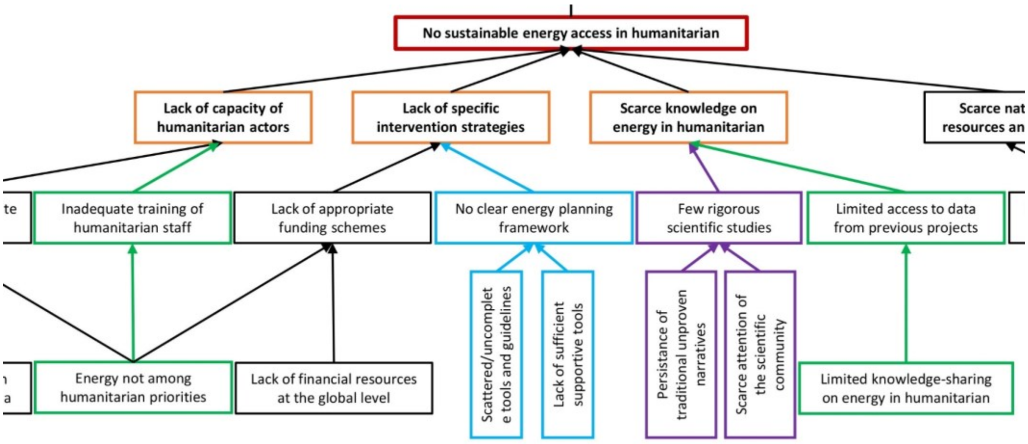

Figure 1.16 Contributions of the specific objectives of the work to the causes of the overall problem. *Author's elaboration*.

Recalling the problem tree, the three specific objectives may contribute to mitigate three out of four of the identified grassroots causes (highlighted in orange in Figure 1.16). In particular, objective one focuses on the scarce knowledge of energy in humanitarian, with particular reference to the lack of scientific studies on the matter (branch highlighted in violet). The second objective concurs to the mitigation of a lack of specific intervention strategies, looking in particular at the sub-cause "no clear energy planning framework" (branch highlighted in blue). Lastly, the third objective is mainly centred on the lack of capacity of humanitarian actors on energy, with a particular focus on training of humanitarian staff. Moreover, it also contributes to enhance the knowledge on energy in humanitarian by promoting the exchange of data from previous projects (branches highlighted in green).

In terms of applied methods for data collection and analysis, the work has been developed by mixing different qualitative and quantitative methods.

Documentary analysis is generally indicated as an efficient and effective method, which also brings the advantage of allowing to expand the spatial and temporal range of analysis in a cost-effective way [45]. Documentary analysis has been used to analyze both scientific and grey resources for the purposes of this work. In particular, it allowed collecting most of data used to depict the situation of energy access under a global perspective and in humanitarian settings (Chapter 1).

Systematic literature review of scientific and grey allowed for a classification of cooking technologies and practices, and the analysis of the impact of past and current energy practices in humanitarian (Chapter 2). According to Petrosino et al., "in systematic reviews, researchers attempt to gather relevant evaluative studies, critically appraise them, and come to judgments about what works using explicit, transparent, state-of-the-art methods. Systematic reviews will include detail about each stage of the decision process, including the question that guided the review, the criteria for studies to be included, and the methods used to search for and screen evaluation reports" [46].

Whenever possible, triangulation of different documents and sources has been used in this framework to collect more details on each analyzed technology and intervention, and to reduce the risk of biased selectivity [47].

Quantitative and qualitative questionnaires allowed the collection of data and information from the field (Chapter 2 and 3). Quantitative questionnaires have been mainly used to collect data from the SET4food pilots, including, for example, cooking duration and practices, fuel consumption trends, and types of foods consumed by beneficiaries. Qualitative questionnaires have been used to further investigate beneficiaries' opinion and perception, especially in cases where quantitative methods did not succeed due to context logistic and security constraints. Questionnaires helped overcoming logistic and language barriers. For each pilot presented in this work, the questionnaires were: (i) initially prepared by the SET4food team in Italy in English; (ii) transferred to the local staff of the project in the target Country; (iii) translated by the local staff into local language; (iv) delivered by the local staff to the beneficiaries by visiting the community in the field; (v) the results (answers from beneficiaries) were translated back into English; (vi) the results were analyzed by the SET4food scientific team in Italy. As further discussed in the next paragraphs, it is worth noting that the dissemination and translation of all the questionnaires was done by experienced COOPI – Cooperazione Internazionale staff; furthermore, interviewers were instructed to limit misinterpretation of questions [48]. All beneficiaries involved in the pilots were informed about the project aim and scope. Where relevant, statistical significance of sample and results were checked.

Direct *observation* in the field helped to add further context elements to the case studies. Observation was limited to the evaluation of the geophysical and natural context. It was used in particular to help completing the different phases of the pilot project in Lebanon (Chapter 3). For example, it allowed to assess the conditions of the electric system in the target building, and the available space for installing the power systems. It also allowed adding details to the assessment of potential beneficiaries' living conditions and needs.

Mathematical modelling, in particular *optimization,* was used to estimate the load curve and develop the techno-economic analysis of the micro-grid for the case study in Lebanon, as described in Chapter 3. Data loggers in the field allowed for collection of technical data from the micro-grid.

1.3 The SET4food project

As discussed in the previous paragraphs, the role of energy has not been fully recognized by the humanitarian system yet, resulting in negative impacts on several aspects. New solutions are required, in terms of energy planning methodologies, technology development and adaptation, as well as decision-making, sensitization, training, and support to humanitarian actors.

The Sustainable Energy Technologies for food security (SET4food) project aimed at enhancing the capacity of humanitarian actors in identifying, implementing and monitoring efficient and sustainable energy technologies for food utilization in refugee camps and informal settlements.

The project included two subsequent phases. The first phase was developed thanks to the collaboration of the following partners: COOPI - Cooperazione Internazionale as the leading agency; Politecnico di Milano as the scientific partner; and Fondazione Politecnico di Milano, as technical partner. COOPI - Cooperazione Internazionale and Politecnico di Milano maintained the same role also during the second phase, while the Global Alliance for Clean Cookstoves (GACC), the World Food Programme (WFP) and the Food and Agriculture Organization of the United Nations (FAO) joined the consortium. All the new partners entering the consortium were among the co-chairs of the Safe Access to Fuel and Energy Working Group (SAFE WG). Both the phases of

SET4food were financed by the same donor, the European Commission's Humanitarian Aid and Civil Protection department (ECHO).

SET4Food focused in particular on the interlinkages between food utilization and energy availability, energy efficiency, and energy sustainability. However, the SET4food action also encompassed energy access more widely.

In fact, the overall objective of the project was to enhance the capacity of the humanitarian sector in ensuring energy access in critical contexts. In order to do so, different capability challenges were identified, as regards the energy-food nexus, and more in general energy access:

(i) *Knowledge and awareness of energy relevance*: humanitarian actors have little awareness as regards knowledge of the importance of alternative energy options, especially but not exclusively about food security (in particular food utilization);

(ii) *Capacity in planning, implementation, monitoring and evaluation*: humanitarian actors have limited technical capacity and supportive tools to identify, design and implement appropriate energy solutions, both at the headquarters and field level. Methodologies to collect, share and analyse data about access and use of energy are not well-known and standardized, thus evidences and reliable data are not easily available. Humanitarian actors rarely have knowledge of Monitoring and Evaluation (M&E) procedures and impact evaluation frameworks for energy projects;

(iii) *Coordination*: despite the effort of SAFE and its members, the humanitarian system is scarcely coordinated about energy-related issues, at local and global level. Information sharing among actors from different sectors, including private companies and research centres is limited as well, especially on issues related to people displacement or emergency.

The first phase of the project was implemented in 2014-2015 with the aim of improving the response capacity of humanitarian actors in identifying and implementing efficient and sustainable energy technologies, in particular for food utilization. All the activities contributed to make energy utilization more efficient and sustainable. The main project beneficiaries were humanitarian actors (operators and organizations), in order to make them more effective to support food security among refugees and IDPs. A second phase of SET4food started in 2016, and lasted until mid-2018. The specific objective of this second phase expanded the previous one, by focusing not only on enhancing the capacity of the single actors, but also by promoting coordination and collaboration among them. The new partners from the SAFE WG were invited to join the consortium. In particular, partners played a role in the discussion about which tools and actions could be more effective and needed from the point of view of the organizations working in the sector. Moreover, the discussion was also based on the clear indications from DG ECHO itself, about the importance and need to create a new platform for knowledge exchange on energy in humanitarian settings.

Thus, SET4food phase 1 and 2 included the following main components, which contributed to provide a response to the three previously mentioned criticalities:

(i) *Training and capacity building*. Training and capacity building on energy have been delivered both in-presence and online to enhance knowledge and awareness of energy relevance. In particular, the e-learning course “Appropriate energy technologies for food utilization in refugee camps and informal settlements: overview, selected criteria, and pilot case studies” is an introductory course to the linkages between energy technologies and food utilization (food preparation and preservation) in humanitarian contexts.

(ii) *Energy planning methodology, pilot testing, and supportive tools*.

  a. Proposal of a draft methodology for energy planning, that was applied in the field, and subsequently re-worked, leading to the proposal for the Comprehensive Energy Solutions Planning (CESP) framework;
  b. Development of supportive tools: a package of tools for decision-making and project implementation was created, composed by: (i) the SET4food guidelines on sustainable energy technologies for food utilization in humanitarian contexts and informal settlements (SET4food Guidelines) [2]; (ii) the Decision Support System (DSS); (iii) the Impact Evaluation Framework interactive tool; (iv) the guidelines on M&E of energy projects. The SET4food guidelines and the DSS support the process of identification and ranking of the most appropriate energy solutions in critical contexts. On the other hand, the monitoring, evaluation and impact assessment tools help not only to assess the achievement of expected objectives during the implementation phase of a project, but also to monitor the impact of the action, providing better data and results evidence.
  c. Implementation of pilot projects in Central African Republic, Haiti, Lebanon and Somalia in order to apply the proposed planning methodology and propose innovative, integrated energy solutions for cooking, food preservation, water purification and lighting. Feedback from humanitarian operators and local stakeholders, including representatives of local communities, constituted an added value to understand replicability and scalability of innovative solutions. It is worth noting that the locations of the pilots were selected among those where COOPI already had a stable presence. This was done to avoid the involvement of third-party organization, and to minimize logistic complications. On the other hand, the sampling logic among all the eligible locations was to select the most diverse countries, in order to compare different contexts and needs.

(iii) *Networking and knowledge sharing*. The Energy Community of Practices (ENERGYCoP) is the virtual platform created by SET4food, where actors from different sectors can share information about energy, and improve networking and collaboration. The platform aims to enable a shift from traditional "technological transfer" to a more participative approach to Co-Design and Technological cooperation activated by a knowledge sharing mechanism. Moreover, several training activities and dissemination events took place in different continents, in order to sensitize humanitarian workers, public officers, academic staff and the private sector regarding the topic, and provide them with the developed tools.

1.3.1 Relevance of the SET4food project in this research work

The SET4food project is intrinsically linked with the work presented in this dissertation. The idea and rationale at the basis of this work actually took shape for the first time during the proposal writing of the first phase of the project, to which the author substantially contributed. Later on, some of the scientific activities carried out in the framework of the SET4food project, and all the scientific products, were built according to such idea and rationale. Vice versa, other project activities, especially those in the field, provided data and results useful to develop further pieces of the present work.

To better underline the linkages between this research work and the project, it is worth describing the different roles played by the main project partners. As already mentioned, COOPI – Cooperazione Internazionale was the leading agency, responsible for the coordination of the whole project. COOPI coordinated the action of the partners, provided administrative and logistic support, and contributed to some of the contents, in particular regarding the capacity building materials and the platform. All the pilots in the field were physically put in place by COOPI's local staff, which carried out most of the practical and logistic work, especially in the most critical areas (Somalia and CAR), under the coordination from the headquarters.

Politecnico di Milano, on the one side has seen the participation of Fondazione Politecnico di Milano and METID as regards the design and implementation of the web platforms, including the SET4food website, the e-learning platform, and the ENERGYCoP platform.

On the other side, three working groups affiliated to the Department of Energy and the Department of Architecture, Built Environment and Construction Engineering carried out the scientific activities. The activities of all the research groups were coordinated by the Author of this work, under the supervision of prof. Emanuela Colombo, responsible of the project.

More in details, the three groups:

- proposed a simplified draft energy planning methodology, and guided its application in the field by setting the questionnaires for the assessment, analysing the data, evaluating the energy needs and loads, designing and sizing the energy solutions to be implemented in the field (including those cited in this work); and adapted the design to the local context;
- developed the indicators and a plan for data collection and monitoring of pilot projects, selected and set appropriate sensors for quantitative data collection, and analysed the data;
- developed all the supportive tools;
- coordinated the design of the e-learning and in-presence courses, recorded several lessons for the e-learning course, and participated in the delivery of the in-presence courses.

In addition to the coordination of the overall scientific and technical work, the Author of this dissertation directly contributed to the following pieces of work:

- main contribution to the overall project: substantial contribution to the proposal writing for both project phases, in particular as regards the identification and formulation of the activities in charge to Politecnico di Milano;
- main contribution to the field pilots:
    - drafting of the energy planning methodology applied in the field, and subsequent continuous re-working and refining of the draft, finally leading to the release of the Comprehensive Energy Solutions Planning (CESP) framework[2];

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[2] It is worth noting that the Author, with the help of prof. Emanuela Colombo and Eng. Lorenzo Mattarolo, proposed the very first idea about the development of an energy planning methodology, in the framework of a previous study produced for a private company, based on the lack of a comprehensive treatise in the scientific literature. Later on, the idea was further elaborated by the Author, and applied in the context of the SET4food action. During the development of the project,

    - identification of the technologies for field testing, with particular reference to those for cooking and food preservation, and proposal for their adaptation. This includes, in particular, the design of the pot-skirts (Lebanon), the conceptualization of the semi-movable PV systems (Lebanon), and the selection of the ICSs (CAR), while the design of the refrigerators (Lebanon and Haiti) was mainly carried out by the colleagues of the ABC department.
    - development of the indicators and of a plan for data collection and monitoring for the staff of COOPI – Cooperazione Internazionale;
    - field assessment of the pilot project in Lebanon;
    - analysis of most of the data available after collection.
- main contribution to the SET4food tools:
    - SET4Food guidelines: (i) sections on cooking technologies and fuels; (ii) sections on water; (iii) coordination and editorial work of the whole publication;
    - Impact Evaluation Framework tool: (i) preliminary development of the concept of the aggregation algorithm; (ii) coordination of the further development of the tool in Excel®; (iii) review of the indicators and of the final algorithm;
    - DSS: (i) development of the concept; (ii) development of the indicators and algorithm of the cooking section; (iii) coordination of the development of the overall tool and of its implementation in both the online and Excel® version;
    - e-learning course: (i) development of the concept and of the syllabus of the course; (ii) review of the contents and coordination of the overall work; (iii) preparation and recording of some lessons.

Despite the strong intrinsic interlinkages prior illustrated between this thesis and the SET4food project, it is worth noting that the overall flux of information related to the project, i.e. the way it is structured and the way most of the data and information has been elaborated, analysed, and presented, is the result of the independent research work of the Author. Therefore, the results, conclusions and comments in the text do not necessarily represent the point of view of other persons involved in the SET4food project.

1.3.2 The flag of the UNESCO Chair in Energy for Sustainable Development

The research work presented in this dissertation, as well as the activities of the research groups that contributed to the SET4food project, were carried out under the flagship of the UNESCO Chair in Energy for Sustainable Development.

The Chair operates in the Department of Energy at Politecnico di Milano since March 2012, and actively contributes to:

- promote teaching and education, working on curricula upgrading, summer schools and international exchanges
- foster scientific research, contributing to human promotion and social development

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the methodology was continuously refined, also thanks to the feedback and findings from the field, which finally led to the definition of the CESP framework described in this thesis.

- enhance technology transfer and community service, fostering industry-university cooperation
- enforce transversal partnerships and dissemination, activating a "virtual" network of knowledge to share international experiences.

The Chair cooperates with international institutions and NGOs, in activities of knowledge sharing and training on issues related to access to energy and sustainable energy strategies.

The public-private partnership is enforced by working with the civil society players and public institutions on research projects funded by public and private bodies for supporting local socio-economic growth.

The Chair promotes international university partnerships with the Global South, supporting the upgrading of higher education in the target countries, and promoting joint research and staff exchange.

Activities have been tailored to combine the innovative and rigorous methodologies for the performance evaluation of energy conversion systems with a holistic and creative approach, which aims at meeting the constraints of economic, environmental and social sustainability. Research and teaching focus on strategies for improving energy access and for the impact evaluation of energy projects. The activities of the Chair also include advisory to NGOs and private companies.

1.4 Concluding remarks

In this Chapter, the research objectives of the dissertation were explained under the light of the global challenges related to energy access, and in particular of those affecting humanitarian contexts. The relevance of the SET4food project was also underlined, establishing the interconnections between the project and this research work. The analysis focused in particular on the energy-food nexus, showing the importance of this particular aspect in the case of energy interventions in humanitarian settings. Given the centrality of food security in the humanitarian response on the one hand, and the scarce attention that the humanitarian system has given to energy access so far on the other hand, the energy-food nexus can be identified as the essential entry point to recall the relevance of energy in situations of displacement. For this reason, the next chapter is dedicated to the exploration of such nexus, and to the assessment of the impact of current food-related energy practices.

2 An essential entry point: the energy-food nexus in humanitarian settings

Food security and nutrition are among the main pillars of the humanitarian response. Both such pillars are strongly influenced by energy access. Energy is fundamental for food processing, preparation and preservation, as well as for safe water provision. Energy for cooking has been the most addressed topic by the humanitarian system so far, the only energy-related topic that has received a significant level of attention until now. On the other hand, other areas of intervention, including food preservation and sustainable power systems also constitute promising emerging sectors. For this reason, in this chapter, the energy-food nexus is explored starting from a general analysis, and focusing on a second step on current cooking technologies and practices, with the dual objective of classify all the technologies currently adopted, and understanding their impact in humanitarian settings. Subsequently, a set of innovative approaches is proposed, drawing on the experience of the SET4food project, as a first pilot attempt to tackle some of the main criticalities emerged from the overall analysis.

2.1 Water-energy-food nexus in critical settings

The concept of *nexus* was first conceived in 2011 during the World Economic Forum [49], as an instrument to underline the intrinsic interlinkages between the use of food, water and energy resources. However, it is important noticing that the concept can be extended more broadly, to also include interlinkages between land, soil, and the ecosystem [50]. This observation also suggests that the nexus can be faced by adopting different perspectives and boundaries of analysis. For example - under an energy centred perspective - according to Brouwer F. et al, the *nexus* is “a concept to link energy with other natural resources”, which unveils their interconnected nature, and has the characteristics of a coherent system [51].

The original definition of the concept was firstly presented under a security perspective (water-energy-food security) [49]. Under such perspective, the concept of nexus expresses the interlinkages between the three concepts of *water security*, *energy security*, and *food security*.

Water security is primarily defined in the SDGs Agenda as “access to safe and affordable drinking water”, but also refers in a broader perspective to “access to adequate and equitable sanitation and hygiene” [52]. *Energy security* is defined by the UN as “access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses” [53]. *Food security* is defined by FAO as "availability and access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for an active and healthy life" [5]. More in details, each of the three concepts include the following main pillars [54]:

- Water security: (i) water access; (ii) water safety; and (iii) water affordability;
- Energy security: (i) continuity of energy supplies relative to demand; (ii) physical availability of supplies; and (iii) supply sufficient to satisfy demand at a given price;
- Food security: (i) food availability; (ii) access to food; (iii) food utilization; and (iv) food stability over time.

Since the main focus of this thesis concerns energy, an energy perspective to the nexus seems the most appropriate. Unpacking the nexus under such perspective, as already anticipated in the introduction of this work, reveals that the strongest interconnections in critical settings are those linking energy to food security, and in particular food utilization.

A more detailed analysis of the concept of food security, on the one hand shows that the attribution of its four pillars is frequently recalled in the literature specifically addressing humanitarian settings [26], [55], [56]. On the other hand, it unveils that the humanitarian response mainly focuses on the first, second and fourth pillar, while food utilization is often neglected [27]. However, food utilization is a key dimension of food security. In particular, the way food is stored, prepared and preserved has an important impact on nutrition and health. For example, during the humanitarian response in Niger, corn soya Blend Plus was distributed with the aim of contrasting famine, and especially to feed children. However, this product needs to be prepared three to four times a day using boiled water. The monitoring of this action showed that due to the scarce availability of fuel, rations were mostly consumed dry (thus limiting their nutritional value) or were prepared using non-boiled water (raising the risk of infections and spreading diseases related to contaminated water) [27].

As per for food preparation, inefficient and polluting traditional cooking systems, such as the three-stone fire, coupled with the consumption of traditional biomass (firewood or charcoal), are generally the most widespread solutions used by refugees and IDPs. Cooking with such systems causes huge impact on the surrounding environment, threatens health and safety, and takes long time. Therefore, people tend to reduce duration and frequency of cooking tasks, and try to stock food remains. However, due to poor storage systems and unreliable energy supply, food loses nutritive properties and is among the causes of various diseases [23].

Thus, more in general, it is possible to observe that better solutions for cooking, food preservation, and safe water provision would be required in critical settings, and all of them are interconnected with the need for clean, reliable and affordable energy services. The finding suggests that many relevant aspects and common interlinkages with energy in humanitarian settings are still neglected. This will be further evidenced in the next analysis by adopting the nexus between energy and food security as the lens that allows unveiling the “secondary” interlinkages with water, environment, and socio-economic issues.

2.2 Energy and food security: facts and figures from the field

In 2015, at the beginning of the present research work, an assessment of energy access and energy systems in humanitarian settings was leaded by the Author in the framework of the SET4food project. A qualitative questionnaire was distributed in refugee camps and informal settlements in Mauritania, South Sudan, Burkina Faso, Uganda, Somalia, Central African Republic, Lebanon, Jordan and Gaza. The assessment aimed at understanding the situation regarding energy access and its linkages with food and water in humanitarian settings.

The assessment showed that in more than 90% of the cases, cooking was performed independently by each family, mostly using firewood or charcoal (Figure 2.1 and Figure 2.2). Middle East regions represent an exception, frequently reporting the utilization of bottled gas (LPG). From this figure, it is possible to understand that in most areas in the world, displaced persons heavily rely on traditional biomass. The dependence is exacerbated by the lack of community services for cooking, that represent a more efficient way (institutional stoves have higher efficiencies compared to small ones), but are unfortunately difficult to be put in place in many situations due to internal conflicts among refugees.

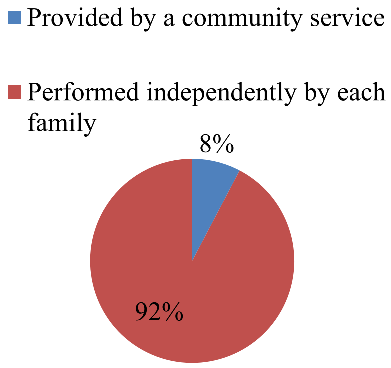

Figure 2.1 Responsible for cooking tasks. *Author's elaboration*.

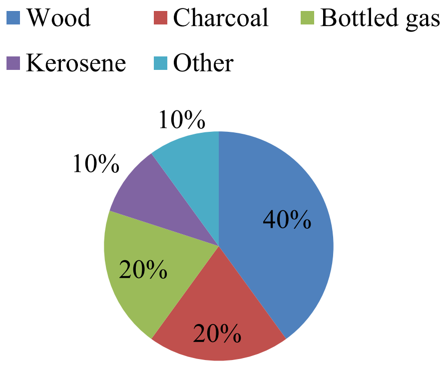

Figure 2.2 Main cooking fuels. *Author's elaboration*.

Therefore, utilization of three-stone fires or traditional stoves at the family level was reported in 67% of the cases, while improved stoves in 20% of cases. Gas stoves were mostly used in Middle East, while in few cases kerosene stoves were also used in SSA (Figure 2.3). From the comparison between Figure 2.2 and Figure 2.3 therefore, an ostensible discrepancy on the coupling between fuel and stoves is evidenced. However, most probably the explanation is because in many cases traditional biomass is used as secondary fuel source even when the first is a different one. Considering that most of the questionnaires were distributed in SSA, in most cases ambient heating was not necessary. However, it is interesting to notice that in 40% of the cases where heating is needed, the respondents declared that cookstoves where used also to satisfy such need (Figure 2.4).

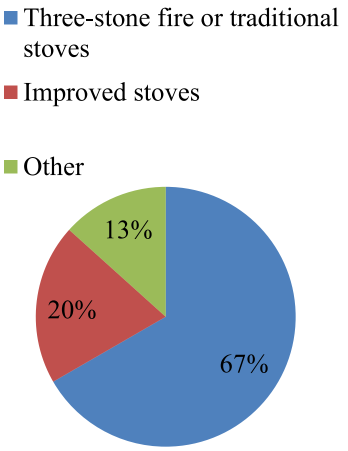

Figure 2.3 Main cooking systems. *Author's elaboration*.

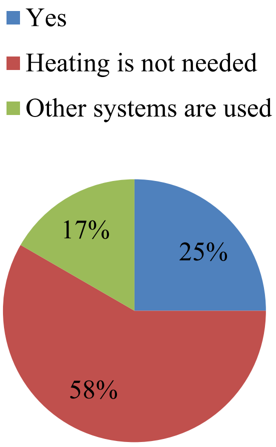

Figure 2.4 Utilization of cookstoves for ambient heating. *Author's elaboration*.

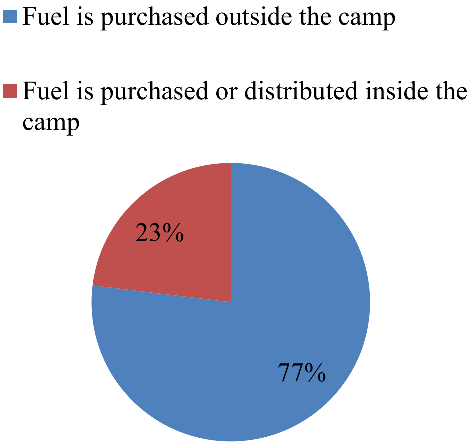

Figure 2.5 Fuel purchase channels. *Author's elaboration*.

Figure 2.5 shows that fuel is mostly purchased or directly collected outside camps: only in few cases (again, mostly in Middle East), shops or markets selling fuel are present inside the settlement area.

Looking at the situation as regards electricity (Figure 2.6), in 46% of the analysed camps and informal settlements electricity is only available for community services such as street lighting, while in 31% of cases also families have access to some kind of service (that, however, is frequently referred as unreliable or only available for few hours due to rationing). In 23% of cases, no electricity at all is available. When available, electricity is mostly used for lighting and refrigeration. Water pumping is also a relevant service, as well as other ones such as running medical devices or telecommunication (Figure 2.7). It is worth underlying that electricity is used in some cases also for cooking, but only as a complementary option. This is why electric cookstoves have not been mentioned among the main cooking systems in the previous diagrams.

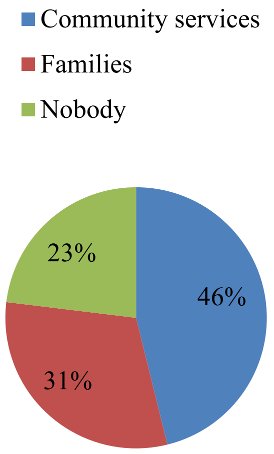

Figure 2.6 Main uses of electricity.
Author's elaboration.

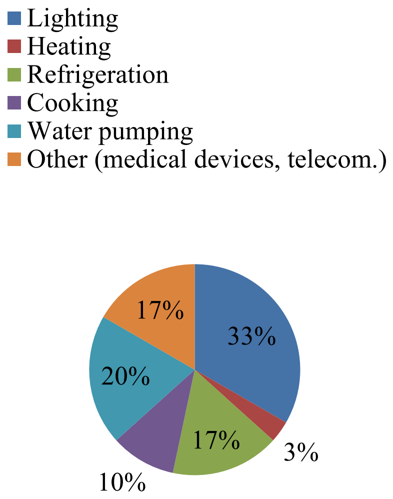

Figure 2.7 Services depending on electricity.
Author's elaboration.

When available, electricity is produced from diesel generators in more the 40% of cases (Figure 2.8). In about 30% of cases, it is supplied from the national grid, while in 21% is produced from renewable energy systems (PV).

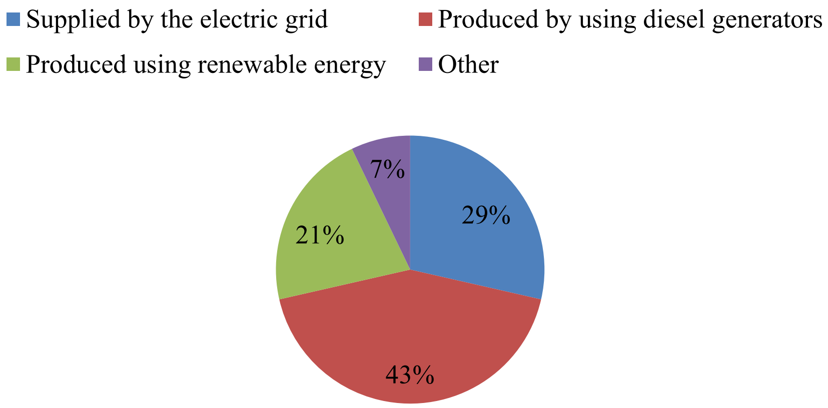

Figure 2.8 Sources of electricity. *Author's elaboration.*

Food storage and preservation were assessed as well. A storage for food is present in 67% of cases (Figure 2.9). However, when this figure is compared with the type of systems used for food preservation (Figure 2.10), it is evident that in some cases the storage is a simple warehouse (45% of respondents declare there is no food preservation system, compared to the 67% declaring the presence of a storage). In the other cases, the electric refrigerator is the most adopted solution, followed by solar and gas refrigerators. Surprisingly, in no case driers are used, which could instead represent a valid option in dry climates.

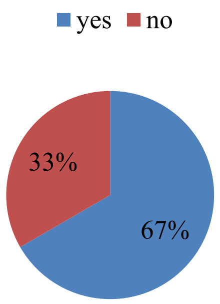

Figure 2.9 Presence of a storage for food. *Author's elaboration.*

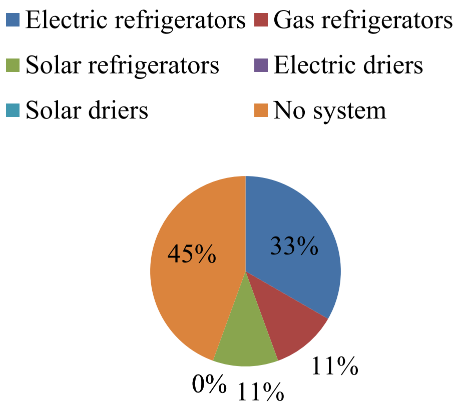

Figure 2.10 Systems used to preserve food. *Author's elaboration.*

Lastly, as regards water, in most cases it is not directly available in the settlement area, thus is transported using tankers, or by hands. Only in 28% of cases, water is pumped from wells inside the camp, or available from the national distribution network (Figure 2.11).

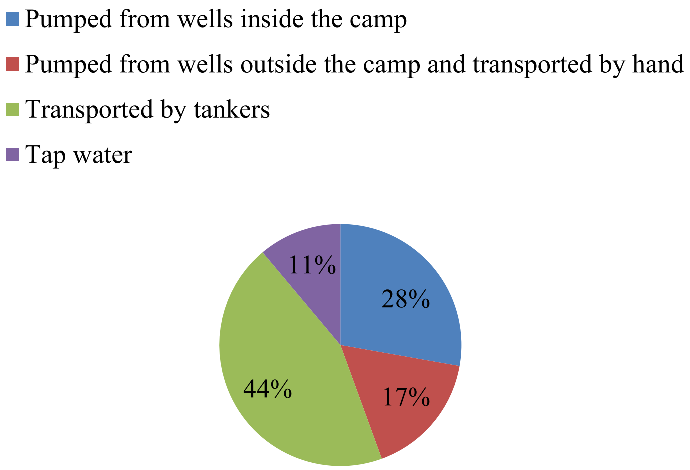

Figure 2.11 Water supply systems. *Author's elaboration*.

Similar results as regards cooking and electricity were reported later on by further analyses carried out by the Moving Energy Initiative, especially in [39], as already reported in the introduction.

The situation evidenced before is clearly far from the ideal one, depicted in the Sphere handbook, the reference handbook reporting the humanitarian charter and minimum standards in humanitarian response in terms of energy-related means for ensuring food security. According to such standards, in fact, "the disaster-affected population has access to a safe, fuel-efficient stove and an accessible supply of fuel or domestic energy, or to communal cooking facilities. Each household also has access to appropriate means of providing sustainable artificial lighting" [24].

The findings from the assessments, on the one hand clearly show the critical situation of energy access in humanitarian settings, while on the other hand clarify and highlight the main linkages between energy, water and food in such contexts. From the reported figures, in fact the nexus between energy and food emerges especially as regards the dependence of food cooking, including water for food preparation and drinking, on fuel quality and availability. Similarly, it is found that appropriate food preservation means are strongly dependent on appropriate energy sources. Despite such strong interlinkages between water, food and energy, as well as between cooking, food preservation, water treatment, and energy, the humanitarian system has focused on cooking only so far, while a review of scientific and grey literature did not allow to identify any intervention on food preservation systems other than those implemented under the SET4food project action [3], [57].

As a matter of fact, the United Nations Inter-Agency Standing Committee Task Force on Safe Access to Firewood and Alternative Energy (IASC Task Force on SAFE), the only official UN initiative on energy in humanitarian settings has mostly focused on cooking, and opened the floor for a discussion on other dimensions only in the very last years[3]. As a consequence, food preservation and sustainable electricity supply systems, such as hybrid micro-grids, represent emerging sectors, for which a scientific analysis can be carried out only on the theoretical technology framework, or throughout field piloting, due to the lack of a significant number of implemented projects and studies on their adoption and impact. On the other hand, cooking in humanitarian has been addressed for more than 20 years, and many projects have been put in place using a number of different systems. For such reasons, in the next paragraphs of this chapter the research will focus on energy systems for cooking. Their different typologies and implementation schemes will be identified, in order to provide a scientific analysis of the challenges related to their introduction in the field, and the results achieved so far in terms of impact on the environment, health, safety, socio-economic and livelihood.

2.3 Technologies for cooking

In this section, an overview and analysis of cooking technologies is presented focusing on their utilization in humanitarian settings. An up-to date classification of the different typologies is proposed in order to report the main characteristics, pros, and cons of each one.

Before proceeding, it is worth to distinguish between the concept of cookstove (or cooking stove) and the concept of cooking system: the first one is defined as the device used to contain the fuel, where combustion occur. The cooking system, instead, is the combination of the cookstove, the pot, the interface between the two, and any other additional device (such as a pot skirt) [58].

As regards the definition of cookstove itself, there is not any standard universally accepted. However, the United Nations have defined some criteria that cookstoves should have to respect in order to reduce health damage, as well as environmental threats. Specifically, they have to be sustainable (from the social, environmental and economic points of view), they have to meet the social, economic, and behavioural needs of users,

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[3] Safe Access to Fuel and Energy (SAFE) Humanitarian Workshop 2016 – Kigali (Rwanda). www.safefuelandenergy.com

suit the resources available, and reach high levels of technological design and performance.

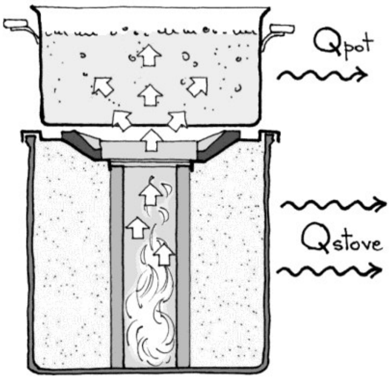

Figure 2.12 Thermal losses in the cooking system. *Source: [2].*

A standard classification of cookstoves does not exist but they are generally classified based on their performance and fuel typology.

Performance - A stove with high performance shows low levels of emissions and a high thermal efficiency. The term “efficiency” here refers to a measurement of the fraction of heat produced by the fuel that is transferred to the pot, compared to the energy that is lost in the environment (Figure 2.12).

Therefore, a higher thermal efficiency indicates a greater ability to transfer the heat produced into the pot. If traditional stoves are characterized by low efficiencies, improved stoves are designed to improve energy efficiency, limit smoke emission, or lessen the drudgery of cooking duties. The particular shape of the combustion chamber also allows the firewood to be better positioned, to increase thermal efficiency. In fact, stove efficiency and emissions are very sensitive to the combustion chamber shape, material, chimney height, chimney diameter, and firewood placement. The stoves with the lowest efficiencies are the traditional ones. This refers to both open fires (also known as three-stone fires) as well as self-made cookstoves with very low or low efficiency. Both open fires and low efficiency traditional stoves are largely used in developing countries, as well as in humanitarian contexts. Open fires, in particular, are the simplest and easiest ‘technology’ for cooking, but their efficiency is very low, typically about 15%, and can cause serious health problems due to harmful emissions (mainly PM and CO). On the contrary, Improved Cook Stoves (ICSs) are stoves with a higher efficiency than the traditional ones and a lower level of emissions. In particular, advanced or modern biomass cookstoves refer to the most recent/latest manufactured cookstoves. These stoves are generally more expensive, and provide the best performance in terms of safety, efficiency, emission, and durability. They include forced air stoves and gasifiers. Finally, gaseous and liquid fuel stoves show the highest performances, both in terms of high efficiency and low emissions.

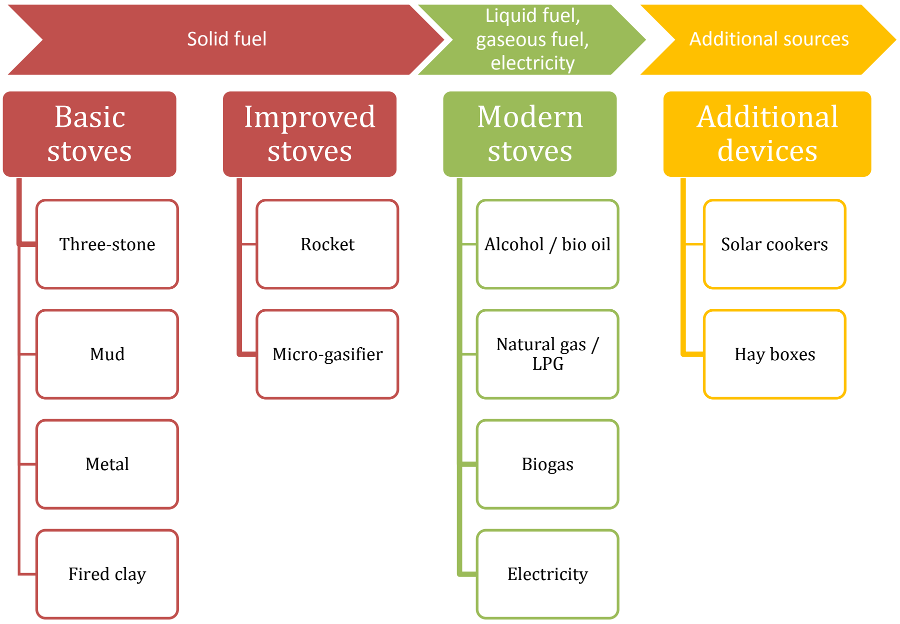

Figure 2.13 Main stoves typologies classified according to fuel typology. *Author's elaboration*.

Fuel typology – The classification according to the fuel typology is the most common and widely adopted. Traditional stoves and improved stoves use solid biomass fuels. Basic stoves include models belonging to traditional culture as well as models that have been readapted or newly introduced, though still basic in terms of materials and design. Improved stoves instead include stoves with improved design, namely rocket stoves and micro-gasifiers. Modern stoves include stoves using modern fuels, i.e. liquid or gaseous fuels, or electricity. Finally, additional technologies are devices that can be considered as complementary to cookstoves. They include solar cookers and hay boxes (Figure 2.13).

In the next paragraphs, the different typologies of stoves are described, subdivided according to the three main categories previously defined, based on fuel typology.

2.3.1 Solid fuel cookstoves

Basic stoves - Usually, the term identifies very cheap or no cost models of stove. It includes both traditional devices, whose use is well established within people's traditional habits, and re-adapted basic models. In most cases, they are characterized by very low efficiency and high CO and PM emissions. The literature commonly identifies four models of basic stoves: *three-stone fires*, *mud stoves* (Figure 2.14), *metal stoves* (Figure 2.15) and *fired clay* (*viz.* ceramic, Figure 2.16) *stoves*. The former, often named "open-fires", are simple fires built directly on the ground where three stones work as the pot support.


Figure 2.14 Mud stove *[2]*.


Figure 2.15 Metal stove *[2]*.


Figure 2.16 Fired clay stove *[2]*.

The main drawbacks of such devices are the large amount of thermal losses toward the environment, the huge amount of PM produced during the combustion, and the exposure to open burning flames. On the other side, the fact that the flame surrounds the pot makes them sometimes more efficient than other cooking devices, and their simple design and materials generally makes them the cheapest solution [59], [60].

According to the literature, mud stoves have been introduced in Mugungu and Goma camps in the Democratic Republic of Congo, Darfur, South Sudan and Rwanda [19] [61] [62] [63] by different institutions, such as FAO and UNHCR. The no-profit organisation ProAct Network states that mud stoves and metal stoves were the most widespread models used among IDPs, refugees and local residents in West Darfur until 2008 [64]. The main problem here is that in most cases such stoves where constructed directly by the users. This fact results in low efficiency and durability of the devices, when appropriate design principles are not applied in a rigorous manner, also leading to increase the CO and PM emissions and Indoor Air Pollution (IAP) [2].

In the case of fired-clay stoves, the specific skills of potters are always required, as well as stencils or molds and tools for kneading the material [2]. Traditional models promoted by international programmes in refugee camps are the *Upesi* stove in Kenya and the *Chitetezo Mbaula* in Malawi [65]–[67] [65], [66] [68] [69]. The use of clay stoves in refugee camps is indicated as a mean for substitution of the 3-stone fires in [70] [71] [72]. For example, Thulstrup and Henry report that two models of stoves were selected by IDPs in South Sudan. Recently, a metal cladding has been introduced in some cases to increase durability by protecting the stove structure from accidental blows and natural crumbling in Ethiopia, Cambodia and Kenya [72] [73].

Improved Cooking Stoves (ICSs) - The term "improved" has been historically referred to cooking stoves installed in "legacy" programs. Usually, such stoves are characterized by an enclosed combustion chamber and sometimes a chimney, but there is no international standard as regards their performances yet [74]. A number of cooking stoves are classified as "improved" based on their design, as well as on indicators of performance, usually evaluated through laboratory-based tests. Based on the definitions of ICS, sometimes also traditional mud, metal and clay stoves may be referred as "improved" compared to a traditional three-stone fire. In particular, the UNHCR has promoted such devices as improved, since they could potentially achieve energy savings up to about 20 - 30% compared to three-stone fires, that is usually the most wide-spread adopted cooking method in humanitarian contexts [75]. In any case, what mainly distinguish an ICS from a traditional stove is the particular design of the combustion chamber. Typical examples of ICS are rocket stoves, and gasifiers.

The main characteristic of rocket stoves is the L-shape combustion chamber (Figure 2.17).

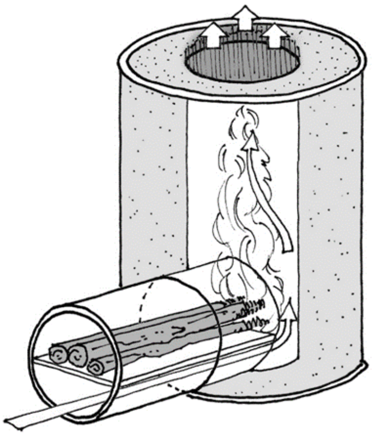

Figure 2.17 L-shape combustion chamber. *Source: [2]*.

Thanks to this design, a pressure drop is created by the large temperature difference between the inlet and the outlet of the chamber. This effect contributes to reduce the production of CO and particulate, and the production of smoke.

In many cases, rocket stoves also adopt other expedients, such as an insulated body, or pot-skirts

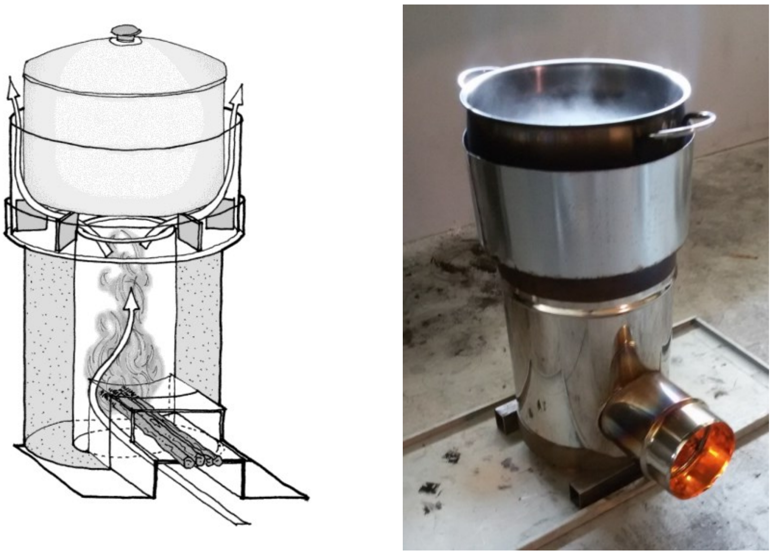

Figure 2.18 Pot-skirt. *SET4food\UNESCO Chair E4SD*.

