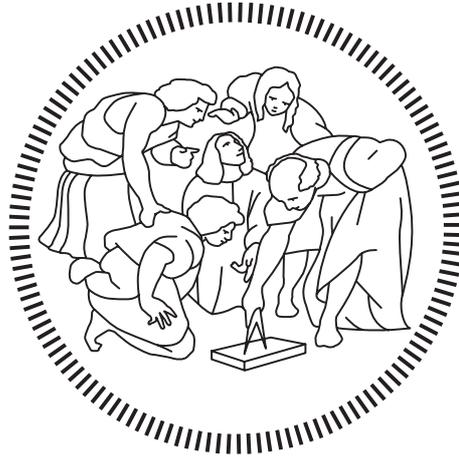


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Italian Involvement in Rural Electrification: Lessons Learnt and Way Forward

Supervisors

Prof. Emanuela Colombo

Nicola Morganti, ACRA Foundation

Co-Supervisor

Nicolò Stevanato

Candidate

Vittorio Botto Poala – 900060

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English abstract

This work has a twofold objective: first of all, it aims to carefully analyse the involvement of Italian players in the mini-grid market in the African continent; secondly, it intends to structure a detailed and holistic strategy to be adopted for the planning of energy access rural interventions in developing countries, in order to efficiently ensure long-term and sustainable impacts. The first part of the dissertation is therefore dedicated to the study of the identified projects implemented by the different Italian players (non-profit organisations, private companies and academic institutions), with particular attention paid to the outlining of the intervention methods adopted. Based on the outcomes of this investigation, the author defines the guidelines for the planning of integrated and cross-sectorial energy access projects, through the in-depth analysis of the Comprehensive Energy Solutions Planning (CESP) framework; this second part is focused in particular on the study of the applicability and benefits of modelling tools for the design of mini-grids, and the identification of techno-economic and social solutions useful for the sustainability of mini-grid projects.

Italian abstract

Questo lavoro ha un duplice obiettivo: prima di tutto, mira ad analizzare attentamente il coinvolgimento degli attori italiani nel mercato delle *mini-grid* del continente africano; in secondo luogo, si propone di strutturare una strategia dettagliata e olistica da adottare per la pianificazione di interventi rurali per l'accesso all'energia nei paesi in via di sviluppo, in modo da garantire impatti sostenibili e a lungo termine. La prima parte della dissertazione è dunque dedicata allo studio degli identificati progetti implementati dai diversi *player* italiani (organizzazioni di società civile, compagnie private e enti accademici), con particolare attenzione rivolta alla delimitazione dei metodi d'intervento adottati. Sulla base dei risultati di quest'indagine, l'autore definisce le linee-guida per la pianificazione di progetti per l'accesso energetico integrati e intersettoriali, attraverso l'analisi approfondita della *Comprehensive Energy Solutions Planning* (CESP); questa seconda parte si focalizza, in particolare, sullo studio dell'applicabilità e dei vantaggi degli strumenti di modellazione per la progettazione di mini-grid e sull'identificazione di soluzioni tecno-economiche e sociali utili per la sostenibilità di tali progetti.

Extended Abstract

Introduction

The importance of modern energy, and therefore of electricity, is explicitly stated in the SDG7 of Agenda 2030 promoted by the United Nations, which aims at ensuring “access to affordable, reliable, sustainable and modern energy to all”. The achievement of this ambitious goal is strictly related to the electrification of African rural areas, in which only 35% of the population has access to electricity; the mini-grids are indeed a viable alternative to the costly extension of underdeveloped national power grids to provide electricity to sparsely populated remote areas.

According to the “Mini-grid policy toolkit” published by the European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF) mini-grids are defined as systems involving “*small-scale electricity generation (10 kW to 10 MW), which serves a limited number of consumers via a distribution grid that can operate in isolation from national electricity transmission networks*”; they are typically powered by local renewable sources and supported by one or more backup diesel generators and a battery storage system. Today there are about 1500 mini-grids installed around Africa, and other 4000 are planned to be built, in order to exploit the high renewable potential of the continent, which could meet the energy needs of its entire population.

This work, conceived out of a collaboration between Politecnico di Milano and the Italian NGO ACRA Foundation, aims primarily to investigate how much Italian actors (non-profit, private and academic) are actually involved in the emerging African mini-grid sector, and about the role they play within it. Based on the outcomes of the analysis of Italian mini-grid projects, guidelines for integrated and holistic energy access interventions in developing countries are proposed through the study of the Comprehensive Energy Solutions Planning (CESP) framework; in particular, the author aims to show the applicability and benefits of modelling tools for the mini-grid design, and to identify techno-economic and social solutions useful for the sustainability of mini-grid projects.

1. Methodology

Since the primary goal of the dissertation consists in carefully analysing the involvement of Italian players within the mini-grid sector in Africa, it is necessary, first of all, to precisely define the parameters that would guide the selection of the projects to be included in the study, and the starting point is represented by the taxonomy for small-scale generation systems in rural areas of developing countries, proposed by Mandelli et al. This work is supposed to be focused on those rural systems equipped with a distribution grid, and therefore it is limited to the analysis of decentralised and distributed mini-grid projects, shown in the “Off-grid Systems Matrix” in the Figure 1.

| OFF-GRID SYSTEMS MATRIX | DECENTRALIZED | | DISTRIBUTED |
|-------------------------|--------------------------|---------------------------------------|---------------------------------------|
| | Stand-alone Systems | Micro-Grid Systems | Hybrid Micro-Grid Systems |
| Rural Energy Uses | | | |
| Household basic needs | Home-based Systems | Systems including a distribution grid | Systems including a distribution grid |
| Community services | Community-based Systems | | |
| Productive uses | Productive-based Systems | | |
| Consumer Number | Single | Multiple | Single OR Multiple |
| Energy Sources | Single | | Multiple |

Figure 1 – Off-grid Systems Matrix.

The difference between the two systems is mostly structural: decentralized mini-grids are powered by a single conversion unit that exploits a single energy source; the distributed ones, on the other hand, rely on multiple conversion units and thus may be powered by multiple resources. Mini-grids connected to the national power grid are also included in the study, as long as the primary objective of the considered projects was the development of the local context through access to electricity. Given the scope of the work, the last fundamental prerequisite set is the presence of at least one Italian player among the developers of the mini-grid intervention.

The research of Italian NGOs involved in mini-grid projects in Africa began from the 2019-updated list of all non-profit organisations with registered office in Italy, released by the Italian Agency for Development Cooperation (AICS). The interaction with the individual communication offices of the identified potential implementers and the established telephone and email collaborations guaranteed the fruitful collection of reports and specific materials, which gave the possibility of carrying out a detailed analysis dedicated to each of their mini-grid projects.

As regards the identification of private Italian mini-grid implementers, the contacts provided by key figures of Italian international cooperation proved to be fundamental to carry out interviews addressed to people working for companies involved in the mini-grid sector and to collect useful material. This, integrated with data retrieved from journal articles and the databases and archives of international cooperation institutions, allowed to define a careful study about the role that each of the identified firms plays within the African mini-grid market.

The strengths, weaknesses and potentialities pointed out throughout the in-depth analysis of the Italian mini-grid projects led to the proposition of the Comprehensive Energy Solutions Planning (CESP) framework, which defines a six-phase path that mini-grid projects design should follow, according to a holistic and cross-sectorial approach, in order to efficiently ensure long-term and sustainable impacts. In particular, the benefits of each phase are highlighted by practical examples and case studies taken from the Italian projects previously analysed and from the literature. The validity and applicability of modelling tools as RAMP and MicroGridsPy are finally tested and shown through the sizing process of two mini-grids conducted by the author for the hypothetical electrification of two rural villages: Namanjavira Sede (Mozambique) and Kitole (Tanzania).

2. NGOs

The methodology adopted for the research of Italian NGOs involved in mini-grid projects in Africa led to the identification of eight organisations: CEFA The seed of Solidarity, ACRA Foundation, COOPI International Cooperation, SOFIA Salvatorian Office for International Aid, Kilalo-Ponte Onlus, ICU Institute for University Cooperation Onlus, AVSI Foundation and COSV Coordinating Committee of the Organisations for Voluntary Service.

2.1 *CEFA The seed of Solidarity*

Since 1976, when the organisation began working for the electrification of rural areas in Tanzania, CEFA has implemented three hydropower mini-grids in the African country. The first one has been built in collaboration with the Catholic Diocese of Njombe and commissioned in 1984, to provide electricity to the villages of Matembwe and Image, in the District of Njombe (Njombe Region); it has an installed capacity of 120 kW and it was originally thought to power the poultry farm and the animal feed production set up in Matembwe by CEFA; Matembwe mini-grid can today count on about 620 connections, including households, private activities and public services. The second mini-grid realised by CEFA started operating and serving the villages of Bomalang'ombe and Lyamko in the District of Kilolo (Iringa Region) in 2001, when the Italian NGO inaugurated a reservoir hydropower plant with a nominal capacity of 250 kW and its distribution grid, which today serves 331 users. In 2004 a third mini-grid was commissioned in Ikondo (Njombe District), where CEFA built a run-of-the-river hydropower plant, with 83 kW of installed power. This system was intended to serve the income-generating activities implemented as part of the integrated development programme, and today it has more than 500 connected customers. In 2011, CEFA launched the upgrade of the original Ikondo project, increasing its nominal power up to 433 kW, connecting the local mini-grid to the mini-grid in Matembwe and extending the resulting distribution network to five more villages and to the national grid (important anchor client). Including the latter interventions, the total investment required for the implementation of Matembwe-Ikondo programme was 3,781,131 €, funded through the grants coming from different African and European donors.

In all the three actions, CEFA has acted according to a comprehensive approach, integrating access electricity projects with interventions aimed at alleviating local food security issues and stimulating the development of income-generating activities. In particular, CEFA follows the so-called WEF Nexus model, which preaches the importance of providing access to the three crucial resources, i.e. water, energy and food. Moreover, collaborating with local authorities and stakeholders, the NGO established two community-based utilities: the Matembwe Village Company (MVC Ltd), which owns and manages Matembwe-Ikondo mini-grids and the business activities implemented in the two villages; the Bomalang'ombe Village Company (BVC Ltd), in charge of the ownership and management of the local electrical system. Finally, in the different villages involved in the projects, CEFA, with the help of local partners, has organised activities to raise the local awareness about the use of electricity and capacity-building programmes addressed to the staff of the implemented systems.

2.2 ACRA Foundation

ACRA, like CEFA, has intervened for the electrification of the rural region of Njombe, in Tanzania, realising two mini-grids, both powered by a run-of-the-river hydropower plant, respectively in the villages of Mawengi, in Ludewa District. The first one was commissioned in 2006 and upgraded between 2011 and 2013, resulting in a 300-kW installed capacity, nine served villages and 1433 connections (households, activities and public services) in 2019. The second one has a nominal capacity of 1.7 MW and a user base of 20 villages and 3648 connections (including the national grid). Both projects were financed by a mixture of local, Italian and international funders for a total investment of 7,748,265 € in Mawengi and 7,567,677 € in Lugarawa.

In order to transfer the ownership and the management of the installed infrastructures to the served communities, ACRA, similarly to CEFA, established two local non-profit utilities, whose members coincide with the mini-grid users: LUMAMA Electricity Association in Mawengi and Madope Company Ltd. in Lugarawa. Indeed, intensive capacity-building activities have been held to train the technicians in charge of managing the O&M of the systems, and, in order to foster a wider local socio-economic development, ACRA worked according to a holistic plan, which included the rehabilitation of water supply systems, school and education programmes, reforestation activities, sustainable agriculture training, and a business programme (i.e. provision of business capacity training and creation of 20 small and medium enterprises). It is lastly important to highlight the provision of individual meters and the adoption of a pre-paid tariff system, to increase the service revenues and reduce non-paying users.

2.3 COOPI

Between 2014 and 2018, COOPI took part in Promoting Renewable Energy Services for Social Development in Sierra Leone (PRESSD-SL), a project mainly funded by the European Union, with the aim of contributing to the socio-economic development of six districts of Sierra Leone, starting from electricity access interventions. COOPI, in particular, has been selected as implementer of the solar mini-grid for the electrification of Gbinti, a village in Debia Chiefdom, in the District of Karene: the PV field provides a nominal output of 56.7 kW and it is equipped with a battery storage system, supplying electricity to 25 households and 22 commercial activities (in 2019). Gbinti mini-grid can also count on two important telecommunication anchor clients as Africell and Sierratel. The project had an investment cost of 315,000 €.

Before, during and after the implementation phase, COOPI was committed to involving and mobilising the local community, through sensitization and information meetings and workshops, and the establishment of a local committee in charge of empowering Gbinti people and representing them in the decision-making phase. Particularly noteworthy is the installation of SparkMeter system to manage and monitor the consumption data and the customer payments. COOPI has been now evaluating an exit strategy and potential local operators that could acquire the ownership and the management of the whole system, ensuring its sustainability.

2.4 SOFLA Salvatorian Office for International Aid

The Salvatorian Office for International Aid, through its development office SOFIA Global, commissioned in 2015 a 200-kW hydropower mini-grid to electrify five rural villages in the Territory of Kapanga, in the Province of Lulaba (Democratic Republic of the Congo). In 2019 the distribution network served 365 users, including 3 hospitals, 3 health centres and 5 schools; the investment cost of the project (€ 1.4 million) was funded by the European Commission (75%) and the Katanga Province (15%).

In 2013, SOFIA Global had already instituted ELKAP ASBL, a local non-profit organisation, in charge of managing the electric system and the sale of electricity, and promoting the socio-economic development of the territory, through the involvement of local institutions and the promotion of new businesses and social projects. All the plant operators have been recruited on field and participated to training session throughout and after the implementation phase. ELKAP ASBL also changed its tariff strategy in 2017, switching from flat tariffs to consumption-related tariffs, through the installation of pre-paid meters.

2.5 Kilalo-Ponte Onlus

Kilalo-Ponte Onlus promoted the project for the electrification of Mweso, a small isolated centre in the North Kivu Province, in the Democratic Republic of the Congo. Together with the Comité des Agriculteurs pour le Développement Participatif (CADEP), a local non-profit organization, a 100-kW hydropower mini-grid was commissioned in 2018, and at the beginning of 2020, the connected users were about 75, including households, public services and private activities. The Italian Prosolidar Foundation was the main funder the project, whose investment cost was €182,088.

Kilalo-Ponte played the role as intermediate between Prosolidar and CADEP, which, together with a selected local enterprise, implemented the project with the aim of improving the local quality of life, electrifying the local hospital and education institutions, fostering the agricultural and food value-chain development and stimulating the enhancement of income-generating activities. Moreover, CADEP has been directly responsible for the sensitization campaign addressed to the dwellers, and it took on the whole system as owner in charge of the management and the maintenance.

2.6 ICU Institute for University Cooperation Onlus

Between 2015 and 2017, ICU designed the project for the electrification of different rural areas of Burundi, through the renovation and the commissioning of four existing hydropower plants out of operation, and through the rehabilitation and the extension of the respective connected distribution grids, respectively in the sites of Ryarusera (Muramvya Province), Kigwena (Bururi Province), Butezi (Ruyigi Province) and Nyabikere (Karuzi Province); ICU also reinforced this latter plant with the implementation of a coupled 40-kW PV field. The total capacity of the four plants, whose mini-grids are independent of each other, is 462.2 kW, and they supply electricity to the mentioned villages, for a total of almost 10,000 users in 2019 (the

distribution networks are all grid-connected). The project, whose investment cost amounted to € 2.8 million, was funded by the European Union and private donors.

ICU integrated the energy intervention with different complementary activities, such as providing intensive training courses to the technicians and directors of ABER (the local utility in charge of rural electrification, partner of the project and responsible for the ownership and management of the mini-grids) and carrying out an insistent on-field information campaign, supported by local utilities and institutions.

2.7 On-going Projects

A mention should be also made of mini-grid projects that are in the start-up or stalled phase.

CEFA is now working on two larger projects in the Tanzanian region of Njombe, modelled on Matembwe-Ikondo action: two hydroelectric plants, with capacity of 6 and 9.9 MW respectively, are under construction in Ninga and Luganga sites, and they are expected to electrify 16 rural villages in the area. Within these interventions CEFA has inaugurated an innovative approach based on a non-profit/for-profit partnership, collaborating, in particular, with ENCO Engineering consultants (an Italian company from Belluno) and Energy and Environment Partnership Programme (EEP) of Southern and East Africa.

Finally, AVSI and COSV have just launched a double project that provides for the installation of two hybrid solar-diesel mini-grids, respectively in Cabo Delgado Province (200 kW of PV and 70 kW of diesel) and Zambezia Province (60 kW of PV and 36 kW of diesel), in Mozambique. The whole programme aims to meet the basic energy requirements of the local communities and to strengthen public health and education service, through the implementation of the mini-grids and the sale of individual solar systems and biomass improved cooking stoves. Furthermore, AVSI and COSV intend to focus on various social activities aimed at promoting women's empowerment.

3. Private and academic actors

With regard to Italian private companies and academic institutions involved in the African mini-grid sector, the research led to the identification of few players, operating according to different approaches and providing diverse services.

3.1 Absolute Energy S.r.l.

The only private and properly Italian company that has so far developed, as owner, mini-grid projects in Africa is Absolute Energy S.r.l., an enterprise focused on renewable sources and environmental technologies and committed to provide universal energy access and productive uses of energy in developing countries. This engagement translates into a comprehensive and multi-partner action, typically revolving around the installation of a mini-grid, integrated with complementary socio-economic interventions.

To date, Absolute Energy has implemented three solar mini-grid projects: two in Uganda, respectively on the islands of Kitobo (228.8 kW of PV and 60 kW of diesel) and Bukasa (100

kW of PV), in the Lake Victoria; and one in the Rwandan village of Rutenderi (50 kW of PV and 30 kW of diesel), in the District of Gatsibo. Kitobo mini-grid provides electricity to about 520 domestic and commercial users and to the ice-production activity implemented within the electrification programme. On Bukasa Island the company opted for the design of a community PV plant to electrify the commercial activities created as anchor load and economic accelerator. Lastly, the mini-grid installed in Rutenderi, which serves more than 600 users, has been integrated with activities of businesses incubation and enhancement of productive uses of electricity and clean water.

3.2 Other private companies

The other identified private actors active in the mini-grid sector in Africa have been divided into turn-key suppliers and non-Italian companies founded and still run by Italian figures.

In the first category are included SAET Padova S.p.A., which developed and installed a hybrid solar-diesel smart mini-grid (3.4 MW) in the new campus of Rwanda Institute for Conservation Agriculture (RICA) in Bugesera (Rwanda); and Heliopolis S.p.A., which, since 2014, when it acquired Moçitaly Lda (a Mozambican enterprise) has provided FUNAE (the public energy utility in Mozambique) with 11 solar mini-grids, for a total output of 590 kW.

In line with the objective of this work, the author then identified two companies that do not have registered offices in Italy but were founded by Italians. The first one is Devergy, headquartered in Tanzania and engaged in the installation of small solar mini-grids (max 10 kW) in rural areas of the country, equipped with a smart system for data management and monitoring and integrated with the sale of high-efficiency electrical appliances. The second one is Equatorial Power, which is based in Uganda and recently implemented its first hybrid solar-diesel mini-grid (57 kW) in DRC, according to a holistic approach that promotes the productive uses of electricity.

ENGIE Eps, the Italian company acquired by the French energy giant, has also been included in the study, as it has maintained all the offices and production in Italy. This firm has supplied a turn-key solar-diesel-wind mini-grid (4.95 MW) to NEC SOM (National Electric Corporation of Somalia), to electrify the town of Garowe. Furthermore, it has recently started working on the implementation of two solar-diesel mini-grids (22 MW in total) respectively in Anjouan and Mohéli, the two smaller islands in the Union of the Comoros; the company will be in charge of the of the management of the plants and the electricity sale service.

It is finally important to highlight that Enel Green Power, despite being the leader among private operators in the global renewable energy sector, has never carried out real mini-grids installations, limiting itself only to donations and Corporate Social Responsibility activities.

3.3 Energy4Growing by Politecnico di Milano

Among Italian academic institutions, Politecnico di Milano is the only one identified by the author to have actually collaborated in the implementation of a mini-grid in Africa. The Energy4Growing research team intervened to provide the secondary school of Ngarenanyuki, in the district of Arusha (Tanzania), with a hybrid mini-grid, which is powered by a micro-

hydroelectric system (3.2 kW), few PV panels (940 W) and a diesel generator (5 kW). In particular, the team installed an energy hub, which manages the different energy flows in order to ensure an efficient balance between the production and the consumption sides. Several local and Italian partners have collaborated to the action, engaging in providing training courses addressed to the local users responsible for the management, the control and the maintenance of the system.

4. Comprehensive Energy Solutions Planning (CESP)

The holistic CESP framework is built on the idea that the provision of electricity to developing realities cannot be thought as an end, since it represents one of the fundamental drivers to the socio-economic development of local communities. This work proposes a framework specifically addressed to mini-grid projects, in which the discussion of each phase is strictly related to the outcomes of the previous analysis.

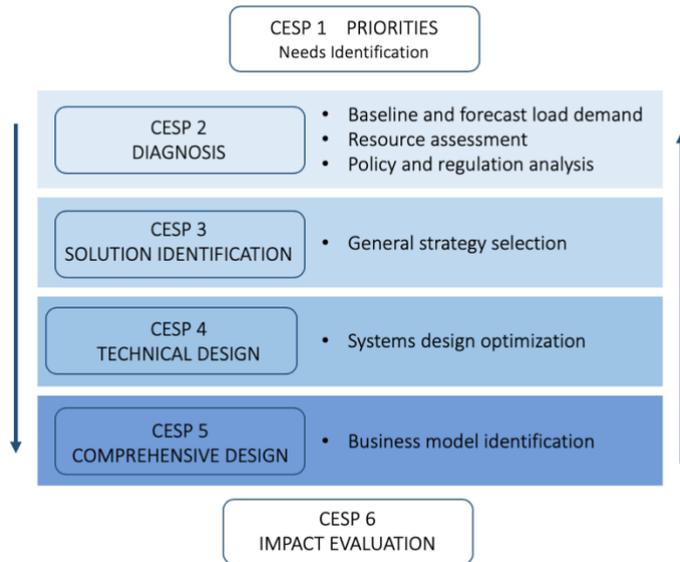


Figure 2 – CESP framework.

4.1 CESP 1: *Priorities*

An appropriate and successful rural electrification programme must be consumer-driven and the whole planning has to start from the identification of the most urgent local needs that target beneficiaries express, extending the assessment also to the socio-economic context. In order to be effective and realistic, this phase must be carried out on the field, by using means as surveys and interviews, and the help of local authorities may be fundamental to engage the community.

4.2 CESP 2: *Diagnosis*

In the Diagnosis phase the information previously collected are used and modelled in order to define the inputs necessary for the following techno-economic design. First of all, it is necessary to model the forecast load demand on the basis of users' energy habits and taking into account the complex socio-economic dynamics triggered by the electricity arrival; the use of engineering modelling tools, such as System Dynamics and RAMP, is essential to obtain realistic projections. Developers should then focus on a careful study of the energy resources landscape that the target area offers and on the attentive inspection of the policy and regulatory framework ruling the specific context.

4.3 CESP 3: *Solution Identification*

Here it is important to exploit all the gathered information and the realised models in order to structure a general action strategy, tailored to the target community and its identified needs. It is therefore necessary to define the macro-areas on which the implementers intend to intervene, the electrification approach to be adopted and the stakeholders to involve. As far as mini-grid projects are concerned, it must first be established whether to opt for a decentralised or a distributed system and which resources to focus on, to provide a reliable and affordable service.

4.4 CESP 4: *Technical Design*

In this phase, implementers resort to the utilization of high-resolution sizing tools, aiming at designing and dimensioning an optimised energy system that is capable of properly satisfying the computed load demand through a cost-effective solution. It is important that the used tool offers a wide range of technological options and a high spatial and temporal resolution; moreover, it has to be open-source, customisable and adaptable to user- and context-specific needs. MicroGridsPy, a tool specifically conceived to optimise the dimensioning process of rural mini-grids through the minimisation of their net present cost, meets all these prerequisites.

4.5 CESP 5: *Comprehensive Design*

In CESP 5, the developers must address the issue of identifying an effective business and management model, which is able to ensure the multi-dimension sustainability of the whole electrification programme. In particular, it is essential to define a fruitful strategy for the sale of electricity and to organise a comprehensive framework of all the interconnected activities and partnerships. Different solutions (inspired by the analysed projects) can be adopted in order to increase the chances of success and sustainability of a mini-grid intervention: the installation of scalable and dynamic systems, the use of smart meters and a pay-as-you-go strategy, the demand side management, the sale of high-efficiency appliances, the identification of anchor clients, the promotion of productive uses of electricity, the adoption of WEF Nexus model and the organisation of engagement social activities.

4.6 CESP 6: *Impact Evaluation*

The last step of CESP analysis has to be devoted to the assessment of the impacts that the electrification intervention is expected to generate, intended as the “positive and negative long-term effects on identifiable population groups produced by a development intervention, directly or indirectly, intended or unintended”. A proper holistic Impact Evaluation Framework (IEF) has to be people-oriented, multi-dimensional, extended in time and space, open and customisable, and it has to offer quantitative results; the IEF elaborated by Colombo et al. has been developed according to these principles.

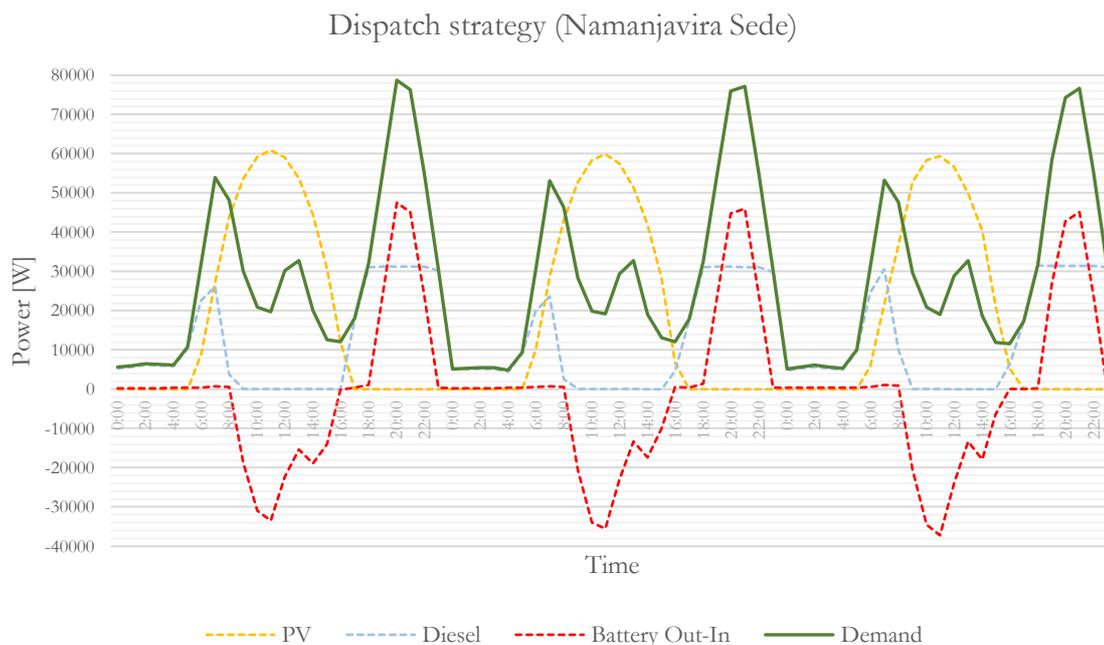
5. CESP applications

On the basis of the concepts acquired from the analysis of Italian projects and the study of CESP framework, the author carried out a mini-grid design path focused on the more technical CESP phases, which led to the dimensioning of two mini-grids for the unelectrified rural villages of Namanjavira Sede (Mozambique) and Kitole (Tanzania). The proposed applications are developed according to the three consequential linked steps: the definition of the type and order of magnitude of the electrical appliances that are realistically used in the considered village; the calculation of its daily and annual load curves thanks to the use of RAMP; the technical design and sizing of an off-grid plant able to meet the identified energy needs, using MicroGridsPy.