A pot-skirt is a simple round piece of metal which is placed at the top of the combustion chamber (Figure 2.18). It encloses the pot and forces the flame and hot gases to its sides. The presence of a pot skirt can reduce fuel consumption and emissions by improving heat transfer to the pot.

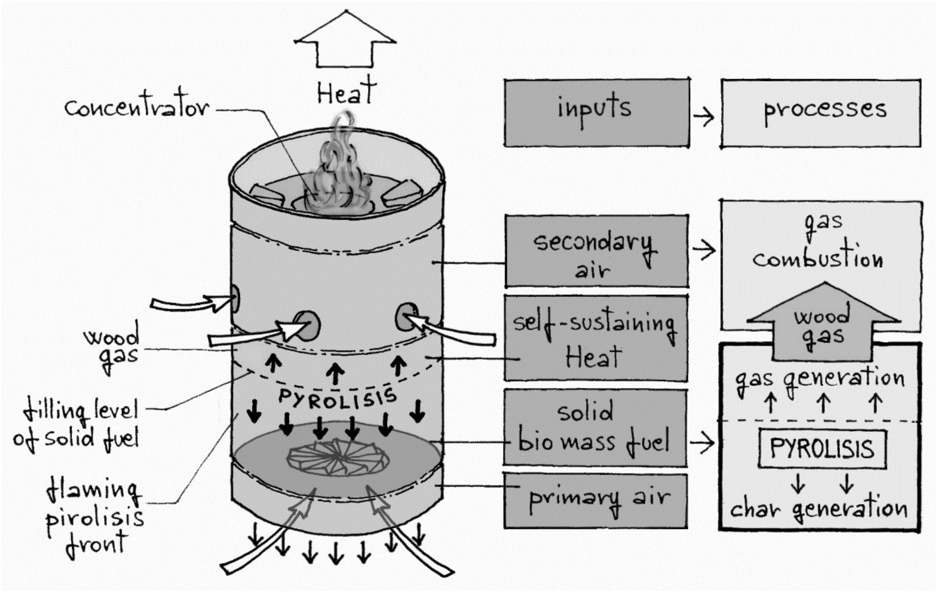

Figure 2.19 Functioning scheme and principles of a micro-gasifier. *Source: [2]*.

Micro-gasifiers are stoves that work through a two-phase combustion process in which biomass fuel is first burned in the lower part of the combustion chamber with a reduced supply of air (i.e., oxygen). This causes the conversion of solid biomass into a syngas, which is then burned thanks to the injection of secondary air at the top of the combustion chamber (Figure 2.19). Micro-gasifiers can achieve high efficiencies and very low level of emissions compared with three stone fires (up to 90% of reduction).

They can work with a wide range of biomasses: wood, dung, residuals such as peanut shells, rice and coconut husks, sugar cane bagasse, and bamboo. However, most of gasifiers cannot be re-fueled once the flame is ignited, and require fuel to be split in small parts, which makes their operation quite complex.

As regards the utilization of rocket stoves in humanitarian settings, TChad Solaire report the utilization of the *Save 75* rocket stove in Touloum Refugee Camp, Chad [76], while GTZ (now GIZ), Divisional Environmental Committee, UNHCR and Government of Kenya in 2008, considered to promote rocket stoves by training refugees of Kakuma and Dadaab camps in Kenya [77]. USAID reports a pilot test made in the Dadaab refugee settlements on two rocket stoves of the “Envirofit International’s Family of Rocket Stoves” and “StoveTec family” [69]. Pilots of different commercial models have been carried on with *Save80* and *Berkeley Tara* in Darfur and Chad [78] [79]. In other cases, forced air rocket stoves have been introduced as well according to [72], [80] [81], [82]. For example, BioLite *CampStoves* were used for cooking and generating electricity by many hurricane Sandy survivors [83].

Micro-gasifiers in humanitarian contexts were introduced in Haiti by WorldStove [84], which stresses the need to supply IDPs and disaster victims with affordable and reliable cooking devices. An application of the *PekoPe* model in a refugee camp in Uganda is reported in [85]. Moreover, Birzer et al. [86] investigated the potential use of TLUD micro-gasifier for humanitarian purposes. The performance of *Vesto* micro-gasifier, and other models of commercial rocket stoves, were also evaluated for their utilization in Dadaab refugee camp (Kenya) [69].

2.3.2 Liquid fuel, gaseous fuel, and electric cookstoves

All stoves using liquid or gaseous fuels, or electricity, are generally referred as *modern-fuel cookstoves*. In fact, liquid and gas fuel stoves include stoves that utilize modern fuels such as kerosene, Liquefied Petroleum Gas (LPG), biogas, liquid alcohols or ethanol gel, vegetable oils, or that work with electricity [87] (Figure 2.20 - Figure 2.22).

Figure 2.20 Alcohol stove *[2]*.

Figure 2.21 Kerosene stove *[2]*.

Figure 2.22 Gas stove *[2]*.

Generally, their thermal efficiency is high (up to 55%), and the level of pollutant emissions is very low or null (except for kerosene stoves). However, emissions may be substantial in the case of improper use of fuel, for example the improper use of vegetable oils such as jatropha oil. There are also hybrid stoves fuelled by more than one fuel, for example kerosene and vegetable oil, or paraffin and ethanol gel [2].

Some of such stoves can represent a valid option in humanitarian settings, due to their characteristic, in order to reduce the environmental impact due to the consumption of firewood, especially when the fuel could be produced locally, for example, vegetable oils, alcohols and biogas, or when LPG is locally available. In Ethiopia, ethanol stoves have been successfully disseminated by “Gaia Association” in place of kerosene stoves in refugee camps [88]. Rogers [15] states that Gaia has distributed almost 4,000 ethanol stoves throughout refugee camps in the surroundings of Addis Abeba. The use of the ethanol stove *CleanCook* in Kebribeyah Refugee Camps in Ethiopia is also documented in [89][90] [91]. The UNHCR and the Forest National Corporation (FNC) introduced LPG stoves in Sudan refugee camps [92], while Practical Action facilitated the development of a local LPG market in North Darfur, in peri-urban and rural villages and IDP camps [39]. LPG stoves where also used by IDPs in West Darfur [93]. GIZ [94] carried out a pilot project in the Kakuma Refugee Camp in Kenya about ethanol stoves. As per electric stoves, their utilization for baking injera is reported by Bizzarri in Mai Aini refugees camp in Ethiopia [95].

2.3.3 Additional devices

The term *Additional devices* here refers to a category of devices that can be used as supplementary or additional cooking devices, typically at family level. The introduction of such technologies helps to decrease fuels usage, and consequently the related costs and emissions with respect to using only solid, liquid, gas or electric fuel stoves. On the other hand, the duration of cooking is generally increased respect to other devices. For these reasons, such devices can be useful where the cost of fuel is high, and/or the performance of the commonly adopted cookstoves is low [2]. There are two main typologies of additional suitable devices for humanitarian contexts: *hay boxes* and *solar cookers*.

Hayboxes (viz. haybaskets or fireless cookers) are highly insulated containers where a pot with food that has been partially cooked and pre-heated on a stove can be stored in order to continue cooking without the necessity of a further source of heat (Figure 2.23).

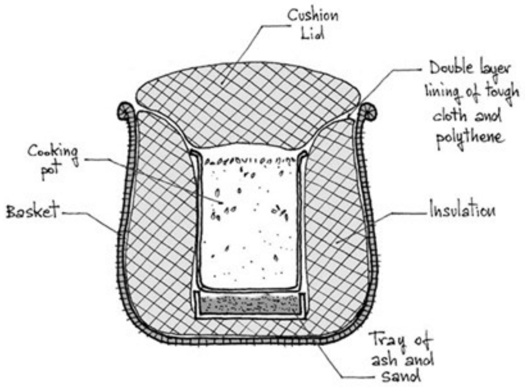

Figure 2.23 Scheme of a haybasket. *Source: [2].*

Hayboxes are most suitable for foods that require long-lasting cooking at low temperatures, such as rice or beans. For example, a pot of rice can be initially brought to the boiling point with a traditional stove and then placed in a haybox to complete the cooking task without burning any further fuel. Obviously, the duration of the cooking task is longer when using a haybox instead of a cookstove.

The Vajra Foundation Holland [96] has introduced hay boxes in the Bhutanese refugee camps in Nepal since 1995. After 2006, the Foundation distributed more than 12,000 hay boxes to families in the camps, and carried on extensive trainings on their use and maintenance. Other proofs of hay boxes utilizations in humanitarian settings come from the UNHCR [97], concerning refugee camps in Chad, Djibouti, Ethiopia, Kenya, Rwanda, Sudan, Togo and Uganda.

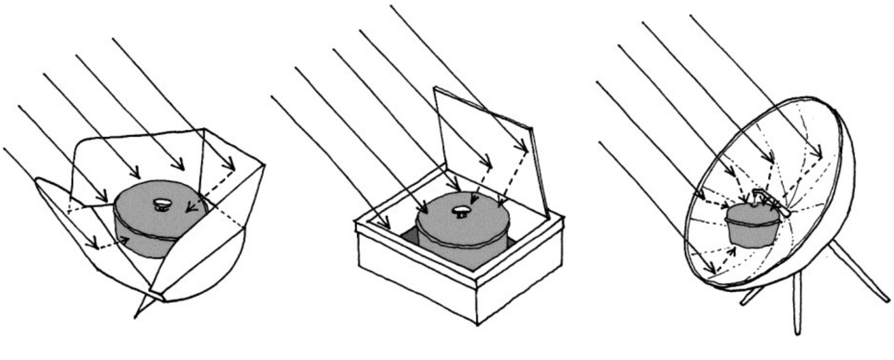

Figure 2.24 Types of solar cookers. *Source: [2].*

Solar cookers - Cooking with the sun is a feasible option, especially in tropical areas. A solar cooker concentrates solar radiation for heating, cooking or pasteurizing food or drinks. Different types of solar cookers exist, and they can be categorized according to three main categories: panel (a), box (b) and parabolic (c) cookers (Figure 2.24). Solar cookers should always be considered as additional devices, since their operation rely on weather conditions and they can only be used in daylight. Solar cookers can be an ideal solution for warm up pre-cooked foods without the need of a cookstove.

In 2005, 15,000 *CooKits* panel solar cookers were introduced in the Iridimi camp through a Solar Cooker Project carried on by TchadSolaire, Cord NGO, KoZon Foundation, Jewish World Watch, and Stichting Vluchteling [98], [99]. In 1995, Solar Cookers International started to disseminate solar panels in the Kakuma refugee camp in Kenya. The project reached over 15,000 families and it was one of the earliest to introduce solar cooking in refugee settings [100]. Thanks to a project run by Tchad Solaire and by the British NGO CORD, more than 50,000 people in four Darfur refugee camps are using locally made *CooKits*. *CooKit* stoves made of reflective cardboard were piloted also in the Aisha Refugee Camp in Ethiopia. It was found that almost 95% of households used the *CooKit* for some of their cooking activities, achieving up to 44% firewood savings and 78% charcoal savings [101].

Trans World Radio pioneered the introduction of homemade box cookers in the Kenyan Kakuma Refugee Camp in the early ‘90s [102], while Trust in Education started distributing solar panel and box cookers in refugee camps in Kabul (Afghanistan) later on [103].

The Vajra Foundation Holland has worked in Bhutanese refugee camps in Nepal since 1995 to bring parabolic solar devices, reaching more than 85,000 refugees [96]. The use of parabolic devices has been noticed also in Kakuma Refugee Camp in Kenya [100]. From the literature, it was found that also new and innovative models of solar cookers are emerging. For example, Regattieri et al. [104] developed a portable parabolic solar cooker that can be used in refugee settlements, by recycling the card board box used for the packaging of humanitarian supplies and aluminium kitchen sets.

2.4 Impact of current cooking practices in humanitarian settings

A systematic review and in-depth analysis of the available scientific and grey literature on the impact of cooking technologies on refugees and IDPs, and environment in humanitarian settings is presented here. The research is based on the analysis of peer-reviewed papers by Science Direct editorial platform and Scopus database, and reports within the grey-literature produced by international organizations and institutions within the Union of International Associations – IGO Search engine [105] and PubMed.

A set of keywords was used for the interrogation of the databases included the followings (and their combinations): *refugees*, *displaced people*, *humanitarian settings*, *cook, cooking, improved stove, food, fuel, traditional biomass, charcoal.* After obtaining a first collection of documents, further ones were searched following a concept-centric approach, starting from most relevant publications, and moving backword and forward, as suggested in [106].

The resulting collection of documents was further reviewed by applying the following rules:

i. context of the documents related to humanitarian settings;
ii. documents related to ICSs and biomass cooking technologies. Documents not providing detail on the technology and/or not mentioning impact on people, economics or environment were discarded.

More than 100 documents have been finally selected, published from 1995 to 2016. Whenever possible, triangulation between different sources was done on facts and figures distilled from grey literature.

Information have been organized according to four main areas of study and research: (i) *Environmental impact*; (ii) *Health*; (iii) *Safety*; (iv) *Education, livelihood, and social issues*. In turn, such categories have been defined based on the main issues and research themes arising from the analysis of the selected literature. Interestingly, the peculiar context of humanitarian settings drives a specific focus on health and safety in most of the selected documents, in addition to the traditional socio-economic and environmental dimensions of sustainability. Based on this finding, such differentiation was maintained in the analysis.

2.4.1 Environmental impact

The presence of refugees can constitute a shock to the ecological system of the host area due to the sudden increase in the population. Refugees or IDPs can cause severe additional environmental impact not only in the camps or settlements areas, but also in the surrounding. One of the most relevant issues is deforestation or forest degradation, which in turn worsen and concur to erosion, sedimentation, floods, decline in ground water availability, loss of wildlife, desertification, etc. For example, M. Bizzarri [107] reports a number of different impacts in Darfur: (i) depletion of soil due to the over cultivation and overgrazing in reachable areas, and (ii) eradication of traditional seasonal harvesting, livestock migration and disputes. In North Darfur, the problem is exacerbated by the no-longer-sustainable demand of environmental resources and the increased reliance on fuelwood [107].

Environmental damage often also threatens the livelihood of hosting communities, as well as wildlife and natural heritages. On the short-term, the use of timber and poles for construction plays a major role, while in the long-term the collection of firewood is the most impacting activity [19], [108].

At the global level, it is estimated that more than 64,000 acres of forest are burned each year by refugees and IDPs [39]. A selection of quantitative information about specific cases is given in Table 2.1, while qualitative evaluations are found in [15], [16], [22], [70], [78], [95], [107], [109].

Table 2.1 Documented deforestation and forest degradation due to firewood uses in humanitarian crises. *Source:* [78].

Place	**Number of refugees**	**Reference period**	**Reported impact**
Malawi	> 1 million	1985-1995	Consumption rate of firewood estimated in between 500,000 – 700,000 m3 per year. Evidence of extensive deforestation around the camps.
Zimbabwe		1985-1994	58% reduction in woodland cover around the camps.
Tanzania (North-Western)	524,000	1994-1996	Consumption rate of firewood estimated at 585,000 m3 per year in Ngara district (2.64 kg/person/day). Overall, 570 km2 of forest in Tanzania affected, of which 167 km2 severely deforested.
DRC (Virunga region)	≈ 730,000	1994-1996	Consumption rate of firewood estimated at 1,000 tons per day. 105 km2 of forestland impacted by deforestation, of which 35 km2 totally denuded.
Sudan (Darfur)	2 million	2003-2008	Consumption rate of firewood estimated at 1,500 tons per day (5 kg per household). Distance for firewood collection have increased from few km up to 15 km.

Overexploitation of woodlands forcing refugees to sell or barter some food in change of firewood was observed in Kenya (Kakuma and Dadaab camps) [110], and Malawi [111].

The demand for firewood or charcoal depends on cooking technologies as well as other factors such as the type of food, and climatic conditions [112]. The use of traditional stoves causes the consumption of big amounts of energy, while the choice of foods distributed by humanitarian organizations also influences the consumptions. For example, according to S. C. Babu and R. Hassan [111], pigeon peas that have been distributed to refugees in Malawi, require at least 50% more fuel for cooking than other foods.

Carbon dioxide emissions from refugees and displaced people at global level are a small amount in terms of share of total world's emissions, but, on the other hand, the estimated emission of 13 million tonnes of CO_2 per year appears to be disproportionately high in absolute terms [39]. In addition, traditional cooking devices emit huge quantities of black carbon, with unclear effects on global warming [113], [114].

Whit the aim of looking at possible mitigation actions, it is useful to report a list of social and technical considerations from a couple of key documents published by UNCHR [71], [108]:

1. The potential of energy-efficient cooking technologies should not be over-estimated;
2. Centralized and community cooking systems improve the efficiency of cooking operations and limit fuel consumptions;
3. Energy sources other than firewood or charcoal should be examined;
4. Right cooking techniques can save substantial amounts of energy;

5. Afforestation and environmental policies play a fundamental role.

Efficient cooking technologies; centralized and community cooking - As regards efficient cooking technologies, ICSs may have the potential to save energy and fuels, and to reduce as a consequence environmental impact on forests and green areas [39], [108], [115]. For example, T. Bodson and C. Kavira [116] report that in Goma (DRC), the utilization of the Jiko Nguvu Nyeusi stove saved up to 50% of charcoal and about 3,000 hectares of natural forest. Significant savings have been reported also in Darfur [64]. Centralized cooking can lead to even greater savings, up to 80% according to [71], but can bring negative social consequences at family level.

Fuel shift - Shift to a clean fuel is another possible mitigation action. In Kebribeyah and Shimelba camps, the CleanCook ethanol stove was possible thanks to the utilization of waste molasses to produce the fuel [15], [117]. The introduction of the new technology and fuel were responsible for firewood use reductions between 42% and 100%, depending on the area. According to M. Debebe, this can suggest savings of about 6,600 tons/year of CO_2 equivalent [118]. The opportunity of a shift to cleaner fuels is underlined also in many other cases, such as [19], [22], [93], [107]. Apart fuel shift, other approaches can also be suggested: (i) regulation of firewood collection, through organized wood supply; (ii) purchase of fuel from other areas [22].

Appropriate cooking techniques - Capacity building for a correct utilization of the devices, as well as complementary energy-saving practices, such as firewood drying, careful control of the fire and air supply, accurate simmering, pre-soaking of foods, and the use of lids [71], are fundamental in order to enforce results [22], [70]. For example, Ahmed [93] reports a case in Darfur, where displaced people received a ICS but did not use it regularly, since only few people received training on how to use and maintain it.

Afforestation and environmental policies - According to Bizzarri, environmental protection and recovery can be achieved by reducing soil degradation and deforestation, as well as by "investing in the regeneration of the forest base through interventions such as woodlots, community forests and tree-planting" ([107], p. 33). Other best practices are suggested in [110] [108], such as: (i) provision of tree seedlings for tree plantations; (ii) monitoring of firewood harvesting; (iii) conducting Environmental Impact Assessments (EIAs) and Environmental Audits (EA) in compliance with the local Government, while user-pay-based measures for regulating firewood utilization do not show to be effective [111].

2.4.2 Health

According to the latest Global Tracking Framework report of the International Energy Agency (IEA) and the World Bank [119], about 7 million people die every year due to outdoor and indoor air pollution. A large share of this picture occurs in low- and middle-income countries, and is related to the combustion of traditional fuels [29] [18], [120]. The case of refugees and displaced people is just a subset of the global picture. The Chatham House reports as a broad estimate that about 20,000 forcibly displaced people could die prematurely every year due to IAP caused by traditional cooking methods [39]. Few quantitative information is reported in the literature, but many studies report qualitative observations. For example, in Shimelba camp (Ethiopia), 74% of the interviewed cooks report a cough, 64% suffer from headaches, 50% experience eye irritation, 31% suffer from shortness of breath, and 21% have constant phlegm [117].

Other studies in refugee camps show similar results ([121] [15].) A couple of papers results of an interesting analysis on the different impacts of IAP on different sub-groups of refugees in Bangladesh, due to different characteristics of households and habits, including place of cooking, households structures, ventilation (present or absent), cooking hours, etc. [122], [123]. Moreover, even when considering the same group of refugees, different cathegories of people are influenced in a different way: women and children are in general more exposed, since they often reside in poorly ventilated dwellings, and are in charge for food preparation [15], [124]. Efficiency improvements and fuel shift can bring significant reduction of dangerous emissions. D. Pennise et al. [89] collected field data from the *CleanCook* ethanol stove and the *Gyapa* wood-burning improved stove, finding significant improvements in both cases, with a reduction of average 24-hour PM2.5 concentrations in between 52% and 84%, and of average 24-hour CO concentrations in between 40% and 76%. Such results are in line with findings from qualitative evaluations carried out in [91] and [125]. The introduction of solar cookers in Iridimi camp (Chad), gave similar findings [98]. In addition to the benefits from reduced emissions, A. Thulstrup and W J. Henry [115] also underline nutritional and health benefits due to the fact that the new, more efficient devices, reduced the risk of undercooking food due to a lack of sufficient firewood.

2.4.3 Safety

Protection - Protection-related issues, such as sexual violence, and attacks from armed people, are among the most frequent problems associated to the collection of combustible biomass. Sexual harassment and GBV, in particular rape, stay in the spotlight. According to the literature, harassment or GBV occur with particular frequency in the African context, such as in Ethiopia [15], [95], [118], [126], Uganda [113], Kenya [127], [128], Sudan [98], [107], South Sudan [129], Namibia [22], Chad [22], [129], Tanzania [129]. However, risk of sexual harassment and rape is also mentioned out of the African context, such as in Nepal [22], and other countries [78], [130]. In addition, the risk of being intimidated or attacked by militia, rebels, or even local population which is worried from the idea to share their scarce wood resources with thousands of refugees is reported in [98], [127], [131]. However, in 2005, S. Ziebell [128] identified a number of gaps in the literature regarding the link between fuel provision and GBV: (i) literature mainly focuses on environmental impact and not on security; (ii) the causes of GBV in humanitarian context are poorly understood; (iii) direct fuel provision is unsustainable; and (iv) there has been lack of coordination in the provision of fuel alternatives. In many cases ICSs and/or modern-fuels stoves have been provided to refugees to decrease violence episodes and sexual assaults by reducing the dependency on biomass. The idea is that reducing the need to leave camps directly improves the security of refugees. However, in most cases, only qualitative and general data are available regarding the fulfilment of this objective (see, for example, [90], [98], [126], [128]), and the efficacy of this kind of interventions is debated. According to S. Abdelnour and A.M. Saeed, the effectiveness of efficient stoves in incrementing safety remain questionable [132][133]. Apart from violence, fuel collection practices expose refugees to the danger of gas holes, insects, wild animals, and landmines and unexploded ordnances [109], [131], as well as to dehydration, back injuries, scrapes, broken limbs, and exhaustion due to the arduous work [15], [90], [118], [126], [130]. Regarding these issues, the effectiveness of ICSs, and/or of fuel shift, seems more evident [126].

Risk of injuries and accidents - Three-stone fires and traditional cooking stoves, as well as kerosene lamps, are frequent cause of injuries and accidental fires [134]. For example, G. Lahn and O. Grafham report the following testimony of an UNHCR camp official in South Sudan: “House fires, kids’ burns and hospitalization of individuals with severe burns are common, especially during the dry season when the country is dry and there are strong winds” ([39], p. 12). They also describe the case of three huge fires in Thai refugee camps in 2013, which led to a number of deaths. Similar risks are reported in [98], [78] and [83]. Despite the high frequency of accidents, only few leading humanitarian agencies provide recommendations, in particular regarding fire strategies, while the following could be introduced: (i) utilization of safer stoves and fire retardant materials; (ii) promotion of energy-efficient cooking practices; (iii) utilization of centralized cooking facilities; (iv) safe design of chimneys [83] [78]. Solar cookers or ethanol stoves, proved to introduce significant improvements as regards the previously mentioned hazards [117] [98]). However, B. F. Nielsen also warns regarding risks related to the introduction of new technologies, referring to cases where refugees were injured from explosions while cooking with gas [135].

2.4.4 Education, livelihood, and social issues

Many cooking stoves projects have failed due to cultural and social issues. G. Lahn and O. Grafham [39] report interesting examples, such as: (i) the case of biogas for cooking in Somalia, which introduction failed because beneficiaries were not feeling comfortable using products related to human waste; (ii) the case of solar parabolic cookers in Nepal, that sometimes led to problems, with families which were not provided with the technologies asking to share food even if uninvited; (iii) the case of fuel briquettes from waste biomass, that are often rejected due to an unusual smell and to a different taste of the food.

On the other hand, programmes on efficient and modern cooking stoves can bring improvements regarding many aspects of education and livelihood. Traditional devices require huge quantities of firewood. Being children and women mainly in charge for firewood collection, this duty takes time away from their education [136]. An increase in the time available for education is confirmed as one of the most important social progress associated with cooking stoves projects [15], [91], [125]. The provision of efficient devices to schools can also ensure that the cost of fuel is not an obstacle to school attendance, and can help in spreading the knowledge about the advantages related to efficient technologies [110].

As per livelihood and related issues, the main advantages can be classified into the following main categories [64]: (i) cash savings; (ii) time savings; (iii) income generation from stoves production and sale. Findings are reported in different reports as regards all categories, and in particular categories (i) and (ii), such as in [15], [90], [98], [117], [125]. Referring to category (ii), in Sudan, Ethiopia and Chad, interviewed women stated that they had more time for activities such as farming, laundering and bathing of their children, and for social activities [15], [98], [125].

2.5 Piloting innovative context-based solutions

The analysis reported in the previous paragraphs of this chapter allowed understanding in depth the linkages between energy, water and food in humanitarian settings. It was shown that cooking is the only area related to food utilization that has been actively and systematically addressed by the humanitarian system so far. However, the in-depth review of the literature revealed that the effectiveness of interventions on cooking in humanitarian settings is not always supported by the evidence of positive results. This is probably due to a mix of factors, including: (i) very challenging context of action; (ii) shortage of funds and energy resources; (iii) inertia of the humanitarian system against new supply schemes, and lack of a room for innovation and experimentation. Moreover, it was also shown that other areas of intervention have not been explored so far, even if the potential benefits may have high relevance.

While the first identified factor is an endogenous characteristic of humanitarian settings, and the second one mainly depends upon causes only partially controllable by the humanitarian system, opening a room for innovation may represent a viable starting point to enhance the efficiency and effectiveness of the humanitarian response on energy.

Referring to the definition of innovation given by J. E. Aubert [137], "in a global perspective three forms of innovation can be distinguished. The first one relates to local improvements based on the adoption of technologies which are more or less available worldwide or locally ("technology adoption" from a global perspective). The second type of innovation materializes in the building up of competitive activities with some adaptation made to existing technologies ("technology adaptation"). The third type of innovation is the design and production of technologies of a worldwide significance ("technology creation" from a global perspective)".

Based on such definition, different pilots were put in place in the framework of the SET4food project to test innovative approaches aimed at promoting more effective and context-based energy solutions for food security.

More in details, the SET4food action tried to implement the largest possible set of different approaches instead of concentrating all efforts on a smaller set, with the aim of paving the way to further experimentations by stimulating other actors to follow a similar approach or to scale up similar ideas.

The experimented approaches included:

- Adoption of existing technologies, based on the comparison of different solutions responding to the same need in a specific context, in order to determine the best one in terms of cost-benefits ratio and acceptance rate;
- Adaptation of existing technology concepts to new uses or to different energy sources, in order to improve the functionality or the efficiency of solutions already in use in other contexts with a limited amount of additional resources;
- Adaptation of modular and flexible solutions that can be moved or re-adapted to different conditions in case of people relocation, other than common very basic appliances such as solar lights, using a mix of existing technologies available in the local market;
- Creation of technology systems based on win-win matching of local capabilities and materials with the proven reliability of industrial products from developed markets.

Each approach was applied in a different pilot, based on the local context, people's needs, and locally available resources. To avoid the involvement of third-party organizations, the locations for the pilots were identified by selecting among the countries where COOPI – Cooperazione Internazionale was already operating with one or more active projects. On the other hand, the leading criterion was that of selecting the most different contexts, in order to better identify which parameters are most influenced by the local socio-economic and environmental situation. As a consequence, three different world areas were touched, namely Middle East, Sub-Saharan Africa, and Latin America.

In particular, the first assessment of the context itself of each target location provided information that brought to the formulation of the main idea at the basis of each approach. In the next paragraphs, four pilots are described, and some considerations are discussed, based on the achieved results.

2.5.1 Technology adoption: context-based selection of ICSs stoves in CAR

Central African Republic is one of the poorest countries in the world. The situation has increasingly worsened during the last years, starting from December 2013, when violence spread across the country and armed groups started to control different areas. Hundreds of thousands of people were forced to leave the country, or to move internally. Today, more than half million people are hosted in neighbor countries, and about 700,000 people are internally displaced [138], living with less than 2 USD per day. On the other side, CAR has been hosting refugees from other countries, including Sudan and Congo, for many years. During the SET4food action, a pilot was developed in CAR in a refugee camp mainly hosting Congolese refugees. In this camp, the assessment on energy-food needs revealed that all refugees depend on firewood for cooking, since it is the only affordable fuel in the area. In some cases, firewood is purchased in the local market (0.2 USD/pile), while in other cases firewood is directly collected by refugees. Three-stone fires or traditional stoves are the only solutions in place.

Figure 2.25 Improved Cooking Stoves in CAR. *Credits: SET4food/COOPI.*

Based on such findings, the introduction of improved cooking devices was the only feasible solution to improve the conditions. Two different models of Improved Cooking Stoves (ICS) were distributed and tested: a commercial model imported from Kenya (EcoZoom Dura) was distributed to 70 families, and a locally-made ICS (Centrafricain improved stove) to other 25 families[4] (Figure 2.25).

The choice of testing the two different models was dual: on the one hand, the comparison between a locally-made and a commercial solution in the field under the same conditions, in order to investigate if the expected differences in terms of performances (reported in Table 2.2) would have been confirmed. On the other hand, to

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[4] Reported results are based on a sample of 25 and 15 families respectively for the case of the commercial and locally-made stove, due to the impossibility (logistic and security constraints) to collect data from a larger number of beneficiaries.

understand the reactions of the beneficiaries to different designs and layouts of the same kind of technology.

Consistently with the case of the pot-skirts, both quantitative and qualitative data collection were planned in this pilot. Local staff of the project was appointed for regular weighting of the firewood used by the beneficiaries before and after the introduction of the stoves, in order to assess any fuel savings, and qualitative questionnaires were delivered to beneficiaries to capture the evidence of changed perception. In this case, the utilization of a mix of qualitative and quantitative methods allowed for a better comparison between the two different solutions.

Table 2.2 Performances from laboratory testing of selected stoves. *Source:* [139], [140].

	EcoZoom Dura	**Centrafricain improved stove**
Average fuel savings compared to 3stone fire	43%	35%
Efficiency	27%	20%
Price	100 USD	≈ 10 USD

Table 2.3 Performance of selected change perception indicators for ICSs. *Author's elaboration of SET4food data.*

Category	**Indicator**	**Description**	**% of positive answers - EcoZoom**	**% of positive answers – Centr. IS**
Energy	Energy needs	Do you think that now you better meet your energy needs due to a better energy availability (including cooking and food preservation)?	100%	100%
	Opportunity from energy	Do you think that now you have new opportunities due to the new technologies introduced?	96%	100%
Food consumption	Cooking practice	Have you changed your cooking practices due to the introduction of new technologies?	96%	88%
	Cooking stability	Do you think that your cooking practices are more stable, now?	90%	89%
	Nutrition	Do you think that your feeding has been improved from a nutritional point of view since the introduction of new technologies?	94%	88%
	Satisfaction	Are you happier about the food you consume now?	94%	100%
Other aspects	IGA development	Have you developed new IGAs due to the introduction of new technologies?	14%	50%
	Economical aspects	Do you think that your family expenditures decreased or are more efficient due to the new technologies?	100%	100%
	Change simplicity	Was the introduction of new technologies simple?	80%	67%

Cultural compatibility	Do you think that the new technologies are in compliance with your culture?	100%	100%

Table 2.3 shows the results of the surveys on change perception about the new technologies. 20-30% of the respondents did not agree on the fact that the shift to the new technology was perceived as simple at the beginning. However, both the ICS models were much appreciated by everyone, since they found the technology in compliance with their culture, and immediately noticed a strong reduction in fuel consumption, as well as in time for wood collection or money spent for fuel purchase. All beneficiaries agreed on the fact that both the stoves are "really better than their traditional 3 stones system", and that the duration of the overall cooking tasks was reduced (which is the main reason why almost all the respondents declared that they had changed their cooking practices). Fuel reduction was confirmed by quantitative data collection (Table 2.4), which revealed a change of more than 50% in firewood consumption for both the commercial and the locally-made stove, and a significant reduction of the time dedicated to fuel collection. For the case of the commercial ICS, a reduction of fuel expenditures of 41%[5] was also noticed, while it was not possible to get any statistically significant conclusions for the case of the locally-made ICS. However, 100% of the respondents to the qualitative surveys declared they noticed a decrease in the energy expenditure. The substantial reduction of fuel consumption also introduced the general perception that cooking practices were made more stable (according to 89-90% of respondents).

On average, ICS were used more than twice a day by each household, which confirms a shift from three-stone fire. Such results stimulated local entrepreneurship. 50% of the beneficiaries that received the local ICSs declared they had developed new income generating activities after the introduction of the stove. In particular, some beneficiaries started a local business for the construction of ICSs.

Table 2.4 Savings due to ICS distribution in CAR. *Author's elaboration of SET4food data.*

	EcoZoom Dura	**Centrafricain improved stove**
Wood consumption	-63%*** (16%)	-61%*** (20%)
Time to collect wood	-54%*** (35%)	-64%*** (33%)
Fuel expenditure	-41%** (59%)	Not significant

*Standard deviation in brackets. **, and *** indicate significance at the 95% and 99%, respectively.*

It is interesting to notice that the beneficiaries considered the locally-made model more robust, even if on the long-term the commercial model showed better performances in terms of durability. This fact shows how people experience can influence their perception and acceptance of a given technology. It is also interesting to underline that both ICSs performed in a similar way in the field, even if the commercial model was supposed to be more efficient, based on laboratory tests. Moreover, in both cases fuel savings in the specific context of utilization were found higher than those expected from lab results. This fact gives evidence that users' behavior and practices, and local

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[5] In some cases, fuel was purchased from other refugees, while in others it was directly collected by final users. This fact explains the decoupling between data on fuel consumption and expenditures.

environment conditions, strongly influence the real performances of stoves in the field, thus results from laboratory tests should not be used as the only and most important parameter to select the best ICS model [141].

In conclusion, the locally-made ICS showed to be more appropriate to the specific context by combining the following characteristics: (i) similar performances to the commercial model in terms of reduction of fuel consumption; (ii) significantly lower price, potentially affordable for the refugees without incentives; (iii) possibility to build the stoves locally and to drive new business development.

In more general terms, the pilot confirmed that the choice of the most appropriate solution is often not obvious, and techno-economic parameters are not sufficient to drive the selection. This is especially relevant in the case of technologies related to issues strongly influenced by social behavior, such as food preparation. Therefore, the approach here described may be successfully applied also in other contexts and regarding other technology systems, in order to identify the most appropriate system during a pilot phase before scaling up the intervention to the whole population of beneficiaries.

2.5.2 Technology adaptation: pot-skirts for gas burners in Lebanon

Lebanon is hosting about 1 million Syrian refugees. Less than 30% of them have a job in the country, so that in average only one member per family is responsible for supporting the whole finances of the family. Most of them are not formally employed, and work irregularly. According to UNHCR data, the average income of a family is less than 200 USD, compared with an expenditure for food and rent around 500 USD/month. The disparity between the average income and expenditure forces the families to get into debt (940 USD per family in average in 2016) [138]

Even worst figures were found for the case of the beneficiaries of SET4food pilots in the country during the assessment phase, where refugees were interviewed using structured questionnaires (template questionnaire available in Annex B), and direct observation was carried out in the field. On average, a family of six declared to spend 400-480 USD/month for food and 150-200 USD/month for house rent. The expense for fuel for cooking (bottled gas) was declared around 30-40 USD/month, which represents 6-8% of the total expenditure, and more than 15% of the average monthly income.

In the community where the SET4food pilot here presented was put in place, the assessment also revealed that in most cases, women were cooking outdoor using basic movable gas burners (Figure 2.26).

Figure 2.26 Movable gas burners used for cooking in the target settlement. *Credits: the Author*.

Figure 2.27 The SET4food pot-skirt. *Credits: the Author*.

Figure 2.28 Utilization of the SET4food pot-skirt in a household in Lebanon. *Credits: the Author*.

The windy conditions typical of the area had a bad influence on the efficiency of the systems, and prevented optimal combustion.

Based on such observations, the experimentation of simple pot-skirts was proposed as a possible innovative solution to improve the cooking systems already in place. Therefore, the objective of this pilot was to show that in some cases, already-existing technologies can be adapted to systems already in place to improve their performances and reduce operative costs.

A pot-skirt is a simple round piece of sheet metal, which is placed at the top of the combustion chamber where the flames are in contact with the bottom of the pot. It encloses the pot and forces the flame and hot gases to its sides [2], [142]. Pot-skirts are widely proposed as add-ons to improve the performances of biomass ICSs in the Global South, but their utilization is not common with gas burners. However, when applied to gas burners, pot-skirts may reduce the heat losses, increasing the overall performances of the stoves and decreasing fuel consumption. Moreover, they can protect the flame from wind, and reduce the risk of burns and scalds. The proposed model was specifically designed by the SET4food team for the gas burners used in the settlement (technical drawings in Annex C), and was produced in Lebanon by a local artisan. An external thermal shielding was also added to further improve the overall safety of the cooking system (Figure 2.27 and Figure 2.28). The post-skirts were distributed to the 13 families in the target settlement, living in small rooms in a building made of hollow blocks.

To assess the effects of the pot-skirts, both quantitative and qualitative data collection were planned: on the one hand, local staff of the project was appointed for regular weighting of the gas bottles used by the beneficiaries before and after the introduction of the pot-skirts, in order to assess any fuel savings. On the other hand, qualitative questionnaires were also delivered to the beneficiaries.

Table 2.5 Performance of selected change perception indicators for pot-skirts. *Author's elaboration of SET4food data.*

Category	**Indicator**	**Description**	**% of positive answers**
Energy	Energy needs	Do you think that now you better meet your energy needs due to a better energy availability?	100%
Food consumption	Cooking practice	Have you changed your cooking practices due to the introduction of new technologies?	0%
	Cooking stability	Do you think that your cooking practices are more stable, now?	20%
	Satisfaction	Are you happier about the food you consume now?	100%
Other aspects	Economical aspects	Do you think that your family expenditures decreased or are more efficient due to the new technologies?	100%
	Change simplicity	Was the introduction of new technologies simple?	100%
	Cultural compatibility	Do you think that the new technologies are in compliance with your culture?	100%

Unfortunately, the collection of quantitative data about fuel savings was prevented by the adverse conditions in the settlement: local Lebanese authorities in fact denied the permission of accessing the refugees' community on a regular and short-term schedule. which made it impossible to obtain reliable data. However, on qualitative terms, beneficiaries expressed a high appreciation of the technology. All respondents to selected indicators[6] about change perception (Table 2.5) declared they could better meet their energy needs for cooking, and the technology was found very simple to use. Also, they agreed on the fact that there was no need to change anything respect their cooking practices to adapt to the new technology Also, a perceived saving in terms of fuel was

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[6] The overall set of change perception indicators and further questions used in the SET4food pilots is available in Annex D.

reported by everyone. In particular, they added that gas cylinders could last longer, and that cooking outside was made easier thanks to the sheltering action of the pot-skirts against wind.

On average, it was found that each family used the pot-skirts 5-6 times per week, over a period of 7 months, without observing any particular problems in terms of usability or deterioration of the materials. Thus, despite the fact that it was not possible to quantify the reduction of fuel consumption, the pilot showed a promising potential of this simple technology in critical contexts, not only when biomass is used in combination with ICSs, but also when bottled gas is the main fuel.

The pilot showed how the adaptation of a simple existing technology concept (pot-skirt for ICS stove) to a different use or energy system (bottled gas stove) may represent a viable innovation bringing several benefits with a very low expenditure (few dollars per pot-skirt). Of course, it is worth noting that the same idea of providing gas stoves with pot-skirts may be effectively put in place in other similar contexts, such as other refugees or IDPs settlements in Northern Africa or in the Middle East.

2.5.3 Technology adaptation: semi-movable systems for lighting and food preservation in Lebanon

This pilot was developed in the same settlement previously described for the case of pot-skirts. Lack of food preservation systems and unreliable electricity supply were found as further challenges other than those related to cooking. During the assessment, the refugees declared their diet was mostly based on dry food, such as lentils, bulgur and rice, and Arabic bread. Some vegetables were purchased on daily basis due to the lack of food preservation capacity, and meat was consumed rarely due to both lack of preservation capacity and economic reasons. Electricity was mainly used for charging phones and for lighting, but due to the unreliability of the grid and rationing, it was available for few hours every day.

Based on such figures, a system was proposed, combining different components, i.e. small solar photovoltaic units and thermoelectric refrigerators, with the aim of assessing the effectiveness of flexible solutions for basic needs. In particular, the proposed solution was supposed to provide different advantages:

- Reliability of power supply for basic needs (lighting and phone charging);
- Possibility to preserve food using a simple refrigeration system;
- Possibility to disassemble the system in very short time, and to reassemble it in another place (refugees in Lebanon frequently move from one location to another);
- Overall solution potentially affordable for refugees in Lebanon in case of scale up[7].

More in details, the solution consists in a simple photovoltaic DC system (Figure 2.29) that can be easily dismantled and moved to another location, should the beneficiaries being resettled. The components of each unit are 2 photovoltaic panels (100 W_p each), a 100 Ah@12V battery, a charge controller and a fuse for system's and users' safety.

The system was provided to the 13 families living in the settlement, and was installed by a local company, only using components available in the Lebanese market. The system powers 4 LED lights (5 W each) for indoor and security lighting, and a small

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[7] The cost of each system for the pilot was around 800 USD, however there is a huge room for reducing the cost in case of scale up and standardization of the concept.

thermoelectric refrigerator (capacity: 24l; nominal power: 50 W; daily consumption less than 180 Wh; Figure 2.30).

Figure 2.29 Main components of the standalone PV system. *Credits: the Author*.

Figure 2.30 Thermoelectric refrigerator powered by the PV system. *Credits: the Author*.

The thermoelectric technology was chosen as a viable option since fridges are available small size, require low maintenance and have great durability due to the absence of moving parts and overall robustness of the system.

According to the beneficiaries, the new electric system was much more reliable compared to the main grid, characterized by frequent and long-lasting blackouts and cutoffs.

Given the scope and objective of the pilot, qualitative surveys only were defined as the assessment method, while measurements of quantitative technical data such as energy produced by the systems would have added very little, considering the simplicity of the systems, and the high cost-benefit ratio between collected data and cost of required sensors.

It was found that fridges were mainly used by the families to preserve different types of food, including: vegetables and fruits (16%), bread (30%), and food leftovers (12%).

Table 2.6 Performance of selected change perception indicators for semi-movable power systems. *Author's elaboration of SET4food data.*

Category	**Indicator**	**Description**	**% of positive answers**
Energy	Energy needs	Do you think that now you better meet your energy needs due to a better energy availability?	100%

	New energy consumption	Have you introduced any new use of energy (including electrical energy)?	40%
	Opportunity from energy	Do you think that now you have new opportunities due to the new technologies introduced?	100%
Food consumption	Nutrition	Do you think that your feeding has been improved from a nutritional point of view since the introduction of new technologies?	40%
	Diet variety	Has your household diet varied due to the introduction of new technologies?	0%
	Food purchased	Has your grocery shopping changed due to the introduction of new technologies?	0%
	Food safety	Do you think that food preservation has been improved due to the introduction of new technologies?	100%
	Satisfaction	Are you happier about the food you consume now?	100%
Other aspects	Shopping frequency	Have you reduced your shopping frequency due to the introduction of new technologies?	0%
	Security due to lighting	Do you feel safer due the improved means of lighting?	100%
	Economical aspects	Do you think that your family expenditures decreased or are more efficient due to the new technologies?	100%
	Health	Do you think that your family health improved due to the new technologies?	100%
	Change simplicity	Was the introduction of new technologies simple?	100%
	Cultural compatibility	Do you think that the new technologies are in compliance with your culture?	100%

Qualitative surveys on change perception (Table 2.6) revealed that the beneficiaries perceived an improvement in the access to energy and the means of food preservation. As regards the latter, they also reported that preserved food was considered safer and healthier, and that a positive effect on health was determined. Family expenditure was reported to be reduced thanks to the both the power and refrigeration systems. In some cases, it was also reported the feeling of an improvement of nutritional aspects. However, surveys also revealed that the potential of the refrigeration technology was not fully exploited by the users, and that refrigerators were less used than initially expected, due to a limited availability of food to be preserved, and the unfamiliarity of people with this kind of refrigerators. In particular, this was confirmed by a negligible effect on the frequency of shopping and on the diversification of purchased goods, as well as by the fact that, except for one case, the permanence of any foods in the refrigerator was very short (1.3 days on average, over a monitoring period of 7 months). Therefore, the monitoring of the pilot allowed the following main considerations: (i) on the one hand, it is confirmed that systems based on a similar concept may offer multiple advantages compared to traditional solutions, and their concept is easy to scale up; (ii) on the other hand, the pilot confirms the need for capacity building of the beneficiaries in case of new practices, such as food preservation through innovative systems.