In the case of Namanjavira Sede, the mini-grid is supposed to serve domestic users only, while in Kitole the power consumption of some business activities and public services were also included.

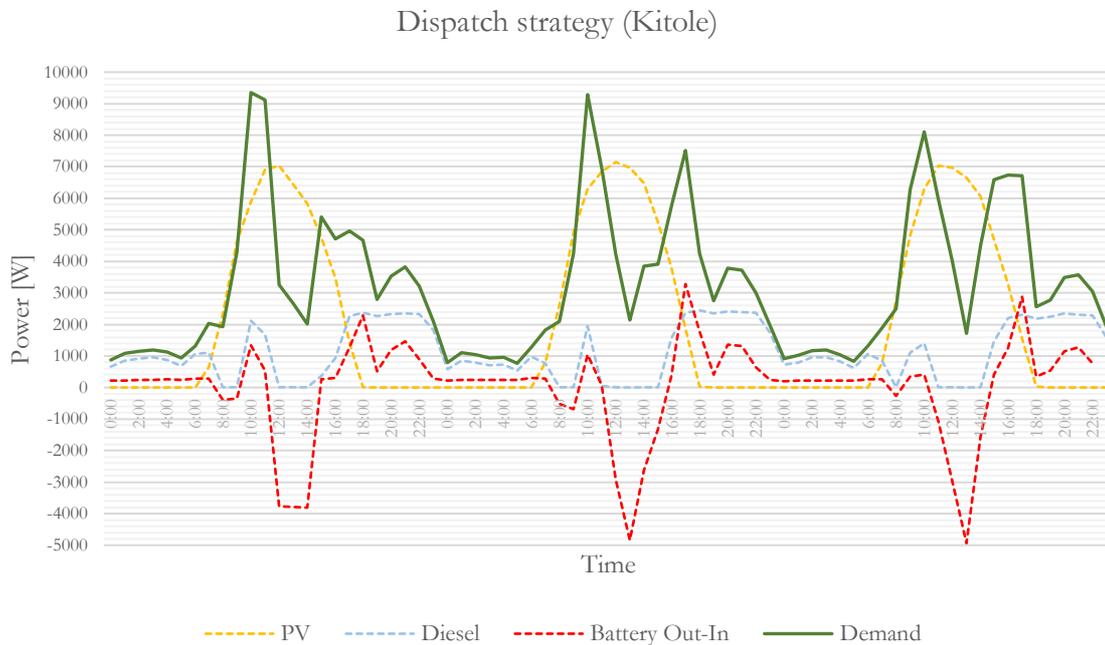
5.1 Namanjavira Sede, Mozambique

Based on the interviews carried out in Namanjavira Sede by the SESAM Group, the author modelled the domestic users of the village into four income-based categories, according to the appliances they owned. Thanks to the use of RAMP and on the basis of the results of the previous step, the expected load curve of local households was calculated. Finally, after making appropriate and literature-based assumptions about project and technologies techno-economic parameters, a cost-effective hybrid mini-grid has been dimensioned, by using MicroGridsPy: the power production is ensured by an 85-kW PV field coupled with 31.5 kW diesel generation and a Li-ion storage system of 187.5 kWh. The total investment necessary for the plant is USD 244,623, while the minimised net present cost is equal to USD 578,003 and the levelized cost of the produced electricity is USD 0.29 per kWh.



5.1 Kitole, Tanzania

The approach adopted for the sizing process of the mini-grid in Kitole is the same as the one used for Namanjavira Sede application, with the difference that, in this case, the system is also supposed to meet the energy needs of some identified income-generating activities, a health centre and a school. The information needed to outline the framework of the appliances used in the village was obtained from the on-field studies of Fabrizio Colombelli. The forecast load curve obtained working on RAMP was then used as input to MicroGridsPy, in order to optimally dimension a hybrid mini-grid with a PV nominal capacity of 10 kW, a diesel capacity equal to 2.7 kW and an 18.3-kW Li-ion storage system. The plant requires an investment of USD 26,463 and it is characterised by a net present cost of USD 48,261 and a levelized cost of electricity equal to USD 0.34 per kWh.



Conclusions

Mini-grids represent a suitable solution for the provision of electricity in poorly inhabited remote rural areas, but the total investment required to build a mini-grid is still high and the cost recovery is still long: almost all the considered Italian interventions has been strictly dependent on the grants received by donors. Another evident barrier to investments in the mini-grid market is represented by the African unclear and unreliable energy policies. However, the approach adopted by the different Italian players identified is not limited to the installation of energy systems only, but it is moving towards a more holistic and cross-sectorial direction. The CESP methodology, appropriately conducted and supported by precise modelling tools, could significantly help to precisely structure these holistic interventions, increasing their cost-effectiveness and providing a reliable and affordable provision service to the target community.

Table of Contents

| | |
|--|-------|
| Acknowledgements | III |
| Ringraziamenti..... | V |
| English abstract | VII |
| Italian abstract..... | IX |
| Extended Abstract..... | XI |
| Table of Contents..... | XXIII |
| List of Figures..... | XXV |
| List of Tables | XXVII |
| Introduction..... | 1 |
| 1 Methodology..... | 5 |
| 2 NGOs..... | 10 |
| 2.1 Tanzania..... | 12 |
| 2.1.1 CEFA The seed of Solidarity | 13 |
| 2.1.2 ACRA Foundation | 19 |
| 2.2 Sierra Leone..... | 27 |
| 2.2.1 COOPI International Cooperation..... | 29 |
| 2.3 Democratic Republic of the Congo (DRC)..... | 34 |
| 2.3.1 SOFIA Salvatorian Office for International Aid..... | 36 |
| 2.3.2 Kilalo-Ponte Onlus | 39 |
| 2.4 Burundi..... | 42 |
| 2.4.1 ICU Institute for University Cooperation Onlus | 43 |
| 2.5 Ongoing Projects | 46 |
| 2.5.1 Ninga and Luganga Projects by CEFA | 46 |
| 2.5.2 Projects by AVSI and COSV | 47 |
| 3 Private and academic actors..... | 49 |
| 3.1 Absolute Energy S.r.l., the only private Italian developer | 50 |
| 3.2 Turn-key mini-grids suppliers..... | 52 |
| 3.2.1 SAET Padova S.p.A..... | 53 |
| 3.2.2 Heliopolis S.p.A..... | 54 |

| | | |
|-------|---|-----|
| 3.3 | Non-Italian companies founded by Italians | 55 |
| 3.3.1 | Devergy | 55 |
| 3.3.2 | Equatorial Power..... | 57 |
| 3.4 | ENGIE Eps, a hybrid example | 58 |
| 3.5 | Enel Green Power and its approach to rural electrification..... | 59 |
| 3.6 | Energy4Growing by Politecnico di Milano | 61 |
| 4 | Comprehensive Energy Solutions Planning (CESP) | 64 |
| 4.1 | CESP 1: Priorities | 66 |
| 4.2 | CESP 2: Diagnosis..... | 68 |
| 4.2.1 | Baseline and Forecast Load Demand | 68 |
| 4.2.2 | Resource assessment | 72 |
| 4.2.3 | Policy and Regulation Analysis..... | 74 |
| 4.3 | CESP 3: Solution Identification | 75 |
| 4.4 | CESP 4: Technical Design | 78 |
| 4.5 | CESP 5: Comprehensive Design..... | 84 |
| 4.5.1 | Business model classification..... | 84 |
| 4.5.2 | Hints for the sustainability of mini-grid projects..... | 86 |
| 4.6 | CESP 6: Impact Evaluation | 89 |
| 4.6.1 | Impact Evaluation Framework (IEF)..... | 90 |
| 4.7 | CESP applications | 93 |
| 4.7.1 | Namanjavira Sede, Mozambique..... | 94 |
| 4.7.2 | Kitole, Tanzania..... | 101 |
| | Conclusions..... | 109 |
| | List of Abbreviations..... | 112 |
| | Bibliography..... | 116 |

List of Figures

| | |
|---|----|
| Figure 1 - Press review about mini-grids outlook in Africa. | 1 |
| Figure 2 - Population without access to electricity by country in Africa in 2018 [1]. | 2 |
| Figure 3 - Off-grid systems matrix for rural electrification systems in developing countries [9]. | 5 |
| Figure 4. Map of the African countries in which Italian NGOs have installed mini-grids. | 11 |
| Figure 5. Highlighting of the mini-grids installed by CEFA and ACRA (red spots) in the regions of Njombe and Iringa, Tanzania. | 13 |
| Figure 6 - Simplified layout of the Smart Rural System proposed by SAET [82]. | 53 |
| Figure 7 - Electrical layout of the hybrid mini-grid implemented in Ngarenanyuki school [107]. | 62 |
| Figure 8 - Essential diagram of Comprehensive Energy Solutions Planning (CESP). | 65 |
| Figure 9 - Example of a causal-loop diagram representing the interrelations between electricity demand and household economy [113]. | 69 |
| Figure 10 - Comparison between the load curve predicted by the feasibility study and the one computed with LoadProGen for the Ninga SHPP [115]. | 71 |
| Figure 11 - Comparison between measured data (weekdays November 2016) and the load profile generated with RAMP [118]. | 72 |
| Figure 12 - Example of a Sankey diagram describing the energy resources framework of a village in Chile [119]. | 73 |
| Figure 13 – Graphic representation of decentralized and distributed mini-grids [9]. | 77 |
| Figure 14 - Schematisation of MicroGridsPy architecture. Author’s elaboration based on [47]. | 80 |
| Figure 15 - Example of optimised generation and storage time series produced by MicroGridsPy. | 81 |
| Figure 16 – Load demand projected evolution according to three different scenarios [129]. .. | 83 |
| Figure 17 - NPC reduction with the only multi-year formulation (A) and with the addition of the capacity-expansion logic (B) [129]. | 83 |
| Figure 18 - Typical hierarchy structure of Impact Evaluation Framework [139]. | 91 |
| Figure 19 - Radar Diagram with the impact scores of the five capitals (A) and shares of the General Impact Score among capitals (B) [12]. | 92 |

| | |
|--|-----|
| Figure 20 - Daily load curves of Namanjavira Sede households, generated by RAMP..... | 97 |
| Figure 21 - Investment costs share of the mini-grid in Namanjavira Sede..... | 100 |
| Figure 22 - Outlook of the energy dispatch of the mini-grid in Namanjavira Sede (6th-8th of June)..... | 101 |
| Figure 23 - Daily load curves of Kitole users, generated by RAMP..... | 104 |
| Figure 24 - Investment costs share of the mini-grid in Kitole..... | 107 |
| Figure 25 - Outlook of the energy dispatch of the mini-grid in Kitole (6th-8th of June)..... | 108 |

List of Tables

| | |
|--|-----|
| Table 1 – Mini-grid projects selection requirements. | 6 |
| Table 2 – Contacted NGOs and related energy projects. | 7 |
| Table 3 – Identified private companies and sources of data and information. | 8 |
| Table 4 - Main details about Matembwe project by CEFA. | 15 |
| Table 5 - Main details about Bomalang’ombe project by CEFA..... | 16 |
| Table 6 - Main details about Ikondo project by CEFA..... | 17 |
| Table 7 - Main details about Mawengi project by ACRA. | 21 |
| Table 8 - Main details about Lugarawa project by ACRA..... | 22 |
| Table 9 – Donors of Mawengi project..... | 23 |
| Table 10 – Tariff strategy set by LUMAMA. | 27 |
| Table 11 – Funders of PRESSD-SL project | 30 |
| Table 12 – Main details about Gbinti project by COOPI..... | 32 |
| Table 13 – Tariff strategy set by COOPI in Gbinti..... | 33 |
| Table 14 – Main details about Kapanga project by SOFIA Global. | 37 |
| Table 15 – Main details about Mweso project by Kilalo Ponte. | 41 |
| Table 16 – Main details about Ryarusera, Kigwena, Butezi and Nyabikere projects by ICU. .. | 44 |
| Table 17 – Technologies used in mini-grid projects implemented by Absolute Energy..... | 51 |
| Table 18 – Decentralized and distributed mini-grids taxonomy..... | 77 |
| Table 19 – Framework of Users Types and appliances used in Namanjavira Sede. | 96 |
| Table 20 – Project and techno-economic parameters about Namanjavira Sede mini-grid. | 98 |
| Table 21 – Technical and economic data about the dimensioned mini-grid in Namanjavira Sede. | 99 |
| Table 22 – Framework of Users Types and appliances used in Kitole. | 103 |
| Table 23 – Project and techno-economic parameters about Kitole mini-grid. | 105 |
| Table 24 – Technical and economic data about the dimensioned mini-grid in Kitole..... | 106 |

Introduction

This work was conceived out of a collaboration between Politecnico di Milano and Fondazione ACRA, an independent and lay Italian non-governmental organisation committed to alleviating poverty through sustainable, market-based and participatory solutions, and the dissertation intends to begin with a provocation.

For several years now, the concept of mini-grid has been on everyone's lips in the energy sector: there is an insistence on the idea that these technologies, halfway between the large national electricity networks and small individual energy systems, could represent the solution, at least partial, to the problem of rural electrification in Africa. As can be seen from the press review in Figure 1, this also applies to Italian newspapers and energy companies, which have never spared words of praise for mini-grids. If, however, Western countries as Germany, France and United States, through private, public and non-profit actors, concretely invest on the diffusion of these off-grid systems in rural areas of Africa, how much are Italy and its players actually involved in this emerging sector? What role do they play in the complex African mini-grid market?



Figure 1 - Press review about mini-grids outlook in Africa.

Before getting to the heart of the matter, it is necessary, however, to outline the African energy framework and the characteristics of the considered technology.

In 2000, the African population was around 817 million, representing about 13% of the world's population; in the following years this percentage grew continuously up to 17% in 2018, with almost 1.3 billion people living in the continent. Of these, about 85% (1.1 billion) live in Sub-Saharan Africa. This growth does not seem to be slowing down and, on the contrary, the

population on the continent is expected to double by 2050, when, in particular, about 23% of the world population will be Sub-Saharan [1], [2].