2.5.4 Technology creation: SPARK refrigerators in Haiti as a match of local products and industrial technologies

The earthquake in 2010 destroyed more than 300,000 buildings in Haiti, forcing more than 1.5 million people to live in displacement conditions. According to the International Organization for Migration (IOM) data, about 100,000 people were still displaced in 2014 (40,000 in 2017). Shelter and food security have always been targeted as the two most relevant concerns for IDPs, followed by water and sanitation [143].

The assessment carried out in the framework of SET4food in the first months of 2015 showed that IDPs have a very limited access to energy, which affects several aspects of their life, including food security. When present, access to electricity was mainly obtained through illegal connections often causing fires, and charcoal and firewood were the only fuels used for cooking. Food preservation technologies were not used because they were not affordable for people, and electricity supply was not reliable. This fact was reported as a major cause of a reduced consumption of fruits and vegetables, with negative effects on nutrition.

In such context, the SET4food action aimed at piloting an innovative win-win solution matching the value of local competences and resources with the reliability of industrial technologies. The *Solar Photovoltaic Adaptable Refrigeration Kit* (SPARK) was designed by Politecnico di Milano to allow communities to locally assemble solar-powered refrigerators using locally available materials with a competitive price [144].

The electric and mechanical parts, i.e. a compressor (75 W DC), a roll-bond evaporator pre-charged with refrigerant, and plug-in connectors for the refrigerant circuit, are commercial components provided in a compact kit that can be shipped almost everywhere. The envelope and the compartments are locally constructed using different materials. The photovoltaic panels (one panel for each unit, 240 W_p) were purchased locally. Although SPARK is designed to be equipped with a thermal storage, in this first pilot application the system was modified to increase its reliability by adding a battery (100 Ah @ 12 V). On the other side, the envelope of the refrigerator was designed and assembled in the field by local artisans, using plywood for the body structure, and polystyrene foam as the insulating material [144].

The solution couples the advantage of using local materials and labor to that of adopting reliable mechanical components. Moreover, since the envelope is locally made, it can be designed according to the specific needs. For example, the refrigerator can be divided into lockable compartments, so that different users can be assigned with different compartments.

Figure 2.31 SPARK refrigerators in Haiti. *Credits: SET4food/COOPI.*

In order to test the solution, six refrigerators were assembled in the target settlement in Haiti, with a capacity of 500 liters and 4 lockable compartments each (Figure 2.31). Planned methods for the assessment of the results only included surveys, since the provided systems were very simple from the technology point of view, and energy-related data, such as daily power consumption of the system, were not particularly relevant to the main objective of the pilot.

Based on qualitative responses from beneficiaries, the refrigerators helped in the preservation of vegetables (mainly carrots, onions, potatoes, sweet potatoes, tomatoes, egg plants, cabbage, leek, sweet pepper), fruits (mainly papaya, oranges, shadek - a sort of local grapefruit), water and juices, thanks to their reliability compared to traditional refrigerators. The proposed system was also a leverage for small business activities. For example, one of the beneficiaries improved the trade of meat thanks to the better and cheaper means of preservation compared to buying ice every day.

Even if some problems arose during the construction of the first prototype, due to a limited expertise of the local manufacturers, the overall success of the experimentation shows that in some contexts, an approach combining commercial components locally assembled and integrated with local products may represent a further innovative option in contexts of displacement.

2.6 Concluding remarks

In this chapter, the energy-food nexus in humanitarian settings was explored, focusing in particular on cooking as the most important need linking food and energy in situations of displacement. It was shown how, despite several technologies exist, which can be considered appropriate depending on the specific context, there have been few examples of fully sustainable interventions until now. In fact, in most cases the excessive exploitation of local resources and the utilization of inefficient technologies and approaches, led to negative impacts not only on the environment, but also on people's health, safety, education and livelihood. Such findings prove the need for piloting innovative context-based solutions and approaches. Some cases developed in the framework of SET4food were presented as possible examples to pave the way on this perspective on the specific case of the energy-food nexus. However, the findings from the literature and the results of the pilots also underline that best achievements could be reached by adopting a comprehensive approach towards all energy uses, which would allow to consider the overall problem of energy access, opening the room towards a holistic response. In fact, it was found that interventions combining multiple actions are more likely to be effective. The same was found from the SET4food pilots, where different needs were addressed at the same time (e.g. electricity, lighting and refrigeration). For this reason, in the next chapter a novel framework for Comprehensive Energy Solutions Planning is proposed for the case of critical contexts, and further adapted in more practical terms to be applied in the case of humanitarian settings.

3 Expanding the horizon towards a holistic approach to energy

Food plays a central role in humanitarian interventions. However, in situations of displacement, and, more in general, in critical contexts, energy is interlinked to many other needs. Access to energy is not only fundamental to ensure appropriate means for food cooking, transformation and preservation, but also to improve safety during night hours, support education and health, power telecommunication systems. Moreover, energy plays a fundamental role in boosting income-generating activities. Such strong interlinkages suggest the opportunity of adopting more holistic approaches towards energy provision. Despite different methodologies have been proposed for appropriate energy planning in critical contexts, the literature lacks of a comprehensive framework covering all the planning phases of energy interventions. For this reason, in this chapter a novel framework for Comprehensive Energy Solutions Planning is presented. Firstly, the theoretical framework is defined looking at the general context of critical areas of the Global South. In a second step, more practical indications are added for the application of the framework in humanitarian settings. Lastly, the framework is applied to a case study in a refugees' settlement in Lebanon.

3.1 Energy planning in critical settings: state of the art and a novel framework

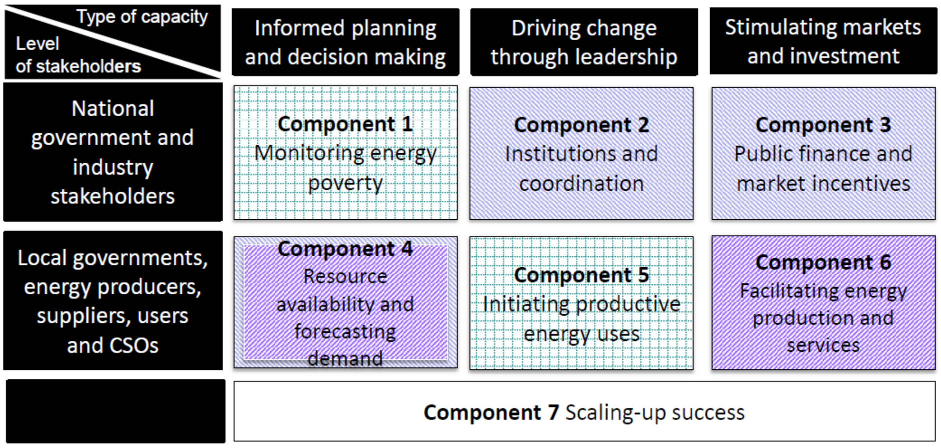
Comprehensive energy solutions planning is an essential element for strengthening the efforts towards energy access and sustainable energy systems, in order to extend or improve the energy services in a sustainable and efficient way. Based on their review of different definitions of energy planning, R. D. Prasad et al. [145] conclude that "a good energy plan is based on sound research on the national energy consumption and energy supply, energy prices, demand and supply technologies, population growth, environment and social impacts, success of an energy harnessing technology and influence of political situation", thus underlining the multi-faceted nature of the issue.

Looking at the case of developing countries, in most cases, energy planning traditionally comes with a strong techno-economic focus. However, according to Herington et al., rural energy planning often ignores socio-cultural and political issues, which affects the sustainability of technical interventions. In fact, they suggest that "strengthening the capacity of energy planners to examine and model complex socio-ecological, technological and political interactions of rural energy solutions that taken together may determine the longevity of energy interventions" [146]. This statement finds confirmation in the literature when looking at studies on the most frequent barriers and causes of failures of energy projects and programmes in developing countries. Alhborg and Hammar indicate that a lack of local participation in planning, and access to human capital, are barriers as relevant as technical matters to rural electrification [147], while Hossain et al. underline the importance of the involvement of local stakeholders and awareness programs from the beginning of any energy programmes [148]. J. Terrapon-Pfaff et al. [149] confirm as well that soft factors such as local provision of technical knowledge and skills, grade of users' satisfaction, and sense of ownership among the beneficiaries "influence the sustainability of energy projects over the entire lifespan of the technology". For this reason, they underline the importance of including such factors from the planning and conceptualization phase, which should search for information about the suitability of a given technology based on geographical, cultural and ecological considerations. Similar considerations arise from many other studies as well: the following are the main determinant factors which are in general referred as essential to ensure long-term sustainability of energy interventions, as regards system reliability and lifetime, as well as success in terms of acceptability and number of users [150]–[156]:

- Development of a continuous monitoring and technical support system, ideally guaranteed by a local entity provided with sufficient skills to face systems faults;
- Training programmes delivered to the users and other stakeholders involved in the utilization or operation of the systems;
- Development of a sense of ownership and of a high rate of acceptance of the technology by the users and community;
- Adoption of suitable and innovative financial and business schemes, such as social business schemes;
- Design of the systems reflecting users' needs;
- Consideration of local social and cultural factors from the beginning of the planning process;
- Local availability of spare parts and utilization of good in-house technical know-how;
- Detailed assessment and analysis of resources availability and continuous supply;
- Incorporation in the planning process of activities going beyond energy access, such as environmental protection, sustainable agriculture and capacity building;
- Development of a baseline study to understand the context and to allow the quantification of project outcomes after implementation.

From the analysed literature, it is evident that on the one hand, some of such determinant factors are frequently put in place during the planning of energy projects, but on the other hand, it is also evident that very few projects have been planned considering all the factors together. This fact is a consequence of the lack of a comprehensive energy planning framework addressing the peculiar characteristics of developing countries.

In fact, energy planning has been widely addressed from different perspective in the case of the developed world. In particular, according to [157], the importance of using integrated energy planning approaches in the sustainable development of cities and territories has been recognized by the scientific community as well as by institutions such as the European Commission. For example, the IEA developed the Advanced Local Energy Planning (ALEP) framework, which is based on tools and methods for the technical planning process of local complex energy systems [158], while other methods and tools have been reviewed in [145], [157], [159], [160].



Type of capacity Level of stakeholders	Informed planning and decision making	Driving change through leadership	Stimulating markets and investment
National government and industry stakeholders	**Component 1** Monitoring energy poverty	**Component 2** Institutions and coordination	**Component 3** Public finance and market incentives
Local governments, energy producers, suppliers, users and CSOs	**Component 4** Resource availability and forecasting demand	**Component 5** Initiating productive energy uses	**Component 6** Facilitating energy production and services
	Component 7 Scaling-up success		

Figure 3.1 Energy planning diagram according to EnergyPlus guidelines. *Author's elaboration based on* [161].

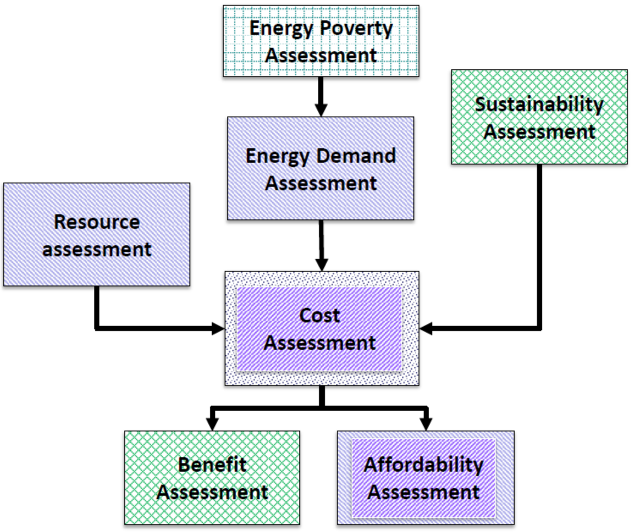


Figure 3.2 Energy planning diagram according to Shrestha and Acharya. *Author's elaboration based on* [162].

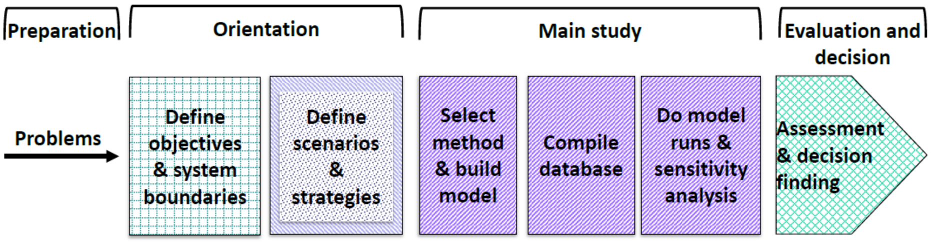


Figure 3.3 Energy planning diagram according to Steidle et al. *Author's elaboration based on* [158].

On the other hand, few studies proposing comprehensive frameworks for energy planning in developing countries, and in particular for the context of critical areas, are available in the literature. Such studies include: [161]–[165]. All these works contribute to the issue from different perspectives and levels. For example, Shrestha and Achaya base their analysis on different components, which allow collecting the information required for a Sustainable Energy Access Planning (SEAP). The report focuses on practical tools and methods for the assessment [162], but they do not stress the accent on the importance of defining a clear strategy, nor introduce the theme of business models, and systems management planning. The Energy plus guidelines [161], instead, define different components to be considered in an energy access programme, but report few technical details as regards the assessment and design of the energy systems. ASEAN Guideline has a similar approach, but in this case the document only deals with off-grid rural electrification [165].

Even if each of the cited works presents its peculiar perspective and structure, the analysis of the existing frameworks allows identifying some recurrent similarities in terms of phases of the planning process. In particular, Figure 3.1, Figure 3.2 and Figure 3.3 show the schemes proposed in [161] and [162], as well as the general framework initially proposed by IEA in [158]. Patterns and colours in the figures have been defined to highlight the identified similitudes between the phases of each scheme. For example, even if presenting non-negligible differences, the first core phase of the ALEP framework is *Define objectives & system boundaries*, which, in substantial terms, recalls the content of *Component 1* and *Component 5* in the EnergyPlus guidelines, as well as of the *Energy poverty assessment* phase described in [162]. It is also possible to identify similarities between the second core phase of ALEP (*Define scenarios and strategies*), *Component 2* and *3* of the EnergyPlus guidelines, and the *Energy demand assessment* and *Resource assessment* of the framework by Shrestha and Acharya. The same argument applies to the other phases.

The presence of strong similarities among the different frameworks, suggests that their integration and harmonization may lead to a more comprehensive structure. An effort towards such objective, based on the simplest and most effective integration of the different phases identified in the reference literature, brings to the definition of the novel Comprehensive Energy Solutions Planning (CESP) framework represented in Figure 3.4. It is possible to observe that on the one hand, the CESP integrates the core phases already present in the existing literature (which is highlighted in the graphical representation by using the same colours and patterns). On the other hand, the structure is made linear, by proposing a simple step-by-step process including five consequential phases, while all the relevant principles and concepts are included, which fills in the gaps identified in some of the cited works. In this sense, the CESP framework is a conceptual framework. i.e. a theoretical structure of all the relevant elements that holds together the ideas constituting the concept and providing understanding of energy planning in critical settings [166], [167].

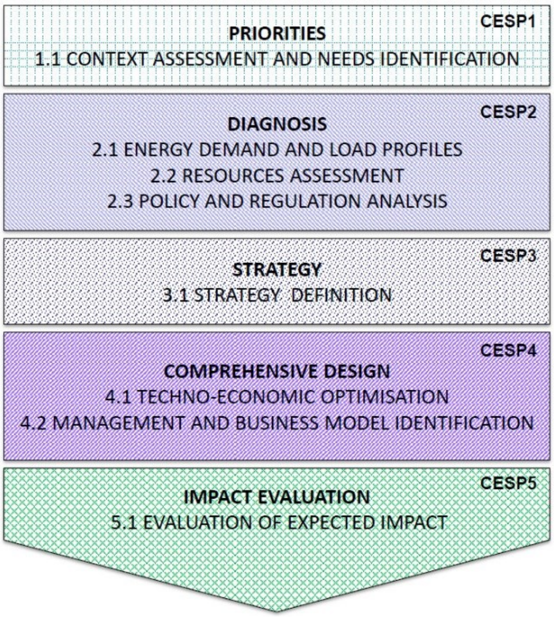


Figure 3.4 Comprehensive Energy Solutions Planning diagram. *Credits: the Author.*

The first phase of CESP is the context assessment and identification of the *Priorities* (CESP 1), which allows to understand the context and to identify the most important needs of the local population. Such needs are therefore defined as the priority elements to be addressed by the intervention. The *Diagnosis* phase (CESP 2) follows, where: (i) the main needs are correlated and/or translated into an energy demand and load profiles; (ii) The assessment of the available energy resources paves the way for demand-resources matching; (iii) Policy and regulation are explored in order to understand opportunities, threats and barriers which are determined by the surrounding political and regulatory framework. The Diagnosis phase therefore discloses the relationships between the needs, the energy demand, and the resources that can contribute (positively or negatively) to fulfil such demand.

During the *Strategy* phase (CESP 3), the intervention strategy is fully defined by determining its boundaries and the overall approach to energy provision, i.e. the overall plan of action of the project. The *Comprehensive design* phase follows (CESP 4). In this phase: (i) different configurations of selected technologies are designed and compared, in order to find an optimal solution, according to specific criteria; (ii) a suitable management and business model is identified. Therefore, the term comprehensive here indicates an extension of the design concept intended under an engineering perspective (techno-economic design and sizing of a system), to also include the concepts of economic and managerial sustainability. Finally, an evaluation of the expected impact is carried out in the *Impact evaluation* phase (CESP 5).

The main guiding principle of the CESP framework is that the design of the overall energy system should be defined to tailor the services needed to support local development respecting sustainability principles. An appropriate planning process ensures the provision of reliable and affordable energy allowing a sustainable utilization of local resources. Consequently, energy systems designed in a proper way, such as carefully looking at the local scale, provide key advantages in terms of improvement of the human living environment, creation of jobs, mitigation of mass migration to urban areas, decrease of the dependence on imported fuels, and environment preservation. Moreover, locally-driven design, maintenance and optimization contribute to support the local economy, thus empowering local communities, and ensuring long-term sustainability of the systems.

The aim of the proposed framework is therefore to support researchers, practitioners and policy makers with a clear identification of the different phases and actions that characterize the energy planning process from needs assessment to impact evaluation.

In the next paragraphs, the five phases of the CESP framework are described in details, extensively referring to relevant works available in the scientific and grey literature whenever appropriate.

3.1.1 Phase 1: Priorities

The first phase in the framework is a general context assessment, including in particular a focus on the needs expressed from direct beneficiaries or other key stakeholders, in order to define priorities for the intervention.

The analysis of needs can be carried out based on information collected with different methods, such as direct observation, surveys, consultation with relevant stakeholders, as well as meetings with local authorities and public bodies. Depending on the focus of the action and context, needs can be explored:

- at the household level;
- at the community level (community services);
- at the productive level (energy for agriculture, artisanal activities, and rural industries).

In the context of critical areas of developing countries, at the household level, energy is in general needed as an instrument for satisfying basic needs, such as lighting and cooking, as well as for operating small domestic appliances and for entertainment and information and communication (e.g., for charging mobile phones).

At the community level, most frequent needs include street lighting, water pumping, fuels and electricity for schools, health clinics and social centres. In fact, energy is a key factor for improving access to education, health, and other social services. For example, in rural schools after-dark study requires illumination. In health clinics, the lack of electricity and illumination, together with the daily drudgery, the physical burden of fuel collection and the poor transport means, all contribute to poor sanitary response. Increased availability and affordability of energy within a community, and a shift toward modern energy services, also trigger positive feedback on other social issues such as gender equality and women empowerment, and reduction of the digital divide [168], [169].

At the productive level, increased access to energy can improve the agriculture and rural industry sectors. An increased use of modern energy services can contribute to add value all along the food supply chain and to move away from subsistence agriculture [170]. In particular, direct usages of energy for land preparation, cultivation, irrigation, harvest and post-harvest processing, storage, and transportation, are essential for moving from human and animal labour-based agriculture to a more productive mechanization [171]. The development of artisanal activities and rural industries is another essential component of rural economic transformation, which requires heating, cooling and cooking processes, as well as the utilization of ICT and mechanical devices [172].

Table 3.1 Main approaches to energy poverty assessment. *Author's elaboration based on [12,13].*

Approach	**Description**	**Sources**
Minimum level of energy	Minimum amount of energy required to meet basic energy needs	[173]–[177]
Energy affordability	Level of energy consumption compared to income or expenditure poverty level	[178]–[180]
Energy demand	Household energy expenditure in relation to income and prices of different energy sources	[174], [181]
Energy or fuel poverty line	Average level and type of energy consumption of people characterized by an income matching the official poverty line	[179], [180]
Indexes	Multidimensional indexes measuring energy poverty based on different parameters such as education, health and other living standards	[169], [182]–[184]

The assessment of energy-related needs is enclosed in the concept of energy poverty, which mainly deals with the definition of a minimum level of energy services. The concept of energy poverty is largely adopted in the literature [179], [180], [185], [186]. However, there is no general consensus on its standard definition, mainly due to the fact that the minimum amount of energy necessary for the fulfilment of basic needs is location-specific because of the different environmental and climatic conditions in different places. As a result, based on the concept of energy poverty, different approaches have been proposed in order to link the assessment of needs with a corresponding minimum energy requirement and associated economic cost of provision. According to a review by Shrestha and Acharya, "the main point is related to the evaluation of the minimum amount of energy needed to meet direct energy needs" [162]. Based on their work, the different approaches can be grouped in five main categories (Table 3.1).

Depending on the approach, different kind and amounts of data are required. Therefore, there is no one single best practice, but, as stated in the Energyplus guideline, "the most suitable approach for measuring energy poverty or lack of energy access is likely to depend on resources available for data collection and the level of accuracy deemed necessary" [161]. Whatever the approach, the assessment activities also represent an opportunity for maximizing the involvement of local communities and final beneficiaries, which is crucial for a full success of the action, with the objective of increasing community awareness via promotional programs, meetings with leaders, and organization of focus groups [187].

3.1.2 Phase 2: Diagnosis

The *Diagnosis* phase allows to translate needs into energy demand and to assess potentialities and constraints in terms of local resources. Moreover, it also concerns the analysis of the policy and regulatory framework. Therefore, the activities carried out in this phase produce data necessary in the following phases, paving the way for the definition of a proper strategy and for the techno-economic design.

Baseline and forecast energy demand are evaluated or estimated as energy flows, based on the information collected during the *Priorities* phase, and are than translated into load profiles.

The analysis of energy flows is useful to depict how energy resources are actually used to meet various energy services, i.e. energy balance, and can be graphically represented using Sankey diagrams [188], which helps understanding the dynamics in case of complex systems. In this way, the interactions between primary energy sources, energy drivers and final energy users can be clearly identified, which helps in understanding the local energy supply chains already in place.

The characterization of load profiles is instead necessary to proceed with the sizing of power sources and storage systems, to analyse and optimize energy fluxes, and to define how to control the systems. Load profiles capture the variation in the energy load versus time. Therefore, they are not only based on the total amount of energy consumptions (defined based on the energy poverty assessment), but they refer to the amount of energy the targeted users require in given time steps. Load profiles vary along the year, due to seasonal factors such as ambient temperature variations and the time of sunrise and sunset. The estimation of load profiles in critical areas of the developing world is particularly challenging, since most of the times there is a complete lack of quantitative information about energy consumptions: in many cases, historical data are not available because of different reasons [189], [190]. For example, in the case of electricity: (i) the intervention could bring power to an area where electricity was not used before; (ii) diesel generators are used in the area, so that no data are available about peak power and energy consumption; (iii) users are adopting illegal connections. On the other side, looking at energy for heating and cooking, in most cases energy needs are satisfied by using traditional biomass which is directly collected by end users, or traded out of the official markets.

Different methods are found in the literature for the estimation and forecast of load profiles in less critical contexts, including top-down approaches (based on economics at a macro level) and bottom-up approaches (based on technological and local factors) [191]. However, at the very local level, demand projections are typically engineered as a function of a limited number of key parameters (such as population density, location, and target energy access levels), while at the country or regional level, a variety of methods are used to project total energy demand [164], [192]. To face this problem, for the case of electricity, Mandelli et al. have proposed a novel methodology for the estimation of load profiles in such cases, based on a stochastic bottom-up approach, which have been implemented in the the software LoadProGen [189]. The methodology has been recently further enhanced by Lombardi and Colombo, that propose the open-source bottom-up stochastic model (RAMP) specifically conceived for the generation of multi-energy loads for systems located in remote areas [193].

The assessment of resources is the second activity that is carried out in this phase. Resources assessment is complementary to the definition of load profiles and it aims at determining the availability of hydro, solar, wind, biomass, and any other useful resources. The resource assessment is necessary in order to establish the spatial distribution, and temporal availability patterns over different periods. Moreover, the assessment provides information as regards the cost of resources harnessing, in particular as regards biomass and hydro. Proximity to users, ease of access to the resources, and adequacy of the resources given the current and future demand for energy are further information obtained within this step [162]. A number of approaches and methods exist, depending on the resource, context, and cost-benefit ratio. A general classification includes:

- International GIS databases, such as PVGIS [194], IRENA global atlas [195]; National Aeronautics and Space Administration [196];
- National GIS databases;
- Data from local meteorological or airport stations;
- Direct data collection on the field.

In general terms, direct collection on the field is the best approach to obtain reliable and accurate data, however such methods can be both costly and time consuming. On the other hand, international and national GIS databases allow easy access to datasets, which however can have different levels of accuracy: on the one hand, solar radiation databases provide quite accurate information in every area of the word, while data as regards wind, hydro and biomass should be carefully verified. For further information on assessment methods for the specific case of rural areas in Developing Countries, and references to detailed description of assessment methodologies, refer to [162], [197].

In addition to understanding and forecasting energy demand, and assessing resources, the last activity included in this phase is the exploration of policies and of the regulatory framework. Governmental agencies and international organizations, development banks and funds, power utilities associations, NGOs and others, undertake actions addressing energy-related challenges. The fragmentation of the policies and action plans and the lack of harmonization represent one of the main barriers for planning energy interventions, also due to the fact that the different involved actors have priorities and roles that often differ or even overlap [18]. In fact, the lack of adequate policy, legal and regulatory frameworks results in the presence of high levels of uncertainties and risks, thereby limiting potential investment in the sector [198]. For this reason, a deep analysis of the policy and institutional framework is a fundamental phase in the planning process, which is suggested to be considered as a crosscutting phase, in the sense that all the actions occurring in the other phases should be carried out keeping in mind the barriers and opportunities defined by regulatory and policy framework. For example, feed-in tariffs can be a valid opportunity in order to make a small electrification project profitable, but not all the regulatory frameworks allow for power injection in the main grid. On the one hand, subsidies and incentives are creating opportunities for energy access projects. They include: (i) fund raising through increased tariffs, cross subsidies, or taxes; (ii) tax credits; (iii) secure power or fuel purchase agreements; (iv) grants or direct payments; (v) capacity building and dissemination; and (vi) support to supply chain development.

On the other side, there are elements that can act as barriers. For example, import taxes, which can be: (i) defined for given categories of goods, such as electronic products, also including inverters or other renewable energy related devices; (ii) higher taxation rates can be defined for heavily imported goods such as photovoltaic panels and batteries [161].

3.1.3 Phase 3: Strategy

Once that the previous phases have been completed, all the relevant data are available in order to proceed with the definition of a proper planning strategy.

The *Strategy* phase is pivotal to the comprehensive design of the energy systems, since it allows to identify the macro-areas of the intervention, and, as a consequence, the stakeholders that will play a key role in the design, implementation, and management of the systems. In terms of energy services, it is possible to identify three main cases: (i) thermal energy (mainly for cooking, heating and cooling); (ii) electrification; (iii) a combination of the previous (energization).

Focusing on thermal energy, different options to be analysed regard the macro-category of fuel (traditional biomass; modern gaseous, liquid or solid fuel; direct utilization of solar radiation; electricity) which can be used for meeting the different needs (cooking, heating, cooling).

Focusing on the case of electrification, a first distinction can be given between the top-down, on-grid approach, i.e. grid extension, the bottom-up, off-grid approach, i.e. the development of new systems not interconnected to the main grid, and a combination of both top-down and bottom-up. More in details, bottom-up electrification strategies are based on decentralized systems (stand-alone and micro-grid systems) or distributed (hybrid micro-grids) systems. Grid extension is recommendable only where costs are reasonable, while micro-grids in villages where the expenditure for the grid extension is too high, and stand-alone systems in scarcely populated areas with weak demand [199] [187].

The selection of the most suitable approach depends on a number of factors intrinsic to the context, being the most relevant ones (i) the density of population in the target area, and (ii) the distance occurring among the different settlements and the grid. As a matter of fact, these parameters deeply affect the infrastructural cost of electricity transmission. On-grid supply is the most adopted and cost-effective solution in densely population areas, such as urban areas or large settlements, whit enough demand potential to justify the high investment costs of transmission lines. According to the latest findings from the IEA, the maximum economic distance for extending the grid tends to reduce over time, as the costs of generation in off-grids systems such as mini-grids come down, and beyond a certain distance, the costs of grid extensions become prohibitive [9]. This case typically occurs in rural areas, and determines a switch from on-grid to off-grid electrification strategies. Within off-grid systems, the density of population is the main parameter for the choice between stand-alone and micro-grid systems, with higher density favouring the development of the latter. Hence, micro-grids are mostly suitable where grid extension is not economically attractive but where communities live in villages with houses in close proximity [187].

The selection of the most appropriate and effective strategy to be put in place typically depends also on a number of other variables, such as logistic constraints, social and cultural constraints, legislation and regulations, prioritization of different services to be supplied. Looking at the technical perspective, each option needs to be preliminary evaluated according to a neutral approach, fostering local manufacturing where feasible, in order to reduce procurement and maintenance costs, and promote local economy. Moreover, social and cultural preferences can influence the success of the intervention as well. The selection of the best strategy also relies on practical aspects such as ease of operation and maintenance, and delivery mechanism as equipment availability or access to spare parts and services. The design must reflect the capabilities of the service providers, to ensure quality, appropriate technical standards, and performance requirements [200].

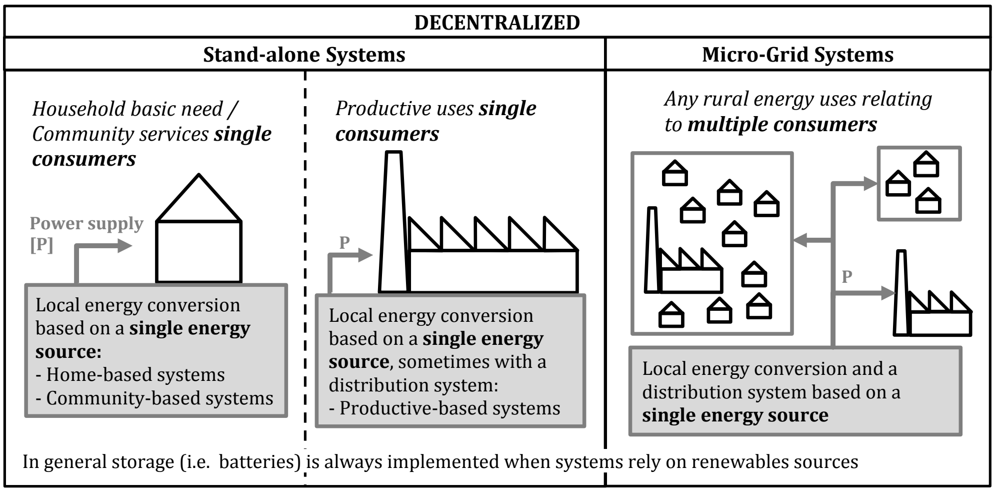


Figure 3.5 Graphical representation of decentralized power systems. *Source:* [199].

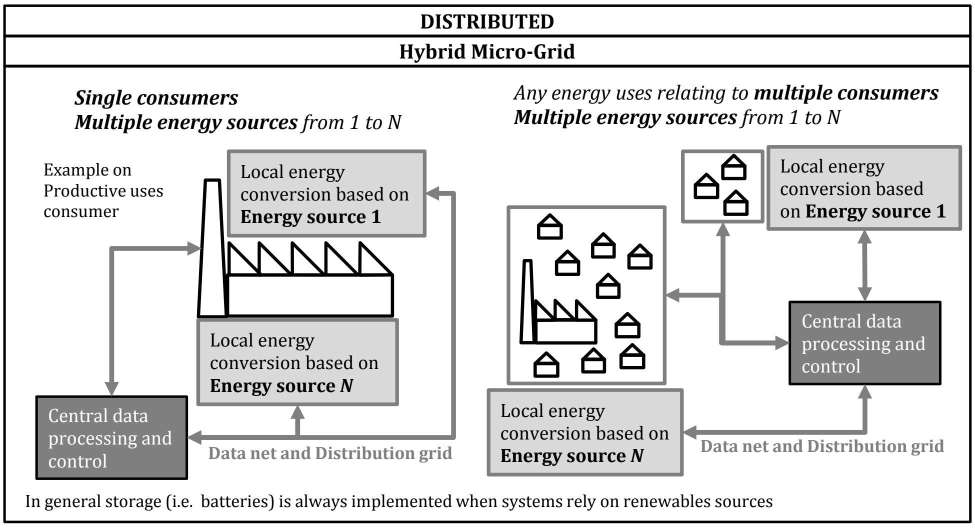


Figure 3.6 Graphical representation of distributed power systems. *Source:* [199].

On a second step, it is worth considering the possible interactions between different systems. Decentralized systems are constituted by autonomous units where production, conversion and distribution have no interaction with other units (Figure 3.5). On the other hand, distributed systems are made up by decentralized production and conversions units, which are interconnected to form a virtual power plant with a centralized control unit, which can be either self-standing, or connected to the main grid (Figure 3.6) [201].

For these reasons, the combination with already existing power systems should always be considered as a further possibility [165].

Given the multifaceted nature of the problem in complex cases, a better strategy definition can be obtained through a multi-criteria analysis, which allows to take into account main relevant aspects. In the literature, several methods (such as Weighted Sum Method [202], AHP [203], TOPSIS [204] and Outranking methods [205]) exist, which can be applied to the problem.

In general, the following suggestions apply independently from the chosen method:

- Evaluate different categories, including tangible and intangible aspects;
- Use different dimensions (economic, environmental, social, institutional);
- Identify key criteria, and appropriate indicators to measure such criteria.

For further information on the different methods, a couple of exhaustive reviews are [206]–[208].

It is worth noting that on the one hand this phase allows to define a single general strategy (for example: "energization through a shift to modern gaseous fuel and mini-grid for electric power generation"). On the other hand, the definition of further details (for example, the selection of the optimal technology mix for power generation) is demanded to the next phase.

3.1.4 Phase 4: Comprehensive design

This phase first regards systems design and optimization. This can be made not only in techno-economic terms, but also in terms of management and business models, which are fundamental to ensure the self-sustainability of the interventions on the long term.

For a detailed design of the systems, different configurations and technology mix may be considered.

As regards thermal energy, as previously stated, it mainly refers to cooking, heating and cooling purposes. The different technology categories for cooking can be grouped as: (i) traditional cooking technologies, (ii) Improved Cooking Stoves (ICSs), (iii) modern-fuel cooking stoves, and (iv) additional energy saving cooking devices [3]. On the other hand, for the case of heating, in most cases cooking stoves are also used at the household level for satisfying this additional need. However, also other stoves, as well as thermal solar panels, and electric or modern-fuel boilers are a viable solution, depending on the context. Lastly, cooling can be performed through electric devices (compression refrigerators), using thermal energy (sorption or thermoelectric refrigerators), or by using passive cooling methods [2], [177].

As regards the more complex case of power generation, three are the main categories: conventional (diesel), non-conventional (running exclusively on renewable energy resources), and hybrid (running with mixed sources) [209]–[211]. Conventional systems have been widely used to improve the access to electricity for rural communities and for emergency applications in the last decades. On the other hand, nowadays the relevance of non-conventional energy systems based on Renewable Energy Technologies (RETs) is rapidly rising. Hybrid systems combining fossil fuel and renewables power generation can bring considerable flexibility, high reliability, and continuity of supply, thus keeping the positive peculiarities of RETs use and the overall investment costs [212].

Systems design and optimization is a phase that typically requires an iterative approach. The complexity of the process of optimization depends on the technology and type of configuration. For the case of very small home-based applications, typically no specific design is required, since the system itself is purchased as a pre-assembled product. On the other side, more complex systems require proper optimization. Complexity increases with the size of the systems and with the number of different technologies and resources that are integrated. Optimization models differ according to the reference time step and period (for example, one year, or many years), as well as the analysis and simulation of loads and resources along the day and the year. Moreover, some models are designed for modelling of electric power systems, while others for thermal energy. As a third option, some models are able to consider both electric and thermal loads at once. Shrestha and Acharya present a general classification of the different models according to the following categories [162]:

- Cost assessment (techno-economic) modelling;
- Cost of Providing Electricity Access;
- Cost of Providing Cleaner Cooking and Heating;
- Calculation of Incremental Energy Access Cost;
- Calculation of Incremental Cost of Access to Clean Energy for Cooking.

Such models have been integrated in different tools that can be used in practice. Table 3.2 provides a list of the most common software (for further tools, also refer to [213]).

Table 3.2 Energy systems design and simulation software. *Author's elaboration based on* [163].

Name	**Description**	**Website**
Techno-economic design		
HOMER	Homer is a tool for the techno-economic design of stand-alone or interconnected energy power systems. It allows to determine the feasibility and optimization of renewable and non-renewable technological options.	www.homerenergy.com
RETSCREEEN	RETScreen is similar to HOMER, and allows to consider several options for both electricity and heat production.	www.retscreen .net
Electric network design		
NEPLAN Electricity	NEPLAN Electricity is a tool to analyse, plan, optimize and simulate electricity networks. The software allows the user to perform case studies adopting a modular concept which inludes transmission, distribution, generation and industrial networks and is optimized for the integration of renewable energy systems.	www.neplan.ch
POWERWORLD	PowerWorld is an interactive tool for the simulation of high voltage electric grids.	www.powerworld.com
Design on territorial scale		
LEAP	The Long-range Energy Alternatives Planning software allows to define long-term energy and environmental scenarios, including information on energy use, conversion, and production.	www.energycommunity .org
GEOSIM	GEOSIM (GEOgraphic SIMulation for rural electrification) is an integrated GIS tool for the definition and analysis of highly interactive rural electrification planning scenarios. It allows the optimization of energy services in the target area, with the aim of maximizing the economic and social impact of rural electrification.	http://www.geosim.fr

The identification of an appropriate management and business model comes together with the optimization of the proposed solution, in order to ensure the sustainability of the system itself, the investment, and the organization that is in charge of its management [214].

According to the Energyplus guidelines, three main approaches can be explored, depending on the context, the type of energy system, and the involved stakeholders [161]:

- *Private sector-led energy services*. In this case, systems are developed and managed by private producers and suppliers. Typically, the size of the companies varies from small to medium. The main advantage of this approach is given by well-established markets and delivery model, however smaller enterprises may lack of proven business models, in particular in remote areas, where users have a limited ability to pay and the level of uncertainty as regards energy consumptions reaches high levels.
- *Community-led energy services*. This approach directly involves local communities, in most cases in collaboration with local or national governmental bodies or NGOs. Community engagement can be a relatively simple option for integrating productive uses of energy, however, in most cases this approach relies on the investment and support of the other actors.
- Government-led energy services. In this case, governments group villages into clusters, large enough to ensure profitable business operations, taking into account the high transaction costs due to the remoteness of the areas. Clearly, such an approach can be heavily dependent on the government, even if the opportunity for public- private partnerships can arise.

It is worth noting that in the framework of energy access provision, for-profit organizations remain important actors. However, significant examples exist of collaborations between companies and local community associations, such as NGOs or social enterprises, including, for example, collaboration in the form of micro-franchising [215]. In other cases, business is directly managed by NGOs, community groups or local social enterprises [216], [217]. Such perspectives can be integrated through particular business models, such as the “base of the pyramid” (BoP) model (inclusive business model), which is based on the idea that the users themselves can actively participate in the management of the systems, together with other stakeholders such as public organizations, social entrepreneurs, and NGOs [218], [219].

3.1.5 Phase 5: Impact evaluation

Impact evaluation concerns the assessment of the impact of an intervention on target beneficiaries or costumers after its implementation. Ideally, the evaluation should detect all the “positive and negative long-term effects on identifiable population groups produced by a development intervention, directly or indirectly, intended or unintended” [220]. These effects can be economic, socio-cultural, institutional, environmental, technological. The importance of distinguish the impact assessment from more direct project results arises from the different methodological approaches that may be required. Impact should be detected in the long run and on a large scale, considering a number of relevant factors related to people and their development, which the project may affect. From this consideration, the need for a multidisciplinary and people-oriented approach emerges [221].

Recalling the objectives of CESP, i.e. to present a planning framework for energy access interventions in developing areas, the aim of this last phase of the planning process is here mostly limited to forecasting the expected impact that the intervention will have.

In the literature, many evaluation methods refer to the concept of sustainability assessment. Therefore, most of them refer to the three main dimensions of sustainability: environmental, economical, and social. In addition, also technical and institutional dimensions are often included to complete the framework. Shrestha and Acharya note that all the approaches to sustainability assessment involve estimation of composite indexes, such as the energy sustainability index [222], the general sustainability index [223], the total score [224] and the total utility score [225]. According to the authors, such indexes not only differ on the type of information they rely on, but also in the calculation and aggregation method [162]. On the other hand, other methods refer to the so-called Sustainable Livelihoods Approach (SLA), firstly formulated by the UK Institute for Development Studies (IDS) [226], [227]. The approach describes people as operating in a Vulnerability Context (the external environment, which is outside people's control), which directly affects Livelihoods Assets, not only including the community basic material assets, but also people capabilities to use them. Such assets are defined as five *capitals*: natural (water and land resources, ecosystem, etc.), physical (infrastructures, houses, roads), human (education, health), social (network and local organisations), and financial (wages, savings) [226]. A first decision support system to select appropriate sustainable energy solutions in remote areas has been developed based on this approach within the Renewable Energy for Sustainable Rural Development (RESURL) project [228]. Later on, the methodology has been integrated by Colombo et al. [229] into an impact evaluation methodology specifically addressing the case of energy access interventions in DCs. In particular, the framework fully adapts the evaluation at the concerning context and scenario, allowing evaluators to consider only relevant indicators to assess the impact on each capital. Moreover, it also allows for a quantification of the disparities that may arise between current and potential capitals after a specific energy solution has been introduced.

3.2 Practical indications to CESP in humanitarian settings

In the case of humanitarian settings, all the considerations about the lack of a comprehensive energy planning framework previously discussed, are exacerbated by the fact that energy supply for households, community and camp management in refugee camps or informal settlement has not been considered as part of the primary humanitarian protection mandate so far. Therefore, no clear guidelines have been provided, covering all the aspects of sustainable energy provision in humanitarian settings.

Current energy supply and planning schemes are very limited, and focus primarily on the electrification of humanitarian offices as well as of basic camp infrastructures, and are mainly based on the use of inefficient diesel generators, while energy-related needs of displaced people are often overlooked in the immediate response phase, while they may receive firewood and improved cookstoves to a limited extent when sufficient funds are available. However, if energy for cooking represents a key element in this context, in the previous chapters of this dissertation it was shown that there is a strong nexus between energy and other areas of humanitarian services, such as water, sanitation, health and education. A strong energy planning scheme is therefore needed in order to contribute to meet minimum standards in all such areas in a sustainable way.

Compared to development contexts, interventions in humanitarian settings mainly differ on time scales, which may vary from the very short term of acute emergency, to middle-term (few years), to protracted crisis situations (many years). If acute emergency situations require a very quick response that do not leave a big space to the implementation of complex planning schemes, middle-term and protracted crisis situations actually present many similarities with development contexts. In fact, according to Lahn & Grafham, many displaced people face challenges of poverty and energy access similar to those encountered by host populations [39] in developing areas.

Based on such considerations, it is possible to observe that the overall CESP framework can be easily adapted to humanitarian contexts, in particular after the initial acute emergency phase. However, there is a need for its integration with more practical indications in order to make the framework more useful and quickly available to practitioners in the field, especially as regards the phases 1-4. The next paragraphs are the result of a first attempt in this direction, that (i) adds essential nuts and bolts to the theoretical and general treatise of the previous sections, and (ii) integrate a review and a short description of all the tools actually available on energy in humanitarian, suggesting how and when they may be successfully used to support the planning process.

3.2.1 Priorities

Recalling the concepts from the general CESP framework, the context and the needs of the beneficiaries are investigated in this phase. Different levels of details may be considered acceptable depending on time (urgency) constraints and emergency acuteness, as well as financial and logistic constraints.

In all cases, a list of the main elements that should be assessed is provided hereafter, as the result of their selection from multiple literature resources including: [24], [230]–[232]. The list is organized according to the main categories of needs that characterize humanitarian settings.

General context assessment

1. Understanding the size of the problem and the general characteristics of the area of intervention.
    - Type of settlement (refugee camp, informal settlement, …);
    - Basic demographic information (number of inhabitants by gender and age);
    - Typical family composition;
    - Information about camp organization and management;
    - Shelter characteristics and constructive types;
    - Topography of the area;
    - Climate of the area;
2. Understanding the level of integration and the acceptability of interaction and collaboration between people.
    - Status and origins of displaced people;
    - Household sizes and compositions;
    - Sources of income, and type of support provided by external organizations;
    - Level of social integration;
    - Level of acceptability of group activities (e.g. participation to trainings or focus groups) or to share technologies (e.g. cooking facilities to be used in groups) between different groups of displaced people.

Assessment of needs and habits related to food preparation and preservation

1. Understanding food typologies, quantities and purchase modalities.
    - Characterization of the most common typologies of food;
    - Quantity of food consumed per capita;
    - Food supply or purchase frequency and modalities;
    - Average expenditure related to food;

    - Amount of organic waste produced;
    - Presence of elements or conditions which negatively affect consumption of particular types of food (e.g. high environment temperature, missing tools for food processing, …).
2. Understanding main weaknesses and constraints of actual cooking process.
    - Frequency and duration of cooking;
    - Technologies and fuels used for cooking;
    - Fuel purchasing modalities and related expenditures;
    - Presence of cultural or religious barriers affecting cooking or food preparation;
    - Characterization of community services for cooking, if any.
3. Understanding potentialities and barriers as regards food preservation.
    - Characterization of any systems or technique adopted for treating food (e.g. drying, salting, canning, …);
    - Characterization of modalities and facilities for food storage;
    - Presence of cultural or religious barriers affecting food preservation;
    - Lack of knowledge on food preservation practices.

Assessment of needs and habits related to water

1. Understanding characteristics and weaknesses of the actual water supply system.
    - Location and typology of water sources (rain water, surface water, ground water);
    - Technologies adopted for water pumping;
    - Per capita water availability;
    - Functional order of any storage and supply systems.
2. Understanding quality of supplied water and main sources of contamination.
    - Water quality and presence of contaminants and pollutants (biological, chemical, physical);
    - Functional order of any water treatment systems;
    - Knowledge of basic hygiene practices;
    - Occurrence of water-related diseases among displaced people.

Assessment of other energy-related needs and habits

1. Understanding electricity availability and related needs.
    - Availability (which users have access to electricity) and reliability (for how many hours on average) ;
    - Generation and/or supply systems: diesel generators, renewable energy, legal/illegal grid connection;
    - Main electric loads at the household level (such as phones, rechargeable lamps, …) and family electricity expenditures;
    - Main electric loads at community (schools, health centers, …) and productive (shops, artisanal activities, …) level.
2. Understanding heating/cooling needs.
    - Periods when space heating or cooling may be needed;
    - Technologies used for space heating or cooling.

Information shall be collected using different methods, including qualitative and quantitative techniques. According to [233], the use of structured questionnaires can provide detailed quantitative socio-economic data such as the size of the household, sources of fuel for cooking, consumption of fuel, etc. Thus, such kind of tools generally constitute the basis for the assessment. However, their use can be successfully integrated with qualitative methods such as semi-structured interviews and Participatory Rural Appraisal (PRA) techniques (focus groups and mapping exercises), in order to add further in-depth information [234].

The main existing tools providing advice and guidelines as regards needs assessment in critical areas, and in particular on the definition of questionnaires, interviews, etc. are:

- *Fuel-efficient stove programs in humanitarian settings: an implementer's toolkit – USAID* [230]. This tool provides specific guidelines and questionnaires for site and household assessment on food preparation (cooking fuels and stoves). The Priority phase is covered in particular by Steps 1-4.
- *Assessing woodfuel supply and demand in displacement settings – FAO* [233]. A practical handbook describing a methodology for the assessment of biomass demand (firewood consumption) and supply. The methodology has been implemented in a practical worksheet (see [235]), and partially covers the Diagnosis phase as well.
- *Environmental Needs Assessment in Post-Disaster Situations – UNEP* [236]. Guidelines for the assessment of environmental impacts and concerns following natural disasters, with a particular focus on elements affecting people's safety and well-being, including energy access. In this phase such guidelines are useful to better identify "hidden" needs of people affected by natural disasters.
- *Energy Assessment Toolkit – D-Lab* [231]. The toolkit is a comprehensive set of documents and preset spreadsheets which allow to collect and analyze information on many aspects of energy access, including needs, supply chains, and relevant stakeholders. Document groups A and B are particularly relevant for the *Diagnosis* phase. It is worth noting that this tool is not specific to humanitarian settings, however its modularity allows to select only some of the tools depending on the scope and scale of the assessment.

In the case of acute emergency and/or particularly strict time or budget constraints, it may be impossible to proceed with a full assessment of needs. In such case, it is suggested to proceed at least with the following actions:

(i) Administration of brief questionnaires to a sample of households, to collect essential information;
(ii) Direct observation of the settlement and surrounding environment;
(iii) In-depth interviews to representatives of key international or local organizations working with refugees.

3.2.2 Diagnosis

Evaluation of the energy demand

In the diagnosis phase, the needs are translated into energy demand. Energy demand is evaluated or estimated in terms of energy flows through different energy carriers, based on energy consumptions by final users, and in terms of load profiles.

The estimation of energy consumptions shall be carried out considering: (i) two different macro-categories (electricity and thermal energy); (ii) different energy carriers (biomass, liquid or gaseous fuels, renewable energy resources, national grid), and (iii) different classes of users, including households, community services (such as schools, clinics, public lighting, cold rooms, pumping stations, etc.), local businesses (such as small shops, phone charging stations, …), and camp administration offices [237].

In the case of electricity, the best option for the evaluation of the daily electricity consumption is achieved by direct measurements in the field, by installing analogic or digital energy meters on the main line(s) serving the camps or settlements, if any. When this is not possible, the daily energy consumption $E_{C,el}$ for different users and different electrical appliances can be estimated as follows [190]:

$$E_{C,el} = \sum_{j}^{User\ Class} N_j * \left(\sum_{i}^{Appliance} n_{ij} * P_{ij} * h_{ij} \right) \quad [Wh/day] \tag{3.1}$$

where:

- i refers to the type of electrical appliances (e.g. light, mobile charger, radio);
- j refers to the user class (e.g. household, school, clinic);
- N_j refers to the number of users within class j;
- n_{ij} refers to the number of appliances i within class j;
- P_{ij} refers to the nominal power rate [W] of appliance i within class j;
- h_{ij} refers to the functioning time of the appliance i within class j [h].

The values to be assigned to the different variables shall be computed or estimated by analyzing the information collected in the *Diagnosis* phase.

It is worth noting that the parameter h_{ij} is always hard to be directly measured, and most of the time should be estimated based on the general habits and behavior of the beneficiaries.

If a value of $E_{C,el}$ is computed for each time step of the day (for example, for each hour of the day), a load profile is obtained as the energy consumption trend as a function of time. Once again, the installation of a logger on the main electric line that can measure power absorptions in a continuous way is the best solution in order to capture real load profiles (Figure 3.7).

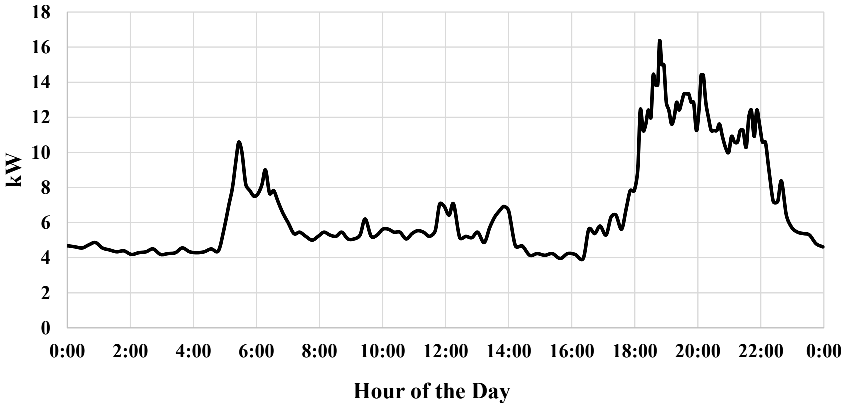


Figure 3.7 Example of daily load profile. *Source:* [190].

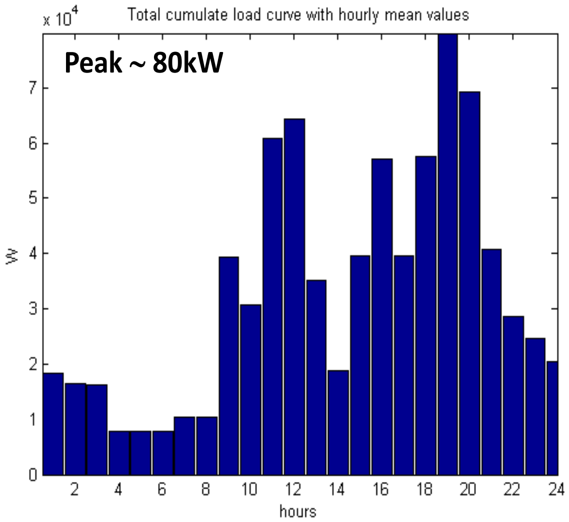


Figure 3.8 Example of estimated load profile. *Source:* [190].

Otherwise, in order to artificially estimate a load profile, the *functioning window(s)* of each consumer class appliance ($W_{F,ij}$) *is/*are a further parameter that is needed [189].

The functioning window(s) represent the period(s) during the day when a given appliance is running.

Therefore, for each appliance *i*:

$$\sum duration(w_{F,ij}) = h_{ij} \tag{3.2}$$

Figure 3.8 shows a graphical representation of a load profile resulting from this approach.

To evaluate the consumptions in terms of energy carriers, when electricity is supplied by the national grid, its consumption is easy to be assessed since in most cases it is tracked by one or multiple meters.

If electricity is generated using local gensets, the energy carrier consumption $C_{C,el}$ (diesel or petrol) can be easily and precisely estimated using the average consumption reported in the genset logbook, that is generally available in most cases.

Otherwise, a broad estimation can be obtained as follows:

$$C_{C,el} = E_{C,el} * f \tag{3.3}$$

where *f* is the average specific fuel consumption [kg/kWh] of the genset.

Thermal energy - In the case of thermal energy, the procedure is similar to that reported for electricity. In fact, the best way to compute the daily thermal energy consumption is to directly collect data about the consumption of the different energy carriers, such as kerosene, diesel for vehicles, fireweed, etc. Unfortunately, in most cases the consumption of traditional fuels such as firewood or charcoal is not easily tracked, especially in the frequent case where refugees collect fuel autonomously.

When direct data are lacking, it is necessary to resort to an estimation. In this case, the first step is to calculate the daily consumption K_{th} of each different energy carrier *k:*

$$K_{th} = \sum_{j}^{User\ Class} N_j * \left(\sum_{i}^{Appliance} n_{ij} * C_{ij} \right) \quad [unit/day] \tag{3.4}$$

where:

- i refers to the type of thermal appliances (e.g. three stone fire, Improved Stove, boiler);
- j refers to the user class (e.g. household, school, clinic);
- N_j refers to the number of users within class j;
- n_{ij} refers to the number of appliances i within class j;
- C_{ij} refers to the average energy carrier consumption rate of appliance i within class j [unit/h] (the unit can be kg or liters of fuel);

In terms of energy, $E_{C,th}$ is evaluated as follows:

$$EC_{th,k} = \sum_{k}^{Energy\ carrier} K_{th,k} * LHV_k \quad [Wh/day] \tag{3.5}$$

where LHV_k is the calorific value of the energy carrier k.

There is no specific tool for the estimation of baseline and forecast energy demand and energy profiles in humanitarian contexts. However, the following resources could be useful to integrate the general procedure:

- *Powering Health, Electrification Options for Rural Health Centers – USAID* [238]. Handbook providing useful information as regards typical appliances and electricity needs for different typologies of rural clinics. It is useful to find references to estimate the consumption and load profiles of health facilities.
- *Energy Assessment Toolkit – D-Lab* [231]. The toolkit is a comprehensive set of documents which allow for information collection and analysis as regards many aspects of energy access, including needs, supply chains, and relevant stakeholders. Part B is particularly useful for the Diagnosis phase.
- *Assessing woodfuel supply and demand in displacement settings – FAO* [233]. A practical handbook describing a methodology for the assessment of biomass demand (firewood consumption) and supply.

Assessment of local energy resources

The assessment of local energy resources is the second step in the diagnosis phase. A complete assessment should consider both renewable resources in the specific location, such as sun and wind, and the resources which are available through the local market.

A particular attention should be reserved to “hidden” resources, such as waste organic materials, which may be successfully converted into useful fuels for cooking or heating.

Assessment of biomass resources - In most refugee and IDP settlements, traditional biomass is one of the most common sources of energy. Unfortunately, accurate assessment of biomass resources is a very complex task. On the other hand, to understand the maximum amount of biomass that is possible to harvest is mandatory in order to avoid or minimize negative effects on the woodlands.

In the case of acute emergency, time, financial and security constraints can act as strong barriers against an in-depth assessment of biomass. In such case, a preliminary and very broad assessment can be achieved through a short survey on the field. Three are the main actions to carry out:

(i) All the different kinds of biomass resources should be identified, including biomass and organic residuals, such as saw dust, straw, rice husk, oil seed shells, and so on. In fact, it is worth to underline that biomass is not only restricted to woodlands, but also include biomass residuals, and the utilization of the latter may reduce the impact on the local ecosystems. For example, sawdust can be transformed into briquettes, and biogas can be produced from food waste and animal or human sewage.

(ii) Considerations should be done on the distance between the resources and the camps or settlements, and on all the logistic and security aspects regarding the transportation of the fuel from the area of collection or purchase to the settlement or camp.

(iii) The direct observation of the area where biomass collection occurs can allow to detect at least the evidence of macro-effects of environmental degradation due to excessive fuel harvesting, while the observation of the areas around the camps or settlements can reveal the availability of unexploited resources.

In any case, the results from this preliminary assessment should be integrated as soon as possible with a more accurate study. A detailed methodology based on the acquisition of data from satellite images is provided in a technical handbook by D’annunzio et al. [233], and is characterized by the following main steps:

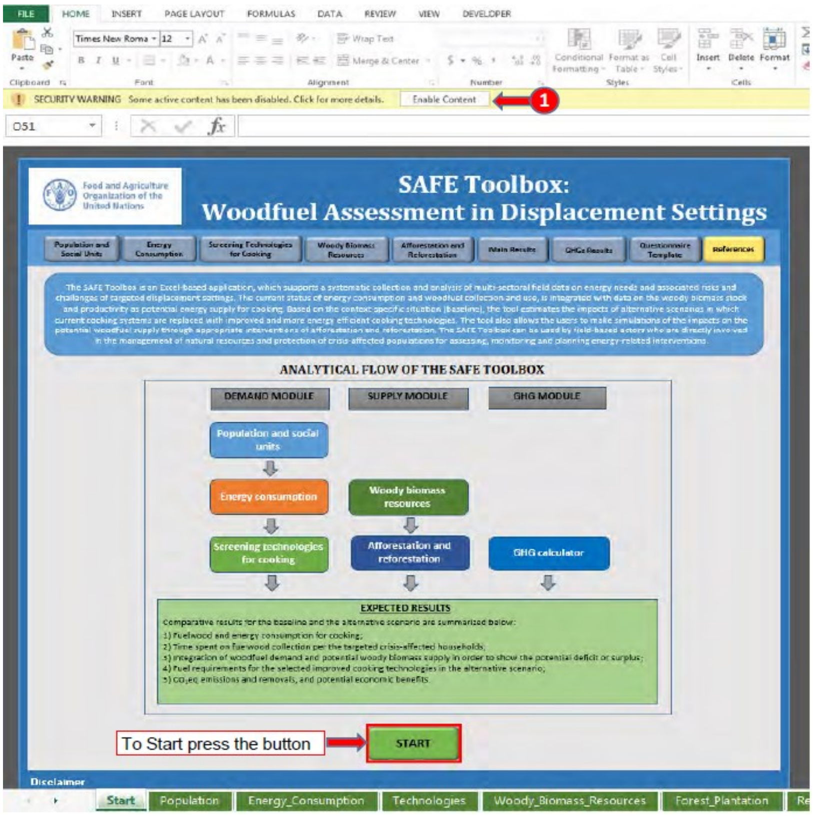
(i) Define the sources of fuelwood: in this step, the different sources of fuelwood are identified and characterized, based on the analysis of satellite images and local data collection;

(ii) Map the distribution of fuelwood resources: the collection area is identified and mapped, characterizing the different land cover classes and assessing changes in the land cover;

(iii) Estimate stocks: the biomass stocks are estimated through a combination of GIS and field assessment techniques;

(iv) Assess stock changes: changes in the biomass growing stocks are assessed and tracked, in order to define appropriate scenarios for the minimization of the environmental impact.

The *Safe Access to Fuel and Energy (SAFE) toolbox* is a very useful excel tool to support field actors and researchers, which combines the assessment of biomass (fuelwood) resources and the assessment of energy needs for cooking in displaced settings (Figure 3.9). The tool is supplied with a step-by-step user guide [235].



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SAFE Toolbox:
Woodfuel Assessment in Displacement Settings

The SAFE Toolbox is an Excel-based application, which supports a systematic collection and analysis of multi-sectoral field data on energy needs and associated risks and challenges of targeted displacement settings. The current status of energy consumption and woodfuel collection and use, is integrated with data on the woody biomass stock and productivity as potential energy supply for cooking. Based on the context-specific situation (baseline), the tool estimates the impacts of alternative scenarios in which current cooking systems are replaced with improved and more energy efficient cooking technologies. The tool also allows the users to make simulations of the impacts on the potential woodfuel supply through appropriate interventions of afforestation and reforestation. The SAFE Toolbox can be used by field-based actors who are directly involved in the management of natural resources and protection of crisis-affected populations for assessing, monitoring and planning energy-related interventions.

ANALYTICAL FLOW OF THE SAFE TOOLBOX

EXPECTED RESULTS

Comparative results for the baseline and the alternative scenario are summarized below:

1) Fuelwood and energy consumption for cooking;
2) Time spent on fuelwood collection per the targeted crisis-affected households;
3) Integration of woodfuel demand and potential woody biomass supply in order to show the potential deficit or surplus;
4) Fuel requirements for the selected improved cooking technologies in the alternative scenario;
5) CO_2eq emissions and removals, and potential economic benefits.

To Start press the button

Figure 3.9 Flow structure of the SAFE toolbox. *Source:* [235].

Assessment of solar resources - Solar radiation is the most diffused type of renewable resource. Solar radiation can be successfully converted to electricity by using photovoltaic systems, or converted into thermal energy

Solar radiation is universally available, with higher intensity closer to the Equator, but the intensity at ground-level significantly varies from place to place due to geographical, morphological and local climatic conditions. Moreover, the conversion process of solar radiation to thermal energy or electricity is also influenced by seasonal variations. In tropical areas, insolation is usually higher during the dry season than during the rainy season.

Many databases are nowadays reliable sources of data for solar radiation [5], including in particular:

- The photovoltaic geographic information system (PVGIS), which provides a map inventory of solar resources and a first round estimation of electricity production from photovoltaic systems in Europe, Africa and South-West Asia. The tool is dedicated to the specific context of distributed generation or stand-alone generation in remote areas [239];
- The IRENA Global Atlas, which provides radiation maps and tools for the assessment of technical potential of many renewable resources, including solar energy [195].

Assessment of wind resources - Wind resources are site-specific, and average wind speed can vary depending on the period of the year. Speed is high influenced by topography and physical obstacles. For this reason, turbines are usually placed along ridges or at top of hills to minimize the influence that obstacles can have on the speed profile. Clearly, wind potential also changes during the day and can be significantly different during the different seasons. For such reasons, in most cases local data are necessary in order to carry on a reliable assessment.

In general, wind speed in the range of 3-4 m/s is the minimum to make a system feasible from the economic perspective [9]. Most effective and accurate data for a specific site are obtained installing towers equipped with anemometers and wind vanes in order to measure speed and direction of the wind. Due to possible variations of average speed along the year, data should be collected during significant periods of time (ideally for a period of one year).

When a field campaign is not feasible due to time or economic constraints, the utilization of secondary data could be a good compromise: for example, data from nearby meteorological stations, military camps, or airport facilities [240], [241].

Online databases, such as the IRENA Global Atlas [195], also include data on wind. However, unlike the case of sun, they can only provide very general information, since wind resource strongly depends on the specific characteristics of the area of interest. In addition, wind maps mostly report velocities at 50 meters from the ground, while for the case of small wind installations it is required to assess wind speed at 30 meters or below. Therefore, data from online databases generally represent the very last chance.

Assessment of hydro resources - Hydro resource is strictly site-specific: the exploitable potential in this case is given by the combination of two elements: flow rate and the height of water fall (head). Also in this case, the resource is affected by seasonal variability, which often requires a direct and case-by-case evaluation. For such reasons, very few examples of online studies exist, providing useful data at sub-country levels, such as the case of the database developed by ECOWAS mapping hydro resources in West Africa [242].

When online data are not available, or not accurate, in-field data collection is necessary. There are several methods to measure the flow [243][244]. The most common ones are the following:

- Velocity-area method: this method is used for medium size rivers. The flow rate is estimated by measuring the cross-sectional area of the river and average velocity of the flow.
- Weir method: this method is useful for the case of small rivers, where it is possible to build a temporary dam. The estimation of the water flow is obtained by measuring the difference on the level between the surface of the water upstream and the bottom of the dam.
- Floating object method: in the case of small rivers with regular flows, the velocity is estimated by measuring the time taken from a floating object to cover a measured distance downstream.

In addition to the flow, head estimation is also required. In particular, gross head is defined as the height difference between where the water enters into the hydro system and where it leaves it. Therefore, gross head measurements can be done with different methods, such as using theodolites, lasers or GPS levels, or by measuring the pressure gauge using a flexible pipe [245].

Further details and procedures for the assessment of local energy resources can be found in the following tools and publications:

- *Safe Access to Fuel and Energy (SAFE) toolbox - SAFE* [235]. As already described, this is a comprehensive tool including a spreadsheet and guidelines for the assessment of biomass (firewood) resources. It is also useful to estimate actual fuel consumptions and the balance between demand and supply.

- *Micro hydro power scout guide* - *GTZ* [246]. A comprehensive manual on micro hydro power systems, including detailed description of the different methods for the assessment of the hydro resource.
- *Handbook on renewable energy sources – ENER-SUPPLY* [247]. Detailed handbook on the assessment of renewable energy sources, including biomass, hydro and wind. The handbook mainly refers to the context of developed countries. however, the assessment methods are fully applicable in other contexts.

3.2.3 Strategy

In general terms, the process of definition of a strategy in humanitarian settings does substantially not differ from other contexts. However, it is possible to report some indications, specific to humanitarian settings, that may help in the identification of the possible scenarios.

Depending on the context and the typology of settlement (formal or informal), displaced people may be organized at different levels. The most basic form of organization is at the household level: small informal settlements may not be organized at a higher level, which means that every family or group of families with common relatives almost operate as independent units. In the case of bigger informal settlements, including tens or hundreds of households, some sort of organization at the community level is more frequent. A different situation is represented by formal refugees' camps, which are typically organized on a central level, and at the level of districts and blocks.

The organizational level can therefore act as a support for a certain level of centralization or decentralization of the energy systems. On the other hand, the level of centralization or decentralization is also determined by the type of system to be put in place.

Table 3.3 Scheme of the main possible strategies for thermal energy supply. *Author's elaboration.*

Energy uses	**Single HH**	**Groups of HHs in adjacent shelters**	**Block / District**	**Whole settlement / camp**
Cooking	- ICS - Modern-fuel stove - Electric stove	- Shared large ICS - Shared modern-fuel, multiple-burner stove - Multiple-plate electric stove	Centralized kitchen equipped with community ICSs or large-scale modern stoves	
Heating	- Same technology used for cooking - Other biomass stove - Other modern-fuel stove - Electric heater	- Same technology used for cooking - Other biomass stove - Other modern-fuel stove - Electric heater	Centralized district heating/cooling system*	
Cooling	- Electric fan - Electric AC	- Electric fan - Electric AC	Centralized district heating/cooling system*	

*Technically feasible, but very unlikely due to very high cost and very high complexity in terms of logistics and construction.

Starting from the case of *thermal energy*, the most important need is cooking, while other ones mainly include space heating and space or food cooling. Table 3.3 reports a summary scheme of the different possible technology options depending on the grade of organizational level. Obviously, the solutions that are feasible at lower organizational levels remain valid options at higher levels as well (e.g., a strategy based on the distribution of ICSs at single HH level can be applied also in the case of a large refugees' camp organized in districts and blocks).

Examples of strategies for thermal energy provision therefore can include:

- Totally home-based strategies, where all the necessary technologies are given at HH level. For example: provision to each HH of a small ICS for cooking and heating, and small electric fan.
- Community-driven strategies, where all the technologies are provided as community services whenever possible. For example: community canteen equipped with community ICS, and fossil fuel heater connected to multiple shelters.
- Hybrid strategies, combining the two different approaches in different areas of the settlements or for different services.

It is worth noting that "shared" or "centralized" cooking solutions are generally characterized by higher energy efficiency and lower capital and O&M costs. However, such strategies necessarily imply a high degree of collaboration and interaction between displaced people, which is not always culturally or socially acceptable, may represent a cause of tension or conflicts in the community.

Regarding the case of *electricity services*, the argumentation presented in the general CESP framework remains valid, however in this case the discussion about the density of population and the level of power demand of the different users has to be made within the boundaries of the target camp or settlement. Table 3.4 presents a summary scheme of the main possible strategies for the supply of electric services, from the simpler case of decentralized, stand-alone, single-user systems, up to distributed or on-grid solutions, organized in the so-called power system matrix.

Table 3.4 Scheme of the main possible strategies for electricity supply. *Author's adaptation from* [199].

POWER SYSTEMS MATRIX	**DECENTRALIZED**		**DISTRIBUTED**	**ON-GRID**
Energy Uses	**Stand-alone Systems**	**Micro-Grid Systems**	**Hybrid Micro-Grid Systems**	**Systems connected to the national grid**
Household basic needs	Home-based Systems	Systems including a distribution grid	Systems including a distribution grid	Distribution grid connected to the national grid
Community services	Community-based Systems			
Productive uses	Productive-based Systems			
Number of HH	Single	Multiple	Multiple	Single OR Multiple
Energy Sources	Single (Traditional or renewable)		Multiple (Traditional and/or renewable)	[-]

In general terms, all the different strategies here outlined are suitable to provide power to any type of electric appliances, however it is worth noting that systems with bigger power generation units tend to reach better cost/benefit ratios as the power required by users increases.

Examples of strategies for the provision of electricity include:

- Totally home-based strategies, where home-based systems provide power to all appliances in each shelter, and community or productive-based systems independently supply the necessary power to each center, shop, etc.
- Strategies based on multiple-user micro-grid or hybrid-micro-grid, or grid-connection, with one or more large generation units providing power to all the beneficiaries, including community services and productive centers.
- Hybrid strategies, combining the two different approaches in different areas of the settlements or for different services. For example: one micro-grid providing power to all the HHs and shops, and multiple stand-alone systems providing power to each community service.

Thermal energy and electricity strategies can be combined in an overall *energization strategy*, especially when thermal energy supply is partially or totally provided by using electric devices such as electric plates for cooking, electric heaters, fans, etc. In fact, the presence of such devices causes an intrinsic interconnection between the supply of thermal and electric energy.

The *SET4food Decision Support System* is the only existing tool specifically targeting the strategy phase of CESP in humanitarian settings [248]. The tool helps humanitarian operators and practitioners to proceed with a preliminary selection of appropriate energy technologies with a strong focus on technologies related to food security.

Other useful resources include:

- *SET4Food guidelines on sustainable energy technologies for food utilization in humanitarian contexts and informal settlements* [249]. The guidelines provide in-depth description of energy technologies related to food security. Pros and cons of each type of technology are discussed in the light of the specific characteristics of humanitarian settings.
- *Fuel Analysis, Comparison & Integration Tool (FACIT) - GACC* [250]. This tool allows to compare expected impact and trade-offs of different biomass fuels for cooking, which can help in the selection of the best fuel according to the specific context.
- *IASC task force matrix and decision tree - SAFE* [251]. A practical toolkit for determining an effective, multi-sectoral fuel strategy.
- *Biomass Energy Sector Planning Guide – EUEI, GIZ* [252]. A planning guide for sustainable biomass utilization in developing countries with energy purposes, including heating and cooking.

3.2.4 Comprehensive design

The *Comprehensive design* is the most technical phase. Once that all the necessary data and estimations have been obtained through the previous phases, and that one or more scenarios have been defined in the strategy phase, the methodology for the design of the energy systems in humanitarian contexts does not significantly differ from applications in development contexts. However, it is worth noting that needs of people may differ, and, the technical details of the proposed solution are likely to be substantially different.

In any case, in this section an overview of the different energy systems' components and main possible layouts, from home-based solutions to large-scale systems, is presented in order to complement with some practical information the theoretical framework of CESP.

Before proceeding with the overview, it is worth noting that data on needs, available resources and thermal and electricity consumptions (load curves) are essential but non-sufficient elements to proceed with the comprehensive design phase. In fact, techno-economic data on the main systems' components are yet to be collected during this phase, before proceeding with technical calculations, and O&M costs have to be carefully estimated as well. Project lifetime and annual interest rate (where relevant) complete the list of necessary input parameters.

In the case of *thermal energy systems*, most of the times the term design will actually sound excessive in practice. Since the case of complex buildings and large volumes rarely applies to humanitarian settings, usually this phase is more dedicated to the selection of standard, almost-turnkey systems than to a full design of custom ones. Heating and cooling units for domestic, office, or small community services are available with different sizes and configurations in most markets all over the world. The same consideration is, in general, also valid for the case of cooking systems: many different models are available for all cookstoves categories (see Chapter 2), from biomass stoves to modern stoves, and for different sizes, from small single burner/plate to large and/or multiple burners/plates. Community biomass stoves built with materials such as cement and bricks are an exception, since in this case shape and size can be changed depending on the desired performance and surrounding building structures.

Useful tools and other materials for the selection and/or customization of cooking systems suitable for humanitarian settings include:

- *Clean cooking catalog – GACC* [253]*; Cooking stoves catalog – Politecnico di Milano*[8]. Two global databases of cookstoves, including hundreds of stoves models. It is possible to apply multiple search filters, based on indicators on performance, construction materials, type of fuel, etc.
- *Design Principles for Wood Burning Cook Stoves* [254]. Manual on design principles of improved cookstoves, including reference drawings and measures of some selected stoves models.
- *Handbook for Biomass Cookstove Research, Design, and Development* [255]. Practical guide to biomass stoves custom design considering the most recent science advances.

The case of *electric power systems* is much more complex in terms of different components and possible layouts. Apart from the case of very simple cases, the design of power systems without the support of specific software requires advanced modeling of the individual components and their interaction. Therefore, a list of available software that can be used to carry out techno-economic analyses of power systems has been already indicated in paragraph 3.2.4, while hereafter the different general systems configurations are briefly described, according to the type of exploited resource and size for the system in terms of main components and possible configurations.

Solar photovoltaic (SPV) systems - SPV systems typically consist of the following main components:

- Solar panels;
- Batteries and charge controller;
- Inverter;
- Wirings, cables and other electric hardware.

Referring to the categories of Table 3.4, SPV systems can be classified as follows:

- Stand-alone home-based systems
    - Pico SPV systems;
    - Solar home systems.
- SPV community-based and productive-based systems.
- Micro-grid SPV systems.

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[8] Available at https://bit.ly/2wPFXeR

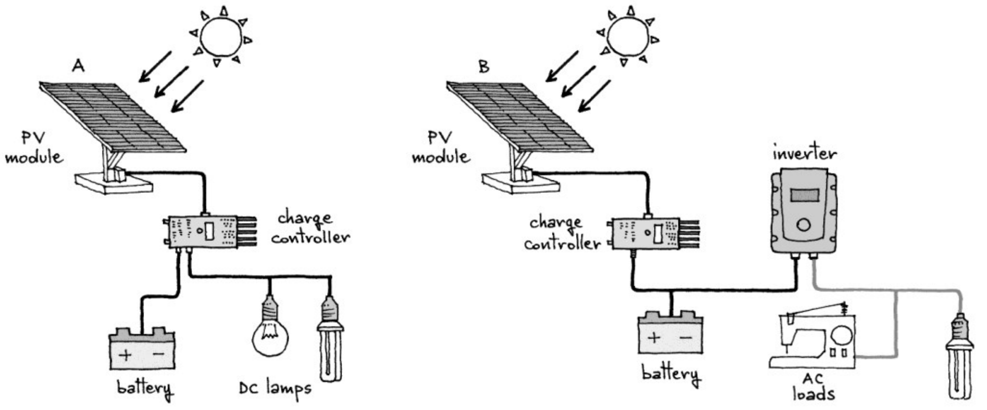

Figure 3.10 Solar home-based system without inverter (A) and with inverter (B). *Source: [2]*.

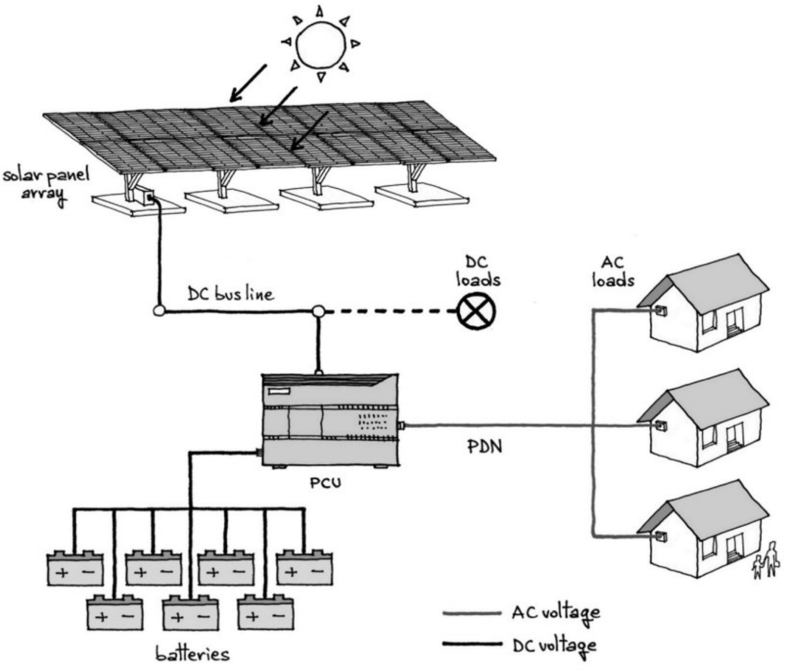

Figure 3.11 Micro-grid SPV system. *Source: [2]*.

Stand-alone solar home-based systems are generally pre-assembled systems built for a particular purpose, such as lighting or water pumping. Pico PV systems are very small systems with power output ranging 1-10 W, mainly used for lighting or charging of small appliances such as phones or other USB devices. Solar torches are a typical example of pico solar systems used in humanitarian settings in order to replace kerosene lamps or candles. Pico PV systems integrate a small PV panel and a battery as a unique object [256]. Bigger solar home-based systems include a SPV module, a charge regulator, storage (Figure 3.10 A), and optionally an inverter (Figure 3.10 B). Power output of such systems ranges up to some hundred Watts. When such systems are coupled to DC loads like lamps, radios, and DC fridges are used, the inverter is not needed. Systems without inverter are more efficient and less expensive.

Community-based and productive-based systems are bigger stand-alone PV systems that can provide energy to health centers, schools, shops and small factories. The main components of such systems are the same of solar home systems, with bigger capacity, and the inverter is needed most of the times due to the presence of AC loads (FFigure 3.11). Power output in this case ranges from hundreds to thousands Watts, and storage banks work at 24/48 V [257]. Charging stations are a particular typology of community-based system that can be successfully installed in humanitarian settings: in this case, a PV array charges a large storage unit, that is used by people to recharge individual lanterns or other rechargeable devices. A DC-DC converter is used to regulate power and voltage [258], [259]. This solution can allow to reduce costs and logistics compared to the delivery of home-based systems.

Micro-grid SPV systems are medium to large systems providing power to multiple users, including households, community services and productive activities (Figure 3.11). Power output is tents to hundreds of kW, and a distribution network is required to deliver electricity to all the users. Such systems are the most complex, and include the following main components [240]:

- PV array;
- Battery banks for electricity storage;
- Power conditioning unit (PCU) consisting of junction boxes, charge controllers, inverters, distribution boards and necessary wiring/cabling;
- Power distribution network (PDN) consisting of conductors, insulators, wiring/cabling.

Small wind (SW) systems – Wind generators convert the kinetic energy of wind into electric power through rotor blades connected to a generator. Micro-wind turbines typically range from 100 W to 300 W, while mini wind turbines are available up to some hundreds of kW.

Wind turbines can be divided into two main classes: horizontal axis wind turbines and vertical axis wind turbines. Horizontal axis are the most popular type, characterized by the highest efficiency. They typically rotate slowly, in order to limit mechanical stress due to the tip speed, and need to be oriented according to the wind speed direction to optimize energy production. Vertical axis turbines include Savonius and Darrieus turbines. They are more suitable in the case of low wind speeds and do not need to be orientated, however they are less efficient, and Darrieus turbines need a starter to begin rotating.

Also in this case, SW systems can be classified according to the power systems matrix:

- SW home-based systems;
- SW community-based and productive-based systems;
- Micro-grid SW systems.

The layout of SW home-based systems is similar to that of SPV home systems. Micro turbines range from 50 W to some hundreds Watts. They can operate with wind speeds from 1.5 m/s to 25 m/s, and survive to wind speeds of up to 70 m/s. Rated wind speed ranges from 10 m/s to 13 m/s. Most micro wind turbines produce DC power at low voltage (12 to 48 V). In addition to the wind turbine, that can be can be mounted roof-top or on a pole, a SW home-based system also includes a charge regulator and batteries for energy storage [2], [5].

SW community-based and productive-based systems require bigger power capacity. Turbines rated in the range 1.5–15 kW are suitable in this case. They are an ideal, cost-effective solution to power dwellings, schools, hospitals, water-pumps, and so on, when sufficient wind resources are available in the target location. SW systems can be used to create charging stations, similarly to the case of PV systems.

If the load to be supplied is larger, it is necessary to adopt mini turbines, ranging from 15 kW to 100 kW. The layout of the system is similar to that of SPV micro-grid systems. The range of acceptable wind speed for mini turbines is the same as for micro turbines, while rated wind speed is higher, ranging from 14 m/s up to 20 m/s.

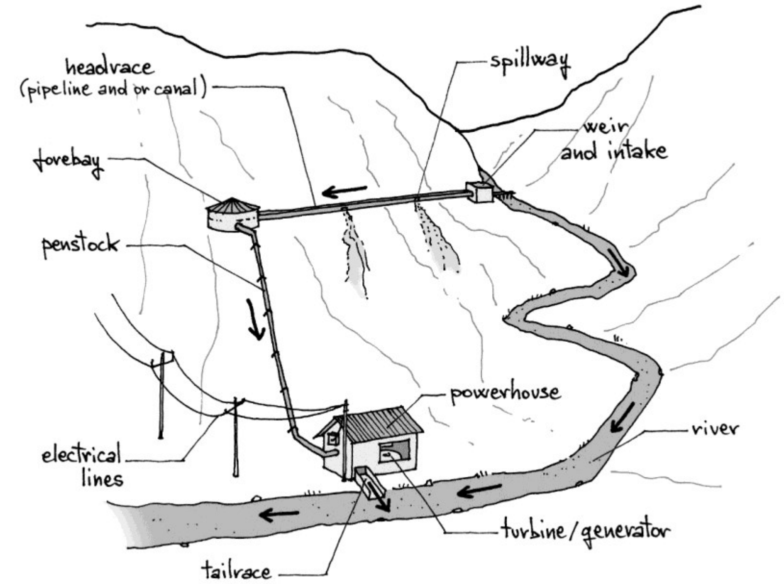

Figure 3.12 SHP system scheme. *Source: [2].*

Small hydropower (SHP) systems – A typical SHP system include the following main components (Figure 3.12):

- weir and intake to extract water from the water source;
- channel, to transfer the water from the intake to the forebay tank;
- settling basin;
- forebay tank, connecting the channel and the penstock;
- penstock;
- hydro turbine coupled to electric generator;
- tailrace to discharge water back into the river;
- control panel.

There are many types of hydro turbines, and the two most important parameters for their election are the available water flow and head (i.e. the available hydrostatic column of water, proportional to the height difference between forebay tank and the turbine). Most suitable turbines for SHP systems are classified in Table 3.5 according to the parameters previously mentioned. The utilization of standard pumps as turbines (PAT) represent a particular case. The lower cost and larger availability of spare parts are the main advantages of such option. On the other hand, pumps are not optimized for reverse functioning, therefore the conversion efficiency is lower, and pump characteristics in turbine mode are not easy to be found [260], [261].

Table 3.5 Main hydro turbine typologies for SHP systems. *Source: [2]*.

	Available Site Head		
	High ($H>150$m)	**Medium ($20 \leq H \leq 50$)**	**Low ($2 \leq H \leq 20$)**
Impulse	Pelton	Cross flow (Mitchel/Banki)	Cross flow (Mitchel/Banki)
	Turgo	Turgo	
	Multi-jet Pelton	Multi-jet Pelton	
Reaction	-	Francis	Propeller (axial flow)
	-	Pump-as-turbine (PAT)	Kaplan (modified propeller)

The classification of SHP systems according to the power systems matrix brings to the same results obtained for the case of PV and wind systems. However, the utilization of a home-based SHP system in humanitarian settings is very unlikely due to its cost and complexity.

Community-based and productive-based SHP systems are instead more suitable, where any hydro resource is available. Micro-hydro plants in this category have generating power ranging from some kW up to tents of kW. Most systems are run-of-river type, thus no water storage or barrage is needed.

Small SHP systems are also suitable to create micro-grids, with typical electrical power from tents to hundreds of kW. In the case of large plants, extensive civil works to implement larger infrastructures may be required, including the creation of a basin and/or a small dam, and the construction of an electricity distribution network is necessary. The complexity of regulation of the generator and turbine increases as well [262].

Internal combustion engine generators - There is a wide range of internal combustion engine generators, from small portable units rated few hundreds Watts to very large units reaching capable to supply hundreds kW and more. In humanitarian settings, the interest is mainly focused on small to mid sizes.

At the household level, small-size gasoline engines are theoretically the most suitable solution. However, their utilization in humanitarian settings is very unlikely due to the high investment and operation cost. Diesel generators (gensets) are the best solution in case of mid-size generation units, from tents to hundreds of kW, and are widely utilized to supply power to humanitarian organizations' offices and to essential services in refugee camps such as water pumping or street lighting [39]. Their popularity is mainly due to their ease of installation, limited capital cost, and very high power density (about 20 kW/m^3). However, diesel gensets present extremely high O&M costs, not only due to fuel consumption (conversion efficiency ranging 25-40% depending on the type and age of the engine), but also to periodic servicing, including on average oil change, air filter cleaning and fuel filter substitutions every 250-500 hours of functioning. Moreover, their lifetime is relatively short, typically ranging in between 10,000-20,000 functioning hours, and they can emit considerable amounts of pollutants [2].

For such reasons, stand-alone gensets may still be considered a viable option in acute emergency situations, while are hardly competitive on the mid- to long-term perspective. On the other hand, they can successfully be integrated as components of hybrid micro-grid solutions, as explained hereafter.

Hybrid micro-grid systems – Hybrid micro-grid systems are capable to supply multiple users (HHs, community-based and productive based) by coupling two or more power generation units using different energy sources.

The most common configuration is composed by SPV and Diesel. In this case, SPV generally generates most of the energy (baseload supply), while the genset balances the fluctuations of solar irradiation, and allows to cover power peas. Hybrid SPV/Diesel systems generally present many advantages compared to single-source systems. The presence of the diesel genset allows for a reduction of the PV array size, as well as for a reduction or total elimination of battery banks. On the other hand, the presence of a PV array drastically reduces fuel consumption and O&M costs, and extends the genset lifetime.

Other hybrid configurations include:

- Wind/Diesel, with similar characteristics to the SPV/Diesel configuration;
- SPV/Small hydro or Wind/small hydro;
- More complex systems, such as SPV/Wind/Hydro or SPV/Wind/diesel.