Such a sharp demographic growth led to an increase in Africa's energy demand, which, however, accounts for only 6% of global demand, and it inevitably caused serious problems in terms of electricity supply: in the early 2000s the number of people without access to electricity continued to increase and it peaked at 610 million in 2013. Although these numbers have slightly declined in recent years, especially thanks to the progress done by countries as Kenya, Ethiopia and Tanzania, the electrification rate in Sub-Saharan Africa was still particularly low in 2018 (45%) and the picture is even worse if only rural areas are considered: 26% of the people living in rural areas of SSA had access to electricity and the figure drops to 6% in central African countries [1].

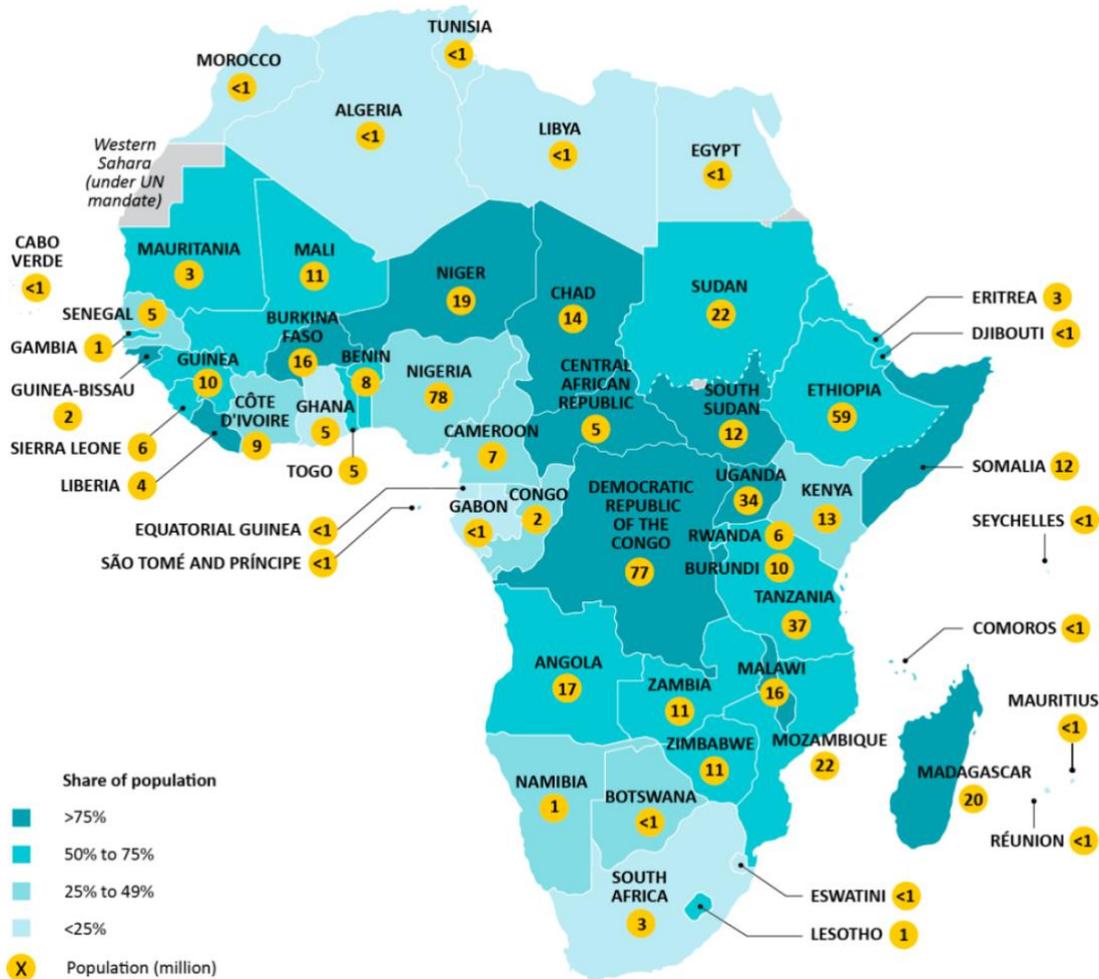


Figure 2 - Population without access to electricity by country in Africa in 2018 [1].

The importance of modern energy, and in particular of electricity, is explicitly stated in the seventh Sustainable Development Goal of Agenda 2030 promoted by the United Nations. SDG7, in fact, aims at ensuring “access to affordable, reliable, sustainable and modern energy to all”, in order to open new economic opportunities, empower women and children, provide

better education and health, generate more sustainable and inclusive communities, and guarantee greater resilience to climate change [3].

Given the numbers shown above, the achievement of this ambitious goal is strictly related to the electrification of African rural areas, where hundreds of millions of people still live without access to electricity. Most rural communities are located in areas that are too remote and isolated to be reached by the national power grids, which, in the African context, are typically underdeveloped both in size and technology; moreover, the connection of sparsely inhabited areas does not justify the high costs required by the grid extension. For these reasons, decentralised and distributed off-grid systems have become increasingly popular in the recent past, as they ensure more cost-effective and suitable solutions for the electrification of scarcely populated remote rural communities. Off-grid technologies are generally divided into stand-alone systems, which typically power single households, and mini-grids, on which this work is focused [4], [5].

According to the “Mini-grid policy toolkit” published by the European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF) mini-grids are defined as systems involving “*small-scale electricity generation (10 kW to 10 MW), which serves a limited number of consumers via a distribution grid that can operate in isolation from national electricity transmission networks*” [6]. An important advantage offered by mini-grid technologies, in compliance with SDG7 parameters, is their typical exploitation of local renewable resources, whose potential in Africa, especially in terms of hydropower, solar and wind power, is larger than the current and projected power consumption of the continent [7] (despite this, the renewable capacity installed today in Africa amounts to only 50 GW [1]); however, in order to ensure a reliable supply service, mini-grids are generally supported by one or more backup diesel generators and a battery storage system. It is important to point out that the electricity delivered by these off-grid systems is typically characterised by a higher levelized cost than that ensured by centralised solutions, and that the significant initial investment cost needs to be justified by a certain demand threshold (otherwise stand-alone systems are preferable, as more cost-effective) [6].

According to the 2019 report drafted by the Energy Sector Management Assistance Programme (ESMAP), the mini-grids installed across Africa are around 1500 today, and other 4000 are planned: thanks to the continuous reduction of renewable-based technologies’ costs and the simplification of the policies regulating foreign investment, the mini-grid market in the African continent is expected to grow more and more in the near future [8].

This thesis, therefore, is developed out of this articulated and constantly evolving framework, with the aim, as already mentioned, of outlining a precise picture of Italian involvement in mini-grid sector in Africa, conducting a detailed analysis of the projects implemented and the approaches adopted by the different identified players.

Based on the outcomes of this study, the author intends to propose guidelines for integrated and holistic energy access interventions in developing countries: the Comprehensive Energy Solutions Planning (CESP) framework, elaborated by the Sustainable Energy Systems Analysis and Modelling (SESAM) research group from Politecnico di Milano, will be illustrated in detail, highlighting the importance of adopting a bottom-up holistic approach, which does not only

focus on purely technical aspects of the project. In particular, this work is proposed to show the applicability and benefits of modelling tools for the mini-grid design, and to identify techno-economic and social solutions useful for the financial sustainability of mini-grid projects.

According to the objectives set, the body thesis is structured into four chapters, as follows:

- Chapter 1, Methodology: the author illustrates the methodology adopted for the identification of Italian mini-grid projects, for the collection of data and material related to them, for their analysis and for the definition of a CESP framework specifically addressed to this type of rural electrification interventions;
- Chapter 2, NGOs: the identified mini-grid projects carried out by Italian non-profit organisations are analysed in detail, starting from the specific socio-economic context in which they were implemented; particular attention is given to the technologies used, the method of intervention adopted and the resulting outcomes;
- Chapter 3, Private and academic actors: the author carries out a study on the context of Italian private companies and academic institutions engaged in mini-grid projects in Africa, analysing the type of service provided and the approach adopted by each of them;
- Chapter 4, Comprehensive Energy Solutions Planning (CESP): the CESP framework is presented in detail, through a meticulous investigation of the six steps that constitute it; the study aims to show the validity and applicability of the method and the modelling tools useful to plan a comprehensive mini-grid project, also with their direct application to two specific case studies.

A final chapter is devoted to the conclusions reached by the author throughout the conducted work and on the basis of the results of the study itself.

1 Methodology

This chapter is dedicated to the description of the methodology adopted by the author to achieve the established goals, explained in the introduction to the work.

Since the primary goal of the dissertation consisted in carefully analysing the involvement of Italian players within the mini-grid sector in Africa, it was necessary, first of all, to precisely define the parameters that would guide the selection of the projects to be included in the study. As regards purely technical parameters, the starting point for such selection is represented by the taxonomy for small-scale generation systems in rural areas of developing countries, proposed by Mandelli et al. [9]. This classification, unlike most of those found in literature, aims to be specifically dedicated to the rural energy context of developing countries; precisely because of its specificity, this taxonomy does not take into account centralised energy solutions (rarely suitable for the electrification of isolated and sparsely populated rural centres), but it is limited to considering off-grid systems with a maximum power output of 5 MW, detailed in the matrix in Figure 3.

| OFF-GRID SYSTEMS MATRIX | DECENTRALIZED | | DISTRIBUTED |
|--------------------------------|----------------------------|---------------------------------------|---------------------------------------|
| | Stand-alone Systems | Micro-Grid Systems | Hybrid Micro-Grid Systems |
| Rural Energy Uses | | | |
| Household basic needs | Home-based Systems | Systems including a distribution grid | Systems including a distribution grid |
| Community services | Community-based Systems | | |
| Productive uses | Productive-based Systems | | |
| Consumer Number | Single | Multiple | Single OR Multiple |
| Energy Sources | Single | | Multiple |

Figure 3 - Off-grid systems matrix for rural electrification systems in developing countries [9].

The matrix, first of all, divides off-grid systems into two main categories, decentralised and distributed systems: the former are in turn divided into stand-alone and mini-grid systems, while the latter correspond to the so-called hybrid mini-grids. In particular, this dissertation is supposed to be focused on those rural systems equipped with a distribution grid, and therefore it was limited to the analysis of decentralised and distributed mini-grid projects. The former ones refer to technologies constituted by one single conversion unit, exploiting the energy produced from one single source and supplying it to multiple, similar or different, consumers, through an autonomous distribution network. In contrast, the power provided by distributed

mini-grids is generated by more than one decentralized conversion unit, which can rely on multiple different energy sources; these units are then interconnected through a distribution grid serving a single or several users [9]. It was decided to include in this study also mini-grid solutions that are connected to the national grid, provided that the primary objective of the considered projects was the development of the local context through access to electricity.

As it is easy to assume from the title of the thesis, a fundamental prerequisite considered in the selection of projects to be analysed was the presence of at least one Italian actor (private, public, academic or non-profit) among the developers of the mini-grid interventions, since, as already explained, one of the main objectives of this work consists in studying the actual entity of Italian action in African mini-grid projects.

| | |
|--|---|
| <p>Mini-grid Projects Selection Requirements</p> | <ul style="list-style-type: none"> • Distribution grid • Decentralised or distributed systems • Single or multiple resources • Grid-connected or not • Goal of local development • Italian developing partner |
|--|---|

Table 1 – Mini-grid projects selection requirements.

Starting from these selection parameters and premises, it was possible to undertake the data collection, which proved to be complex and particularly extended in time. As regards the projects carried out by Italian NGOs, the research began from the 2019-updated list of all the so-called Organizzazioni di Società Civile (non-profit organisations) with registered office in Italy [10], released by the Italian Agency for Development Cooperation (AICS). Analysing the websites of the different organisations, it was possible to identify the NGOs engaged in the energy sector and therefore potentially involved in mini-grid projects in Africa. The author then interacted with the individual communication offices of the identified potential implementers, thus establishing telephone and email collaborations that ensured a fruitful collection of reports and specific materials. These gave the possibility of carrying out a detailed analysis of each of the selected projects, according to a precise three-level structure:

- study of the political, socio-economic and energy context of the African country in which the project has been implemented;
- introduction to the Italian non-profit organisation responsible for the development of the project;
- meticulous investigation of project details (e.g. developers, funders, investment cost, used technologies, served communities) and method of intervention adopted for its design, implementation and management.

Table 2 lists all the NGOs contacted by the author for more information about their identified energy projects; in light blue are highlighted the projects that meet the selection parameters previously illustrated.

| NGO contacted | Energy Project Location |
|----------------------|---|
| ACRA Foundation | Mawengi, Lugarawa (Tanzania) |
| Amici del Popolo | Butare, Janjagiro (Rwanda) |
| ARCS | Dschang, Batchman, Fumbot (Cameroon) |
| AUCI Association | Kenge (DRC) |
| AVSI Foundation | M'paka (Mozambique) |
| CEFA | Matembwe, Ikondo, Ninga, Lugarawa (Tanzania) |
| CES.VI.TE.M. | Labè (Guinea) |
| CIPSI | Pikine (Senegal) |
| CMSR | Kondoa (Tanzania) |
| COOPERMONDO | N'djamena (Chad) |
| COOPI | Gbinti (Sierra Leone) |
| COSPE | El Warraq (Egypt) |
| COSV | Namanjavira Sede (Mozambique) |
| DEAFAL | Maputo (Mozambique) |
| ENGIM | Lunsar (Sierra Leone) |
| ICU Onlus | Ryarusera, Kigwena, Butezi, Nyabikere (Burundi) |
| MCO Onlus | Laikipia (Kenya), Dianra (Ivory Coast) |
| Kilalo-Ponte Onlus | Mweso (DRC) |
| Istituto OIKOS | Oldonyosambu (Tanzania) |
| PRO.DO.C.S. | Kinshasa (DRC) |
| PROSUD | Kialoleni (Kenya) |
| VISES | Blantyre (Malawi) |

Table 2 – Contacted NGOs and related energy projects.