Useful materials for the design of power systems include:

- *Renewable energy for unleashing sustainable development* [8]. A book that analyze energy technologies and business models for energy provision in development regions.
- *SET4Food guidelines on sustainable energy technologies for food utilization in humanitarian contexts and informal settlements* [249]. The guidelines provide information on renewable and traditional energy power systems characteristics and design indications.
- *Mini-grid design manual - ESMAP* [263]. A comprehensive manual for the technical design of mini-grids.
- *Low cost grid electrification technologies – EUEI PDF* [264]. Guidelines on the development of low-cost grids and networks for electricity transmission and delivery to rural and critical areas characterized by low power consumptions.

3.2.5 Impact evaluation

In terms of procedures and methods, there is no significant difference between the evaluation of (expected) outputs and outcomes of an energy project in development or humanitarian settings. Moreover, it has been shown that energy provision is actually a mean to guarantee a certain level of fulfillment of different beneficiaries needs. In humanitarian settings, such needs may include food security, healthcare, education, HH economic status, and many others, which have been discussed in the previous chapters of this dissertation.

Clearly, a complete analysis of various impact assessment method in general, and particularly those applied in humanitarian contexts, goes far beyond the scope of this work. Different methods exist, characterized by different levels of complexity from simple to strenuous ones. References on general methods applied in development settings have already been indicated in paragraph 3.2.5, while a selection of documents on methods specifically applied in humanitarian settings includes [265]–[268].

Beyond the specific evaluation method that is chosen, the most important difference concerning the evaluation of energy access projects in humanitarian settings compared to other contexts consists in the identification of specific outputs and outcomes. In fact, to get a COMPREHENSIVE evaluation, a set of elements specific to energy issues in humanitarian settings targeted by the project action(s) should be added to other more general ones. The most common outputs or outcomes in fact may be described with the aim of measuring the changes the overall programme causes, which in humanitarian settings, typically targets the health, protection, or economic and market systems sectors. On the other side, when an energy component is developed, it is important as well to understand the direct effect of such component on the overall action. A list of typical observable outputs and outcomes for energy projects is suggested in Table 3.6[9], based on [160], [221], [229], [269], [270], and adapted to the specific context of humanitarian interventions. Depending on the specific objective of the project, and of the implemented strategy and energy systems, some of such factors may result relevant or not. Therefore, relevant ones should be selected from time to time based on the characteristics of the project itself, and one or more appropriate specific indicators should be associated to each of such factors.

Table 3.6 List of observable outputs or outcomes of energy projects. *Author's elaboration based on [150], [209], [217], [257], [258].*

Topic	**Observable outputs / outcomes**
	Techno-economic dimension
Capacity	- Generation capacity of the electric power system - Capacity of ambient heating system - Capacity of ambient cooling system - Capacity of refrigeration system
Availability	- Availability of improved or modern stoves - Availability of appropriate fuels for cooking or other uses - Level of penetration of the electric supply service (share of users physically connected)
Reliability	- Reliability of electric supply service - Reliability of fuel supply - Reliability of ambient heating / cooling systems
Quality	- Voltage stability of the electric service - Variability of heating value of fuel affecting cooking tasks
Affordability	- Affordability of electricity - Affordability of cooking fuels - Affordability of other energy expenditures
Efficiency	- Efficiency of the new energy systems / components - Fuel savings obtained thanks to the new energy systems
Income generation	- Development of new activities due to local production of energy technologies or fuels - Income generation activities due to improved energy services
Appliances	- Increased number of basic appliances at HH level - New appliances used at the community or productive level thanks to the larger energy capacity
Safety	- Safety of the electric system (risk of electrocution, fires)

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[9] The list of relevant topics here presented is partially organized according to a classification of the energy attributes considered in the Multi-Tier Framework (MTF) developed by the World Bank, which provides with a metric to measure access to energy [12].

Topic	**Observable outputs / outcomes**
	- Safety of cooking-related tasks (risk of burns, poisoning, injuries, fires) - Food safety related to enhanced cooking and preservation
	Environmental dimension
Land	- Deforestation or land degradation occurring due to energy uses of wood - Area of land occupied by energy systems
Water	- Amount of water polluted or depleted by the energy systems - Alteration of natural water systems due to energy exploitation
Air	- Local air pollutant emissions due to energy systems - GHG emissions
Waste	- Solid waste produced by the energy systems (e.g. ashes, packages, exhausted batteries) - Liquid waste produced by the energy systems (e.g. exhaust lubricants)
	Social dimension
Satisfaction	- Overall beneficiaries' satisfaction of energy services, including: o Beneficiaries' satisfaction of cooking systems o Beneficiaries' satisfaction on ambient temperature conditions
Legality	- Legality of connections to the electric service - Legality of cooking fuel fabrication and purchase
Health and nutrition	- Frequency of air pollution related illness - Frequency of poisonings due to misuse of toxic fuels - Improvement of health services - Change of dietary diversity related to energy interventions - Improvement of nutritional contents of food due to better means for food preservation or cooking
Time	- Time savings in cooking-related activities, including: o Time savings on fuel purchase activities o Other time savings related to energy systems
Security	- Level of security of cooking-related tasks (risk of GBV, risk of violence) - Level of security due to public lighting
Capability and education	- Ability of beneficiaries to maintain and repair cooking systems - Ability of beneficiaries for local production of cooking stoves - Level of knowledge of safe/efficient cooking practices - School facilities related to energy
Relations and habits	- Relations between hosting and hosted community - Respect of cooking traditions and habits - Variation of cooking practices

All factors included in the list have to be evaluated through specific indicators, by comparing the situation ex-ante and ex-post.

Useful materials on evaluation of energy projects adaptable to humanitarian settings include:

- *A guide to monitoring and evaluation of energy projects - M&EED international group* [221]. Comprehensive guidelines on monitoring and evaluation of energy projects, including a detailed list of outputs, incomes and suggested related indicators. The guidelines target the development context, but most of the considerations can be easily applied in humanitarian settings as well.
- *Fuel-efficient stove programs in humanitarian settings: an implementer's toolkit – USAID* [230]. This tool provides specific guidelines and questionnaires for site and household assessment on food preparation (cooking fuels and stoves). The evaluation phase is covered in particular by Step 11 (monitoring, testing and reporting).
- *Measuring social impact in the clean and efficient cooking sector toolkit* [271]. A toolkit including a conceptual framework, indicators, surveys and a how-to guide [272] to measure social impact in cookstoves interventions, with particular reference to biomass stoves.
- *Mainstreaming gender in energy projects* [273]. Handbook on gender in energy projects, particularly useful to understand the relevance of such issue in energy projects, providing indicators to measure the impact of interventions on gender.

3.3 Application in humanitarian settlement: pilot project in Lebanon

A simplified version of the CESP framework was applied in a pilot project in a refugee settlement in Koura district in Lebanon, within the SET4food action. The beneficiary community was constituted by a group of Syrian refugees. The pilot contributed to test the effectiveness of the proposed approach, and provided useful information to further refine the framework. In the next paragraphs, the process of development of the pilot is described, following the different phases of the CESP framework[10].

3.3.1 Priorities

Context and needs assessment were carried out using a rapid assessment questionnaire and direct observation in the field. The questionnaire is available in Annex B.

General context information

The target community was constituted by Syrian refugees. A couple of Syrian males working in the construction field in the area (south of Tripoli) started to occupy an empty unfinished shopping mall before the spread of hostilities in their original country (Figure 3.13).

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[10] The exact location of the target community is not disclosed for privacy and security reasons.

Figure 3.13 Aerial view of the unfinished shopping mall. *Source: Google maps*.

Due to the spread of the Syrian war, the number of families living in the site increased and reached the number of about 130 (more than 600 persons) when the assessment was carried out. Most of them had been living in the place since the beginning of the Syrian war, however 20-30 families arrived later on to join their relatives there. The HH average size was five persons, with one child under five. Some HHs were woman headed. Most of the refugees were aged between 30-50 years old with children aged between 2-15 years old.

All the refugees were officially registered by UNHCR. Families were living in shelters inside the unfinished building and in the surroundings. The building was a cement structure with 4 floors and about 60 commercial spaces organized around a courtyard and a common space at ground level. Every HH was accommodated in one of the commercial spaces.

The settlement was officially considered as a collective centre (20+ HHs), however no specific management plan was put in place by any agencies, except for a basic waste management system. On the other side, the following aid services were offered by a mix of different stakeholders of the international community:

- 300 packs of Arabic bread distributed daily;
- Regular water supply with tank trucks;
- Distribution of food vouchers.

The average expenditure for food purchase was determined around 70 USD/month per person. Of this amount, 30-50 USD were provided through food vouchers distributed by the international community.

In general, there was no conflict among the refugees, nor between the refugees and the hosting community, also thanks to the fact that the place was surrounded by rural landscape. Moreover, it was reported that refugees used to share food, cooking facilities and other technologies with other families, when any relatives were in common.

Food

The assessment revealed that most of food was purchased dry. People reported that fresh food sometimes was too expensive, and that they were lacking of any possibilities to preserve it safely. Most common food items were bread, rice, dry beans, wheat (300 g/day per person) and hummus (100 g/day per person). Sugar was also cited as an important element, while fruits and vegetables were rarely purchased. Each family was cooking independently using their own gas stove indoor, once per day on average. However, families with common relatives were used to share the place to store food and the cookstoves. Few quantities of raw food were wasted due to deterioration; however refugees stated that some food leftovers were usually thrown away due to the absence of means to preserve it, except for the case of few families having a small refrigerator, which however was not always working properly due to the discontinuity of electricity supply from the grid. Most of the food items were purchased from a couple of shops located inside the building itself.

Water

The building was not connected to the aqueduct. Drinking water was provided by the international community using tankers, with regular deliveries every two days. Water was stored in water tanks located on the rooftop and in the basement of the building, that were shared by the whole community. The total amount of water used for cooking and hygiene practices (shower) was estimated to be around 35 l/day per person.

Energy

Cooking was performed by using movable gas burners (Figure 3.14). Bottled gas was purchased directly from a truck regularly visiting the building. On average, each family was purchasing a couple of 12 kg gas bottles per month, with an expenditure of about 30 USD/month. Bottled gas was indicated as the most common fuel for cooking also within the Lebanese hosting community. Gas was used for space heating as well, when needed.

Figure 3.14 A kitchen inside one of the shelters. *Credits: the Author.*

Figure 3.15 View of the inside structure of the building, giving evidence of the precarious conditions of the electric system. On the roof, the water tanks are visible. *Credits: the Author.*

Electricity was supplied through an artisanal connection to the main grid, and was used by the families mainly for lighting, and cell phones and portable lamps charging (the latter were used during night time, when electricity was often not available from the grid). Some families also had a small TV. The service was described as sufficiently reliable, but was available only for few hours per day due to rationing schemes, which also affected cooking operations during night time. Direct observation revealed the very dangerous and precarious conditions of the electric system in the building, where artisanal wiring was made by the refugees without adopting any safety measure, with severe risk of electric shock and fires (Figure 3.15).

Preliminary information on local resources

The building was located in a quite dry area, where no forests or green areas are present, and there was no source of biomass residues to be used as alternative fuels. In addition, there was no water streams or rivers in the surroundings. On the other side, the area was indicated as very windy.

A large amount of different construction materials and technologies ware easily available in the local market, including all components necessary to assemble renewable energy systems such as PV plants. In terms of skills, most of the settlers built their own shelter and had high level of construction skills. Local skilled Lebanese work force was available as well in the surrounding communities.

Priority areas of intervention

Based on the analysis of the information collected in the field and reported in the previous paragraphs, it was possible to draw the following main conclusions:

- In the target settlement, cooking was already performed with a modern system (gas stove). Even if the stove model could be substituted by a better one, the situation was not particularly critical, and the expenditure related to food cooking was in general affordable for all the families.
- Food preservation was a more critical aspect, due to a general lack of any food preservation facilities. Some food, in particular leftovers, was lost for this reason. Moreover, this fact strongly limited the consumption of fresh food, such as vegetables and fruit, especially during the hot season. On the other hand, the refugees were used to deal with refrigerators at their households in Syria before the spread of the war, and indicated such technology as their favorite one.
- Water was another critical issue, since the building where the target community lives is not connected to the water supply grid. However, the problem was fully mitigated by the action of the international community, which ensured the regular provision of drinking water through tankers.
- Most of the families had access to electricity through a connection to the grid. However, the provision of electricity was strongly limited by rationing schemes, and the overall electric system of the building was extremely dangerous due to its artisanal nature and its dilapidated conditions. This situation exposed people to the risk of electrocution and could cause damages to electric appliances.

The analysis therefore revealed that food preservation and power supply could be identified as the two priority services requiring an intervention, also based on the fact that in the specific case, the favourite food preservation technology (refrigeration) is intrinsically dependent on a safe and reliable electricity service.

For this reason, the pilot focused on these two aspects, and the objective of providing the target community with reliable means for food preservation and basic additional electricity access was defined as the main target of the action.

3.3.2 Diagnosis

Energy resources assessment

The preliminary information collected during the *Priority* phase, also through direct observation in the field, revealed that biomass and water resources are extremely scarce in the area. On the other hand, solar and wind resources were reported to be potentially interesting. In order to better assess the potential of both such resources, detailed data were collected and processed as described hereafter.

The potential of solar irradiation was assessed using the data from the SolarGis database from the Global Solar Atlas [274] (ESMAP / The World Bank), which provides high-resolution data of solar irradiation at the global level. As already mentioned before, the target settlement is located south of Tripoli, where the Global Horizontal Irradiation (GHI) is in the range 5.4-5.6 kWh/m^2/day (Figure 3.16). Given the fact that GHI varies in the range 1-7 kWh/m^2/day globally, the solar energy potential of the area of intervention is very promising.

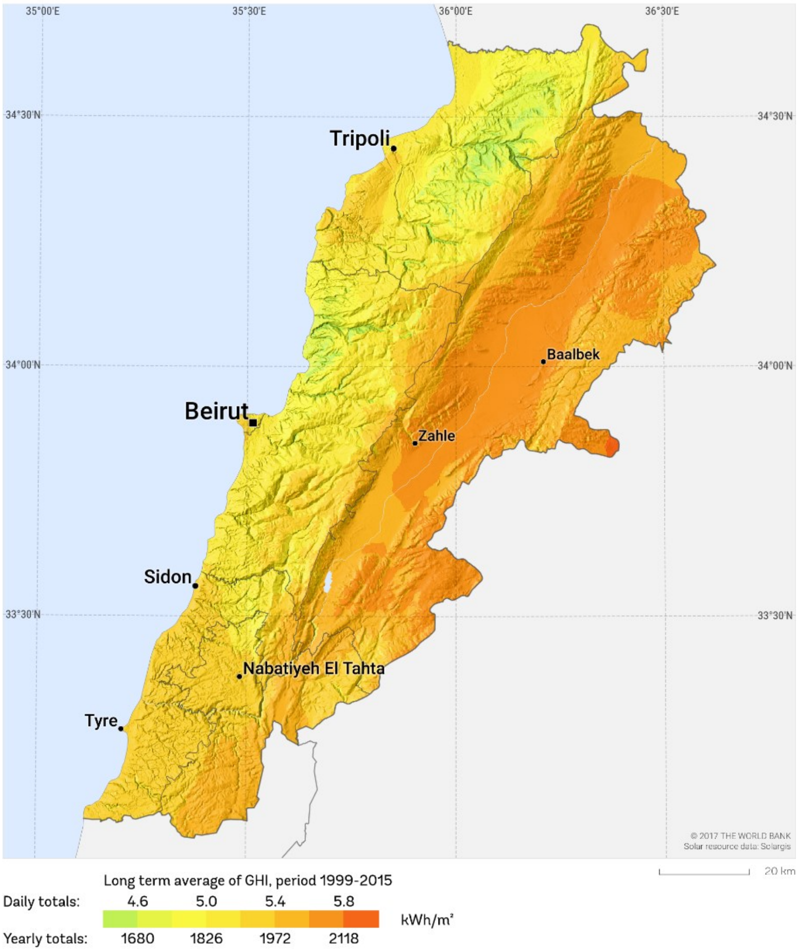

Figure 3.16 Global Horizontal Irradiation in Lebanon. *Source:* [274].

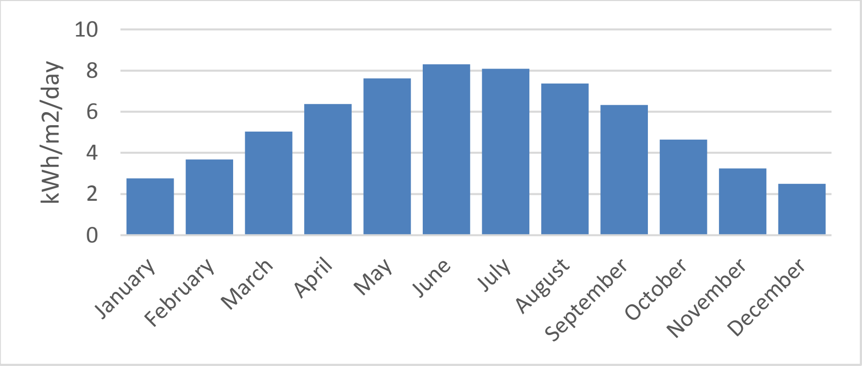

Figure 3.17 Monthly average Solar Global Horizontal Irradiance in the target site. *Author's elaboration of data from* [274].

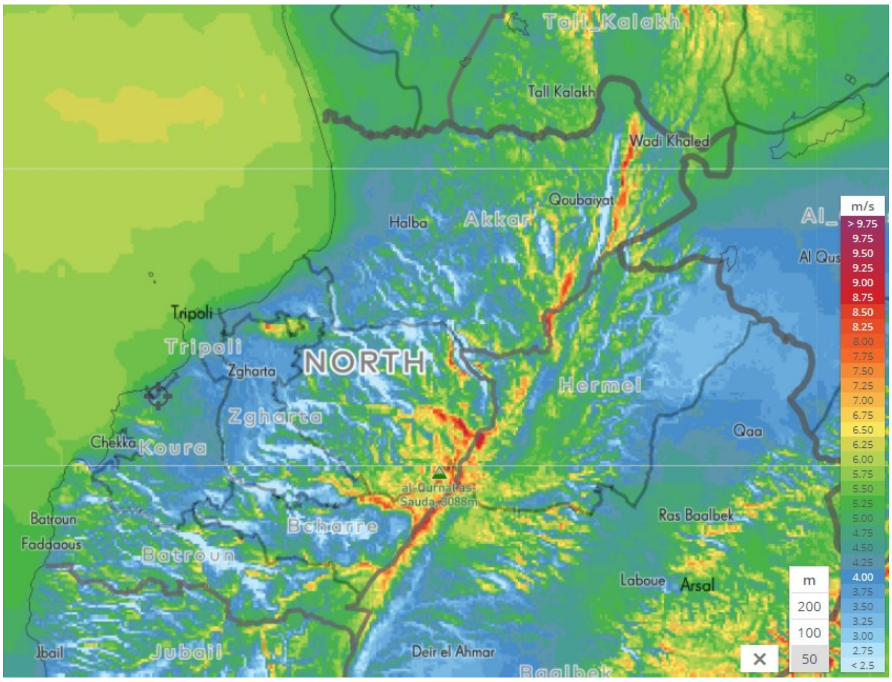

Figure 3.18 Wind speed in north Lebanon at 50 m from soil level. *Source:* [275].

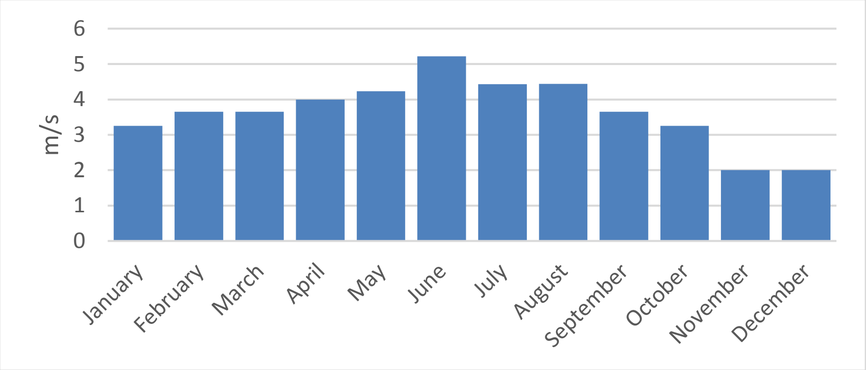

Figure 3.19 Wind speed in target location measured with a cup anemometer installed on rooftop. *Author's elaboration of SET4food data*.

The analysis of more detailed data from the same source permitted to draw the GHI yearly curve, showed in Figure 3.17, which provides sufficient details for the eventual design of a PV system.

As regards wind potential, a Global Wind Atlas is also made available online by the World Bank and the Technical University of Denmark [275] (Figure 3.18).

The data from the Wind Global Atlas revealed a mediocre potential of wind in the area of intervention, in the range 3-3.5 m/s. However, it is worth to recall that online wind data are available only at a minimum height of 50 m from the soil level. Such data are useful for the installation of medium to large size wind turbines, while do not provide sufficient information in the case of small systems. Moreover, the time and space resolution of such data is not sufficient to guarantee high accuracy of the analysis, being wind resource extremely dependent on the specific context (hills, surrounding buildings, trees and other obstacles may strongly influence the real potential of a given place), and potentially highly variable with the period of the year.

For this reason, a cup anemometer was procured and installed on the rooftop of the target building. Wind parameters were therefore monitored, initially for a period of three months, which was extended later on to one year.

The analysis of the data confirmed that the yearly average wind speed is near to 3.65 m/s. However, the monthly analysis also revealed that during summer wind speed can reach interesting values, especially in the period from May to August.

To complete the analysis, ambient temperatures were monitored as well. It was found that temperature varies in the range 10-30 °C, depending on the period of the year (Figure 3.20).

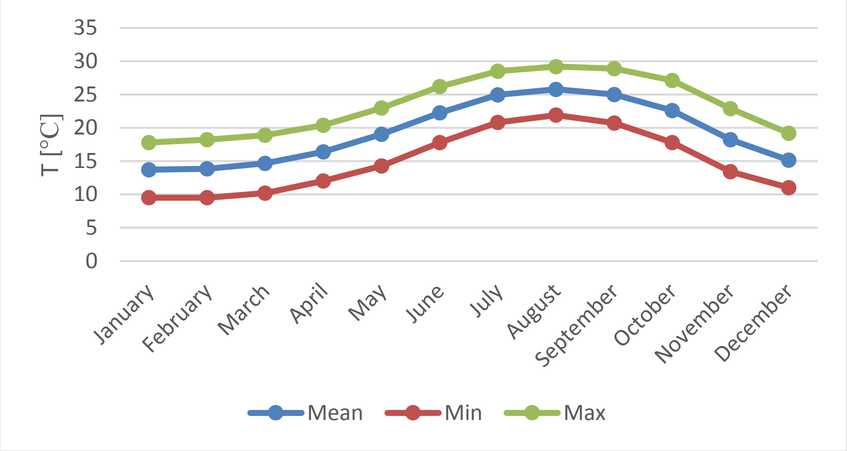

Figure 3.20 Ambient temperature over the year. *Author's elaboration of SET4food data*.

Estimation of energy demand and load profiles

As already mentioned before, the main objective of the pilot was defined as the provision to the community of reliable means for food preservation, and continuous electricity supply for basic uses, mainly phones and portable lamps charging.

Considering that the load due to refrigerators would have been a new one, not present at the moment of the assessment, and that the users behaviour as regards phones and portable lamps charging was most likely extremely biased by the discontinuous supply of the actual electricity service, the estimation of the overall electricity demand and load profile was particularly critical. In fact, no historical data were available to support such task. Therefore, at this stage a first round estimation was done by applying the classical formulation of daily energy consumption. Recalling it, daily energy consumption (E_C) for several users having several electrical appliances can be estimated as follows:

$$E_C = \sum_{j}^{User\ Class} N_j * \left(\sum_{i}^{Appliance} n_{ij} * P_{ij} * h_{ij} \right) \quad [Wh/day] \qquad (3.6)$$

where:

- *i* refers to the type of electrical appliances;
- *j* refers to the specific user class;
- *Nj* refers to the number of users within class *j*;
- *nij* refers to the number of appliances *i* within class *j;*
- *Pij* refers to the nominal power rate [W] of appliance *i* within class *j;*

- *hij* refers to the duration of the period the appliance *i* within class *j* is on [h] (i.e. functioning time).

In our specific case:

- appliances *i* could be: (1) refrigerator; (2) rechargeable light; (3) mobile phone;
- user classes *j* are constituted by refugees' families. To better represent the different behaviour of different families, the 120 families were divided into 6 different user classes. *Nj* was therefore equal to 20.

Regarding the appliances, the estimation of the load was done under the following assumptions:

- number of appliances for each family: one very small refrigerator (rated power: 20 W); one phone (rated power: 5 W); 15 lamps every 20 families (rated power: 10 W);
- *hij* was assigned randomly for the case of the refrigerators (11 h/day of functioning on average), while for the case of phones and lamps, it was assumed that they may be recharged in the interval from 8 am to 9 pm. Average duration of charge was assumed to be 3.5 h for the case of phones, and 3 h for the case of lamps.

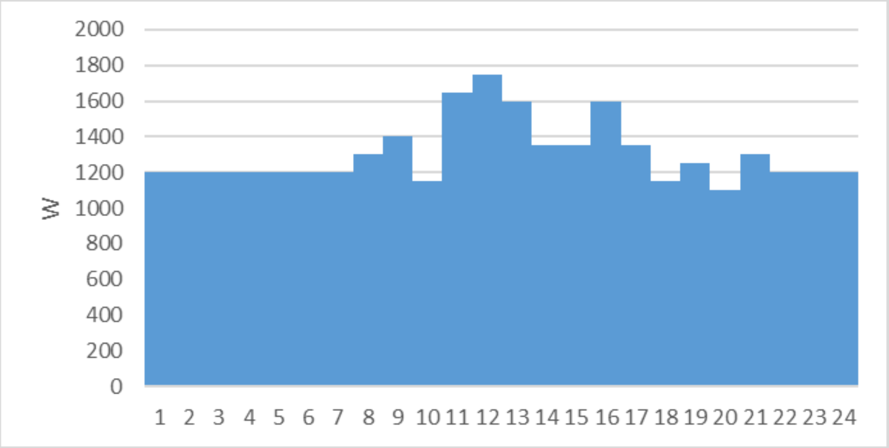

Figure 3.21 First-round estimation of the overall daily load profile. *Author's elaboration based on SET4food data.*

It is worth noting that E_C can also be computed on an hourly base, in this case considering n_{ij} as the number of appliances *i* within class *j* that are in use on a given hour of the day, and being h_{ij} always equal to 1. Such operation brings to the calculation of the overall consumption for each hour of the day, which allows identifying the overall load profile. In the specific case, the result of such operation can be observed from Figure 3.21, while the daily E_C resulted equal to about 25 kWh/day. From the figure, it can be observed that the refrigerators constitute the baseload, causing a consumption that is about constant all over the day, with a total power of about 900 W, while the charging operations of phones and lamps cause the peaks in the load curve.

Thanks to the fact of only considering basic devices, the resulting estimated load profile presents a peak of 1750 W only, which is fully compatible with a small-size renewable power system. However, it is also noticed that there is a constant baseload also during night time. In fact, the presence of a significant load due to refrigerators makes the load profile quite peculiar compared to the typical curve that may be computed in other similar contexts.

3.3.3 Strategy and comprehensive design

The results achieved during the *Priority* and *Diagnosis* phases allowed to proceed with the definition of the overall intervention strategy and to the comprehensive design of the energy system.

Definition of the overall strategy

In terms of loads, the portable lamps and the mobile phones were already in use among the refugees, as previously described. On the other hand, the provision of the refrigerators constituted an integral part of the pilot project. In this regard, two main different configurations would have been possible:

(i) provision of a small refrigerator to each family, i.e. procurement and installation of a small refrigerator to each household or group of households with common relatives, connection of each refrigerator to the new power system, and installation of an electric plug in each shelter to recharge phones and portable lamps;

(ii) installation of a limited number of community refrigerators in a common area of the building, and of multiple plugs for recharging phones and portable lamps, to be shared between all the beneficiaries.

The first option presents the advantage of ensuring the independence and autonomy of each family in the management of the refrigerator; however, the grade of complexity for the implementation would have been very high. In fact, given the dangerous conditions of the electric wiring in place, for safety reasons the option of using the existing electrical wiring had to be excluded. Consequently, any configuration including the utilization of devices within each shelter would have required putting in place a new wiring system throughout the whole building, with a consequent increase of the overall costs of at least 100% compared to the cost of the refrigerators only. On the other hand, the second option presented obvious advantages in terms of logistics, procurement and installation, since a small number of large refrigerators could be easily placed in a designated area and connected to the new power system. Even if the idea of having one refrigerator for each family was indicated as the most preferred, the proposal for community refrigerators was also positively evaluated by the beneficiaries, provided that each family or group of families could have access to a private compartment.

Table 3.7 Single-family vs community refrigerators. *The Author, based on SET4food data*.

	One small refrigerator for each family	**Community refrigerators shared by families**
Beneficiaries' grade of acceptance	+ +	+
Avoided risk of conflicts	+ +	-
Overall reliability	+	+ +
Energy efficiency	-	+ +
Logistics	- -	+
Overall cost	-	+
Possibility of adding thermal storage	- -	+

+ + Very good; + good; - bad; - - very bad

Table 3.8 Off-grid vs on-grid power system strategy. *The Author, based on SET4food data.*

	Off-grid system	**On-grid system**
Power injection	- -	+ +
Optimization of power production	-	+ +
System reliability	+ +	-
Authorization process	+	- -
Feasibility within project boundaries	+	-
Design easiness in the specific context	+	-

+ + Very good; + good; - bad; - - very bad

Based on the previous considerations, the second configuration (community refrigerators) was finally selected as the most feasible and innovative. Table 3.7 provides a summary of all the aspects considered in the comparison, and the associated qualitative evaluation.

Looking at the new power system, instead, the following different options were considered:

(i) Grid-connected system
  a. single source: solar PV;
  b. single source: wind;
  c. hybrid PV-Wind.
(ii) Off-grid autonomous system
  a. single source: solar PV micro-grid;
  b. single source: wind micro-grid;
  c. hybrid PV-Wind micro-grid.

Given the nature of the target settlement, and in particular the structure of the building, no standalone option (such as the provision of stand-alone micro-PV systems to each family) was reasonable, nor practically feasible. For this reason, such systems were not included in the evaluation.

Moreover, it is worth noting that any options considering the presence of a diesel genset were excluded a priori due to the following reasons: (i) impossibility to guarantee the continuous supply of fuel to the area of intervention due to logistic and external constraints, (ii) very high cost of continuous power generation with small gensets, and, (iii) diesel technology out of scope of the project, since the pilot aimed at testing innovative solutions in the target context.

In general, all the grid-connected solutions would have opened the pilot to the possibility of injecting the energy surplus into the grid. On the other hand, the interconnection would have exposed the new system to possible damages due to voltage fluctuations from the grid, and required a very long and complex authorization process, incompatible with both the time constraints of the project and the nature of the settlement itself. Therefore, the off-grid configuration was selected as the most suitable option (Table 3.8 provides a summary of all the aspects considered in the comparison, and the associated qualitative evaluation).

Final definition of loads

The comprehensive design started with the design of the community refrigerators. In order to simplify the logistic aspects, only components already available in the Lebanese market were considered in the design, which allowed to define specifications for a tender for the assembly, procurement and installation. The biggest available refrigerators suitable for normal transport vehicles were selected, with a capacity of 700 litres. Each refrigerator was modified by dividing the internal space into eight independent and lockable compartments of about 90 litres. In such way, it was possible to assign a private compartment to single households or small groups of households, as requested by the beneficiaries. Ideally, 14 refrigerators would have been required in order to assign a compartment to each single household. However, in such case, the overall expense would have overcome the available budget (about 25,000 USD). On the other hand, the information collected during the assessment showed that every compartment could be shared between two households on average, due to the presence of common relatives. Therefore, the optimal number of refrigerators resulted to be seven, in order to both match the budget constraints and meet the needs of the beneficiaries. The technical specifications of the refrigerators are reported in Table 3.9. It is worth noting that each refrigerator was designed to work also in the case of discontinuous power supply by integrating a eutectic plate, which extends the thermal capacity of the system.

Table 3.9 Technical specifications of the refrigerators. *The Author, based on SET4food data.*

Unit cost	3000 USD
Type	Vapour compressor
Dimension	72 x 79 x 205 cm
Capacity	700 litres
Number of lockable compartments	8
Temperature controller	Digital thermostat
Temperature	-2/+8°C
Peak power absorption	350 W
Rated power absorption	250 W
Voltage	230 V/50Hz
Thermal storage accumulation	870 Wh
Thermal storage surface	0.94 m^2

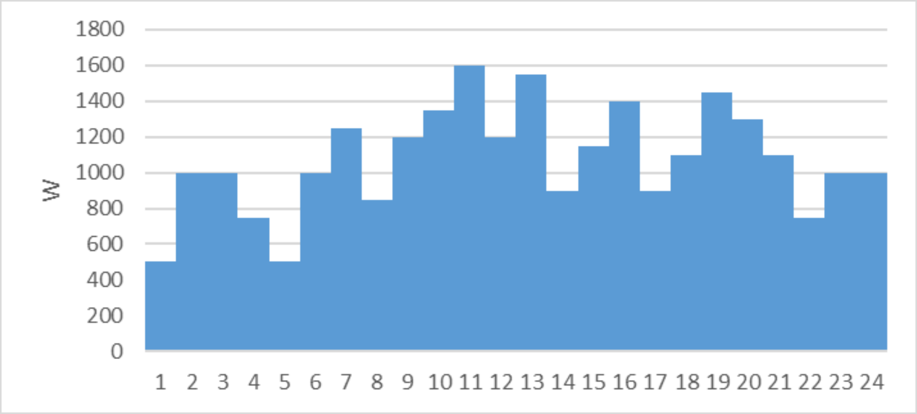

Figure 3.22 Second-round estimation of the overall daily load profile using the model applied for the first-round estimation. *Author's elaboration based on SET4food data.*

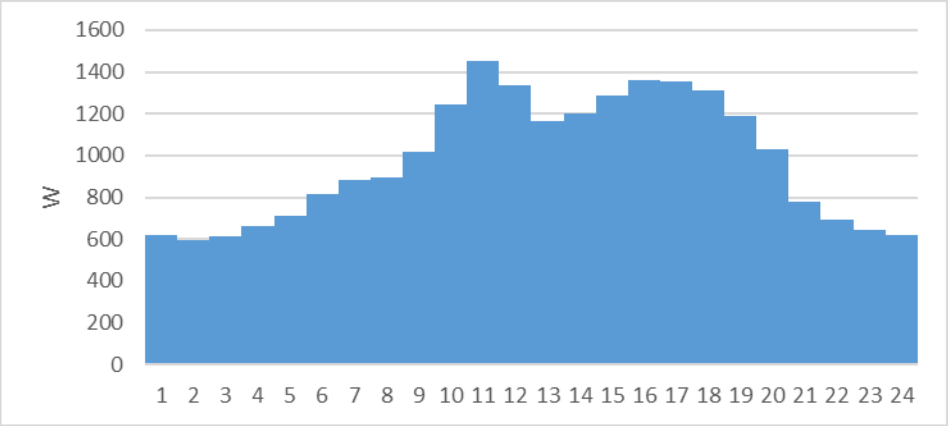

Figure 3.23 Final estimation of the overall daily load profile using the refined model.
Author's elaboration based on SET4food data.

This additional thermal storage permits to maintain the internal temperature for several hours in the case of blackout. The idea of providing the additional thermal capacity was due to two main considerations: (i) the experimental nature of the pilot, which tested innovative solutions in a very challenging and unpredictable context, and (ii) the assumption that allowing an annual shortage capacity in the range 10-15% for the new power system would have significantly reduced the costs respect to a system with negligible probability of power shortcuts. Such hypothesis has been verified later on through a sensitivity analysis, as explained in the next paragraphs.

The definition of the technical specifications of the refrigerators allowed for a second round, more detailed estimation of the overall load profile, to be used as input parameter for the design of the power system. In fact, the initial hypothesis of having one small refrigerator (rated power 20 W) for each family was substituted by the scenario selected in reality (7 community refrigerators). The new simulation for the load profile was performed by adopting a 2-steps approach: a first simulation was done by applying the same model used for the first-round simulation (low level of randomization introduced by defining 6 different user classes with different behaviours). Figure 3.22 shows the result of the simulation: the presence of 7 community refrigerators instead than 120 small ones causes a change in the shape of the curve, and allows to estimate 20% savings of the total daily energy consumption. The estimated maximum peak power is also reduced to 1600 W compared to the previous figure of 1750 W.

A further simulation was run as a second step to refine the estimation, using the advanced RAMP model, which has been specifically defined to simulate multiple energy loads for systems in critical areas. The results are shown in Figure 3.22. Compared to the previous one, the main difference is due to the introduction of advanced randomization functions to better simulate the behavior of multiple users using multiple appliances, which allows to better predict the overall shape of the load curve as well as the expected value of peak loads [193].

Selection of the model and input parameters

At this point, the possible scenarios were reduced to an off-grid autonomous system powering 7 community refrigerators and multiple-socks recharging stations for small devices (phones and portable lamps), configured as:

i. single source, solar PV, or
ii. single source, wind, or

iii. hybrid PV-Wind.

The identification of the best option was done through a comparative techno-economic analysis using the HOMER® (Hybrid Optimization of Multiple Electric Renewables) software. As already cited in paragraph 0, HOMER is a tool for the techno-economic design of stand-alone or interconnected small-scale energy power systems. It allows to determine the feasibility and optimization of renewable and non-renewable technological options [276].

An overall scheme of the HOMER® optimization procedure is reported in Figure 3.24. As evidenced in the figure, the software requires several input parameters, including technical specifications, cost of all the components, and meteorological or renewable resources data form the area of intervention. As a second step, the software is able to simulate and optimize a single source or hybrid system, thanks to a techno-economic model of the different selected technologies and components.

In particular, the software operates according to the following main steps:

i. simulation of the system operation by calculating the energy balance for one year (8760 hours)
    - comparison of loads in a given hour of the day to the energy that the system can supply in that hour;
    - calculation of energy flows to and from each component of the system;
    - setting of the dispatch strategy;

ii. determination of the feasible configurations, i.e. when resources-demand matching is possible under user defined conditions;

iii. estimation of the cost of installing and operating the system over its lifetime, and estimation of the net present cost (NPC) of the system.

The optimization and sensitivity phases, instead, allow to:

i. simulate all the possible system configurations;

ii. produce a list of configurations sorted by net present cost;

iii. repeat the optimization process for each sensitivity variable (if defined).

The main equations implemented in HOMER®, which are relevant for the case here in analysis, are reported in Annex E.

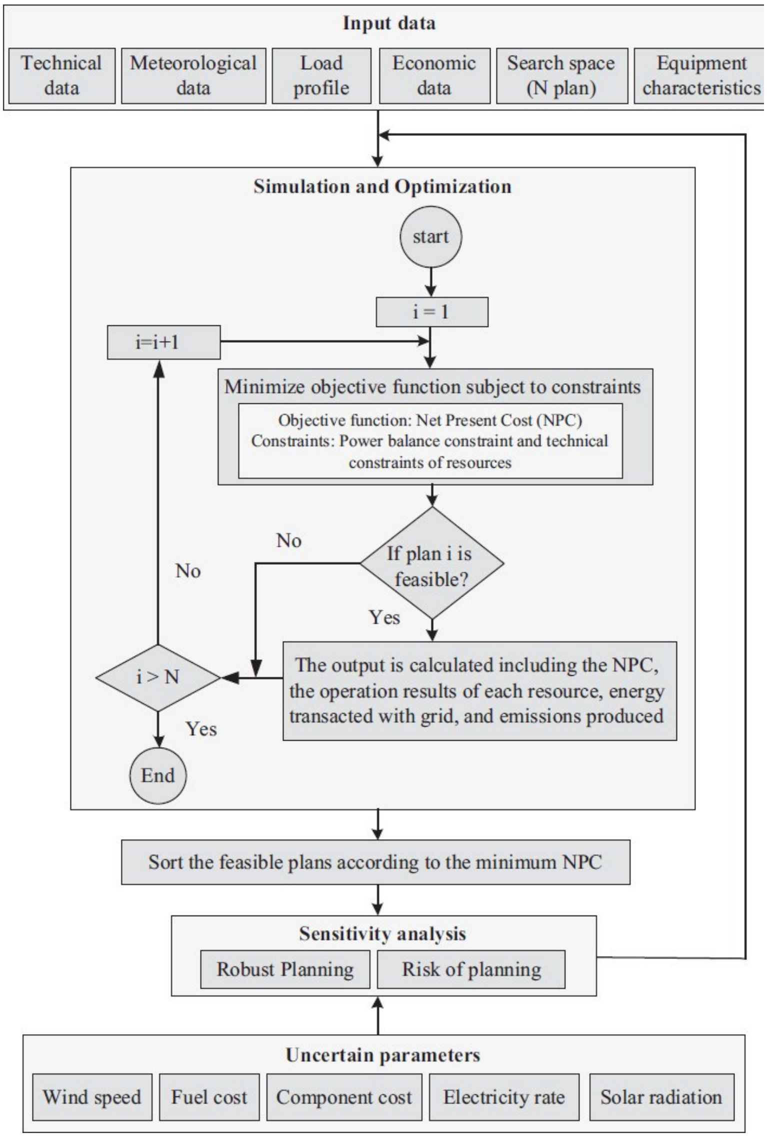

Figure 3.24 Overall scheme of the HOMER® optimization procedure. *Source:* [277].

Table 3.10 Reference techno-economic parameters of the main components. *The Author, based on SET4food data.*

	PV array	**Wind turbine**	**Battery**	**Converter**
Reference size	260 W	2.5 kW	1.87 kWh	3 kW
Capital cost	2100 USD/kW	6000 USD/kW	280 USD	2000 USD/kW
O&M cost	-------------------------- 50 USD/y --------------------------			
Life time	25 yrs	20 yrs		15 yrs
Other info	De-rating factor 80%		Type: Lead Acid GEL	Efficiency: 93%

Concerning meteorological data, the distribution of the resources assessed during the diagnosis phase (solar and wind) were used in the model, while the loads where computed following the final-round estimation of the load curve (Figure 3.23). On the other hand, reference costs and technical details of the main components were assessed in the Lebanese market by COOPI's local staff and are reported in Table 3.10. Moreover, the overall project lifetime was set at 10 years, and inflation rate to 2.47% (5-yrs average historical inflation rate in Lebanon). Annual capacity shortage was allowed up to 12%, in order to reduce the overall costs, because the refrigerators were equipped with additional thermal storage, as previously described.

Simulation and comparison of the different systems

The three system configurations defined as alternative scenarios were simulated using the data previously presented, in order to be compared. The summary results are presented in Table 3.11.

Before commenting the results, it is worth reporting that in all cases the converter was oversized to 3 kW in order to (i) prevent damages or malfunctioning of the system in case of occurrence of eventual peak power higher than expected in special occasions, and (ii) allow an eventual future increase of capacity of the system. The economic impact of this choice is minimal (overall initial capital variation equal to 2.5% in the worst case).

Table 3.11 Summary results for the different system configurations. *The Author, based on SET4food data.*

	PV only	**Wind only**	**Hybrid**
PV size [kW]	7.5	-	6
Wind size [kW]	-	25	2.5
Batteries 156Ah	48	36	32
Converter* [kW]	3 (1.6)	3 (2.4)	3 (1.5)
NPC [USD]	27,316	67,640	25,273
COE [USD/kWh]	0.31	0,77	0,28
Initial Capital [USD]	35,784	166,080	43,713

*All economic results referred to oversized inverter configuration. Theoretical optimized converter size in brackets.

As expected, the wind-only configuration represents the worst case. In fact, the diagnosis phase showed that the wind resource is in general scarce, especially during winter. As a result, the wind-only system requires a very big installed generation capacity (25 kW) in order to meet the demand. All economic parameters grow consequently, making the system uneconomical. This configuration was therefore rejected immediately. The PV-only configuration appears much more feasible, resulting in a system equipped with 7.5 kW of PV panels, which drops down the Net Present Cost (NPC) of 60% compared to the wind-only option, and requires an initial capital of around 35,000 USD. The hybrid configuration, on the one hand requires an extra 20% of initial capital, but on the other hand presents the advantage of a reduced PV surface, and a reduction of 50% of the storage capacity. This second fact is particularly interesting, given the fact that batteries are the most critical element of this kind of systems, especially in critical contexts where regular maintenance may represent a challenge. Moreover, cost of energy (COE) is reduced by 10% compared to the PV-only solution. In addition to such advantages, it is worth recalling that the idea of piloting innovative, nontraditional solutions, constituted one of the main elements at the basis of the SET4food project.

Based on such considerations, the hybrid solution was selected as the most suitable to both meet the needs of the beneficiaries, and the objectives of the pilot.