The relations established with the NGOs have also been very useful for the identification of private Italian mini-grid implementers. The contacts provided by key figures of Italian international cooperation, such as Matteo Leonardi, Carlo Tacconelli and Nicola Morganti himself, proved to be fundamental for the collection of useful material. Important information has also been collected from the databases and the archives of international cooperation institutions, such as the Italian Agency for Development Cooperation (AICS) and the United States Agency for International Development (USAID). Given the reticence of the contacted companies in the disclosure of specific data related to their projects, as regards private actors, it was not possible to carry out an investigation with the same degree of detail as the one carried out for NGOs. Nevertheless, the interviews held by the author and addressed to people working for these companies, integrated with data retrieved from journal articles, allowed to define a careful study about the role that each of the identified firms plays within the African mini-grid market, distinguishing between real project developers, turn-key system suppliers, and companies that are not Italian, but were founded and still run by Italian figures. This classification is discussed in more detail in Chapter 3.

| Identified Company | Data and Information Sources |
|------------------------|--|
| Absolute Energy S.r.l. | <ul style="list-style-type: none"> • OPENAID AICS database • Company website • Journal articles |
| SAET Padova S.p.A. | <ul style="list-style-type: none"> • Company website • A. Z., Sales and Marketing Director |
| Heliopolis S.p.A. | <ul style="list-style-type: none"> • Company website • M. F., Executive Assistant Mozambique Area |
| Devergy | <ul style="list-style-type: none"> • Company website • USAID archive |
| Equatorial Power | <ul style="list-style-type: none"> • Company website • Journal articles • R. C., Operations Analyst |
| ENGIE Eps | <ul style="list-style-type: none"> • Company website • Journal articles • E. C., System Engineer |
| Enel Green Power | <ul style="list-style-type: none"> • Company website • Journal articles • E. P., Head of Global Customers Operation |

Table 3 – Identified private companies and sources of data and information.

Finally, a section is dedicated to the analysis of Energy4Growing project, carried out by a research group of Politecnico di Milano, the only identified mini-grid intervention with an Italian academic institution among the developers. The E4G website and Facebook page, the

book “Storie di Cooperazione Politecnica 2011-2016” and Professor Marco Merlo himself, in charge of E4G, contributed to the collection on data and information related to the project.

The in-depth analysis of the identified mini-grid projects allowed to point out the strengths, the potentialities and, above all, the weaknesses of this relatively young sector. These led to the proposition of the Comprehensive Energy Solutions Planning (CESP) framework, the techno-economic approach elaborated by the Sustainable Energy Systems Analysis and Modelling (SESAM) research group from Politecnico di Milano, which defines the guidelines of the planning phases that energy access interventions should follow, in order to efficiently ensure long-term and sustainable impacts. The decision to propose this framework was precisely dictated by the previous study of Italian mini-grid projects, which have generally moved towards the adoption of a more holistic and cross-sectorial approach: the step-by-step CESP structure defines an engineering and linear method of intervention, made of six consequential phases that allow to build a complete and multidimensional mini-grid implementation, as shown in Chapter 4. The section dedicated to each of these phases has therefore been structured so as to highlight the decisive advantages resulting from its correct and precise application; in particular, the importance of each individual CESP phase is made even more evident by the practical examples and case studies reported in the text and taken from the Italian projects previously analysed and from the literature.

Finally, in Section 4.7, the author carried out the sizing process of two mini-grids for the electrification of the rural villages of Namanjavira Sede (Mozambique) and Kitole (Tanzania), applying the technical design steps proposed by the CESP framework, thanks to the use of engineering modelling tools as RAMP and MicroGridsPy. In both cases, the application study was conducted according to three main steps: the delineation of potential users’ energy habits starting from surveys and interviews carried out in the target areas; the modelling of a realistic load curve for the two villages, by using the bottom-up stochastic tool RAMP; the cost-optimal sizing of the mini-grid components, through the use of MicroGridsPy, an open-source software specifically conceived to optimise the dimensioning process of hybrid mini-grids. The goal is to illustrate the applicability of technical CESP phases, showing their validity and the complementarity of the used modelling tools. The methodology adopted to carry out these CESP applications are explained in more detail in Section 4.7, where the two case studies are presented step by step.

2 NGOs

The first step, in order to map all the mini-grid projects implemented by the different Italian NGOs in the African continent, has been to identify all the non-governmental organizations recognized by the Italian Ministry of Foreign Affairs, to which the Italian Agency for Development Cooperation (AICS) is subjected. It is necessary to highlight that the legislation 125/2014, which governs the international development cooperation and established AICS, introduced the concept of Organizzazione della Società Civile (OSC), referring to all the actors who deal with cooperation. This recognition includes, among the others, the non-governmental organizations.

From AICS website it is possible to download the 2019-updated list of all the OSC with registered office in Italy [10]. All these NGOs have always worked in many countries in the world, collaborating on programmes in diverse areas of intervention, such as environmental protection, defence of human rights, promotion of peace, health and social care, child sponsorship, social agriculture, education and vocational training. In line with the objective, we have focused on organizations engaged in energy projects for rural electrification in Africa, finding that, in recent years, the promotion of renewable sources has become a very popular field, even for those associations with no long tradition in the sector. Nevertheless, the almost total majority of NGOs working in this field, deal with small projects, involving the implementation of stand-alone systems (photovoltaic panels, in particular) and the diffusion of improved cooking stoves, with the aim of reducing the use of expensive and polluting fossil fuels.

At the same time, we discovered that the commitment of Italian NGOs on the realization of power plants with a proper annexed mini-grid, is much more limited. Among the numerous reasons of this restricted engagement, it is easy to note the large investment necessary only for the infrastructural capital and the consequently difficult cost-recovery, the high level of technical and engineering expertise needed both for the design phase and the O&M activity, the several cross-sectorial interventions required for a positive impact and the long-term sustainability of such a project. After visiting the websites in the list of the registered OSC and contacting their individual communication departments, it has been possible to identify the eight Italian NGOs involved in mini-grid projects:

- ACRA Foundation;
- AVSI Foundation;
- CEFA The seed of Solidarity;
- COOPI International Cooperation;
- COSV Coordinating Committee of the Organisations for Voluntary Service;
- ICU Institute for University Cooperation Onlus;

- Kilalo-Ponte Onlus;
- SOFIA Salvatorian Office for International Aid.

The African countries in which the identified projects are located, are highlighted in red in the map below. In particular, CEFA and ACRA installed, respectively, three and two hydroelectric mini-grids in Tanzania; COOPI worked on the implementation of a solar mini-grid in Sierra Leone; SOFIA and Kilalo-Ponte both installed a mini-grid fed by a hydropower plant in the Democratic Republic of the Congo (DRC); ICU worked on the electrification of rural areas in Burundi through the commissioning of four hydropower plants and the extension of their distribution networks; and, eventually, AVSI, together with COSV, have just launched a project for the installation of two hybrid mini-grids in Mozambique.



Figure 4. Map of the African countries in which Italian NGOs have installed mini-grids.

2.1 Tanzania

The United Republic of Tanzania, founded in 1964 after the union between of the British Colony of Tanganyika (Tanzania Mainland) and the insular British Protectorate of Zanzibar, is placed under the Equator on the east coast of the continent. Tanzania has always been considered relatively safe and stable from a political perspective, since it is one of the few African countries which have not experienced a civil war nor a military dictatorship after its independency. Furthermore, Tanzanian economy has significantly grown in recent years, with an average annual GDP growth rate equal to 6.7% from 2013 to 2018 and a decline in the rate of unemployment from 10.3% in 2014 to 9.7% in 2018 [11]. Nevertheless, according to the Atlas methodology used by the World Bank, Tanzania is still a lower-middle income country, with a GNI per capita equal to 1020 USD in 2018 [12]. Indeed, the economic growth has been accompanied by an intense demographic growth, as the national population rose from 44.9 million in 2012 to 54.2 million in 2018 [11].

Thanks to the aforementioned political stability, Tanzania has been relatively attractive for investors, especially after Tanzania Investment Act of 1997, which established a governmental organization specifically dedicated to the facilitation of foreign direct investments [13]. Other bodies were instituted in order to manage the complex energy landscape: the Energy and Water Utilities Regulatory Authority (EWURA), born in 2001 and handling policy making and regulation of the electricity industry; the Rural Energy Agency (REA) and the Rural Energy Fund (REF), established in 2005 in order to promote rural electrification. Moreover, in 2003, the government of Tanzania outlined its National Energy Policy, containing comprehensive goals related to the reduction in dependence on fossil fuels, the increase of renewable energy share and the achievement of 100% national energy access [13], [14]. Tanzania Electric Supply Company Limited (TANESCO), a utility company owned by the state, dominates the power sector: it covers about 50% of national power generation capacity and it has the monopoly of transmission and distribution [4]. So, in the Tanzanian electrification scenario, there are three key-actors under the Tanzanian Ministry of Energy and Minerals (MEM): EWURA, responsible for technical and economic regulation for energy sector; TANESCO, which manages urban electrification, and REA, in charge of peri-urban and rural electrification [14].

The Electricity Act of 2008 consists in a precise description of the national power sector, which shows all details about generation, transmission, distribution, tariffs renewables strategies and main actors [14]. Furthermore, in 2013, with the National Electrification Program Prospectus, the Government of Tanzania set a strategy for the period 2013-2022, promising “to considerably advance electrification in a cost-efficient way” [15]. The Prospectus defines then a regulation for investments in the sector and the institutional, regulatory and capacity strengthening measures for the implementation. Among them, the feed-in tariff scheme to attract private investors for small power plants using renewable sources, must be highlighted.

Tanzania has heavily invested in local resources, exploiting, in particular, its natural gas reserves (proven 53.3 trillion cubic feet) and the country’s plentiful rivers, so that, 47.9% of the total installed capacity is sourced from fossil fuels, 45.6% from hydroelectric and only 5.6% from other renewables [13]. Despite high aeolian potential (10 m/s average wind speed) and

irradiation levels ranging from 4.5-5 kWh/m²/day, these renewable sources are not yet properly exploited [13]. Also due to this lack of initiative, the power sector is still undeveloped: the national installed capacity is equal to 1553.96 MW [11] and only 32.81% of the whole population has access to electricity (16.76% in rural areas) [16]. Eventually, it is interesting to highlight that, in 2018, only 1.13% of the 7354,6 GWh consumed by Tanzanians was produced by off-grid-systems [11].

It is in this context, favourable to independent power producers and to renewable energies, that CEFA and ACRA have been working with their energy projects. Four of the hydropower mini-grids they have implemented are located in the rural Region of Njombe. CEFA has also worked on the installation of a mini-grid in the Region of Iringa.



Figure 5. Highlighting of the mini-grids installed by CEFA and ACRA (red spots) in the regions of Njombe and Iringa, Tanzania.

2.1.1 CEFA The seed of Solidarity

CEFA (European Committee for Training and Agriculture) The seed of Solidarity is one of the older Italian NGOs actively involved in initiatives of development, cooperation and volunteer service. Since 1972, when it was founded in Bologna under the engagement of a group of agricultural cooperatives, CEFA has been committed to supporting and accompanying local

communities of Africa and Latin America in building sustainable development processes, engaged in actions towards urban poverty alleviation and integrated rural development [17].

2.1.1.1 Projects

In the last decades, the commitment of CEFA has been particularly focused on rural areas of Tanzania, where, since 1976, the association has intervened in the fields of rural electrification, water supply, agro-processing and vocational training. The first mini-grid realised in Tanzania by CEFA, together with the Catholic Diocese of Njombe, was commissioned in 1984, for the electrification of the villages of Matembwe and Image, in the District of Njombe (Njombe Region). It is powered by a reservoir mini-hydropower plant equipped with a Francis turbine capable of generating 120 kW of electricity [18]. The project was financed through grants from a mixture funders composed by the Italian Ministry of Foreign Affairs, the Belgian Ministry of Foreign Affairs, the European Union and CEFA itself [19].

It is necessary to highlight that the project in Matembwe had not started as an energy intervention, but as a livelihoods and food security initiative: together with local stakeholders, CEFA decided to establish a poultry farm and an animal feed production, in synergy with various activities of agricultural training and support. The power plant was intended later, when it was realised that the businesses within the project, especially the incubators for the poultry farm, needed electricity to run. Furthermore, the power produced was initially supplied only to the abovementioned activities. Later on, with the implementation of a proper mini-grid, it has been possible to distribute electricity to other domestic, business and public users, so that, nowadays, with a 19-km network at 10 kV, the mini-grid can count on 620 connections (4 aqueducts included) and an anchor client, TANESCO (the connection to the grid occurred in 2015) [20].

Within the programme, CEFA and the partners established an rural-based integrated company, the Matembwe Village Company (MVC Ltd), which was in charge of running the power project and the related agro-processing businesses; being a multi-utility operating in different sectors, it provides employment for 26 staff and it had originally five shareholders: the Catholic Diocese of Njombe, the District of Njombe, the village of Matembwe, MVC employees and CEFA. After a ten-year gradual process, in 2014 CEFA withdrew its 25% shareholder stake and, at the same time, MVC was turned into an employee co-operative, which currently owns and manages the mini-grid and the connected activities [14], [20]. Moreover, the connection to the national network made MVC the second biggest customer in terms of consumption, thanks to the mentioned productive activities implemented [21].

| Matembwe (CEFA) | |
|--------------------------|--|
| Location | Matembwe Village, Njombe District, Njombe Region (Tanzania) |
| Commissioning year | 1984 |
| Developers | CEFA, Catholic Njombe Diocese |
| Funders | Italian Ministry of Foreign affairs Belgian Ministry of Foreign Affairs European Union CEFA |
| Management and Ownership | Matembwe Village Company (MVC Ltd) |
| Investment cost | 3,781,131 € (together with Ikondo Project) |
| Technology | Reservoir mini-hydropower plant (Francis turbine) |
| Capacity | 120 kW |
| Served Communities | 2 villages (Matembwe, Image) |
| Connections | 556 households 64 public services and private businesses 4 aqueducts Grid (TANESCO) |

Table 4 - Main details about Matembwe project by CEFA.