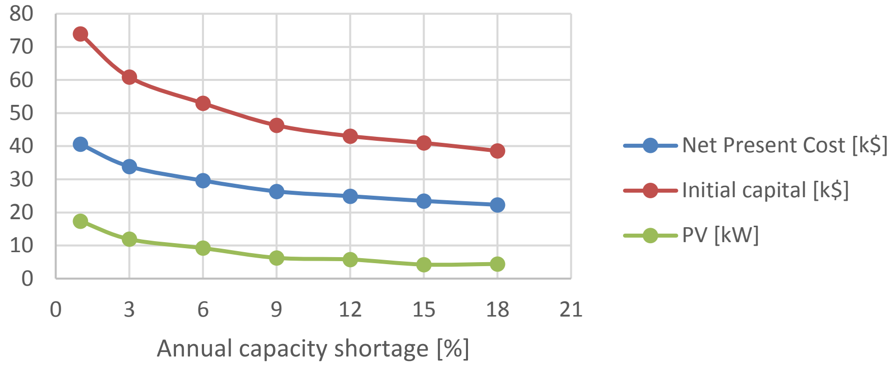

Figure 3.25 Sensitivity analysis varying the annual capacity shortage. *The Author, based on SET4food data.*

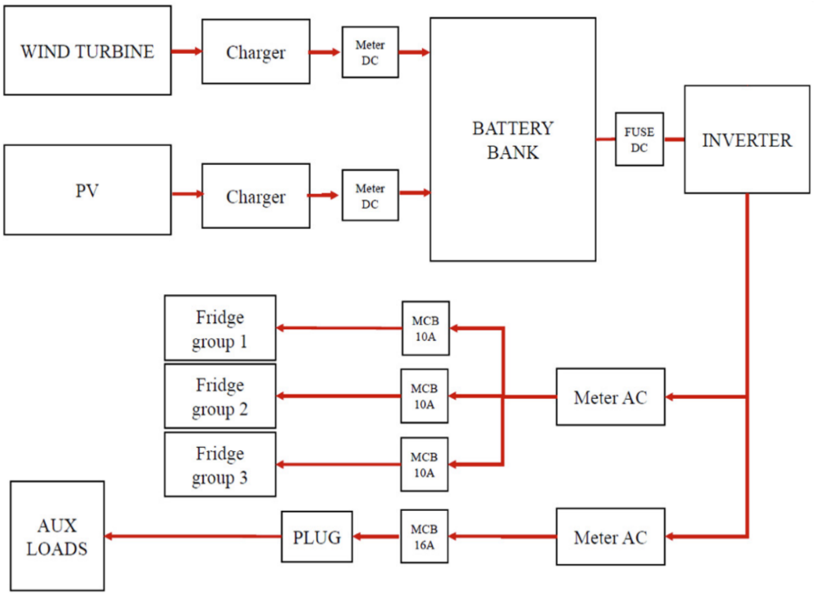

Figure 3.26 Final scheme of the micro-grid. *Credits: SET4food\UNESCO Chair E4SD.*

As already mentioned, all the configurations were compared allowing an annual capacity shortage up to 12%, in order to significantly reduce the overall initial capital expenditure. This value represents the best compromise between cost reductions and an acceptable level of service interruptions. A sensitivity analysis was carried out in order to verify the effect of this choice for the case of the selected hybrid configuration. The graph in Figure 3.25 shows the effect of varying the annual capacity shortage in the range 0-18% on three selected parameters (NPC, initial capital and PV installed power). It is possible to observe that an increment of 3% of capacity shortage brings significant effects on all selected parameters within the range 0-9%, while the effect starts to be less accentuated from a shortage equal to 12% or more. For example, a shift from 0% to 6% of allowed capacity shortage causes a reduction of almost 30% of the required initial capital, and a shift from 6% to 12% corresponds to a further reduction of 19%, while a shift from 12% to 18% has a reduction effect of 10% only. Moreover, it is possible to observe that the initial capital is reduced by almost 60% when a 12% annual shortage is allowed, compared to the 100% reliable case (0% of annual shortage capacity).

Concerning the selected system, Figure 3.26 shows the final configuration of the micro-grid, including all the system's components and the loads (refrigerators and plugs for auxiliary loads, i.e. phones, rechargeable lamps, and any other similar appliances). Some meters were added to the overall system in order to monitor the system during its operation.

Table 3.12 Technical specifications of the components used in the microgrid. *The Author, based on SET4food data.*

PV modules and MPPT	**Wind turbine**	**Batteries**	**Converter**
Model: Philadelphia Solar M60-260 Maximum Power: 260 W Type: mono-crystalline Efficiency: 15% # of installed units: 22 MPPT: OutBack FlexMax 60 Power: 3 kW @ 48 Vdc # of installed units: 2	Model: Proven WT2500 Rated power: 2.5 kW Type: downwind, self – regulating, 3-blades Cut-in speed: 2.5 m/s Generator: Brushless, direct drive, permanent magnet	Model: Ritar DG12-180 Capacity: 156 Ah @ 12 V Type: deep cycle GEL # of installed units: 32	Model: OutBack GVFX3048E Nominal input: 48 Vdc Continuous Power Rating: 3 kVA Efficiency: 93%

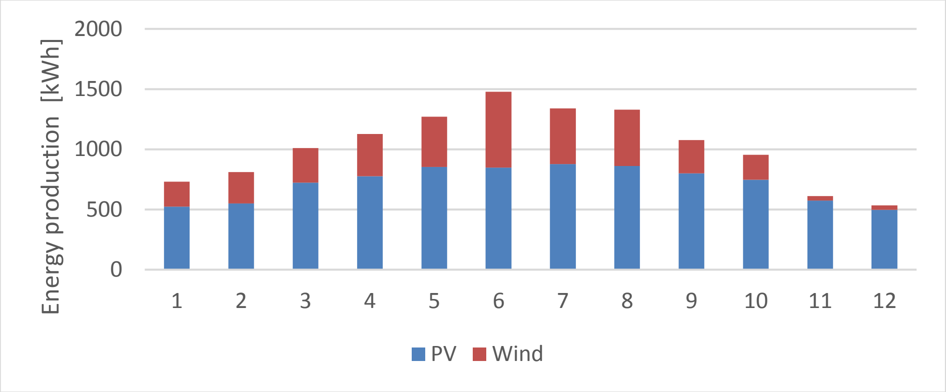

Figure 3.27 Monthly energy production. *Author's elaboration based on SET4food data.*

The technical specifications of the final components used to build the system are given in Table 3.12.

Finally, Figure 3.27 shows the expected energy production. The contribution of both PV and wind vary along the year according to the resources availability. The main contribution is given by solar, while the one of wind is significant during summer, but less interesting during wintertime, as expected.

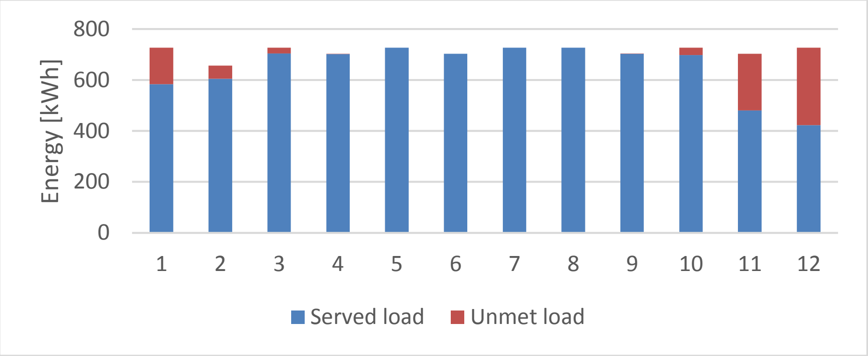

Figure 3.28 Monthly consumed energy and unmet load. *Author's elaboration based on SET4food data.*

In terms of energy consumptions, the analysis allows to identify when it is not possible to reach a full matching between production and consumptions, due to possible capacity shortages: from Figure 3.28 it is possible to notice that the loads are not fully met mostly during nighttime in winter, when the production capacity of the system reaches the minimum. However, it is worth noting that in such periods the ambient temperature is quite low in the target location, which helps to maintain an acceptable temperature inside the fridges, in positive combination with the effect of the additional thermal storage.

3.3.4 System implementation and results

Figure 3.29 PV array and wind turbine on the rooftop. *Credits: the Author.*

Figure 3.30 Inverter and MPPTs. *Credits: the Author.*

The procurement, provision and installation of the overall system was assigned to a local contractor in Lebanon, which received the detailed specifications defined according to the study developed in the previous phases. Figure 3.29 and Figure 3.30 show the PV array and the wind turbine installed on the rooftop, and the controllers including the inverter and the MPPTs, while two of the refrigerators are shown in Figure 3.31.

Figure 3.31 Two of the installed refrigerators. *Credits: the Author.*

The system was put in place as required in the tender; however, its performances were lower than expected, due to the utilization of some components non-compliant with the required technical specifications. In particular, three technical problems were identified:

- Overall energy consumption of the refrigerators exceeding the requirements;
- Capacity of the additional thermal storage (eutectic plates) less than required;
- Power generated by the wind turbine very scarce, due to both the utilization of a controller presenting scarce compatibility with the other components of the micro-grid, and the utilization of a turbine that had been in stock for a long time in place of a new one, as originally required by the tender, which probably caused a partial deterioration of its performances.

Moreover, some beneficiaries started almost immediately to plug some unidentified extra heavy loads by adding artisanal wiring to the system.

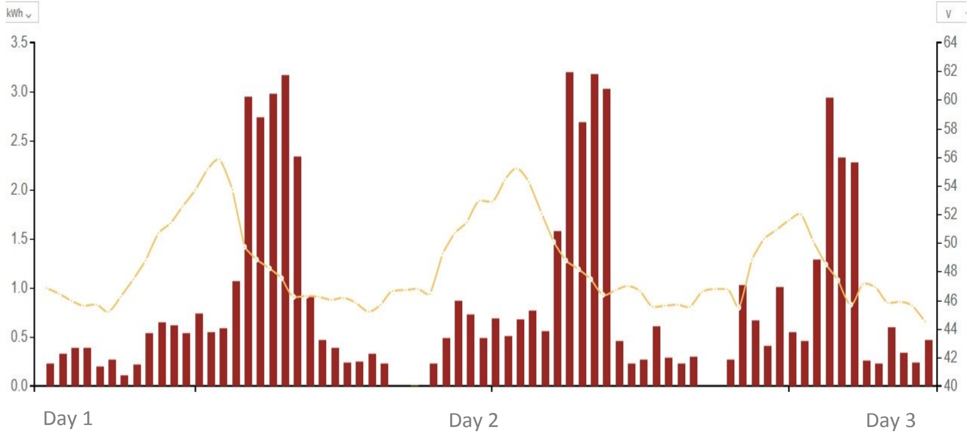

Figure 3.32 Power system under stress due to reduced production capacity and heavy loads (hourly power on the left axis, indicated by the red bars; Voltage of batteries on the right axis, indicated by the yellow line). *Credits: SET4food/UNESCO Chair E4SD.*

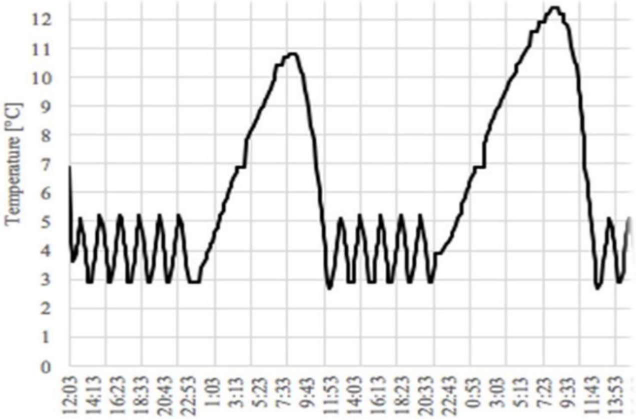

Figure 3.33 Internal temperature trend in one of the fridges due to cyclic power cut-offs (two days period, time of the day on the x-axis). *Credits: SET4food/UNESCO Chair E4SD.*

All such problems together caused a high instability in the operation of the system. This was evidenced by unexpected values of power absorption and production such as those reported in Figure 3.32 for three consecutive days as an example.

In particular, in the figure it is possible to see that the loads (red bars) reached power peaks up to 3 kW, which is a value double respect to the one of design. The energy produced by the system was not sufficient to fully meet such demand, resulting in fast deep discharge of the batteries (yellow line, values below 47.5 V indicate very low charge status of the batteries). During night hours, the voltage was reaching the minimum set point, causing the disconnection of all the loads (in particular, the refrigerators) until the first hours of the following morning, when extra power was again available from the PV array. Luckily, this problem had a limited effect on the performances of the refrigerators, thanks to the presence of the extra thermal storage. Inside temperature in fact tended to arise during nighttime, but was not reaching excessive values (Figure 3.33).

In order to mitigate the incurred problems and reach an acceptable level of performance of the system, the following actions were put in place:

- Substitution of the compressors of the refrigerators with others fulfilling the technical specifications defined in the tender;
- Substitution of one of the batteries that resulted damaged, and re-calibration of the lock-in and lock-out levels of the storage system;
- Reset and reprogramming of the controller of the wind turbine;
- In-depth discussions conducted by the local staff of the project with the beneficiaries, explaining that artisanal connections could damage the system and constituted a serious safety risk.

Thanks to such interventions, the system finally started to work properly. Figure 3.34 and Figure 3.35 present some details on the system after the interventions: in the first figure, a three-day period in January is showed. It is possible to see that the peak loads are in line with the project values, and that voltage of the batteries is always above 48 V. Moreover, wind production is also visible in the graph (green bars). In the second figure the total production and consumption over a period of 30 days in between January and February is also showed. Also in this case, the daily energy consumption is in line with the project values estimated in the diagnosis phase, and the system is able to match the demand with the production.

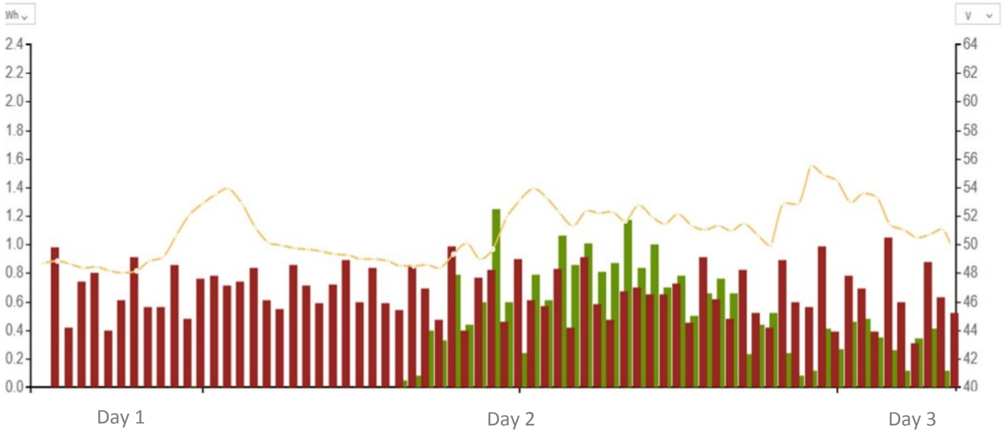

Figure 3.34 Power system correctly operating (hourly power on the left axis, indicated by the red bars; Voltage of batteries on the right axis, indicated by the yellow line; Detail on power from wind indicated by greed bars). *Credits: SET4food/UNESCO Chair E4SD.*

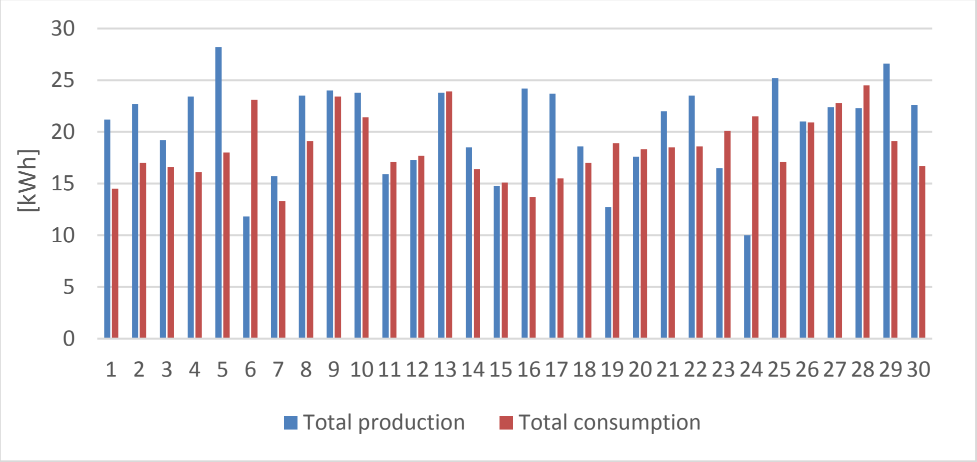

Figure 3.35 Total daily energy production and consumption after fixing the incurred problems. *Author's elaboration based on SET4food data.*

As already anticipated in the strategy and design phase, 56 compartments in total were available in the refrigerators. Clearly, the assignment of each compartment to one or more beneficiary family represented a delicate operation. Thus, previously indicated delegates of the community were appointed to lead this task, in order to ensure a fair and equitable solution. Such delegates also played the role of contact point to interact with the local staff involved in the project in case of any problems related to the system.

Considerations on the overall system and feedback from the beneficiaries

The overall final cost of the system was 78,700 USD. The costs associated to the refrigerators accounted for about 30,000 USD (i.e. about 4,200 USD for each unit, including transport and installation), while the expenditure for the power system was around 49,000 USD. A comparison with the European market shows that the unit cost of the refrigerators was very high (a refrigerator of similar capacity can be found in the market for about 1,200-1,700 USD). However, it is important to remind that the refrigerators were modified according to the custom requests, including the additional thermal storage and the supplementary lockable internal partitions. Moreover, the general prices in the Lebanese market are much higher compared to other contexts. It is reasonable to consider that such prices were also determined by the pilot nature of the action: the price of the refrigerators would have been significantly reduced in case of a scale up of the action and of an increase in the number of purchased items.

The overall cost of the power system was also quite high in absolute terms, with an investment of 5760 USD/kW of installed generation capacity. However, such order of magnitude is fully comparable with the case of other off-grid micro-grids installed in development contexts[11]. A study carried out by the World Bank ESMAP indicates overall capex including installation costs in the range 3,000-12,000 USD/kW for the case of solar PV micro-grids, while IRENA reports capex up to 5,000 USD/kW for distributed PV systems [278], [279]. In particular, the study from the World Bank reports a capex of 5850 USD/kW for the case of a PV micro-grid in Palestine, which is a very good term of comparison for the SET4food case in Lebanon. Of course, it is also very important to keep in mind that the system put in place by SET4food is a hybrid PV-wind system, which increases the overall complexity and likely, the overall fixed costs (as indicated in the previous sections, the cost of the wind turbine and its controllers alone was 15,000 USD).

Given the very peculiar nature of the action and of the main objective of the pilot, i.e. a first tentative exploration of the potential of comprehensive innovative energy systems in humanitarian settings, and the fact that the overall cost was covered by a grant from the European Commission's Humanitarian aid and Civil Protection department (ECHO), no tariff setting scheme was put in place, and the beneficiaries received the electricity for free. However, it is interesting to make some consideration as regards the economic sustainability of the system. The simulation with HOMER® allowed to estimate a cost of energy (COE) equal to 0.28 USD/kWh for the system over a 10 years' lifespan. In comparison, average cost of energy in Lebanon is reported around 0.11 USD/kWh by official channels of the Government[12]. In absolute terms, therefore, the unit generation cost is more than double, however it is important to recall that (i) the resulting COE is strongly influenced by the hypothesis on the overall system lifespan (the longer the lifespan, the lower the COE), and (ii) that the main energy consumption are here associated to a community service (refrigerators). Considering the estimated overall daily consumption of about 25 kWh, it is possible to compute an average monthly consumption of 750 kWh, and a corresponding energy expenditure equal to 1.75 USD/month/HH, which would be a reasonable result compared with the average income of the refugees in the settlement.

Turning the analysis on the feedback from the beneficiaries, as previously reported, the system was not properly operating during the very first period after the installation. This fact obviously caused some negative feedbacks from people, that noticed that the system was frequently disconnecting the fridges and the other loads.

After the major problems were fixed, however, the feedback started to be much more positive. In fact, based on a sample of 30 families (Table 3.13), the beneficiaries reported an overall improvement in household economy and lifestyle. 97% of respondents declared they could better meet their overall energy needs, and 67% felt having new

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[11] Other micro-grids installed in humanitarian settings would represent a better term of comparison, however no study is available on power systems costing in such situations, therefore the context of developing countries has been assumed as the most similar.

[12] http://investinlebanon.gov.lb

opportunities due to the new technologies, even if no one agreed on the fact of having introduced new energy uses (for example, new electric devices).

Table 3.13 Performance of selected change perception indicators. *Author's elaboration of SET4food data.*

Category	**Indicator**	**Description**	**% of positive answers**
Energy	Energy needs	Do you think that now you better meet your energy needs due to a better energy availability?	97%
	New energy consumption	Have you introduced any new use of energy (including electrical energy)?	0%
	Opportunity from energy	Do you think that now you have new opportunities due to the new technologies introduced?	67%
Food consumption	Nutrition	Do you think that your feeding has been improved from a nutritional point of view since the introduction of new technologies?	40%
	Diet variety	Has your household diet varied due to the introduction of new technologies?	3%
	Food purchased	Has your grocery shopping changed due to the introduction of new technologies?	20%
	Food safety	Do you think that food preservation has been improved due to the introduction of new technologies?	80%
	Satisfaction	Are you happier about the food you consume now?	80%
Other aspects	Shopping frequency	Have you reduced your shopping frequency due to the introduction of new technologies?	17%
	Security due to lighting	Do you feel safer due the improved means of lighting?	100%
	Economical aspects	Do you think that your family expenditures decreased or are more efficient due to the new technologies?	30%
	Health	Do you think that your family health improved due to the new technologies?	50%
	Change simplicity	Was the introduction of new technologies simple?	100%
	Cultural compatibility	Do you think that the new technologies are in compliance with your culture?	100%

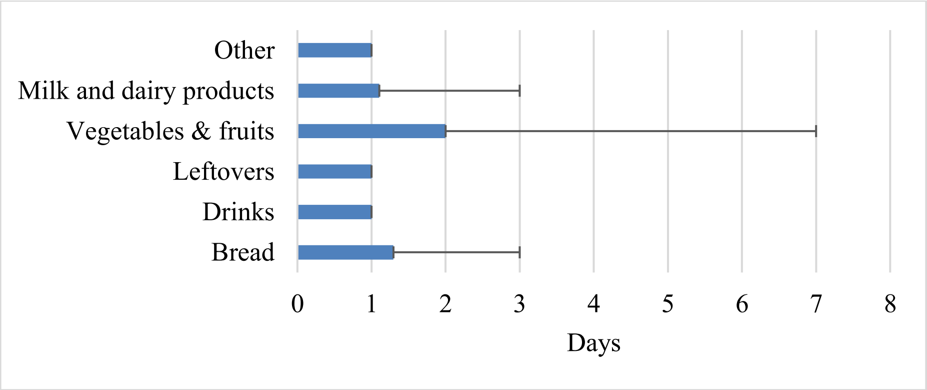

Figure 3.36 Average preservation time declared by the beneficiaries for different foods (error bars represent the maximum observed value). *Credits: SET4food/UNESCO Chair E4SD.*

Figure 3.37 Examples of preserved food by different families. *SET4food/COOPI.*

Table 3.14 Average daily openings of the refrigerators' doors, over a monitoring period of 8 months. *Author's elaboration of SET4food data.*

	Ref. 1	**Ref. 2**	**Ref. 3**	**Ref. 4**	**Ref. 5**	**Ref. 6**	**Ref. 7**
Average daily openings	8 (4.85)	15 (10.35)	16 (8.52)	18 (12.05)	12 (6.33)	15 (9.37)	26 (17.19)

Standard deviation in brackets.

In general, all the new technologies were considered simple to use and compliant with the culture of the beneficiaries.

The improved means of lighting (in this case, improved possibility to recharge lamps) increased the feeling of safety.

Regarding food preservation, 80% of beneficiaries reported that the refrigerators improved their possibilities for food preservation. Some of them specified that refrigerators allowed to store food for a longer period in a safer and healthier way (which is confirmed by the fact that 50% of the respondents agreed on the fact of perceiving an improvement of family health). In fact, refrigerators were mostly used to store beverages, bread, yogurt and labneh (a sort of local fresh cheese). Food leftovers were preserved as well, to be consumed later on, especially by women and children. The graph reported in Figure 3.36 shows the average preservation time declared by the beneficiaries for different foods, while some pictures of preserved foods are provided in Figure 3.37. In particular, some of the beneficiaries declared that "bread is less often thrown away since it is stored in the fridges" and that "cooked food is not thrown away anymore because now it can be stored in the fridge". In fact, 30% of respondents declared that the new systems contributed to reduce the overall HH expenditure, which is likely to be associated with food savings.

Some households also reported that the use of refrigerators changed the composition and frequency of grocery shopping (20% and 17% of cases, respectively). On the other hand, diet variety remained the same in most cases.

In addition to qualitative data collection, sensors measuring the number of openings of the doors were installed in each refrigerator, to get a proxy measure of their rate of utilization. The results showed that the frequency of utilization was about twice per day per family (Table 3.14 considering that each refrigerator was divided into 8 compartments).

The fact that the system was owned by a management committee chosen by the refugee community represented a critical point. In fact, the committee was changed many times due to the high rate of mobility of the refugees. Also, the power system could only cover the very basic energy needs of the community, due to the huge number of households in the settlement. Moreover, the difficulties experienced during the procurement and installation of the systems due to the limited experience of local suppliers showed that materials and expertise in the field of complex renewable energy systems are not always locally available, nor sufficiently reliable.

Lessons learned

On the technical point of view, the pilot experience shows that, technical expertise is essential, but is not sufficient to properly design a complex system such as a micro-grid, especially in a very challenging context such as in humanitarian settings. The application of the CESP framework allowed to consider both technical and non-technical parameters, leading to the successful development of the pilot.

In addition, the following specific considerations which come from the field are worth to be added. Independently of the specific configuration, hybrid systems have to be well-balanced and require appropriate installation, operation and maintenance. The above issues depend on both the designer and the installer. These two subjects have to communicate to each other to avoid misunderstandings and discrepancies as regards technical specifications. The choice of rely on local resources in terms of materials and capacity, on the one side is desirable in order to promote technology transfer, but on the other side can exacerbate the challenges towards a really efficient and safe system. For example, in the case here presented, it has been very hard to get information about the components available in the market, and to verify that the technical characteristics of components that were installed were in line with the requirements. Moreover, many non-technical factors must be considered during the different project phases, such as the capacity of local actors involved in the project, and their experience with installation, operation and repair of the different components. For example, best available solutions from the technical point of view may require an excessive level of knowledge from local manufacturers and installers, with the risk that their potential may not be fully exploited.

To solve such issues, it is fundamental to build capacities of local actors, including NGOs and international organizations operators, in order to make them capable of understanding technical challenges, and to fruitfully contribute to the development of the project by making their knowledge of the specific context available to technicians.

As regards the design of energy systems, it is important to recall that data regarding some renewable energy resources can be difficult to be collected or estimated, while the installation of the components requires specific capacity, especially as regards the appropriate setting of control parameters. The optimal sizing of energy storage units (battery banks), require to estimate fluctuations of both production and consumption, which may be particularly challenging in situations characterized by a high level of uncertainty regarding the type and number of users, likewise in humanitarian and emergency settings. The production and installation of customized technologies, such as the refrigerators adopted in this pilot, require an adequate level of capabilities of local installers. The compliance of the requirements should be always carefully verified by carrying out tests on samples supplied by the contractor before proceeding with the overall installation.

The utilization of local resources is in general preferable whenever possible. However, in case of very innovative solutions not available in the local market, the involvement of international contractors is strongly suggested. If it is not possible (e.g. due to security reason, impossibility to have an in-presence support in case of failures or trouble), a direct involvement of the headquarters of a brand with a locally available dealer and expert installer may represent a good solution, in order to obtain the necessary support on their products, and to receive assistance in terms of capacity building, as well as backstopping and troubleshooting.

Lastly, another key factor to ensure the success of the action is the implementation of an appropriate monitoring architecture of all the systems, as it allows to plan appropriate corrective actions on the design and on the control logics in order to cope with eventual unexpected operating conditions, often occurring in such contexts.

3.4 Concluding remarks

In this chapter, a novel framework for Comprehensive Energy Solutions Planning has been presented in order to provide researchers and practitioners with all the elements necessary to develop effective energy systems in critical contexts. In particular, specific indications have been added to the general framework for the case of humanitarian settings. The framework has been applied to a case study in a refugees' settlement in north Lebanon. The work here described represents a first step towards the implementation of sustainable energy systems in humanitarian settings. However, the humanitarian sector needs to enhance its general analytical capacity and knowledge of energy, and to get aware of existing supportive tools for the implementation of better interventions to achieve such goal. The next chapter introduces the capacity building and knowledge sharing programme launched by SET4food on energy for humanitarian professionals, and describes the supportive tools that were developed during the project action. The programme and tools represent a contribution to strengthen the overall capacity of the humanitarian system as regards energy-related challenges.

4 Enhancing the capacity of the humanitarian system on energy

In the previous chapters of this dissertation, energy in humanitarian settings has been faced starting from the core issue of the energy-food nexus, and expanding the analysis to the overall problem of energy planning. On the one hand, the whole results of the research contributed to improve the knowledge of the scientific community on energy systems in humanitarian settings. On the other hand, they may represent a valuable support towards better humanitarian interventions. However, to maximize the effectiveness of the results, capacity building and knowledge sharing of humanitarian professionals play a fundamental role. Therefore, this chapter presents the knowledge transfer programme of the SET4food project, and describes the supportive tools that were developed during the project action.

4.1 Knowledge transfer programme: from research to action

The research work presented so far aimed at exploring the interlinkages and impact of actual energy systems and interventions in humanitarian settings, and introduced a novel framework for energy planning. However, given the nature of the general topic (energy in humanitarian settings), it seems relevant to also reflect on the problem of transferring all the produced knowledge to practitioners and other key stakeholders operating within the humanitarian system. According to P. Reason and H. Bradbury [280], in fact, the fundamental problem affecting research is self-referentiality, i.e. the fact of creating its own separate island of activity, unless research, capacity-building and practice are treated as interacting domains of a larger system. In this framework, collaborative knowledge transfer may constitute an effective means to mitigate such problem.

The concept of *knowledge transfer* refers to the process of meaningful translation of research into practice [281]. There are three main models of knowledge transfer [282], [283]: (i) producer push, when the producers of knowledge define and implement strategies to instruct the target audience; (ii) user pull, when the users actively act to pull knowledge from identified sources; and (iii) exchange, when there is an interaction between producers and users to enable the knowledge exchange. The latter is referred as the ideal one; however, it is also the most complex and expensive in terms of organization and resources. In all the cases, there is some emerging evidence that the best results are obtained when there is an ongoing interaction between the knowledge producers and the target audience [282].

Based on such reflections, a knowledge transfer programme was developed in the framework of the SET4food project, as the principal contribution to the fundamental step of reducing some of the main gaps evidenced by humanitarian operators, linked to human capital. Powering human capital to promote energy access is in fact considered a key asset for achieving sustainable energy for all by many international institutions, including IEA and the World Bank [284].

At the beginning of this dissertation, Figure 1.14 presented the results of a survey carried out in the framework of the project. Such results evidenced, among other challenges, a lack of human capacity on energy, and in particular as regards sustainable energy solutions. The limited understanding of general issues related to energy suggests the need for capacity building of the main actors. Moreover, a scarcity of tools also emerged as a barrier. It was found that general guidelines, as well as practical tools for needs assessment and analysis, for the identification of appropriate energy technologies or fuels, and for M&E and impact assessment of energy-related interventions in humanitarian settings may have represented a valid support.

Based on such findings, the SET4food knowledge transfer programme was designed to face the capacity gap of the humanitarian system in an innovative and effective way. It was mainly based on a mix of models (i) and (iii), including different components: on the one hand, practical tools were developed based on a review of the main existing gaps, and in-presence and online courses were delivered (components developed mainly referring to the producer push model). On the other hand, a learning community was started, with an initial core group constituted by the members of the project consortium, which was subsequently expanded thanks to the in-presence networking and sharing activities, and to the promotion of an online community of practice (components developed mainly referring to the exchange). Based on the definition in [280], in fact, a *learning community* is "a diverse group of people working together to nurture and sustain a knowledge-creating system, based on valuing equally three interacting domains of activity": research, capacity building, and practice.

In the next paragraphs, the different components of the SET4food knowledge transfer programme are described and commented:

- The tools for humanitarian operators, including the *SET4food guidelines* on sustainable energy technologies, the *Decision Support System*, and the *Monitoring, Evaluation and Impact assessment package*.
- The capacity building components, including the *in-presence and online courses*, and *in-presence and online networking and knowledge sharing* actions.

4.2 The SET4food tools for humanitarian operators

Humanitarian operators often lack of solid knowledge of energy problems, and face important challenges in terms of time constraints, making decisions under pressure. Therefore, selected strategies are not always sustainable or do not consider most effective technologies. SET4food tried to face such need by proposing a package including different tools.

4.2.1 SET4food Guidelines

The *Guidelines on sustainable energy technologies for food utilization in humanitarian contexts and informal settlements* are the first and more generic tool developed in the framework of the project [2], addressing the gap on the general knowledge of energy systems, and more in particular focusing on the identification of appropriate energy-related technologies and fuels (cover in Figure 4.1).

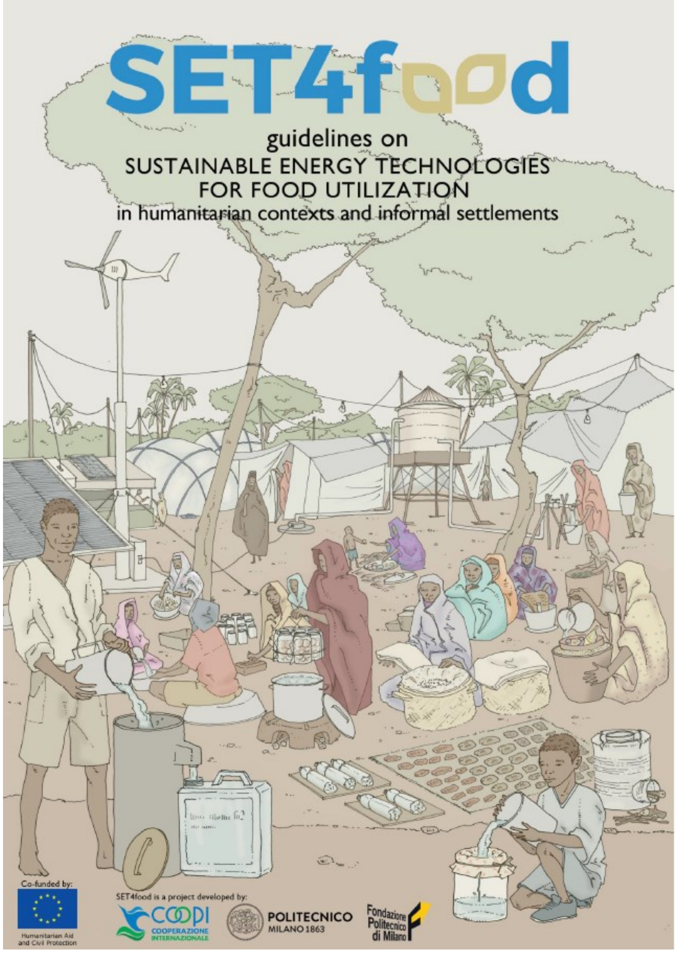

Figure 4.1 Cover of the SET4food guidelines. *Source: [2]*.

The guidelines have been written to describe the main characteristics of the different technologies, starting from the consideration that in most cases field operators do not have a strong technical background.

Technologies have been grouped within four main categories (Table 4.1):

- Technologies and fuels for cooking (e.g. improved biomass cookstoves, biogas stoves, electric stoves);
- Technologies for food preservation (e.g. solar refrigerators, passive refrigerators, canning methods);
- Energy conversion systems for water pumping and purification (e.g. PV pumps, ultraviolet lamps, water filters);
- Modular Integrated Renewable Energy Systems (IRES) for electric supply.

Table 4.1 Categories and sub-categories in the SET4Food Guidelines. *Based on: [2].*

Cooking	Solid fuel stoves Liquid or gaseous fuel stoves Electric stoves Additional cooking technologies Alternative fuel production
Food preservation	Refrigeration and freezing Drying Preservation using chemicals and microbes Heat treatment processing and packing
Water supply	Water pumping systems Water treatment (basics)
Electric power systems	Electricity in emergency conditions Basics of micro-grids Design of micro-grids

The first part of the document introduces the reader to the fundamental concepts of each technology category, providing a general description of existing layouts and models, as well as indications on efficiency and functioning principles. Figures and schemes clarify key issues, illustrating the physical principles of functioning.

In the second part of the book, detailed technical sheets provide an analysis of all technologies grouped within the four main categories, and give indications about their manufacturing, proper utilization, operation and maintenance, and other practical recommendations. The organization in two levels of details allows using the document both as a source of general information on energy systems, and as a more specific instrument to be consulted when a technical detail on a specific technology is needed in the field.

The guidelines are open access, and are available in English, French and Spanish in order to maximize their diffusion in all the main intervention areas. The document raised a great interest, as it is evidenced by more than 900 reads and downloads that have been tracked by the *Researchgate* platform[13].

4.2.2 Decision Support System

The Decision Support System (DSS) is an interactive tool supporting the identification of appropriate energy technologies, based on the specific context in which the user is operating.

The DSS helps humanitarian operators lacking of a technical background on energy to proceed with a preliminary selection of appropriate energy technologies related to food security. Therefore, the DSS is a tool designed mainly for field operators. The structure

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[13] www.researchgate.net

is composed by five core modules that reflect the five sessions of the Guidelines: (i) food cooking; (ii) food preservation; (iii) power generation; (iv) water pumping; (v) water treatment. The preliminary "Module 0" allows enabling or inhibiting access to core modules, based on a set of questions the user is required to answer.

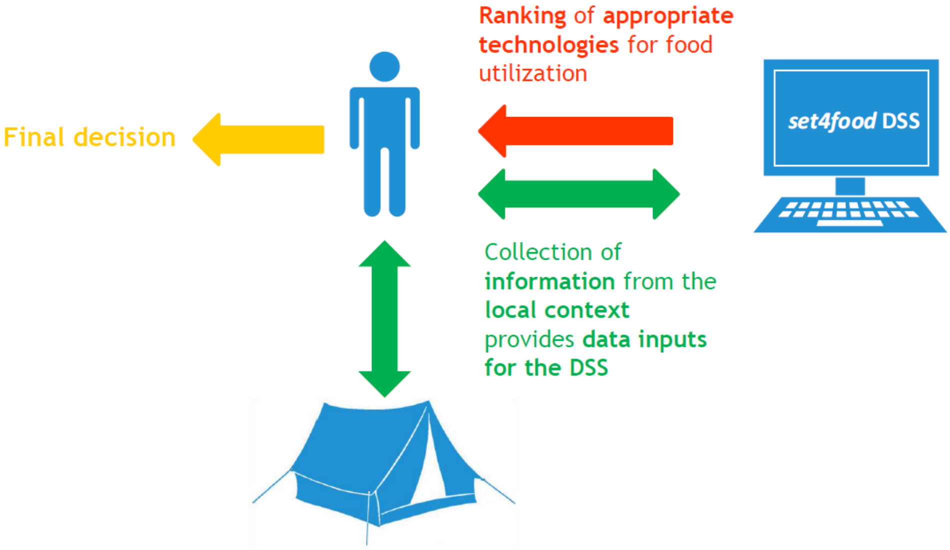


Figure 4.2 SET4food DSS operational logic. *Credits: SET4food/UNESCO Chair E4SD.*

Within each module, specific questions guide the user in providing the requested information. Based on the answers, a set of indicators is evaluated. Such indicators are combined together, and the result is given in the form of a sorted ranking of the different technologies, taking into account technological, economic, social and environmental aspects. Non-appropriate technologies, such as those requiring materials or fuels not available in the area of interventions, are automatically excluded from the ranking. Figure 4.2 gives a graphical visualization of the operational logic of the software.

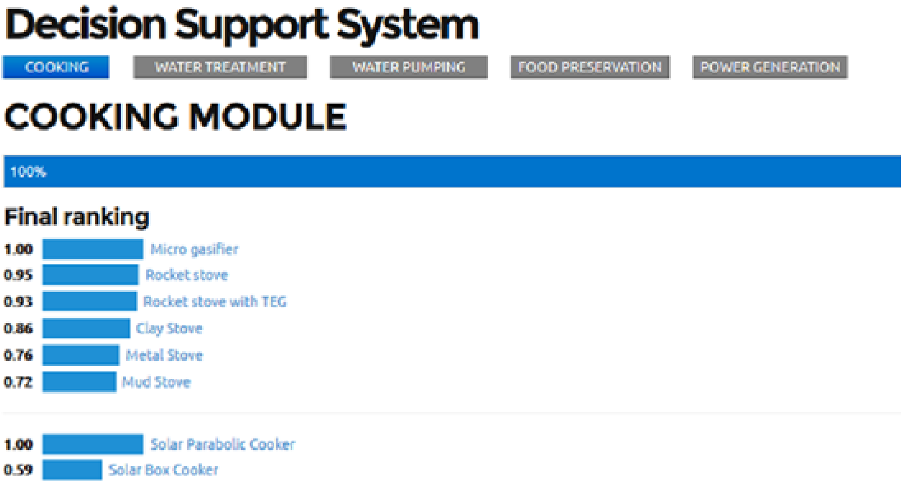
The different core modules differ as regards the criteria and the elements utilized to evaluate and rank the different technologies. Table 4.2 provides an overview of the different technology categories and summarizes the operations made within each module.

Table 4.2 Core modules operational logic. *Author's elaboration.*

	Technologies	**Level 1**	**Level 2**	**Indicators**
Cooking	11 categories *Metal stove; Mud stove; ICS Clay; ICS Rocket; ICS Rocket with fan; Micro gasifier; Gas Stove; Alcohol Stove; Kerosene Stove; Electric Plate; Microwave*	Based on the answers given by the users to questions related to resources and fuels, the DSS excludes some technologies from the ranking.	Based on the answers given by the users to further questions, the DSS assigns a score and a weight to	- Materials cost - Fuel cost - Land degradation and deforestation - Construction ability - Indoor pollution - Protection - Stove

	3 additional systems *Solar Panel Stove; Solar Box Stove; Solar Parabolic Stove*		each technology.	portability - Cooking time
Food preservation	11 categories *Salting or curing; Home canning; Vacuum packing; Sun drying; Solar drying; Smoking; Zeer pot; Mechanical Vapour Compressor; Sorption; Thermoelectric fridge; Root cellars*	Based on the answers given by the users to questions related to available food and available resources and materials, the DSS excludes some technologies from the ranking.	Based on the answers given by the users to further questions, the DSS assigns a score and a weight to each technology.	- Temperature - Relative humidity - Solar irradiation - Materials cost - Fuel cost - Construction ability - Food quality - Technology portability
Power generation	5 categories *Internal combustion engine; Hydro; Photovoltaic; Wind; Hybrid micro-grid*	Based on the answers given by the users to questions related to available resources and products, the DSS excludes some technologies from the ranking.	Technologies are assigned with a corrected pre-computed Levelized Cost Of Energy (LCOE), and the final ranking is generated accordingly.	*N/A*
Water treatment	11 treatment systems *Active carbon; Biofilter; Water boiling; Chlorination; Clay filter; Cloth filter; Membrane filtration; SODIS; Solar distillation; UV lamp; Active alumina*	Based on the answers given by the users to questions related to the type of contaminant in the water, the DSS excludes some technologies from the ranking.	Technologies are ranked based on their effectiveness to remove the selected contaminants	*N/A*
Water pumping	10 pumping systems *Suction hand pump; Direct action hand pump; Deep-well piston hand pump; Electric pump; Diesel pump;*	Based on the answers given by the users to questions related to the morphological	The required energy load is estimated based on the answers from the user	*N/A*

	DC Solar pump; AC solar powered pump; Mechanical wind powered pump; Electrical wind powered pump; Ram pump	features of the camp and the sources of water, the DSS excludes some technologies from the ranking.	on water needs and camp distance from the water source. A suggestion is given about the systems able to sustain the required load.



1.00	Micro gasifier
0.95	Rocket stove
0.93	Rocket stove with TEG
0.86	Clay Stove
0.76	Metal Stove
0.72	Mud Stove
1.00	Solar Parabolic Cooker
0.59	Solar Box Cooker

Figure 4.3 Example of ranking generated from the Cooking module. *Credits: SET4food/UNESCO Chair E4SD.*

Figure 4.3 shows an example of ranking generation for the case of the Cooking module.

The DSS is available in English, French and Spanish, provided with a user manual [248]. An off-line version of the DSS is also available, implemented in Microsoft Excel®[14].

4.2.3 Monitoring, Evaluation and Impact assessment package

The Monitoring, Evaluation and Impact assessment package of SET4food is a first step towards better design and understanding of the effectiveness of energy interventions in critical contexts. In fact, from the literature the scarcity of documentation on effective monitoring, evaluation and impact assessment of energy-related interventions emerged as a further critical element, especially for the case of humanitarian settings. As a consequence of such gap, few quantitative data and evidence-based results are exchanged at the end of most projects [3], [229].

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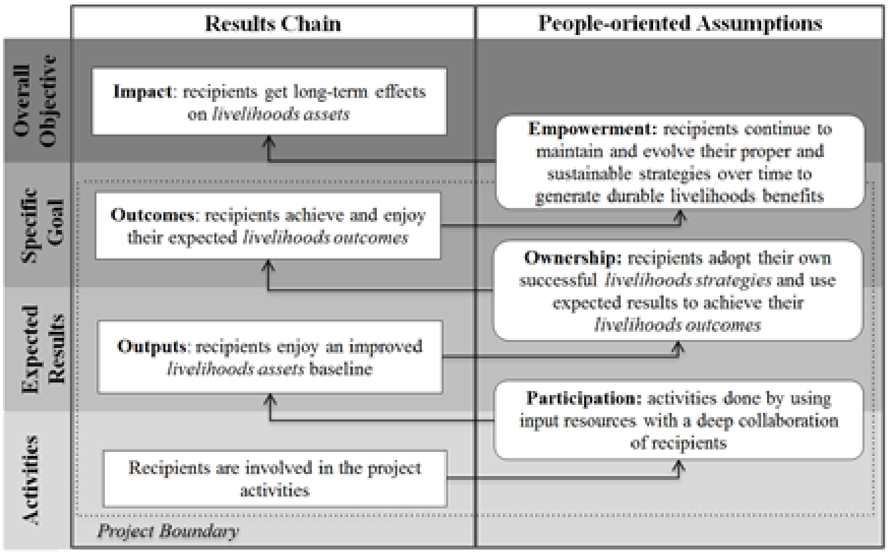
[14] The DSS is available at http://energycop.safefuelandenergy.org

The package is composed by the monitoring and evaluation (M&E) framework, and the Impact Evaluation Framework tool, and is mainly addressed to project managers and evaluators.

To be effective, M&E should not only assess the achievement of expected objectives, but also monitor recipients' roles within the various steps of the project.

From this perspective, the approach proposed by SET4food combines the logical framework approach (LFA) and the sustainable livelihoods framework [226]. While the LFA looks at the project achievements by identifying, and evaluating the different project steps, the sustainable livelihoods framework allows including the people's perspective, identifying the change in terms of people's livelihood.

While the first represents a widely used tool for assessing the achievements of the project steps, the integration with the latter allows considerations of the importance of the recipients' roles within the project activities in order to induce targeted changes in livelihoods (Figure 4.4).



Impact: recipients get long-term effects on *livelihoods assets*

Empowerment: recipients continue to maintain and evolve their proper and sustainable strategies over time to generate durable livelihoods benefits

Outcomes: recipients achieve and enjoy their expected *livelihoods outcomes*

Ownership: recipients adopt their own successful *livelihoods strategies* and use expected results to achieve their *livelihoods outcomes*

Outputs: recipients enjoy an improved *livelihoods assets* baseline

Participation: activities done by using input resources with a deep collaboration of recipients

Recipients are involved in the project activities

Figure 4.4 The M&E integrated approach. *Credits: SET4food/UNESCO Chair E4SD.*

Based on such integration, the new integrated M&E approach helps to define an effective set of indicators to perform a people-oriented evaluation of the project aside from a mere evaluation of the completion of the project phases [229], [269].

The Impact Evaluation Framework (IEF) is further proposed as a complementary practical tool implemented in Microsoft Excel©. The tool aims at enabling the understanding of performance and impact of energy projects. A specific version has been developed in the framework of SET4food, including a set of indicators and recommendations specific to the humanitarian context[15].

The tool allows measuring the effects that a project has on the local livelihoods, assessed in terms of target community's five capitals: natural, physical, human, social and financial. Each capital includes different dimensions (Table 4.3), that are evaluated through a set of specific indicators, and aggregated by assigning scores according to the rules of the Analytic Hierarchy Process (AHP) [203], [285]. The model at the basis of the

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[15] Available at http://energycop.safefuelandenergy.org

tool is an original re-elaboration of the "Sustainable Livelihoods Framework" [226], [229].

Table 4.3 Capitals, dimensions and suggested indicators in the SET4food IEF. *Source: SET4food/UNESCO Chair E4SD.*

Capital	**Dimensions**	**Indicators**
Natural Capital	Land	Deforestation rate
		Solid wastes production amounts
		Area of occupied land
	Water	Amount of water depleted
		Amount of contaminated water
	Air	Local air pollutants emissions
		CO_2 emissions
Physical Capital	Heavy Infrastructures	Extension of public energy services
		Extension of water services
	Light Infrastructures	Access to appropriate means of cooking
		Capacity of local energy systems
		Access to basic appliances
	Smart Infrastructures	Access to mobile phones
		Access to internet
		Access to TV and radios
Human Capital	Education & Competences	Access to school for children
		Access to training courses
		Access to school for adults
	Capabilities	Systems maintenance capability
		Capabilities from vocational training
	Health Status	Level of access to healthcare
		Level of safety
		Indoor air quality
		Adequate nutrition
		Access to safe water
Social Capital	Collaboration & Initiatives	Level of social acceptance of beneficiaries
		Presence of collective initatives
	Equity & Inclusiveness	Equal access to provided services
		Gender equity
		Time availability for social activities
Financial Capital	Economic Status	Energy affordability
		Household earnings
	Formal Economy	Level of employment
		Presence of income generating activities
		Level of market development
	Informal Economy	Level of development of not money-based commercial or working activities
		Level of development of activities for the community

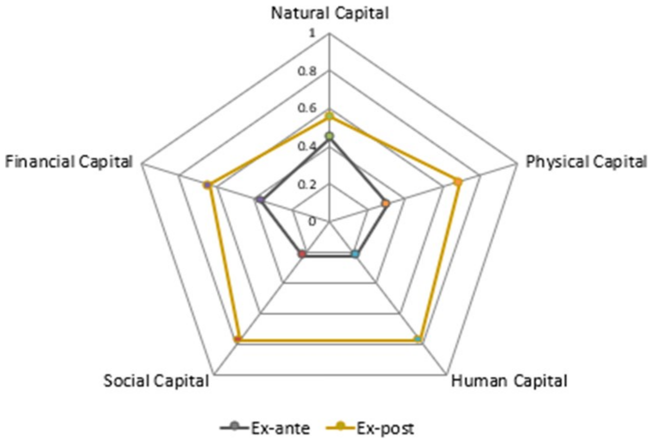


Figure 4.5 Example of graphical output from the IEF tool. *Credits: SET4food/UNESCO Chair E4SD.*

The tool can be applied to obtain an ex-post evaluation, by assessing already completed projects. The performance of each capital and dimension in the baseline situation can be compared with the changes brought by the project and assessed at its end (Figure 4.5). It can also be applied to perform ex-ante analyses, at an appraisal phase, during the selection process among possible project alternatives. In this case, the result shows the expected impact of the intervention, based on the forecasted change of each indicator.

4.3 The SET4food capacity building action

The SET4food capacity building action has been developed with the aim of enhancing the capacity and knowledge of humanitarian actors in the energy field. The programme included different components:

- In-presence intensive trainings;
- Online course;
- In-presence knowledge sharing;
- Online networking and knowledge sharing.

In-presence and online trainings were the most direct channel used to provide humanitarian operators and other professionals with a sufficient background to understand the general challenges related to safe energy provision in emergency and post-emergency situations. On the other hand, networking and knowledge sharing actions aimed at raising the attention of the international community working in the humanitarian field on the relevance of energy access and related needs. Moreover, they contributed at the dissemination of existing tools, methodologies and guidelines on energy in humanitarian and critical settings, and promoted collaboration and interaction among different stakeholders as a means for effective knowledge transfer.

4.3.1 In-presence and online courses

During the SET4food phase 1, in-presence intensive courses were delivered by a team composed by the Author of this work, and other colleagues from Politecnico di Milano and COOPI, to more than 170 persons in the framework of the Master Programs promoted by the Cooperation and Development Network in Colombia (Cartagena), Italy

(Pavia), Kenya (Nairobi), Nepal (Kathmandu) and Palestine (Bethlem). The intensive courses were mainly attended by the students of the master, but they were also open to humanitarian actors, academic staff, local authorities and private companies.

The agenda of the courses is reported in Table 4.4.

Table 4.4 Modules of in-presence intensive trainings. *Source: SET4food/the Author.*

Module	**Description**
Access to energy in humanitarian settings	Introduction to the main needs related to energy in camps and informal settlements.
The energy-food nexus	Introduction to social aspects and nutritional key concepts.
Energy technologies for food preparation and preservation	Overview on energy technologies for food preparation and preservation in emergency post-emergency conditions.
SET4food tools	Introduction to Decision Support System and Guidelines to identify appropriate technologies considering the context of action.
Focus on the DSS	Focus on the structure of the DSS and how to use it effectively.
Analysis of case studies	Presentation and analysis of case studies from the SET4food experience.
Teamwork	Project work on a real case study: identification of different technology options and group discussion; identification of potential impacts of improved access to energy; development of a project proposal (concept).

During the second phase of the project, a further in-presence training was delivered in Milan (Italy). In this case, the *Innovation Brokers for Energy* (IBEs) training was an advanced and more interactive one, designed for professionals already involved in the humanitarian and development sectors, with the aim of strengthening their knowledge on specific energy challenges, and sharing their experience (agenda of the course in Table 4.5). About 20 participants attended the course that promoted a participative approach including a mix of individual presentations and group works.

Table 4.5 Modules of in-presence IBEs training. *Source: SET4food/the Author.*

Module	**Description**
Global energy challenge	Introduction to the global energy challenge for sustainable and human development.
Energy in humanitarian contexts	Introduction to main relevant issues related to energy in humanitarian settings.
SAFE and SET4food	Presentation to the Safe Access to Fuel and Energy (SAFE) Humanitarian Working Group and the SET4food project.
SET4food tools	Introduction to the SET4food tools: Decision Support System; Guidelines; Monitoring & Evaluation guidelines; Impact Evaluation Framework.
Comprehensive Energy Solutions Planning (CESP)	The CESP framework from needs assessment to impact evaluation
Energy technologies for food preparation and preservation	Overview on energy technologies for food preparation and preservation in emergency post-emergency conditions.
Appropriate technologies for water management	Overview on technologies for water supply and water treatment in emergency post-emergency conditions.
Appropriate technologies for power production	Renewable and hybrid power systems from micro to large scale.
Project work	Project works on real case studies.

The e-learning course *Appropriate energy technologies for food utilization in refugee camps and informal settlements: overview, selected criteria, and pilot case studies* was created as a complement to in-presence trainings.

The contents of the course are based on the experience gained from the field and from the SET4food Guidelines. The course includes five modules, composed by four lessons each:

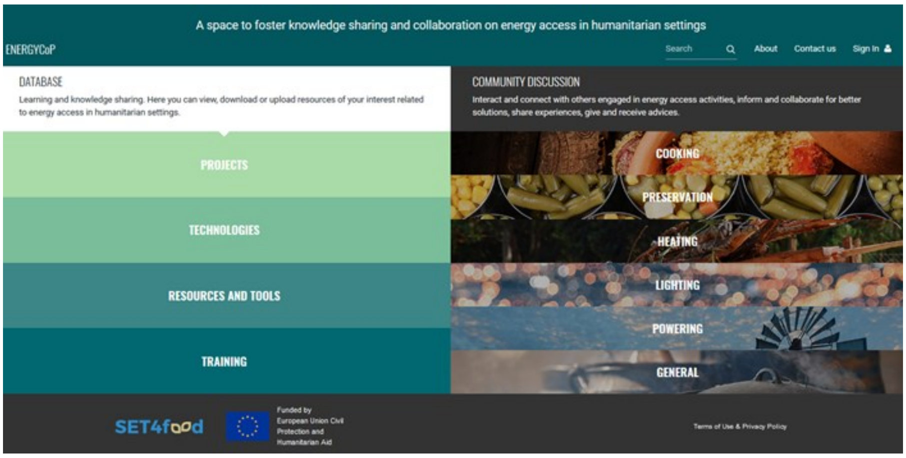
- Module 1 - Access to sustainable energy as leverage to development and human rights
    - L1 - Energy, Sustainable Development and human rights;
    - L2 - The Global Energy Challenge;
    - L3 - Access to Energy: current picture and trend;
    - L4 - Energy Uses: from local needs to energy demand.
- Module 2 - Access to energy in refugee/IDP camps and informal settlements
    - L1 - Introduction to refugee camps and informal settlements;
    - L2 - Assessment of local needs and constraints which may affect energy uses;
    - L3 - Assessment of energy sources within camps and informal settlements;
    - L4 - Energy utilization in refugee camps and informal settlements.
- Module 3 - Energy and food in refugee/IDP camps and informal settlements
    - L1 - Introduction to nutritional aspects;
    - L2 - Implication of Culture and Local tradition on energy uses (social dimension);

    - L3 - Environmental, health and social implications of traditional energy uses;
    - L4 - The shift from traditional to modern energy: from Improved Cook Stoves to LPG and electricity.
- Module 4 - Energy technologies for food preparation and preservation
    - L1 - Overview of appropriate technologies for food preparation;
    - L2 - Rapid overview of appropriate technologies for food conservation;
    - L3 - The electricity option as a further step;
    - L4 - Examples from the field – beyond the traditional dichotomy between emergency and development.
- Module 5 - Identification of appropriate technologies for preparation and preservation: the SET4food decision support system (DSS)
    - L1 - Introduction to the SET4food DSS
    - L2 - SET4Food DSS: structure, criteria and indicators;
    - L3 - An application case for the DSS (one of the 4 pilots);
    - L4 - Data collection, Monitoring and Evaluation.

The whole course is available in English, French and Spanish in the SET4food website and on the SET4food YouTube channel[16].

4.3.2 Networking and knowledge sharing

The most important action as regards networking and knowledge sharing is represented by the development of the ENERGYCoP platform (Figure 4.6).



A space to foster knowledge sharing and collaboration on energy access in humanitarian settings

DATABASE

Learning and knowledge sharing. Here you can view, download or upload resources of your interest related to energy access in humanitarian settings.

COMMUNITY DISCUSSION

Interact and connect with others engaged in energy access activities, inform and collaborate for better solutions, share experiences, give and receive advices.

Funded by European Union Civil Protection and Humanitarian Aid

Figure 4.6 Homepage of the ENERGYCoP platform. *Credits: SET4food/ENERGYCoP.*

ENERGYCoP is an online global community of practice launched during the second phase of SET4food, and subsequently managed by the SAFE (Safe Access to Fuel and Energy) working group, and was officially launched on November 9th, 2017 [286]. Its purpose is to facilitate sharing of information and increase collaboration among a network of different stakeholders who are engaged in providing energy access to crisis-affected

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[16] Available at www.set4food.org The transcripts of the lessons recorded by the author of this dissertation are available in Annex F.

people. Within this community of practice, each individual and organization working on issues related to energy access and energy technologies in humanitarian settings can access resources, connect with partners, and contribute to ongoing discussions on various topics. The platform has been designed following a participative approach including the following steps:

(i) Preliminary survey among humanitarian organizations, including: COOPI, FAO, GIZ, GACC, IOM, ILF, Mercy Corps, Project GAIA, SNV, UNHCR, WFP: the survey helped to understand which characteristics and functions were seen as the most useful by the involved stakeholders;
(ii) Participative meeting in Kigali (Rwanda) during the SAFE humanitarian workshop 2016: during this event the structure of the platform was drafted based on a brainstorming of humanitarian operators, researchers, and practitioners with different backgrounds and from different organizations;
(iii) Collection of inputs from SET4food project partners and SAFE community;
(iv) Transfer of previous SAFE database and resources on the ENERGYCoP platform;
(v) Online release of ENERGYCoP and official launch through a webinar;
(vi) Dissemination of the platform during international events, including: SAFE humanitarian workshop (Nairobi, November 2017) [287], Global Plan of Action workshop (Berlin, January 2018) [288], FAO conference on energy in humanitarian settings (Rome, January 2018) [43], ETHOS conference 2018 (Seattle, January 2018) [289], SET4food closure conference “Comprehensive Energy Planning in critical settings - from emergency to development” (Milan, April 2018) [42].

In all the steps, the interaction between researchers, humanitarian operators form NGOs and international agencies, field practitioners, and consultants constituted a fundamental element, which refers to the concept of a learning community bringing togehter research, capacity building and practice, as introduced in paragraph 4.1.

ENERGYCoP is designed to be an interactive platform with an open-knowledge approach that enables users to search for projects, technologies, tools, and resources related to energy access in humanitarian settings, or to share materials that are considered valuable for the community. It allows to pose questions, ask for advice, or share experiences and best practices with the other members. The platform hosts the most comprehensive database of energy-related projects, technologies, tools, trainings and other resources referring to humanitarian settings at the global level. The database was firstly populated thanks to a review and selection of existing project reports, tools and technologies by combining a previous SAFE database and the result of the work of the author of this dissertation, consisting in the cataloging and selection of about 35 different tools, including those developed by SET4food. After the online official release of the platform, the database has been further populated with documents uploaded by the platform users.

At the moment[17], the database includes more than 150 project reports, 50 technology reports, 200 tools and resources, one full online course and some webinars. On the other hand, the community dissertation section did not work as good as expected so far: the participation of experts and other actors posing questions, discussing different topics, or posting news has been quite low. This represents a partial failure in the original idea of the online community of practice, and gives evidence that the existence of a learning

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[17] September 2018.

community of people that physically meets on different occasions, such as the SAFE and the Global Plan of Action workshops, not necessarily ensures also interest or commitment to online participation. However, it is likely that more participation will occur as soon as the platform will become more known worldwide.

4.4 Considerations on the overall programme

The SET4food knowledge transfer programme included two main components: the development of tools for humanitarian operators, and capacity building. The former was mainly developed by adopting a producer push model, while the latter an exchange (interactive) model.

The SET4food guidelines were the most comprehensive and general tool, and their structure allows their utilization by users with different levels of technical background. This choice revealed particularly effective: the guidelines have been circulated among practitioners, and were downloaded by a number of users that went beyond the initial expectations. The other tools have also been appreciated, even if with a lower grade of utilization. On one side, this was expected from the beginning, due to the very specific nature and focus of such tools, which naturally shrinks the user basin. On the other hand, practitioners showed a certain refractory attitude to adopt new tools, probably mainly due to the strong time and resources constraints typical of humanitarian operations. Moreover, the adoption of a producer push model probably also did not help to align perfectly the development of the tools with the specific needs. Iterated exchanges between producers and users may have produced better results in such terms, however would have introduced a higher level of complexity and required more financial resources.

As per the capacity building component, all the trainings were quite successful, especially in-presence ones, that allowed for more interaction between teachers and participants, not only regarding knowledge sharing, but also networking. The promotion of a learning community was essential for the development of the process that lead to the launch of the ENERGYCoP platform. It also paved the way to create stable professional relationships among some of the participants (for example, some of the persons involved are also members of the Global Plan of Action network, and regularly meet to develop the GPA framework). Moreover, the ENERGYCoP hosts the most complete database of projects, technologies, resources and tools related to energy in humanitarian settings, and is now administrated by the SAFE WG, which ensures its sustainability out of the SET4food project boundaries. On the one hand, new resources are continuously updated, which shows that the members of the platform are active as regards the utilization of the database. On the other hand, a partial failure in terms of active participation of the users to the online discussion is noticed. Further and more continuative promotion actions may help to vitalize this function in the future, especially involving people that need support on the development of new projects including energy components.

4.5 Concluding remarks

In this chapter, the knowledge transfer programme adopted in the framework of the SET4food project has been presented, underlining how such factors are fundamental to ensure the effectiveness of any energy-related action in humanitarian contexts. The action is based on two complementary elements: on the one hand, the creation of a package of supportive tools and training materials contributed to enhance the capacity *of humanitarian actors to deal with energy-related challenges. On the other hand, the creation of an online global community of practice (ENERGYCoP) promotes networking and collaboration among different professionals and stakeholders, in the tentative to minimize the risk of overlapping interventions and maximizing the sharing of best practices and solutions. The overall effectiveness of the programme is evidenced by the number of beneficiaries reached by the action, even if some weak points have also been identified.*

5 Conclusions and way forward

5.1 General considerations

This doctoral thesis is the result of a research line focused on sustainable energy solutions in humanitarian settings. The overall objective of the work was to study the problem of energy access in humanitarian settings, in order to explore the current main criticalities, challenges, and opportunities, and to promote better future energy interventions.

More in details, three specific objectives were set:

(i) Analysis of the energy-food nexus, as the core element of current energy interventions in humanitarian settings.

The fulfilment of this objective contributes to answer a first research question: how are food and energy linked in humanitarian settings? Is it possible to understand which has been the impact of energy systems, and in particular cooking systems, in such contexts?

(ii) Definition of an innovative comprehensive framework for sustainable energy planning in critical contexts.

Such specific objective is defined to answer a second research question: can we set up a comprehensive framework for energy planning in critical contexts, also suitable for humanitarian settings?

(iii) Proposal for a first set of tools and actions to enhance the overall capacity of the humanitarian system on energy.

The work on this third specific objective contributes to fulfil the need of transferring knowledge from researchers to humanitarian professionals and field practitioners.

The general perspective on the global energy challenge and access to energy was introduced in *Chapter 1 - Introduction*. It was recalled that globally, nowadays, about 1.1 billion people do not have access to electric energy and more than 2.8 billion are still relying on traditional biomass for their domestic needs. On the other hand, it was also recalled that access to sustainable energy is essential to ensure socio-economic development, and for other key issues including people's quality of life, global security, and environment protection. The relevance of the matter is in fact confirmed by the international agenda and the Sustainable Development Goals, with particular reference to Goal 7, "Ensure access to affordable, reliable, sustainable and modern energy for all".

A focus on energy access in humanitarian settings revealed that displaced people are among the most affected by energy scarcity: more than 80% of the over 65 million displaced people only have minimal access to both electricity and thermal energy. Access to energy is therefore indicated as one of the major contributors to many challenges of the humanitarian response. In particular, access to energy is essential to guarantee food security of displaced people. A preliminary analysis of the main causes reveals that on the one hand, current technologies and practices may lack of efficiency and effectiveness. On the other hand, financial and institutional barriers bring to the identification of an "energy gap" in the humanitarian system.

Even if the general dimension and importance of the problem clearly emerges from the literature, it is also found that there is a lack of detailed scientific sound studies on what have been done so far. For this reason, *Chapter 2* deepens the analysis focusing on *An essential entry point: the energy-food nexus in humanitarian settings*. The nexus between energy and food emerges in particular as regards cooking, including food preparation, water, cookstoves and fuels. Similarly, it is found that food preservation means are strongly dependent on energy. Despite the interlinkage between many aspects, including cooking, food preservation, water treatment, lighting, and other energy uses, it is found that the humanitarian system has mainly addressed cooking only so far. A focus on this particular aspect allows to conclude the followings:

- Under the technological perspective, very basic devices such as mud and fired clay stoves are the most widespread cookstoves adopted in substitution of three-stone fires. More advanced commercial rocket stoves and LPG stove occupy the second place in terms of diffusion;
- In terms of environmental impact, the utilization of traditional biomass for cooking is a clear cause of rapid and irreversible damage on the local environment. The damage not only affects the refugees, but also threatens the livelihood of hosting communities. The problem is clearly far from being solved, even if the promotion of more sustainable cooking technologies and practices may reduce the pressure on local resources;
- As regards health, the pollution caused by inefficient cooking systems contributes to many diseases, while the promotion of cleaner technologies, especially modern stoves, drastically reduce harmful emissions.
- Regarding safety, GBV, sexual violence, and attacks from armed people or rebels, are the most frequent problems associated to the collection of biomass in the surroundings of refugee camps and informal settlements. The effectiveness of Improved Cooking Stoves on improving safety remains questionable.
- Cooking practices are also correlated with other social issues, in particular education and livelihood.

In a more general perspective, the review of the literature shows that non-technological factors play a crucial role in the success of energy interventions. Interventions based on strategies considering a number of different actions at the same time, including technology and fuel substitution, training of beneficiaries, etc., are most likely to achieve significant outcomes.

Based on such results, a set of innovative approaches that may contribute to improve the success and widen the areas of energy interventions, is proposed under the form of simple case studies, based on the pilots put in place in the framework of the SET4food project action. The innovative approaches include (i) context-based selection of technologies, (ii) adaptation of pot skirts, (iii) development of modular solutions, and (iv) integration of artisanal and industrial components.

A combination of the findings from *Chapter 1* and *2* suggests on the one hand, that access to energy is a complex issue. Energy needs and uses differ according to the region: for example, in sub-Saharan areas displaced people tend to use firewood or charcoal for cooking, not only due to their availability, but also for cultural reasons, while in Middle East people are used to LPG, and consider biomass fuels as poor and unsafe. Moreover, energy in situations of displacement is not only fundamental to ensure appropriate means for food cooking, transformation and preservation, but also to improve safety during night hours, support education and health, power telecommunication systems, and boost income-generating activities. On the other hand, it also suggests that the more the interlinkages between different needs related to energy are considered together, the higher the chances of obtaining sustainable solutions. In other words, the importance of adopting holistic approaches towards energy provision clearly emerges as a key element.

For this reason, *Chapter 3 - Expanding the horizon towards a holistic approach to energy* introduces a novel framework for Comprehensive Energy Solutions Planning (CESP) in critical settings. The proposal is based on the awareness that very few studies in the literature deal with this topic in contexts including rural areas of developing countries and humanitarian settings. The theoretical framework is followed by more practical indications and considerations specific to the humanitarian context, which allow applying it in a refugee settlement in north Lebanon. The case study in Lebanon is described following all the phases of the CESP framework, from the assessment of the needs to a preliminary evaluation of the impacts on refugees' quality of life. The challenges faced during the implementation of the pilot study allow developing further considerations.

It is confirmed that technical expertise is an essential, but not sufficient element to properly design, implement and maintain a complex energy system. Availability of local resources, technical and managerial capacity of partners, appropriate identification of systems requirements based on beneficiaries needs and behavior, choice between local or international contractors, best balancing between potential of innovative solutions and reliability of well-known solutions, appropriate monitoring and evaluation architecture, are all important determinants for the success of a project. Based on the results achieved, it is concluded that the framework may effectively help practitioners and field operators in delivering sustainable energy in humanitarian settings. In particular, the framework allows to overtake the traditional, reductive identification of energy in humanitarian settings as a means only for cooking, fostering the adoption of a holistic approach to interventions.

Chapter 4 - Enhancing the capacity of the humanitarian system on energy completes the overall work by describing the strategy put in place under the SET4food action to transfer the findings to sector professionals, which is fundamental to ensure that the studied best practices will be applied in the field in the future. The strategy is based on two complementary elements: (i) the creation of a package of supportive tools and training materials to on the major energy-related challenges in humanitarian; (ii) the creation of the ENERGYCoP platform to promote networking and collaboration among different professionals and stakeholders. In particular, the ENERGYCoP platform is also the main channel allowing the dissemination of all the supportive tools, which include the *Guidelines on sustainable energy technologies for food utilization in humanitarian* *contexts and informal settlements*, a *Decision Support System* for the preliminary identification of appropriate energy technologies, and a *Monitoring, Evaluation and Impact assessment package* specific to energy interventions.

5.2 Contribution to the "energy gap" and policy implications

The analysis presented in Chapter 1, allowed identifying an "energy gap" in the humanitarian system. Four grassroots causes were described: (i) the lack of capacity of humanitarian actors on energy, (ii) the lack of specific intervention strategies, (iii) the scarce knowledge of the dynamics of energy in humanitarian, and (iv) the scarcity of resources that typically characterize humanitarian settings. The different objectives of this work were therefore set to contribute to three out of four of such causes.

The analysis of the interlinkages between energy and food in displacement settings contributed to mitigate the scarcity of knowledge on energy in humanitarian, by applying a scientific-sound approach based on a mix of qualitative and quantitative analysis. The development of a novel energy planning framework (CESP), instead, was connected to the lack of specific intervention strategies, with a lens focused on the project perspective. Moreover, the knowledge transfer action delivered the results of the research to a network of humanitarian actors, contributing to enhance their skills on energy.

The work carried out in the framework of this thesis and the achieved results allow drawing some policy implications. The most general one is *the necessity to consider energy as a complex matter*. The concept of energy includes thermal energy and electricity, so that both should always be considered. Energy is fundamental for ensuring the fulfilment of many needs, and can be used in different ways. Even in the very specific context of humanitarian settings, energy is fundamental not only to ensure food security, which connects to food cooking, water boiling, and food preservation, but also for people security and safety, which connects to lighting, communicating, and so on. Moreover, energy utilization influences, and is influenced by, several socio-economic and environmental factors. Excessively simplistic approaches only focusing on one particular aspect, such as a particular energy carrier or service, are likely to be scarcely effective, which is the case of many interventions that have been carried out so far.

For example, starting from the specific pillar of food security, it is suggested to *consider the overall supply chain of food*, including in particular all the elements concerning food preparation and preservation, and safe water provision, and their interlinkages with energy. Such interlinkages are intrinsic, as the concept of nexus suggests, and cannot therefore be ignored without affecting the results of the overall intervention.

More in general, the adoption of a holistic approach to planning can significantly enhance the results of energy interventions and programmes. This includes the *need for innovative approaches and solutions*, where the term innovation refers to the adoption, adaptation and creation of new systems or concepts from a local or global perspective.

However, this will be difficult as long as *a home or a general framework for energy in humanitarian* is not provided. The recent launch of the Global Plan of Action for Sustainable Energy Solutions in Situations of Displacement (GPA) represents a recent approach in this sense. The GPA is "a non-binding framework that will provide concrete actions for accelerated progress towards the vision of safe access to affordable, reliable, sustainable, and modern energy services for all displaced people by 2030" [281]. The GPA has been drafted with the main effort of the GPA Steering Group (which includes the following organizations: FAO, GIZ, GACC, IOM, MEI, UNDP, UNEP-DTU, UNF, UNHCR, UNITAR, WF), and the contribution of a number of other organizations, including Politecnico di Milano (represented by the _Author of this thesis). The GPA, in fact, has identified five key Working Areas, namely:

- *Planning and coordination*, which refers to the lack of a formal priority of energy in humanitarian assistance;
- *Policy, advocacy and host-country resilience*, which refers to the fact that displaced people are often not included in national or international energy access agendas;
- *Innovative finance*, which refers to the under-funded situation of energy interventions in humanitarian settings;
- *Technical expertise, capacity building and training*, which address the limited expertise and capacity to implement humanitarian energy solutions
- *Data, evidence, monitoring and reporting*, which refers to the limited amount of data on humanitarian energy needs and solutions.

The GPA adopts therefore a holistic responsive approach to the matter, which is fully aligned with the general findings of this work.

5.3 Next steps

There are several research directions that may extend the work presented in this dissertation. Some of them are discussed briefly hereafter.

- *Evidence-based studies on the impact of current energy interventions in humanitarian.* The research carried out in this thesis evidenced that there is a very limited scientific-sound literature evidencing the positive impact of some strategies that have been commonly adopted in the humanitarian sector so far. This includes, for example, the benefits from extensive Improved Cooking Stoves delivery programmes, including, in particular, environment and security. This is mainly due to the scarcity of scientific studies on the matter.
- *Study of specific energy uses in the humanitarian sector.* The research carried out so far has mainly focused on energy under the perspective of the beneficiaries (displaced people). However, energy in humanitarian is also needed for the operations of the humanitarian sector. This include, for example, electricity and thermal energy for camp offices, and logistics (terrestrial, marine and aerial transports in particular). A detailed assessment of the energy expenditure related to such tasks would pave the way to more efficient operations.
- *Further case studies to enhance the CESP framework.* The development of further case studies to apply the CESP framework would provide useful information to further enhance it, and to better identify other challenges and threats that may arise during project development. Cases that are more complex may include the definition and application of a business model, in order to include also financial sustainability in the analysis.
- *Study of the transition between emergency, post-emergency and development.* The work carried out so far evidenced that it is not possible to determine clearly a separation line among the three situations. Studies on the determinant factors at the basis of the transition would be needed, to understand better how they can influence and be influenced by energy-related issues, in particular in terms of delivery models and role of the public and private sectors. This would also

include a study of innovative financial schemes overcoming the short-term perspective for energy interventions.

- *Study of energy-related supply chains in humanitarian settings.* The literature is lacking of studies on supply chains of energy products and services in humanitarian. Explorative research would be needed to understand the main challenges and opportunities, in order to pave the way to more efficient end sustainable schemes.

More in general, referring to a future continuation of a research and capacity building programme on energy in humanitarian, a possible enhancement could entail the formulation of a more strong overall structure based on the theory of change. The *theory of change* is a rigorous and participative framework for all stages of thinking and acting, which guides groups of stakeholders through a clear identification of the outcome and impact associated to a given set of actions, project, or programme [290]. While theory of change has very recently become more and more popular as an instrument to better formulation and implementation of cooperation projects, its application to research projects is not yet common. Theory of change involves an initial detailed analysis of the context of intervention, the definition of the long-term desired change (impact), the identification of the sequence of actions and event leading to such change, and the explicit definition of the assumptions that shall be verified for the change to happen [290]. Theory of change may therefore help better formulating different research lines, and to define the necessary sequence of actions needed to maximize the impact of the research results, also including best ways for their dissemination.

Annex A – List of work products

The results of the work presented in this dissertation are summarized hereafter in terms of products.

Scientific products

Publications in journals

- Aste N, Barbieri J, Berizzi A, Colombo E, del Pero C, Leonforte F, et al. *Innovative energy solutions for improving food preservation in humanitarian contexts: A case study from informal refugees settlements in Lebanon*. Sustain Energy Technol Assessments 2016. doi:10.1016/j.seta.2017.02.009.

The paper describes some of the outcomes from the project SET4food, focusing on one of the pilot projects. In particular, the paper focuses on the methodological and technological innovations put in place in two different informal settlements in Lebanon to improve living conditions of refugees, highlighting challenges, strengths, and weaknesses in order to provide the basis for more effective technological implementations in humanitarian contexts.

- Barbieri J, Riva F, Colombo E. *Cooking in refugee camps and informal settlements: A review of available technologies and impacts on the socio-economic and environmental perspective*. Sustain Energy Technol Assessments 2016. doi:10.1016/j.seta.2017.02.007

This study presents a systematic review of both scientific and grey literature on cooking technologies and related practices, including a selection of experiences from the implementation of cooking devices in humanitarian projects and programmes. The study lead to the conclusion that improved technologies have contributed to some improvements, while in other cases the current positive narratives are not supported by strong scientific evidence.

- Barbieri J, Leonforte F, Colombo E, *Towards an holistic approach to energy access in humanitarian settings: the SET4food project from technology transfer to knowledge sharing.* Journal of International Humanitarian Action 2018. doi:10.1186/s41018-018-0038-3

The paper presents the rationale, vision, activities and results achieved by the SET4food project phase 1 and 2. The structure of the action is presented according to its main components, namely: (i) training and capacity building programme; (ii) energy planning methodology, pilot testing in the field, and supportive tools; (iii) networking and knowledge sharing. The main challenges faced during the project formulation and implementation, and the achieved results are analysed to provide recommendations for researchers and practitioners on the way forward.

- Barbieri J., Caniato M., Colombo E., *SET4food guidelines on sustainable energy technologies for food utilisation in humanitarian contexts and informal settlements*. Boiling Point, HEDON 2016:22–5.

The publication describes the SET4food guidelines as a tool to provide information on a wide number of technologies for cooking, food preservation, water pumping and purification, and electric power supply in humanitarian settings.

- Colombo E., Romeo F., Mattarolo L., Morazzo M., *An impact evaluation framework based on sustainable livelihoods for energy development projects: an application to Ethiopia*. Energy Research & Social Science, Volume 39, 2018, Pages 78-92, ISSN 2214-6296

In the paper, the Impact Evaluation Framework developed by the joint work of the Authors is presented, and applied to a case study in Ethiopia. The set of information obtained with the IEF is compared to the final expert evaluation, commissioned by the donor and performed at the end of the project, showing the usefulness of IEF as a supportive methodology in the evaluation process.

Paper contributions in conferences

- Caniato M., Barbieri J., Riva F., Colombo E., *Energy technologies for food utilization for displaced people: from identification to evaluation*. Tech4Dev 2016

The paper introduces some preliminary findings from the SET4food project in terms of field activities and knowledge transfer, and was presented at the Tech4Dev conference in Lausanne (2016).

Oral contributions in conferences

- *Safe Access to Fuel and Energy (SAFE) Humanitarian Workshop*, Kigali, December 6-8th, 2016.
  Oral presentation: SET4Food Decision Support System – Preliminary selection of appropriate energy technologies for food utilization in humanitarian contexts.
- *Safe Access to Fuel and Energy (SAFE) Humanitarian Workshop*, Nairobi, November 28-30th, 2017.
  Oral presentation: Technologies for food preservation in humanitarian settings.
- *Energy for Displaced People: A Global Plan of Action for Sustainable Energy Solutions in Situations of Displacement*, Berlin, January 15-16th, 2018. Contributor to working group 5: Data, Evidence, Monitoring and Reporting.
- *What role can energy play in bridging the humanitarian-development divide?* FAO, Rome, January 18th, 2018.
  Session leader: Energy for aid and development - Initiatives and barriers.
- *ETHOS (Engineers in Technical and Humanitarian Opportunities of Service)* Seattle, January 26-28th, 2018.
  Oral presentation: ENERGYCoP Platform: sharing knowledge and collaboration on energy access in humanitarian settings.
- *Comprehensive Energy Planning in critical settings - from emergency to development*, Milan, April 12th, 2018.

Conference organizer and Session leader: The Global Plan of Action for Energy in Humanitarian Settings – the essential Link to the 2030 Agenda.

Products for practitioners

- Barbieri J., Colombo E. (Eds.), *SET4Food guidelines on sustainable energy technologies for food utilization in humanitarian contexts and informal settlements*. Department of energy, Politecnico di Milano, 2015, ISBN: 978-88-941226-0-2. Available on the ENERGYCoP at https://bit.ly/2O8HGSu

The guidelines provide practitioners with information on a wide number of technologies for cooking, food preservation, water pumping and purification, and electric power supply for use in humanitarian settings.

- *Impact Evaluation Framework tool*. Available on the ENERGYCoP at https://bit.ly/2HJKjYF

An Excel® interactive tool for the impact evaluation of energy-related projects in critical contexts, based on a multi-dimensional, people-oriented and context specific approach.

- *Decision Support System*

An interactive tool for the preliminary selection of appropriate energy technologies related to food security in humanitarian contexts. The DSS includes 5 main areas of intervention (cooking, water treatment, water pumping, food preservation, power generation). Available on the ENERGYCoP at https://bit.ly/2Rfxj0Z

- E-learning course *Appropriate energy technologies for food utilization in refugee camps and informal settlements: overview, selection criteria and pilot case studies*.

The course provides an overview of the linkage between energy technologies and food (food preparation and preservation) in humanitarian contexts. The course is structured in five modules: (i) Access to sustainable energy as leverage to development and human rights; (ii) Access to energy in refugee/IDP camps and informal settlements; (iii) Energy and food in refugee/IDP camps and informal settlements; (iv) Energy technologies for food preparation and conservation; (v) Identification of appropriate technologies for preparation and preservation: the SET4food decision support system (DSS). Available at http://www.set4food.org/tools/elearning, and on YouTube https://www.youtube.com/channel/UC7DdnsO916ns6FUY717bw3A

Annex B – SET4food rapid assessment questionnaire

GENERAL CONTEXT OF INTERVENTION

A) Type of settlement:

☐ Camp
☐ Informal settlements
☐ Shelter option

B) Type of main group living:

☐ IDPs
☐ Refugees

C) How many people live in the camp/settlement?

____

D) Please, provide information on the history of the camp or the evolution of the IDPs/refugees' presence.

____

E) Please, provide a description of main duties and tasks concerning the camp/settlement management (who does what)

____

F) Please, describe the main services provided by the international community at the moment (NGOs, International Organizations involved in overall coordination, etc.)

____

G) Please, describe who they are (nationality) and where they come from

____

H) Select their status:

☐ Asylum seekers
☐ People registered by UNHCR
☐ Illegal migrants
☐ Other (please specify)

____

I) Which is the average duration of their stay?

____

J) Please, if possible provide a gender & age matrix

____

K) Please, provide the HH average size and composition

____

L) Briefly describe how the IDPs/refugees are accommodated, and the average area available per HH

____

M) External support provided:

☐ Food
☐ Non-food items
☐ Other (please specify)

____

N) Please, describe if they have any sources of income, and their average expenditure related to food

____

O) Please, describe if they are / are not socially accepted and included by the hosting community, both in the settlement and in the surrounding area they live in

____

FOOD

A) Type of food most commonly eaten:

☐ Fresh
☐ Dry
☐ Other (please specify)

____

B) If the consumption of fresh food is limited, what is the main reason?

☐ Economic (it is too expensive)
☐ Lack of food conservation capacity
☐ Cultural (IDPs/refugees are used to eat dry food)
☐ Food availability (no other food available)
☐ Other (please specify)

____

C) Please, describe the main typologies of consumed food, and the average amount per capita (per day/month). Out of these, specify the average amount of food that needs to be cooked (per capita)

____

D) Please, report the frequency (daily/weekly/monthly) and quantity (per capita) of the abovementioned food items supplied (per each typology)

____

E) Please, provide an estimation of food (both fresh and cooked) wasted due to deterioration (per HH, per week)

____

F) Please, provide an estimation of organic waste generated (per HH, per week)

____

G) Can you describe how food is supplied to and/or purchased by the families?

____

H) Is there an area for food storage in the camp/HHs?

☐ Yes
☐ No

I) If yes, how is food stored and/or preserved?

____

J) If yes, which kind of facilities are used for food preservation?

☐ Electric refrigerators
☐ Gas refrigerators
☐ Solar refrigerators
☐ Electric driers
☐ Solar driers
☐ Other (please specify)

____

K) If no food preservation/conservation technology is used, can you explain why (e.g. “food is distributed every day and immediately consumed”, “food preservation technologies are too expensive”, “the food consumed does not need any preservation technology”)?

____

L) Food cooking is:

☐ Provided by a community service
☐ Performed independently by each family

M) Food is cooked:

☐ Three times per day
☐ Two times per day
☐ One time per day
☐ Once every two days
☐ Other (please specify)

____

N) Are there any cultural/religious barriers which may affect food preparation/ conservation/ consumption?

____

WATER

A) Please, describe location and typology of water sources in use

____

Please, describe how water is stored in the camp and/or at HHs level

____

B) How is water obtained in the camp?

☐ Pumped from wells inside the camp
☐ Pumped from wells outside the camp and transported by hand
☐ Transported by tankers
☐ Other (please specify)

____

C) Water treatment/purification at HH level is needed?

☐ Yes
☐ No

D) If yes, which treatment is usually adopted?

☐ Boiling
☐ Chlorination
☐ SODIS
☐ Filtration
☐ Other (please specify)

____

E) Please, briefly describe hygiene practices related to water consumption, if any

____

ENERGY

A) Can you describe the main energy sources?

____

B) The most used cooking fuels are:

☐ Wood
☐ Charcoal
☐ Bottled gas
☐ Kerosene
☐ Other (please specify)

____

C) Most common cooking systems are:

☐ Three-stones fire or traditional stoves
☐ Improved stoves
☐ Gas stoves
☐ Other (please specify)

____

D) People usually cook:

☐ Indoor
☐ Outdoor

E) Most common cooking systems in the hosting community are:

☐ Three-stones fire or traditional stoves
☐ Improved stoves
☐ Gas stoves
☐ Other (please specify)

____

F) Cooking systems are also used for heating?

☐ Yes
☐ No, heating is not needed
☐ No, other systems are used

G) Where is the fuel purchased?

☐ Fuel is purchased outside the camp
☐ Fuel is purchased or distributed inside the camp

H) In the case of biomass as fuel, is there an energy source management procedure in order to avoid forest degradation or depletion?

☐ Yes
☐ No

I) Electricity is mainly needed for:

☐ Lighting
☐ Heating
☐ Refrigeration
☐ Cooking
☐ Water pumping

☐ Other (please specify)

____

J) Electricity is:

☐ Supplied by the electric grid
☐ Produced by using diesel generators
☐ Produced by using renewable energy
☐ Not available in the camp
☐ Other (please specify)

____

K) Electricity is mainly used by:

☐ Community services
☐ Families

L) If electricity is available, power supply is:

☐ Reliable and available every day during food preparation
☐ Reliable, but available only for few hours every day (not enough for cooking all the meals)
☐ Unreliable (not available everyday/not during food preparation)

M) Can you give an idea about the electric power needed in the camp in average? [kW]

____

N) Are there other issues regarding the linkage between energy and food not investigated by this questionnaire?

☐ Yes
☐ No

If yes please specify

____

O) Are there any other issues concerning energy and its management / sustainability that you think are worth to be reported?

____

LOCAL RESOURCES

A) Please, describe if biomass fuels (firewood, charcoal) are available in the area, and their characteristics (price in the local market, environmental issues/concerns on their utilisation)

____

B) Are you aware of any cultural/religious/legal/institutional barriers concerning the utilization of biomass fuels?

____

C) Is there any water stream/river in the surrounding area? Can you describe it?