Seventeen years after the implementation of the first mini-grid in Matembwe, in 2001 CEFA partially replicated the project in Kilolo District, in the region of Iringa, where, specifically in the village of Bomalang’ombe, a reservoir mini-hydropower plant was built. It is characterised by a nominal capacity of 250 kW, generated thanks to a Francis turbine. Through the connected 17-km mini-grid it is able to provide electricity to more than three hundred users in two rural villages (Bomalang’ombe and Lyamko) [18].

In this case too, the financial support was given by different funders (Italian Ministry of Foreign Affairs, European Union and CEFA) and the plant was initially thought to guarantee the functioning of the food processing facility implemented within the programme. After the model experimented in Matembwe, CEFA, together with the District Council of Iringa and the Village Councils of Bomalang’ombe and Lyamco, instituted a community-based utility, the Bomalang’ombe Village Company (BVC Ltd), in charge of owning and managing the generation and distribution infrastructures [19].

This comprehensive project, even if the connection to the grid has not yet occurred, led to a significant social and demographic development of the considered area, with the population of the village of Bomalang’ombe which has expanded from 5000 to more than 12.500 inhabitants in the last years [19].

| Bomalang'ombe (CEFA) | |
|--------------------------|--|
| Location | Bomalang'ombe Village, Kilolo District, Iringa Region (Tanzania) |
| Commissioning year | 2001 |
| Developers | CEFA |
| Funders | Italian Ministry of Foreign affairs European Union CEFA |
| Management and Ownership | Bomalang'ombe Village Company (BVC Ltd) |
| Investment cost | - |
| Technology | Reservoir mini-hydropower plant (Francis turbine) |
| Capacity | 250 kW |
| Served Communities | 2 villages (Bomalang'ombe, Lyamko) |
| Connections | 252 households 76 public services and private businesses 3 aqueducts |

Table 5 - Main details about Bomalang'ombe project by CEFA.

The third hydroelectric project implemented in Tanzania by CEFA and strictly connected to the first one in Matembwe, has been commissioned in 2004 and located, again, in Njombe District. Differently from the previous two sites, in this case CEFA has opted for a run-of-the-river hydropower plant, with a Francis turbine and 83 kW of installed power. The plant and the related mini-grid were originally intended to foster the development of the only isolated village of Ikondo, providing electricity to the income-generating activities implemented as part of the integrated development programme (a carpentry workshop, a garage, a tailor shop and a sunflower oil mill). The funders of the project were, again, the Italian Ministry of Foreign Affairs, the European Union and CEFA itself [18].

Later on, in 2011, thanks to the funds from the EU, the Provincia autonoma di Trento, Regione Emilia-Romagna and the Rural Energy Agency, CEFA launched the upgrade of the original Ikondo project, named “Increasing Access to Modern Energy Services in Ikondo Ward”. The new programme provided for:

- the installation of a new 350 kW Francis turbine, in order to reach a nominal power of 433kW, and the extension of the network from 8 to 48 km;
- the interconnection between Matembwe and Ikondo mini-grids and the consequent electrification of five more villages between the two;

- the entry of the Ikondo Village Council as a shareholder of the MVC Ltd, supposed to become manager and owner of the Ikondo infrastructures too (previously they were under the direct control of CEFA);
- the connection of the resulted Matmbwe-Ikondo mini-grid to the national power network managed by TANESCO, with the aim of selling the excess electricity.

This way, in 2016, the District of Njombe was provided of a local-community based mini-grid, whose total investment cost is 3,781,131 € [21] capable of supplying electricity to eight villages: Matembwe, Image, Ikondo, Iyembela, Isoliwaya, Kanikelele, Ukalawa and Nyave [18].

| Ikondo (CEFA) | |
|--------------------------|--|
| Location | Ikondo Village, Njombe District, Njombe Region (Tanzania) |
| Commissioning year | 2004 |
| Developers | CEFA |
| Funders | Italian Ministry of Foreign affairs European Union CEFA Provincia autonoma di Trento Regione Emilia-Romagna Rural Energy Agency |
| Management and Ownership | Matembwe Village Company (MVC Ltd) |
| Investment cost | 3,781,131 € (together with Matembwe Project) |
| Technology | Run-of-the-river mini-hydropower plant (2 Francis turbines) |
| Capacity | 433 kW |
| Served Communities | 6 villages (Ikondo, Iyembela, Isoliwaya, Kanikelele, Ukalawa, Nyave) |
| Connections | 410 households 121 public services and private businesses 1 aqueduct Grid (TANESCO) |

Table 6 - Main details about Ikondo project by CEFA.

2.1.1.2 Method of Intervention

Analysing the information material about the introduced projects, it is possible to outline a common ground in the approach used by CEFA for the implementation of the different programmes of rural electrification. First of all, being CEFA a non-profit organisation, thus, working for a social mission, its action has always been characterized by a first phase of

identification of the real needs of the targeted community, starting with an overview of local socio-economic context.

67% of the households in the rural District of Njombe, has a farming activity, and agriculture, which represents the main source of income, is fundamental for their livelihood [21]. People are especially dedicated to the cultivation of local harvests, such as beans, tea and maize; nevertheless, before the intervention, agriculture was still relying on traditional techniques on non-irrigated land, with a consequently low income generated and problems of malnutrition. CEFA stepped in the reality of Matembwe and Ikondo with the primary intention of alleviating these urgent livelihoods and food security issues, providing diverse types of agricultural training and support, based on the use of improved seeds, machinery and other modern inputs to increase yields and labour productivity [21]. During the phase of needs identification, the NGO, together with local stakeholders, recognized another problematic nutritional matter, related to the low intake of proteins, especially caused by the underdeveloped livestock sector in the area. The idea of establishing a poultry hatchery and an animal feed factory was precisely born in order to compensate this crucial weakness [20], [21]. As already mentioned, it was at this point that the necessity of electricity for these activities was manifested; the power plant is the its direct consequence [20], [21]. The same care and the same actions consequentiality were taken in the very similar rural context of Bomalang'ombe, where, in order to tackle the nutritional problems, CEFA decided to intervene with the implementation of a food processing facility to produce jam and sausages and, later, with the installation of the mini-grid [18].

The well-known criticality about water provision has been faced too: thanks to electricity, water is deputed, pumped and distributed through the eight aqueducts activated in the area of Njombe and Kilolo Districts; the installed water access spots, then, provide fresh water to the community [19].

It is easy to note that this demand-driven approach deliberately results in the realisation of an integrated rural development programme, made of diverse initiatives and cross-sectorial activities, aimed at fighting different aspects of the local socio-economic panorama and necessary for the deployment of electricity use. In order to ensure the long-term sustainability of a rural electrification programme, it is particularly important to work on providing integrated access to three crucial resources, i.e. energy, water and food, closely linked each other: energy is fundamental for the treatment (sanitization and potabilization) of water, which, together with energy itself, is needed for crops irrigation, which leads to food production, whose supply chain could not survive without (again) energy. In this scenario, preached by the so called WEF Nexus model, it is clear the essential role of energy as enabler of all the other development activities [21]. As the interventions described above can confirm, CEFA followed this path through the implementation of its rural development programmes.

Nevertheless, such an ambitious project could not be successful without some other fundamental features, such as the multi-stakeholder engagement the community-based approach. In the cases of Matembwe-Ikondo and Bomalang'ombe, the cooperation between the technical experience of CEFA and the influence of local authorities, such as the Catholic Diocese, the District Councils and the Village Councils, have been crucial to conduct incisive

sensitization and awareness campaigns about the external intervention, the use of electricity and the potential positive outcomes of the project. Once obtained the social acceptance by the local community, throughout the duration of the whole installation phase, CEFA insisted on organizing a capacity-building programme, made of courses, workshops and on-field training in order to provide an administrative and technical formation to the staff of the community-based companies established for the ownership and the management of the mini-grid and the related business activities. MVC Ltd and BVC Ltd are private enterprises with the main local institutions and associations as shareholders: the Roman Catholic Diocese of Njombe, the District Council of Njombe, the Village Councils of Matembwe, Iyembela and Ikondo and the MVC's Workers Association for the MVC Ltd, in Matembwe; the District Councils of Iringa and Kilolo, the Village Councils of Bomalang'ombe and Lyamco and the Bomalang'ombe Village Trust Fund for the BVC Ltd, in Bomalang'ombe [18]. In particular, the staff of these cooperatives, after being properly trained, were supposed to autonomously manage the mini-grids O&M services and the sale of electricity.

As regard the tariffs at which electricity is sold to consumers, they are graduated according to use and category of the users. According to the national regulation, the tariffs for other customers than TANESCO had to be approved by EWURA; they were originally lower than those set by TANESCO, but, in order to reach parity with the state-owned utility, they have been increased through the years up to: 250 TZS/kWh for households, 350 TZS/kWh for private businesses and 70 TZS/kWh for public institutions (the exchange rate euro/Tanzanian Shilling (TZS) is about equal to 2500) [20].

CEFA has recently started testing a new approach methodology based on a non-profit/for-profit partnership (NPFPP), in which each partner – international or local, private or public, economic or political – is expected to give its contribution to the considered project, according to its own characteristics and experience; in particular, this method of intervention aims at reaching an efficient synergy between profit and no-profit realities, in order to overcome the main barriers of both operational attitudes, such as the decreasing funds for development cooperation and the difficult cost-recovery of rural electrification projects. According to this approach, CEFA is now working with ENCO Engineering Consultants Srl, an Italian enterprise, on the installation of two other run-of-the-river hydropower plants, with annexed mini-grids, in Ninga and Luganga (Tanzania): the first one, with an output of 6 MW, is foreseen to provide electricity to thirteen villages and 3500 users in the rural District of Njombe; the second one is expected to produce 10 MW and serve three communities, for a total of 900 customers in the District of Iringa. Both the plants will significantly rely on TANESCO as anchor client [18].

2.1.2 ACRA Foundation

ACRA (Rural Cooperation Association in Africa and Latin America) Foundation is an independent and lay Italian non-governmental organisation, born in 1968, and committed to alleviating poverty through sustainable, market-based and participatory solutions, with a

particular attention to the developing realities, both in the northern and the southern hemispheres. The specific aim of the organisation consists in creating and strengthening social enterprise ventures as powerful agents of change, working in four main sectors: education, sanitation, natural resources and energy management and food security. In recent years, ACRA has deeply changed its methods of intervention, shifting from the traditional cooperation approach to an innovative model based on inclusive business [22].

2.1.2.1 Projects

The engagement of ACRA in the rural Region of Njombe, in Tanzania, started in 2006, when ACRA and Njombe Development Office (NDO), an NGO of the Roman Catholic Diocese of Njombe, planned the realisation of a run-of-the-river mini-hydropower plant on Kisongo River, in the rural District of Ludewa. This first phase of the Mawengi energy programme was grant financed by the Italian Ministry of Foreign Affairs, Regione Lombardia and Fondazione Cariplo (a philanthropic bank foundation), and aimed at the partial electrification of three villages in Ludewa District (Mawengi, Madunda e Lupande), thanks to the 150 kW produced by the mini HPP and distributed through a designed mini-grid to 580 users [23]. At the same time, a non-profit community-based utility, named LUMAMA Electricity Association, was established in the District, so that the aforementioned infrastructures were owned and managed directly by the local community, since the service customers are also members of the association [23], [24].

In 2011 the European Commission (through the Ministry of Finance of Tanzania), the World Bank (through REA), Intervita Onlus (an Italian charity association) and the Ministry of Energy and Minerals of Tanzania provided additional grants, in order to finance the second phase of the programme, which consisted in:

- the installation of a second 150 kW turbine, leading to a total installed capacity of 300 kW;
- the extension of the transmission and the distribution networks, up to 54 and 55 km respectively, so that seven new villages in the District were electrified;
- a review of the tariff system and the contextual installation of pre-paid meters.

After the completion of this second phase, the resulted mini-grid, which overall costed 3,426,250 € [13], was thus capable of bringing electricity to nine rural villages (Mawengi, Madunda, Lupande, Kiwe, Mapogoro, Milo, Mavala, Mdetete and Madindu), with more than 1400 connections and the prospect of attachment to the TANESCO national grid [23].

Eventually, in 2013 ACRA started gradually withdrawing the project, leaving all the management and administration up to LUMAMA and respecting the original aim of creating a real local ownership and responsibility. In 2015 LUMAMA has been able to reach breakeven [24].

| Mawengi (ACRA) | |
|--------------------------|---|
| Location | Mawengi, Ludewa District, Njombe Region (Tanzania) |
| Commissioning year | 2010 |
| Developers | ACRA, Njombe Development Office |
| Funders | Italian Ministry of Foreign affairs Regione Lombardia Fondazione Cariplo European Commission Tanzanian Ministry of Energy and Minerals World Bank Intervita Onlus District Council of Ludewa |
| Management and Ownership | LUMAMA |
| Investment cost | 7,748,265 € |
| Technology | Run-of-the-river mini-hydropower plant (2 Francis turbines) |
| Capacity | 300 kW |
| Served Communities | 9 villages (Mawengi, Madunda, Lupande, Kiwe, Mapogoro, Milo, Mavala, Mdetu, Madindu) |
| Connections | 1174 households 33 public services 59 productive enterprises 167 commercial activities |

Table 7 - Main details about Mawengi project by ACRA.

In 2014, the Mawengi project has been followed by a second one, again in Ludewa District. This intervention consisted in the implementation of a much larger storage plant (1.7 MW) in order to exploit the energy of the waterfall of Lugarawa (Madope River) through the utilization of a Pelton turbine. This main plan is assisted by the renovation of the 165-kW mini-hydropower plant which have supplied the Lugarawa St. John Hospital since 1979, so that the whole system will feed 20 villages, where the access rate is supposed to grow from 4% up to about 80% [14]. The programme has been developed by ACRA, together with NDO, the Hospital of Lugarawa and Studio Frosio (Italian engineering firm) and the funds necessary to financially support the realisation of the project came from the European Commission (with the support of the Energy and Environment Partnership Trust Fund), the United Nations Industrial Development Organization (UNIDO) and REA. The total investment cost for the construction of the plant and the mini-grid was €7,567,677 [20].

In 2019, the users connected to the mini-grid were already 3,648, all fitted with meters and distributed between the 20 villages. This is the reason why, since the pre-feasibility assessment, ACRA and NDO foresaw the need of an energy users entity, which, in 2016, materialised with the constitution of JUWALU (Jumuiya ya Watumiaji Umeme wa Lugarawa), mainly responsible for fees collection and customers identification; in 2019, it counted already 5,414 members. This action has been completed with the establishment of Madope Company Ltd., which will manage the system and the electricity distribution. The shareholders of the company are JUWALU and the Lugarawa Hospital [25].

Since the 9,000 MWh which are expected to be annually produced by the plant will exceed the current local demand, the developing partners decided to connect the new mini-grid to the national network. The initial investment cost of this connection was high, about €400,000, but the revenues coming from the electricity sold to TANESCO would significantly contribute to the financial sustainability of the project [26].

| Lugarawa (ACRA) | |
|--------------------------|--|
| Location | Lugarawa, Ludewa District, Njombe Region (Tanzania) |
| Commissioning year | 2019 |
| Developers | ACRA Njombe Development Office, Lugarawa St. John Hospital Studio Frosio |
| Funders | European Commission, UN Industrial Development Organization, Rural Energy Agency |
| Management and Ownership | Madope Company Ltd. |
| Investment cost | 7,567,677 € |
| Technology | Run-of-the-river hydropower plant and water storage (Pelton turbine) |
| Capacity | 1.7 MW |
| Served Communities | 20 villages |
| Connections | 3648 Grid |

Table 8 - Main details about Lugarawa project by ACRA.

2.1.2.2 Method of Intervention

Given the long tradition and experience of ACRA in the field of rural electrification, its approach has evolved throughout the years into holistic programmes made of different action plans, as in the Tanzanian projects just shown in the previous section. First of all, it must be

pointed out that these mini-grids have been implemented in the same local context in which CEFA has also operated, the rural Region of Njombe. Having in common the working socio-cultural framework, obviously, implies many similarities in the operating methods of the two organisations.

Multi-donor dependency – As above mentioned, the energy programme in Mawengi has developed in two stages and its first phase started in 2005, when the Catholic Diocese of Njombe contacted ACRA to propose a collaboration in finding funds for the implementation of the hydropower plant on Kisongo River and a connected mini-grid, to electrify the communities nearby and foster their socio-economic development [27]. The reinforcement of the plant, with the installation of a second turbine and the extension of the rural network occurred in the second phase, between 2011 and 2014. Throughout these two separate stages, ACRA has been capable of mobilizing numerous international and local funders of different nature, in order to overcome one of the main negative aspects of NGO-led development programmes: the patron-client relationship that can be established between donors and NGOs, threatening to create a dependency bond, especially in the case of a unique donor. Table 9 shows the different main funders of the project distinguished by the phase in which they intervened and by the scale of their funding.

| | Donor | Fund [million €] |
|--------------------------------------|-------------------------------------|------------------|
| 1 st Phase (2005-2011) | Italian Ministry of Foreign Affairs | 2.69 |
| | Regione Lombardia | 0.89 |
| | Intervita Onlus (private donations) | 0.54 |
| 2 nd Phase (2011-2014) | Intervita Onlus (private donations) | 1.38 |
| | European Commission | 1.83 |
| | World Bank | 0.41 |

Table 9 – Donors of Mawengi project.

The European Commission provided grants through the Tanzanian Ministry of Finance, while the World Bank funded the project through the Rural Energy Agency. In addition to the ones shown in Table 9, other smaller donors contributed to financing the interventions: Fondazione Cariplo, the Tanzanian Ministry of Energy and Minerals and the District Council of Ludewa [20], [27]. From Table 9 it is then important to note the importance of private donations, which, collected in both the phases of the programme thanks to the Italian organization Intervita Onlus, amount to €1.92 million, about 25% of the whole investment costs [27].

Multi-stakeholder approach – In the programme of Mawengi the multi-stakeholder philosophy is particularly evident, since ACRA aimed to involve many different actors, in order to create a varied and well-mixed partnership. Njombe Development Office, an NGO instituted by the Roman Catholic Diocese of Njombe, is the main local partner and it has cooperated with

ACRA in all the steps of the entire programme. Other important stakeholders, who contributed to the achievement of the objectives, are CAST (Church Alliance for Social Transformation), SHIPO (Southern Highlands Participatory Organization) and LUMAMA, the community-based association established within the programme for the ownership and the management of the mini-grid. It's then important to mention the collaboration of ACRA with the international research project STEEP-RES (Socio-Technical-Ecological Evaluations of Potential Renewable Energy Systems). Also local authorities – district, regional and national – have to be considered among the fundamental stakeholders of the project, so much that, in 2011, the programme was inaugurated by the President of the Republic of Tanzania [23].

The commissioning process followed few years later in Lugarawa has been easier for ACRA, which had the possibility to work in the wake of the project implemented in Mawengi and the gained experience. In particular, the consolidated relationship with NDO and the local authorities and institutions significantly simplified the execution of community involvement activity and of bureaucratic requirements. In this case, ACRA got also the chance to collaborate with local St. John Hospital, whose presence in the governance of the electric system is particularly relevant, given the management of its mini-hydropower plant since 1979. Another fundamental role in Lugarawa has been played by Studio Frosio, an Italian leading company in the hydroelectric field; in 2010 they conducted a preliminary study of the project and, later on, they have provided all the necessary support and experience in the implementation phase, during which other technical partners, such as Greenvalley Rock s.r.l. and Zeco s.r.l. gave their contribution [25], [26].

The multi-stakeholder and participatory aspect of ACRA's approach has been visible from the beginning of its engagement, when, in both the interventions, local authorities have been asked to support the programme among the communities, in order to mobilize the people to participate to meetings and contribute to the project realisation through manual labour and general help [25], [27]. This community-involvement activity has been completed with the organization of sensitization and information seminars on dangers and potential of electricity, as well as on positive economic impact that it could have, stimulating the birth and development of small/medium productive activities. Within this context, the district councils, village representatives and school committees were brought into play to spread awareness and knowledge among dwellers and students [23], [25].

Community-based approach and capacity building – ACRA has always aimed at the realisation of development programmes revolving around the central role of the community. This is why, in 2009, in Mawengi they opted for the creation of a non-profit community-based utility, the aforementioned LUMAMA Electricity Association: its members were the service users themselves and they were given the full ownership of the electricity system. Indeed, during the first phase of the programme, an intensive capacity-building activity was held in order to train the technicians in charge of managing the complex O&M of the system. Nevertheless, after the inauguration of the mini-grid and the connection of the first 260 customers, many difficulties arose among LUMAMA board, especially regarding the administration and the accountancy of electricity selling service. These inefficiencies and the consequently low

revenues, not sufficient to cover the operation and maintenance costs, drove ACRA, during the second phase, to assist the local utility in developing a precise organizational structure and to provide an expert in management and good governance, with the task of helping and training in that sense the local managers [27].

The approach used by ACRA and NDO in Lugarawa is similar to the one experimented in Mawengi, but even more elaborated. Indeed, in this case, they had to set up a local utility guided by a stable and efficient governance scheme, despite it had to represent all the communities of the diverse 20 villages served by the grid. These difficulties led the partner to the establishment of the aforementioned users association JUWALU, whose members (5,414 in 2019), together with the St. John Hospital, are the only shareholders of Madope Company Ltd., the energy utility specifically instituted to manage the power plant, the mini-grid and the electricity commercialization [25]. The board of the Company is constituted by representatives elected from the villages committee and the Lugarawa Hospital, whose staff has gained appropriate capacities from the management of the hospital mini-hydropower plant since 1979. The effective management of the system and of its O&M activities are then entrusted to a recruited staff, whose members and operators have been through administrative and technical training sessions conducted by ACRA and its partners, like GIZ and Zeco [25], [26].

Comprehensive and integrated rural development – Between 2010 and 2014, after further studies, ACRA's plan of integrated rural development took form through many different initiatives aimed at ensuring a comprehensive and long-term local sustainability. In particular, this plan consisted in the rehabilitation of water supply systems, school and education programmes, a Natural Resources Management component (made of reforestation activities, sustainable agriculture training, establishment of farmer groups, land use planning and environmental awareness campaigns) and a business programme [27]. Within this latter component, ACRA provided business capacity training and supported the creation of 20 small and medium enterprises, in order to stimulate the productive use of electricity and ensure stable customers to the electric system. The NGO particularly focused on milling services, because of their social importance and their high electricity consumption, which make them fundamental customers: also thanks to the soft regulatory tool, a miller would have lower production costs with electricity provision comparing to using diesel, making milling affordable for local families [20].

The same integrated approach has been used few years later in Lugarawa, where, in addition to the main electrification intervention, ACRA and NDO particularly focused on two crucial related activities: the protection of the natural resources of Madope basin and the boost to the development of SMEs and social services. The environmental topic has been firstly faced with the organization of awareness raising campaigns about the preservation of the catchment area and the definition, together with the representatives of the villages, of an Environmental Management Plan with precise sustainable actions aimed at the natural preservation itself. ACRA then proceeded with the activities of reforestation of the areas eroded by unsustainable human actions, in which participated also many local schools. Eventually, in collaboration with an environmental committee within JUWALU, seminars and training courses on sustainable

and profitable agricultural production. On the other side, the implementation of SMEs activities has been conducted by ACRA in collaboration with the NGO Fundacion Paraguaya (FP), which, first of all, helped the partners in a market research and the identification of local enterprises that could get and give more advantages from the access to electricity; the 37 selected SMEs got access to financial support and management and technical training for the adoption of electric equipment for productive uses [25], [26].

Financial sustainability – Concerning the sale of electricity, the first system experimented in 2011 in Mawengi consisted of monthly flat tariffs based on the number of power points in the premises for most of the users (only large consumers, workshops and few domestic and public users had meters and per-unit tariffs). Furthermore, the two NGOs set a revolving fund which assisted new domestic users in dealing with the significant expenditure represented by the connection fee (the connection was free for schools and health centres): only 20% of the TZS180,000 wiring cost was paid by the customer, who had one year for the repayment of the remaining 80% [27].

However, issues about payments emerged soon:

- the initially proposed tariffs were lower than the national average and, this way, LUMAMA was not able to generate enough income to cover the system O&M costs;
- the fund for the connection fees ended soon, as many customers were not able to pay back the loan in one year; thus, the connection of new users in need of credit was delayed;
- since the number of new connections grew rapidly, the administration of the flat-tariff system became too complex.

Because of these reasons, during the second phase of the programme, ACRA and LUMAMA settled for a review of the tariff system, replacing the flat tariffs with a pre-paid system and providing meters to all customers, who were divided into five fare categories, according to their use of electricity. A monthly service fee was, then, added to the electric bills. Furthermore, tariffs were increased, becoming comparable to the ones set by TANESCO (100-350 TZS/kWh) and enabling LUMAMA to reach economic viability (coverage O&M, unexpected events and depreciation costs) [27]. Note that tariff increases do not necessarily imply a raise of the costs incurred by the consumers, who are likely to be more attentive to electricity consumption with the new per-kWh tariff. Table 10 shows the tariffs defined in 2014.

| Customer Category | Monthly Service Fee (TZS/m) | Electricity Charge (TZS/kWh) | Average Consumer Cost (TZS/kWh) |
|---|-----------------------------|------------------------------|---------------------------------|
| Households (1-7 power points) | 2500 | 150 | 317 |
| Households and Institutions (>8 power points) | 2500 | 170 | 295 |
| Businesses | 2500 | 200 | 300 |
| Milling machines | 5500 | 270 | 281 |
| Other electric machines | 5500 | 330 | 422 |

Table 10 – Tariff strategy set by LUMAMA.

Since the flat-tariff system experimented in Mawengi early showed different intrinsic issues, ACRA and its partners, since the beginning of Lugarawa project, decided to implementation of pre-paid meters: at the end of 2018 they have already completed the installation of 2596 meters among 18 villages. Madope Company, which is also in charge of the electricity sale service in Lugarawa, is supposed to open a bank account, so that they can resort to the use of M-Pesa, a mobile phone-based money transfer, which could simplify and speed up the revenues collection. In 2019 the whole billing system needed yet to be officialised by EWURA, but the tariffs in Lugarawa are not expected to differ too much from the ones defined in Mawengi [25].

It's eventually important to highlight that, both in the cases of LUMAMA and Madope Company, the revenues coming from the energy sales are primarily used for the system maintenance activities, for the depreciation of the infrastructures and to boost social services and local economic development. Other revenues, fundamental for the financial sustainability of these programmes, are expected to come from the connection to TANESCO national grid. Despite the high investment costs and the difficult legal procedures provided by this connection, the sale of exceeding electricity to TANESCO is expected to be very fruitful, especially in the case of Lugarawa project, where the current energy demand is significantly less than the foreseen average production [26].

2.2 Sierra Leone

The Republic of Sierra Leone is a small country on the southwest coast of West Africa, less developed than the more fortunate Tanzania. Indeed, since its independence from Britain in 1961, during the 1970s and '80s Sierra Leone experienced the authoritarian regime of president Siaka Stevens, a former miner focused only on the consolidation of its benefits and power through the exploitation of the mining sector and careless with the development of small urban centres and rural areas [28]. His administration crumbled the country and its economy, and it resulted in the devastation of 1991-2002 civil war, which destroyed most of the few operating infrastructures [28]. In the aftermath, Sierra Leone experienced a period of socio-economic recovery, with a 3-8% GDP growth per annum, struck down by a shrinking of the global iron

price and by the outbreak of Ebola virus epidemic in 2014 [29]. Today Sierra Leone is one of the poorest countries in the world, with a GNI per capita equal to 490 USD [12], and it ranks 181st out of 189 as regards the human development index (HDI) [30].

Concerning the energy regulatory framework, the National Energy Police dates back to 2009, but it has been reviewed throughout the years. In 2011, with the National Electricity Act, the vertically integrated National Power Authority was unbundled, with the consequent creation of two separate entities: the Electricity Generation and Transmission Company (EGTC), managing generation and transmission, and the Electricity Distribution and Supply Authority (EDSA), in charge of distribution and retail; furthermore, the Energy and Water Regulatory Commission (EWRC) was established [31].