____

D) Please, describe if the area is windy, and possibly report its main characteristics (regularity, intensity)

____

E) Is there availability of construction material, such as timber, metal sheets, clay, cement, stones, …?

____

F) Are there people skilled on artisanal works? Which kind of works they are used to (e.g. carpentry, ceramics, …)?

____

G) Please, describe if technologies and components for energy production are available in the local market or in nearby areas (diesel gensets, PV panels, electrical materials, etc.)

____

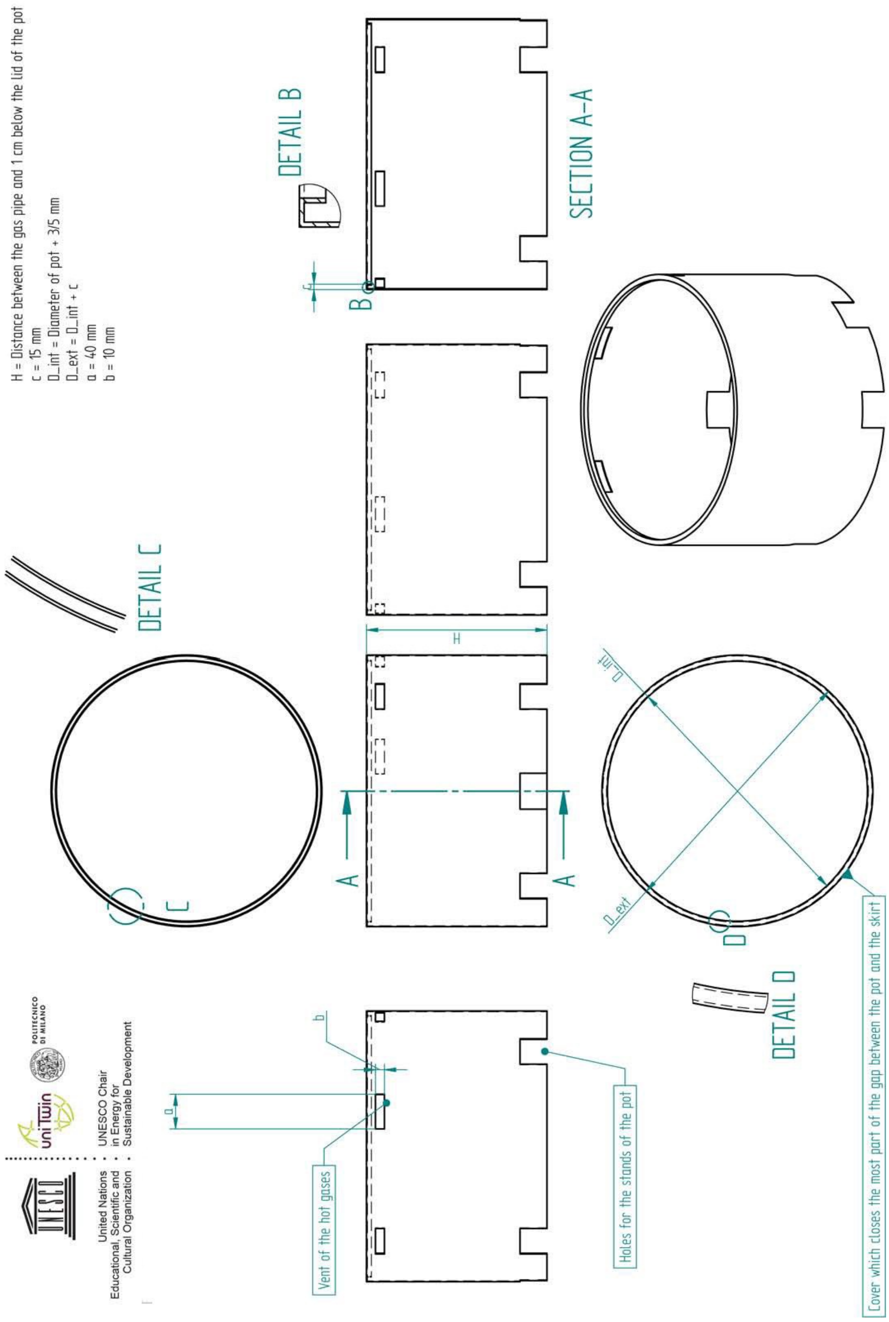
Do you have any other general comments/observations?

____

Thank you for your collaboration!

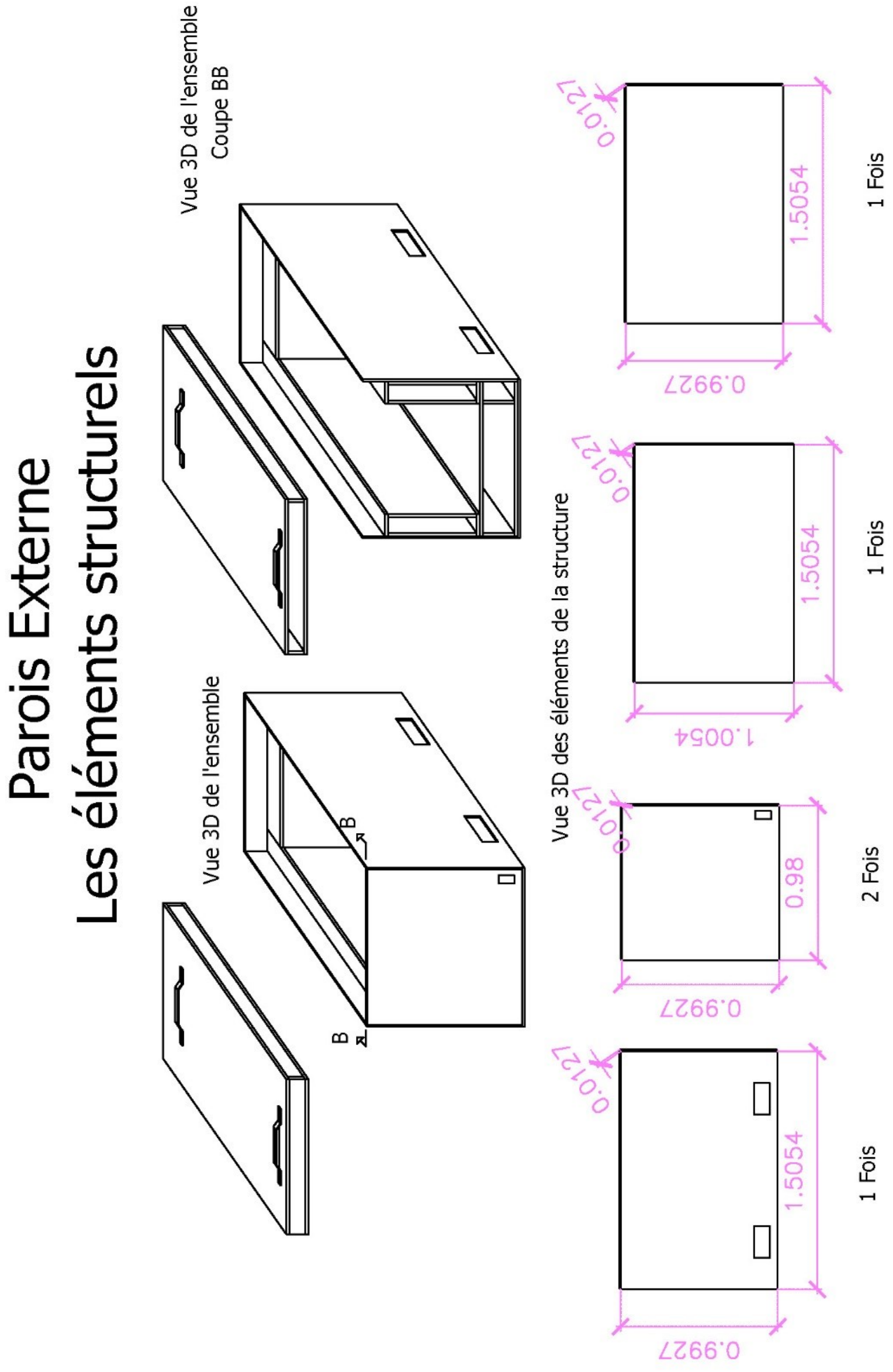
Annex C – Technical drawings

Technical drawings of the SET4food potskirt

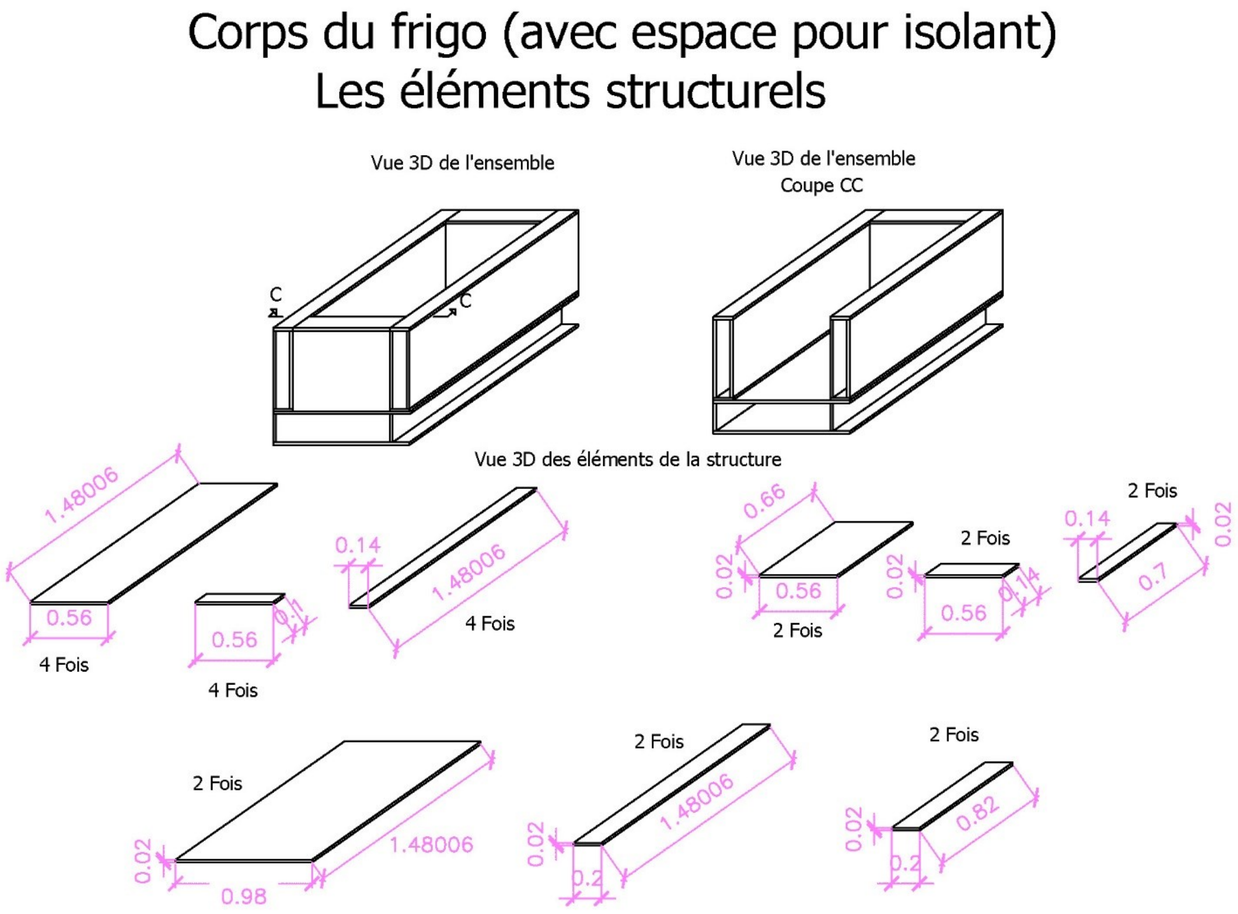


Credits: *SET4food/UNESCO Chair E4SD.*

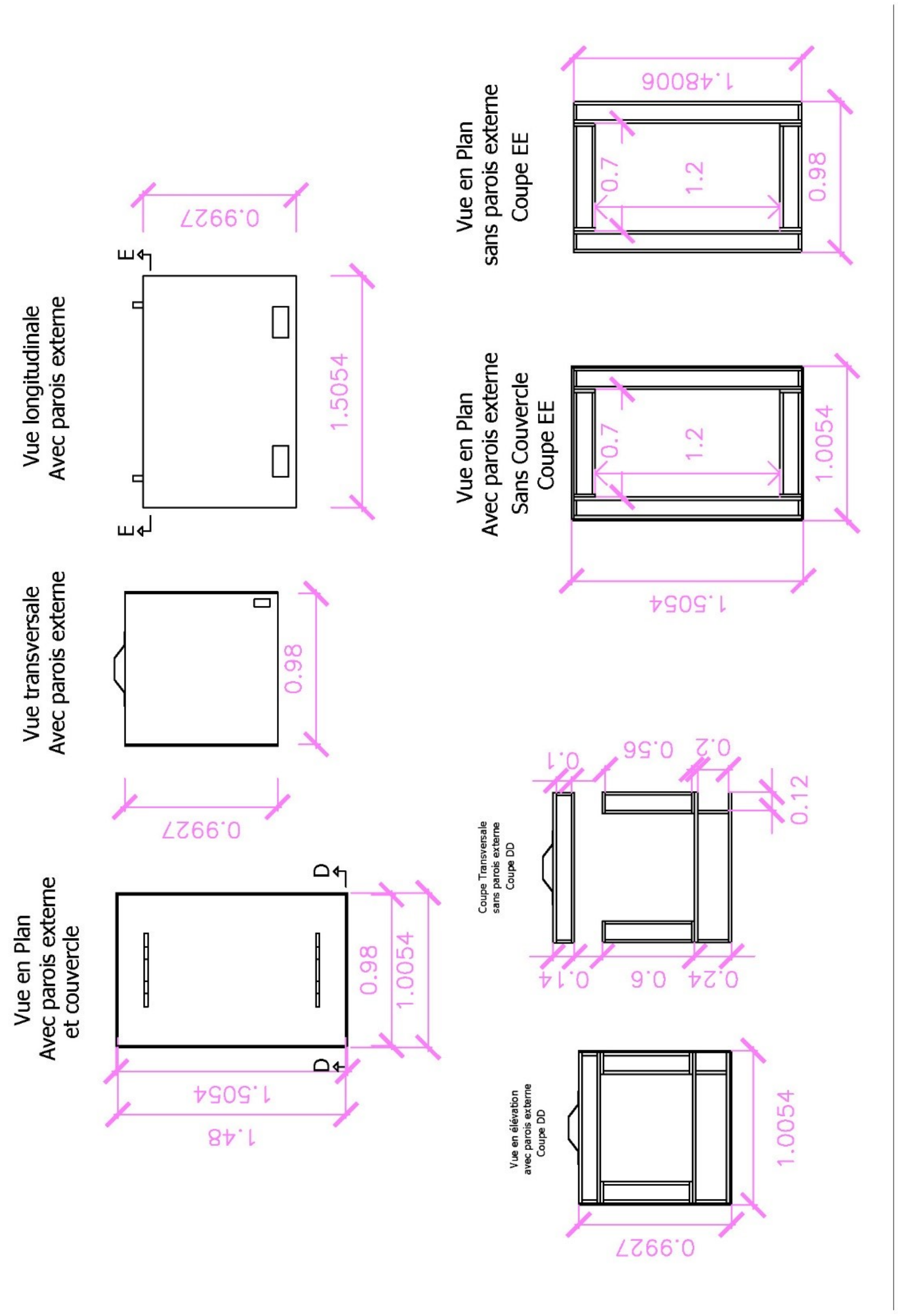
Technical drawings of the SET4food SPARK refrigerator envelope



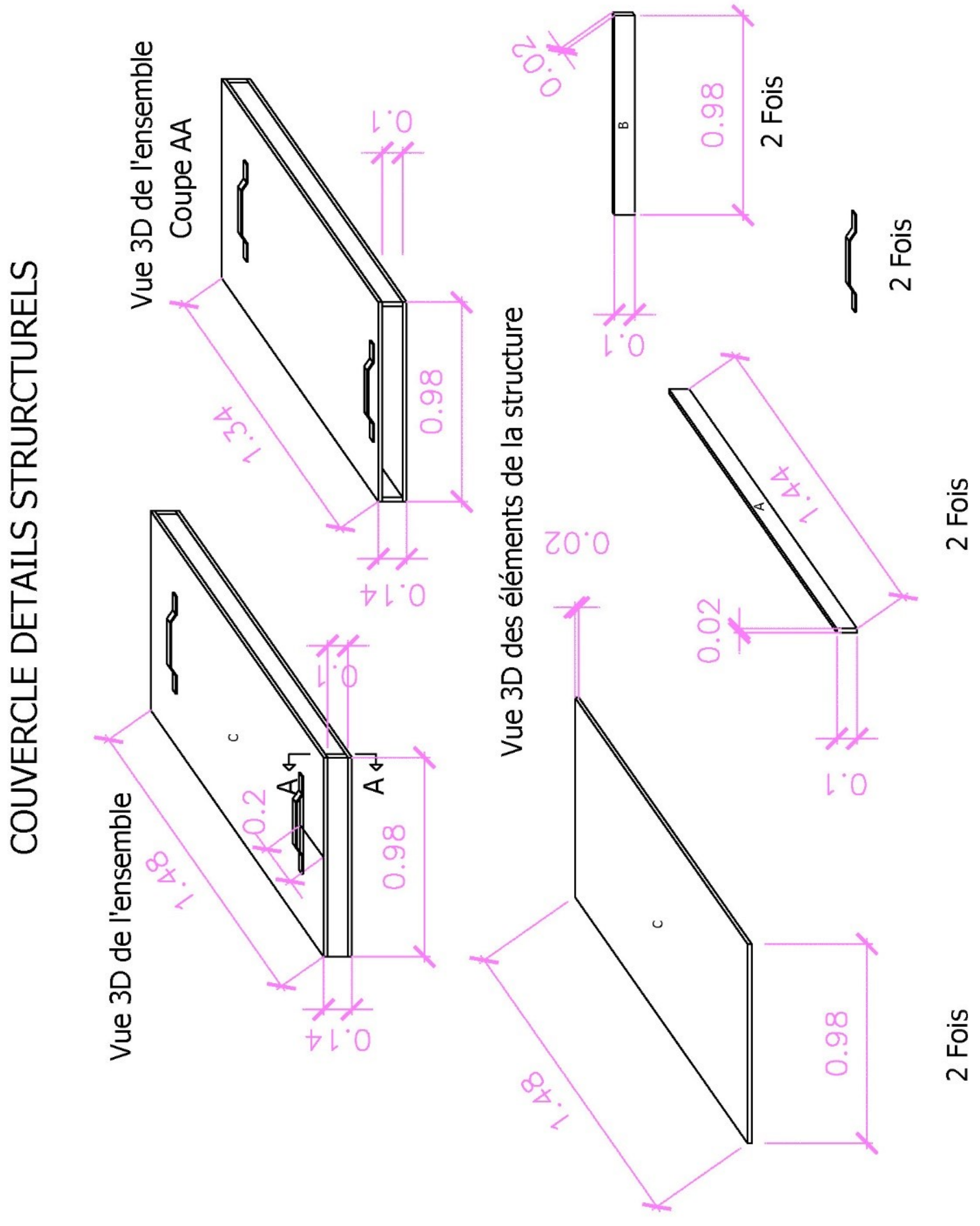
Credits: *SET4food/COOPI.*



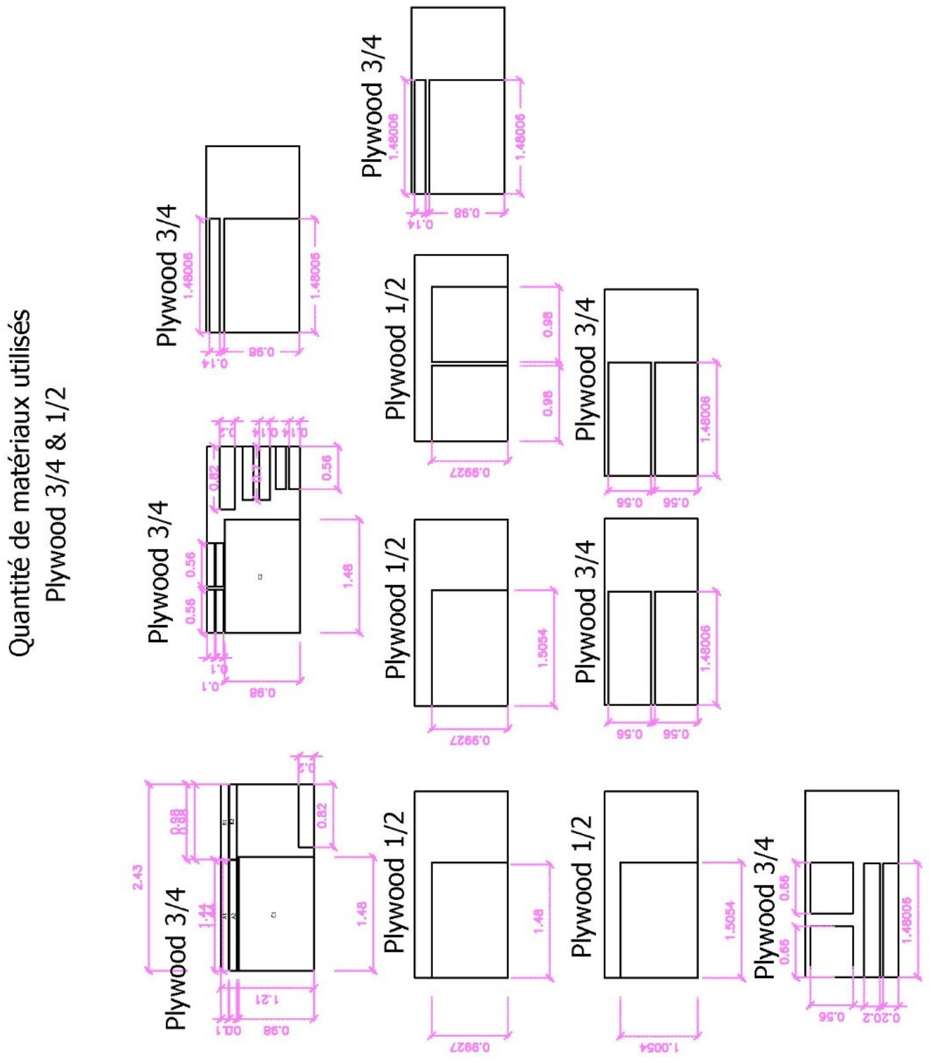
Credits: *SET4food/COOPI.*



Credits: *SET4food/COOPI.*



Credits: *SET4food/COOPI.*



Credits: *SET4food/COOPI.*

Annex D – SET4food qualitative surveys

Change perception questionnaire

Indicator	Description	Answer
Energy - general aspects		
Energy needs	Do you think that now you better meet your energy needs due to a better energy availability?	Yes/no/[nihil]
New energy consumption	Have you introduced any new use of energy (including electrical energy)?	Yes/no/[nihil]
Opportunity from energy	Do you think that now you have new opportunities due to the new technologies introduced?	Yes/no/[nihil]
Food consumption		
Cooking practice	Have you changed your cooking practices due to the introduction of new technologies?	Yes/no/[nihil]
Cooking stability	Do you think that your cooking practices are more stable, now?	Yes/no/[nihil]
Nutrition	Do you think that your feeding has been improved from a nutritional point of view since the introduction of new technologies?	Yes/no/[nihil]
Diet variety	Has your household diet varied due to the introduction of new technologies?	Yes/no/[nihil]
Food purchased	Has your grocery shopping changed due to the introduction of new technologies?	Yes/no/[nihil]
Food safety	Do you think that food preservation has been improved due to the introduction of new technologies?	Yes/no/[nihil]
Satisfaction	Are you happier about the food you consume now?	Yes/no/[nihil]
Other aspects		
IGA development	Have you developed new income generating activities due to the introduction of new technologies?	Yes/no/[nihil]

Shopping frequency	Have you reduced your shopping frequency due to the introduction of new technologies?	Yes/no/[nihil]
Security due to shopping	Do you feel safer due the change of shopping frequency?	Yes/no/[nihil]
Security due to lighting	Do you feel safer due the improved means of lighting?	Yes/no/[nihil]
Economical aspects	Do you think that your family expenditures decreased or are more efficient due to the new technologies?	Yes/no/[nihil]
Health	Do you think that your family health improved due to the new technologies?	Yes/no/[nihil]
Change simplicity	Was the introduction of new technologies simple?	Yes/no/[nihil]
Cultural compatibility	Do you think that the new technologies are in compliance with your culture?	Yes/no/[nihil]

List of additional qualitative questions used in the pilots

- Do you usually preserve food?
- Which kind of food do you preserve?
- Which system(s) do you usually use for preserving food?
- How frequently do you preserve food on average?
- For how long do you store food on average?
- How many meals did you prepare yesterday?
- How many meals did you cook and then preserved (not eaten) yesterday?
- How much time did you totally spend yesterday for cooking?
- How much fuel did you use for cooking?
- How many times did you use the pot skirt yesterday?
- How many times did you use the cooking stove yesterday?
- How frequently do you go to collect wood / purchase fuel?
- How much time do you usually spend for collecting or purchasing fuel?
- How much do you usually spend for the fuel?
- Have you saved any money after the introduction of the new technology? Why?
- Do you have any concerns or doubts on the utilization of the technology?
- Do you have any further comments regarding the technology or the project in general?

Annex E – HOMER equations

The core equations implemented in the HOMER algorithm are reported hereafter, based on [276], [291]. The discussion is limited to those equations relevant for the technologies implemented in the simulation of the case study in Lebanon.

PV array
The PV system power output is estimated as:

$$P_{PV} = Y_{PV} f_{PV} \times (G_T / G_{T,S}) \tag{A1}$$

where Y_{PV} is the rated capacity of the PV array [kW]; f_{PV} is the de-rating factor of the modules [%]; G_T is the incident solar radiation in the given time step [kW/m2]; $G_{T,S}$ is the standard test incident solar radiation [1 kW/m2].

Incident total radiation G_T is calculated as:

$$\begin{aligned} G_T = (G_b + G_d A_i) R_b + G_d (1 - A_i) \left(\frac{1 + \cos\beta}{2}\right) \left[1 + f \sin^3\left(\frac{\beta}{2}\right)\right] \\ + \mathrm{G}\rho_g \left(\frac{1 - \cos\beta}{2}\right) \end{aligned} \tag{A2}$$

where β is the slope of the surface [°]; ρ_g is the ground reflectance [%];G_b is the beam radiation [kW/m^2]; G_d is the diffused radiation [kW/m^2].
Moreover:

$$A_i = \frac{G_b}{G_0} \qquad f = \sqrt{\frac{G_b}{G}} \qquad R_b = \frac{\cos\theta}{\cos\theta_z} \tag{A3}$$

where G_0 is the average extraterrestrial horizontal radiation of the given time step [kw/m^2]; G is the averaged global horizontal radiation on the surface at the given time step [kw/m^2]; θ is the angle of incidence [°]; θ_z is the zenith angle [°].

$$G_0 = \frac{12}{\pi} G_{0n} \left[\cos\varphi \cos\delta (\sin\omega_2 - \sin\omega_1) + \frac{\pi(\omega_{2-}\omega_1)}{180°} \sin\varphi \sin\delta\right] \tag{A4}$$

where G_{0n} is the extraterrestrial normal radiation [kw/m^2]; φ is the latitude [°]; δ is the solar declination [°]; ω is the hour angle (at the beginning and end of the given time step) [°].

$$G_{0n} = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \tag{1}$$

where G_{sc} is the solar constant, equal to 1.367 kW/m^2; n is the given day of the year.

Wind turbine

The wind turbine power output is estimated thought he following steps.
For each time step, wind speed at the hub height is calculated as:

$$U_{hub} = U_{an}\frac{\ln z_{hub}/z_0}{\ln z_{an}/z_0} \tag{2}$$

where U_{hub} is the wind speed at hub height of selected wind turbine [m/s]; U_{an} is the wind speed at the measuring point (anemometer) height; z_{hub} is the hub height of selected wind turbine [m]; z_0 is the surface roughness length [m]; z_{an} is the measuring point (anemometer) height.

The power output of the turbine at standard pressure and temperature $P_{w,stp}$ [kW] is calculated as a second step, referring to the wind turbine's power curve (Figure E.1).

Power output at actual condition is obtained by applying a correction factor:

$$P_w = P_{w,stp}\frac{\rho}{\rho_0} \tag{2}$$

where ρ and ρ_0 are air density at actual and standard conditions, respectively [kg/m^3].

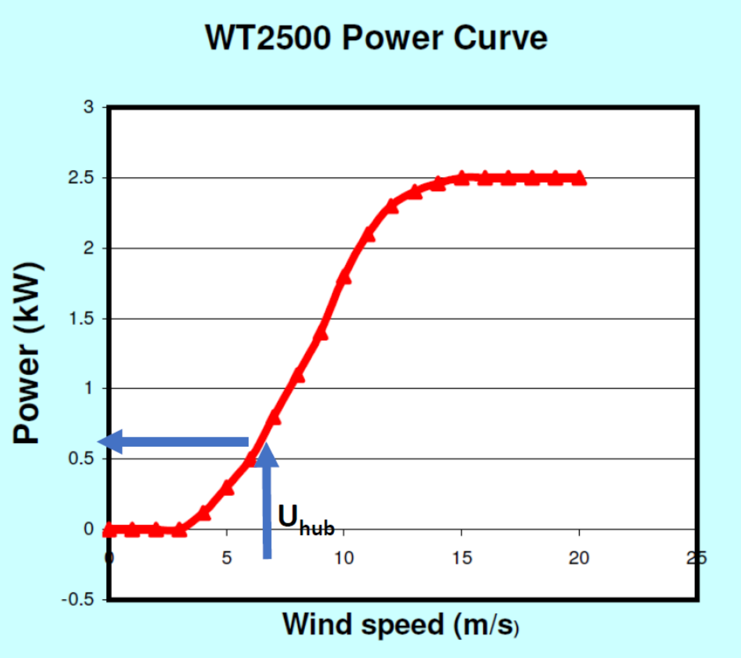


Figure E.1 – Wind turbine's power curve. *Source: [2].*

Battery charge and discharge power
HOMER models the batteries according to the kinetic model, which is able to simulate the shape of a typical battery capacity curve.
curveevaluates the charge and discharge behaviour of the batteries based on two parameters: maximum battery charge and maximum battery discharge power. Therefore, the two parameters respectively determine the fraction of available power that can be directed to the storage, or the maximum power that can be made available by

The maximum battery charge power is determined by imposing three constraints.
The first constraint comes from the kinetic model of the chemical storage. The maximum power that can be absorbed by the storage according to such model is determined as:

$$P_{b,max,kin} = \frac{kQ_1 e^{-k\Delta t} + Qkc(1 - e^{-k\Delta t})}{1 - e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \tag{2}$$

where Q_1 is the energy stored in the battery at the beginning of the given time step [kWh]; Q is the total energy stored in the battery at the beginning of the given time step [kWh]; c is the capacity ratio of the selected battery [-]; k is the selected battery's rate constant [h^{-1}]; Δt is the time step [h].

The second constraint is due to the maximum charge rate of the selected battery.

$$P_{b,max,mcr} = \frac{(1 - e^{-\alpha\Delta t})(Q_{max} - Q_1)}{\Delta t} \tag{2}$$

where α is the maximum charge rate of the battery [A/Ah]; Q_{max} is the total capacity of the storage [kWh].

The third constraint is the maximum charge current of the selected battery.

$$P_{b,max,mcc} = \frac{N\, I_{max} V_n)}{1000} \tag{2}$$

where N is the number of installed batteries; I_{max} is the maximum charge current of the battery [A]; V_n is the nominal voltage of the battery [V].

Maximum battery power charge is set selecting the most limiting among the three constraints, i.e.:

$$P_{b,cmax} = \frac{\min(P_{b,max,kin}\,, P_{b,max,mcr}\,,\ P_{b,max,mcc})}{\eta_{b,c}} \tag{2}$$

where $\eta_{b,c}$ is the charging efficiency of the selected battery [-].

The maximum battery discharge power is determined based on the behaviour of the battery, according to the kinetic model. Over each time step:

$$P_{b,dmax,kin} = \frac{-kcQ_{max} + kQ_1 e^{-k\Delta t} + Qkc(1 - e^{-k\Delta t})}{1 - e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \tag{2}$$

where Q_1 is the energy stored in the battery at the beginning of the given time step [kWh]; Q is the total energy stored in the battery at the beginning of the given time step [kWh]; Q_{max} is the total capacity of the storage [kWh]; c is the capacity ratio of the selected battery [-]; k is the selected battery's rate constant [h^{-1}]; Δt is the time step [h].

Finally,

$$P_{b,dmax} = \eta_{b,d} P_{b,dmax,kin} \tag{2}$$

where $\eta_{b,d}$ is the battery discharging efficiency [-].

Cost of Energy (COE)
HOMER calculates the COE [USD/kWh] as follows:

$$COE = \frac{C_{a,tot}}{E} \tag{2}$$

Where $C_{a,tot}$ is the total annualized cost of the system [USD/yr]; E is the total supplied electric energy [kWh/yr].

$$C_{a,tot} = CRF(i, R_{proj}) C_{NPC,tot} \tag{2}$$

Where CRF is a function for the capital recovery factor; i is the annual discount rate [%]; R_{proj} is the project lifetime [yr]; $C_{NPC,tot}$ is the total net present cost [USD], i.e. the algebraic sum of the total costs and revenues of the system during the entire lifetime reported at the present value.

$$CRF = \frac{i(1 + 1)^N}{(1 + i)^N - 1} \tag{2}$$

Where *N* is the number of years.

Annex F – Transcripts of lessons from the SET4food e-learning course

Module 2, Lesson 2: Assessment of local needs and constraints which may affect energy uses

Energy plays a central role in order to guarantee a safe and secure food utilization. In fact, the lack of access to energy is one of the causes for water shortages and for the use of untreated water. Without adequate energy provision, water pumping and water purification become hard issues, and could not be guaranteed. Insufficient access to energy, together with water scarcity, directly affects all the food supply chain, from crops and livestock production, to food processing and distribution, up to food cooking and food preservation.

A complete assessment is a fundamental phase for selecting the best strategy for an intervention. On the one hand, it is necessary to detect the main needs and constraints regarding the nexus among energy, food and water. On the other hand, all the possible energy sources should be identified. In this lesson, we will focus on needs and constraints, and in particular we will analyse:

- The main constraints specific to the area of intervention
- The characteristics of the site
- The specific needs regarding food, water, and other elements.

Which are the main constraints regarding energy for food preparation?

First of all, in large areas of the world, the main source of energy is traditional biomass, and in particular wood or charcoal. However, the availability of these kind of fuels is often limited.

Alternative fuels such as LPG or kerosene could be available in the market, but for poor people, and in particular refugees or Internally Displaced Persons, they can be unaffordable.

The lack of appropriate technologies, such as Improved Cook Stoves, causes an excessive consumption of traditional biomass. This lack is often difficult to be overcome, due to a lack of devices in the market and a lack of artisans able to locally construct this kind of devices.

When looking at food preservation, the main issue is related to adverse environment conditions: high daily temperatures or high levels of humidity are some of the causes of a fast food degradation.

For this reason, preservatives such as salt or chemical products would be required. Unfortunately, this kind of products are often unavailable or unaffordable in the case of refugees and Internally Displaced Persons.

Moreover, we assist to a lack of technologies for food preservation, such as freezers or dryers, or to a lack of energy supply, that is essential to guarantee the correct functioning of this kind of devices.

Lastly, the lack of expertise of local people is a further issue also in this case.

Last but not least, we focus now on some constraints to access to water.

Unsafe sources of water, and in particular surface water, are one of the main causes of many diseases in refugee camps and informal settlements.

In situations when water is not controlled nor treated, physical, chemical, or biological contamination often occur. In particular, pathogenic bacteria are commonly present in untreated water, causing diarrhoea and other health problems.

Another issue is related to a scarce or insecure access to water: the lack of adequate energy supply reduces the possibilities to pump and purify sufficient quantities of water, and to guarantee the safe transportation and distribution of water to the people.

The lack of knowledge on water and sanitation is again another important constraint, which acts as a huge barrier to basic hygiene practices and to water treatment.

In order to understand local needs and constraints for the specific area of intervention, an assessment is fundamental.

A first visit on the field, and the collection of general information, such as the number of people present in the camps, the status and origin of displaced people, and so on, permits to understand the main characteristics of the area. Also information on the needs, the size of the intervention to be planned, and important social issues, such as the nature of the relationships among the persons which live in the camps, should be collected.

A more specific need assessment focuses on food-related issues: some of the most important things to detect are:

- Which are the typology and the quantities of food consumed by each family
- the modalities commonly adopted for purchasing food: for example, is food purchased in a market internal or external to the camp?
- Which are the most common cooking systems
- if there are particular weaknesses related to food cooking...
- … or a particular need for food preservation

As per water, to understand the quality of the supplied water is the fundamental step: which kind of contaminants are present? and in which concentration?

Also the source of contamination should be analysed in detail, to understand for example if the contamination occurs directly at the source, or during transportation or storage. As a consequence, the main weaknesses characterizing the water supply chain can be detected.

To complete the assessment, other important elements must be considered. In particular, the issue of electric power is very relevant: is electricity available in the area? Is it produced by diesel generators or supplied through the grid?

Are there people with sufficient skills in order to construct devices?

And finally, which construction materials and which technologies are available in the local market?

Module 2, Lesson 3: Assessment of energy sources within camps and informal settlements

The assessment of local sources of energy is complementary to the assessment of the needs. A complete assessment should consider both renewable resources available in the specific location, such as sun and wind, and the resources which are available through the local market.

A particular attention should be reserved to unexploited resources, and to - let’s say - “hidden” resources, such as waste material which could be successfully used with a new and different purpose.

When talking about food preparation and in particular cooking, in refugee camps or Internally Displaced Persons settlements, biomass is of course the most common source of energy. An accurate assessment of biomass resources is a complex issue: in general no detailed data are available for specific sites. On the other hand, to understand the maximum amount of biomass that is possible to harvest in order to avoid negative effects on the woodlands like the case in the picture, is mandatory in most cases.

A good compromise for the assessment of biomass can be achieved through a survey on the field. In particular three are the main actions to carry out:

1. All the different kinds of biomass resources should be identified, also including biomass and organic residuals, such as saw dust, straw, rice husk, oil seed shells, and so on
2. Considerations should be done on the distance between the resources and the camps or settlements, and regarding all the logistic aspects affecting the transportation of the fuel
3. The direct observation of the area of biomass collection is very important to notice eventual negative effects of fuel harvesting, while the observation of the areas around the camps or settlements can reveal the availability of unexploited resources.

As per other renewable sources of energy, sun is the most common and easy to be assessed. Solar radiation can be successfully used by photovoltaic systems to generate electricity, or by systems directly using thermal energy, such as solar cookers.

In both cases, the assessment of solar radiation is easily performed thanks to the consultation of online databases and maps like the one you can see in the figure, or using data from weather forecast centres.

The assessment of wind resource is more difficult, since it is site-specific. Moreover, average wind speed in general can vary depending on the period of the year. For this reason, data from the specific area of interest should be measured all along the year in order to have an accurate understanding of the wind potential. In some cases, it’s not possible to proceed with this direct measurement. A valid alternative could be to obtain secondary data, for example from airports or weather stations present in the proximity of the location of intervention.

Finally, hydro is another resource strictly site-specific: the potential in this case is given by the combination of two elements, that are the flow rate and the height of an eventual water fall. Also in this case, the resource is affected by seasonal variability, which often requires a direct and case-by-case evaluation. On the other hand, small hydro-plants such the one you can see in the figure can provide affordable and reliable power supply. Therefore, this kind of energy source should always be considered, when a stream or a river are present in the surrounding area.

Module 2, Lesson 4: Energy utilization in refugee camps and informal settlements

In refugee camps and informal settlements energy is mostly needed for water provision and food preparation, and in particular for cooking and preservation. Moreover, energy is also fundamental for other purposes, such as lighting.

If we focus on cooking, the most common practices are based on the use of traditional fuels such as firewood or charcoal.

Firewood is burned in three-stone fires like the one in this picture: the efficiency of this system is very low, causing a high consumption of fuel, and the emission of large quantities of smoke, which means particulate matter, carbon monoxide and other pollutants that often cause pneumonia and other diseases.

Charcoal as well is burned using traditional stoves like the one we can see in the second picture. Moreover, the traditional method that is in general used for producing the charcoal starting from wood is characterized by very low efficiency. As a consequence, when considering also the production phase, in some cases cooking with charcoal can consume even more resources than the three stone fire.

As per food preservation, the lack of technologies is coupled to a lack of energy. As a consequence, when refrigeration or other methods are not adopted, high environment temperature and humidity fasten the process of degradation. The natural moisture in many foods can become a breeding ground for organisms like bacteria and fungi, which can be harmful if eaten. The consequent food losses worsen a situation of fuel scarcity already critical by itself.

The lack of preservation may therefore contribute to chronic malnutrition.

Let's now focus on the issue of access to water for cooking and for drinking. A lack of energy acts as a barrier to water treatment, and in particular to water sterilization. Untreated water is one of the main causes for the spread of many diseases such as diarrhoea or cholera in refugee camps or Internally Displaced Persons settlements, and more in general in large areas of Developing Countries. On the other hand, energy supply is essential to power pumps in order to guarantee the supply of water.

Regarding energy for lighting, one of the most common practices is again to use a three-stone fire. On the other hand, kerosene lamps are largely diffused as well. Both the solutions cause the emission of smoke, and expose people, and in particular children, to the risk of burnings.

In other cases, electricity is available from the grid, but people can't afford it or is not entitled to use it. For these reasons, informal access to electricity is a common practice, which means getting electricity through an illegal connection. In the figure you can see the typical result of this practice. This kind of installation increases the risk of electric shock, short circuit, and fire.

Many times, the lack of access to energy is also due to a lack of knowledge of people regarding alternative sources whose use is not considered.

A first example, is energy from waste: both organic waste from agriculture, feedstock, and food processing, and dry biomass residuals such as bagasse, can be turned into cooking fuels.

A second example is a simple exploitation of sunlight: solar radiation can be successfully used for drying food using solar dryers, for keeping foods refrigerated taking advantage of evaporation as you can see in the figure, and also for simple water purification processes like the one showed in this scheme.

Lastly, electricity can be locally produced through the exploitation of one or more renewable sources: small renewable energy systems provide safe and reliable power supply for lighting, refrigeration, water pumping and other important services.

Module 3, Lesson 4: The shift from traditional to modern energy: from Improved Cook Stoves to LPG and electricity

The shift from traditional to modern energy is a very complex issue. Many are the elements, which drive or act as an obstacle to the transition. Some key issues are related to people awareness and perception.

To give an example, in a number of situations in refugee and Internally Displaced Persons camps, but also, in a wider perspective, in Developing Countries, people, like the case in the picture, are not aware of the negative consequences that smoke has on their health. Another example is referred to the impact of uncontrolled biomass consumption, which can cause woodland degradation. In the picture you can see some effects of the overexploitation of wood, in this case used for making charcoal.

The complex mechanism that drives fuel substitution is clearly expressed by many studies. For example, Foley in 1995 wrote: Households energy demand rises with income, but the energy preference is essentially unaffected by increasing income.

As a matter of fact, on the one hand it is difficult to change the traditional habits. On the other, an increase in the income paves the way for higher energy consumptions. Even if a greater purchasing power would allow the transition to modern fuels such as liquefied gas, the usage of this fuels is slowed down by logistic issues or by their scarce availability in the market.

Access to electricity can lead to a better situation, but a complete shift to electricity also for activities such as cooking usually is not possible nor convenient.

Now we can try to identify and analyse a little bit more in detail the main issues that drive traditional energy utilization and the shift to alternative fuels.

A first element is seasonal variability: different climate conditions clearly influence the use of traditional biomass, causing an increase or decrease in consumption according to the different situations. During the raining season, for example, people tends to prefer alternative fuels such as LPG.

A second element to be considered is the family size: thanks to a scale effect, in general, the larger is the family, the lower is the fuel consumption per capita. This phenomenon is due to the fact that large cooking devices are in general more efficient than small ones.

The ease of access to wood is a third factor: when the access to firewood is not easy, people obviously tends to pay more attention in order to save fuel, or to substitute firewood with other fuels.

Another factor affecting fuel typology and consumption is the proximity to urban centres: people who live in peri-urban areas, for example, tends to shift from firewood to charcoal.

The possibility to be connected to the electric grid can act as a leverage at least for a partial fuel shift, as well as the availability of affordable fuels other than firewood and charcoal in the local markets.

Also the nutritional habits can affect the choice of fuel for cooking: sometimes people claims that certain foods lose their taste if not cooked with firewood

In conclusion, we can summarize the main barriers to the shift to modern energy in humanitarian or cooperation projects:

On the one hand, cultural and lifestyle resistance of people to accept the change. On the other hand, in many cases, a failure to understand the real needs of the beneficiaries

The cost of the new devices or of the alternative fuels, that result to be not affordable from the long-term perspective. Limited availability of artisans able to construct and repair improved devices, and scarce availability of new devices in remote areas due to the distance from the main markets.

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