After Ebola crisis, the country was highly motivated to raise the economy, mainly based on agriculture and mining, realizing the crucial importance of energy sector for the recovery. This is why, in 2016, Sierra Leone was the first African country to sign the Energy Africa Policy Compact with the Government of the UK; the former President Koroma consequently launched, in the same year, the Sierra Leone Energy Revolution, which aims at bringing modern energy to all by 2025, with particular attention to the acceleration of distributed renewable energy – solar source most of all – in rural areas [31]. This program involves the collaboration between the Ministry of Energy of Sierra Leone and the UK's Department for International Development (DFID), which established the Energy Revolution Taskforce, to gather donors and stakeholders, and the Renewable Energy Association of Sierra Leone (REASL), a trade association focused on the development of an efficient renewable energy market in Sierra Leone [31], [32]. Other important stakeholders are Power for All, GIZ, the Rocky Mountain Institute and Oxfam IBIS [32].

As well, in 2016, the Sierra Leonean Parliament ratified the Renewable Energy and Energy Efficiency Policies, launched in 2018 to regulate the emergent and promising renewable market, emphasizing the need for private sector involvement both in on-grid and off-grid facilities [33]. In the same years, the Ministry of Energy of Energy, in collaboration with the United Nations Office for Project Services (UNOPS) and the UK DFID, implemented the Rural Renewable Energy Project (RREP) in order to support the Government's goals towards low emissions, climate resilient, gender sensitive and sustainable growth path [33]. In particular, the Project aims at:

- electrifying community health centres and installing community mini-grids (up to 5 MW);
- creating an enabling environment for a private-sector driven rural mini-grid market, in terms of regulations, guidelines and capacity building;
- developing the local private sector, with investment opportunities and an increase access to quality equipment, appliances and services [34].

Thanks to the described measures and initiatives, a significant improvement in terms of national access to electricity is expected: in 2017 only 23.4% of the population had access to electricity, and 90% of those were concentrated in the urban area of Freetown; the data drastically drops to 5.35% if we consider rural areas [35]. Indeed, at the end of 2017 the installed power capacity in Sierra Leone was only 99.6 MW, in the face of around 7 million people, and

the picture is even worse, considering that 45% of produced electricity is lost at transmission and distribution level [29]. The unreliability of the national electric system led people, especially households in rural areas, to rely on diesel generators, kerosene and dry-cell batteries for basic energetic needs, despite the high renewable potential of Sierra Leone (biomass, hydro and solar sources above all) [28], [29].

These are the reasons which pushed the Government and its partners to focus and invest on solar mini-grid projects, like the one implemented by the Italian NGO COOPI in the rural town of Gbinti (Port Loko District), under the EU co-financed PRESSD program, in collaboration with Oxfam IBIS and the Sierra Leonean Ministry of Energy.

2.2.1 COOPI International Cooperation

COOPI International Cooperation is an Italian humanitarian lay and independent organization established in 1965 by Father Vincenzo Barbieri, after the contact with international cooperation movements in Lyon. Today COOPI operates in 30 countries around the world – Africa, Middle East, Latin America and the Caribbean – where it works on 241 humanitarian and development programmes, contributing to fighting poverty of local communities. The main sectors of interventions are water sanitation, environment and disaster risk reduction, education, nutrition security and human rights protection. In 2010 COOPI was transformed into a participation foundation and, today, it counts 72 founding members and more than 2500 international and local operators, which makes it one of the biggest Italian non-profit organizations [36].

The first intervention of COOPI in Sierra Leone dates back to 1971 and its presence in the country has been consolidated throughout the years, intensifying in the aftermath of the civil war – with projects of psychosocial assistance and reintegration for ex child soldiers and war victims – and during Ebola crisis, supporting orphan children and implementing livelihoods and food security programmes [37].

2.2.1.1 PRESSD-SL Project

Between 2014 and 2018, COOPI took part in Promoting Renewable Energy Services for Social Development in Sierra Leone (PRESSD-SL), a project funded by the European Union, with the aim of contributing to the socio-economic development of six districts of Sierra Leone, through the provision of renewable energy services and the promotion of low-carbon technologies. The project starting budget was €7,000,000 and it has been implemented and co-funded by four partners: Welthungerhilfe (WHH), a German non-profit and non-governmental aid agency, leader of the consortium; Energy for Opportunity (EFO), a Sierra Leonean NGO specialized in the promotion of solar energy across Western Africa; Oxfam IBIS, the Danish member of charitable Oxfam confederation; and, indeed, COOPI [38].

| Funder | Fund [million €] |
|------------------------|------------------|
| European Union | 5.25 |
| Weltungerhilfe | 0.8 |
| Energy for Opportunity | 0.4 |
| Oxfam IBIS | 0.3 |
| COOPI | 0.2 |

Table 11 – Funders of PRESSD-SL project

WHH and EFO are the implementing leaders of the project; they wrote the proposal with the help of COOPI, which contributed with local expertise especially on energy-agriculture link, and Oxfam IBIS, specialist in education sector. The multi-stakeholder approach – already evident considering the different origin and nature of the four partners – is accentuated by the strong and prolonged collaboration they have established with Sierra Leonean authorities and actors. First of all, the project was born in collaboration with the Ministry of Energy of Sierra Leone and the Electricity and Water Regulatory Commission, with which different meetings were held, in order to develop a programme aligned with the recent national energy policies. Representatives from the Ministry of Agriculture Forestry and Food Security (MAFFS) also participated in the design phase. Moreover, the partners organised meetings in each of the target districts with local institutions (District Councils, Chief Administrators and District Medical Officers), which also helped in the involvement of potential direct beneficiaries, such as managers and staff at hospitals, schools, financial institutions, farmer associations and, certainly, residents, fundamental in order to identify primary energy needs [39].

Lastly, other international partners active in Sierra Leone, such as UNDP and DFID, helped in the strategy design, with exchange of information [39].

The programme was articulated according to three expected results, developed through numerous activities:

- the improvement of living conditions and the increase of economic revenues of rural communities, thanks to the installation of 100 solar community charging stations, 22 energy hubs and more than 15,000 home lighting systems in the districts of Kenema, Bombali, Port Loko and Karene;
- the enhancement of the quality of local public services, through the implementation of three community mini-grids, respectively in Segbwema (Kailahun District), Panguma (Kenema District) and Gbinti (Karene District) and the provision of stand-alone systems for the electrification of 18 secondary schools, 4 large hospitals, 21 community health centres and 12 financial institutions in the Districts of Kono, Bombali, Kailahun, Kenema and Kambia;
- the spread of awareness, education and capacity about renewable energy systems, through the organisation of campaigns, lectures and training courses for key stakeholders in education and energy sectors, the installation of photovoltaic laboratories in three technical training institutions (Eastern Polytechnic, in Kenema; Government Technical

Institute, in Freetown; Magburaka Technical Institute, in Magburaka Town) and the establishment of a network of pico-PV retailers.

In particular, the project rural electrification has contributed to the creation of more than 300 jobs and the 30% reduction of lighting costs for more than 15,000 households. The direct and indirect beneficiaries of the whole programme are estimated at about 850,000 [38].

As above mentioned, COOPI was selected as one of the four main developers of PRESSD-SL project, especially due to the experience gained on the Sierra Leonean territory, which includes the collaboration with WHH within the Agriculture for Development (A4D) programme. Furthermore, before 2014, they had been already engaged in two EU energy interventions, respectively in Malawi and Ethiopia, for the development of expertise in renewable energy systems for public services and solar energy for modern agricultural technologies [39].

Within PRESSD-SL, COOPI dealt with the electrification of Gbinti, a 1000-household rural town in Debia Chiefdom, in the District of Karene (a new district established during the project implementation), in the Northern Province. The NGO, together with the Ministry of Energy and District Councils, identified Gbinti as one of the main beneficiaries of the project, because of its isolated position with respect to the main communication roads and the national electricity network (there are no plans for the connection of Gbinti in the near future) [40]. According to the original outline of the programme, the electrification of the town was developed on two stages. The first step consisted in the installation of photovoltaic stand-alone systems to equip the public infrastructures in Gbinti, indicated by the Ministry of Energy: the school (10 kW), the market (2.5 kW), the clinic (2.5 kW), the bank and the court barre (5 kW). During the first half of 2019, each of these systems were revised and connected to the town mini-grid – core phase of the electrification plan – that, in the meantime, had been implemented for the provision of electricity to domestic and commercial users [41]. This local network, powered by 180 315-watt PV panels (for a total capacity of 56.7 kW) and supported by 72 batteries (3920 Ah), started being operative in October 2018 and, in November 2019, it could already count on 49 customers, out of which 25 are households, 22 are commercial activities; the last two connections are represented by Africell and Sierratel, two big African telecommunication companies [41].

In Table 12, which outlines the main project details, the investment cost of the mini-grid in Gbinti is considered equal to €315,000, since, out of the PRESSD-SL 7-million budget, €945,000 were allocated for the realisation of the three mini-grid and precise data about the actual costs the Gbinti one are not yet available [39].

| Gbinti (COOPI) | |
|--------------------------|---|
| Location | Gbinti Town, Karene District, Northern Province (Sierra Leone) |
| Commissioning year | 2018 |
| Developers | COOPI |
| Funders | European Union Fondazione Prosolidar |
| Management and Ownership | COOPI |
| Investment cost | 315,000 € |
| Technology | 180 PV solar panels 72 batteries (3920 Ah) |
| Capacity | 56.7 kW |
| Served Communities | Gbinti rural town |
| Connections | 25 households 22 commercial activities 2 industries |

Table 12 – Main details about Gbinti project by COOPI.

2.2.1.2 Method of Intervention

For the realisation of the project, COOPI has allocated a staff made of three people in Gbinti: a branch manager, in charge of keeping relations with the community chief, the local committee and the customers, and two local technicians, working on the installation of the solar field, the power house and the connections. On the other side, the overall management of the project has been directed from Freetown office by the logistic manager and the head of the mission; they managed the long-term strategy and kept in contact with the programme partners. Lastly, an external technical adviser provided the necessary technical support and advice; towards the end of the first operative year, he highly recommended the integration of a diesel generator (at least 35 kW) to support the panels and the batteries, in order to improve the reliability of the system and to ensure a 24/7 electricity provision service [40].

The implementation phase has been preceded, accompanied and followed by important side activities, led by COOPI and aimed at involving and mobilizing the local community:

- the organization of a sensitization and information campaign, made of meetings of mutual understanding, in order to identify the community needs and make them aware about the plans and the objectives of the programme; this activity, in particular, led to the signing of a land-use agreement between the community and the NGO for the utilisation of the solar field and the grid site;

- the establishment of a local committee, made up of 15 people (9 males and 6 females), in charge of empowering Gbinti people and representing them in the decision-making phase;
- the organization of a one-day workshop on lightning protection and a five-day workshop of mini-grid technical training.

As regards the electricity sale service, COOPI needed, first of all, to obtain the renewal of Generation and Distribution License and the approval of the connection fees and electricity tariffs from the Sierra Leone Electricity and Water Regulatory Commission [40]. Tariffs and fees, divided by users category (domestic and commercial), are shown in Table 13 (the euro/Sierra Leonean Leone (SLL) exchange rate is about 10,650). Instead, the two industrial customers – Africell and Sierratel – signed a supply contract based on a monthly flat rate [41].

| Customer Category | Tariff [SLL/kWh] | Connection Fee [SLL] | Operational Fee [SLL/month] |
|--------------------------|-------------------------|-----------------------------|------------------------------------|
| Domestic | 2,500 | 350,000 | 2,000 |
| Commercial | 3,500 | 600,000 | 5,000 |

Table 13 – Tariff strategy set by COOPI in Gbinti.

The consumption data and the customer payments are monitored and managed thanks to the SparkMeter system designed by the homonymous American start-up [42], in which the link between the installed meters (one for each user) and the base station is ensured by a robust software platform, named ThunderCloud [40].

However, in the recent months, COOPI, together with Welthungerhilfe, has been evaluating an exit strategy and potential local operators that could acquire the ownership and the management of the whole system and deal with the electricity sale service. The PRESSD-SL partners would prefer to give the system to an experienced actor, in order to ensure its sustainability; fortunately, in Sierra Leone there are already a range of modern start-ups engaged in rural electrification and renewable energy systems management [41].

In particular, the companies which expressed greater interest are PowerGen and Enercity Corp. The first one is an installer of off-grid systems, born in Kenya and operating in four African countries, including Sierra Leone; the second one is an American corporation, working in Sierra Leone with the Power Leone subsidiary. They are elaborating a technical proposal, which will be evaluated by COOPI, WHH and the other main donors and partners, that, with their decision, will give priority to the sustainability of the system [41].

2.3 Democratic Republic of the Congo (DRC)

“Black shapes crouched, lay, sat between the trees, leaning against the trunks, clinging to the earth, half coming out, half effaced within the dim light, in all the attitudes of pain, abandonment, and despair. [...] They were dying slowly – it was very clear. They were not enemies, they were not criminals, they were nothing earthly now – nothing but black shadows of disease and starvation, lying confusedly in the greenish gloom. Brought from all the recesses of the coast in all the legality of time contracts, lost in uncongenial surroundings, fed on unfamiliar food, they sickened, became inefficient, and were then allowed to crawl away and rest. These moribund shapes were free as air – and nearly as thin.”

Joseph Conrad, *Heart of Darkness*

The personal dictatorship instituted by Leopold II, King of the Belgians, in the area that now forms the Democratic Republic of the Congo, is today considered one of the most heinous examples of colonialism of contemporary history. This atrocity, which is the background of the masterpiece by the Polish-British Joseph Conrad, represents the starting point of DRC’s troubled recent history. Indeed, in the 1870s Leopold II, with help of the explorer Henry Stanley, imposed his authority on the lands of the basin of Congo river and, in 1885, the Berlin Conference recognised his claim on the territory, sanctioning the birth of the Congo Free State, ruled personally by Leopold II and not by the government of Belgium. However, Leopold’s economic crisis and the international protests against the cruel and authoritarian methods of Stanley forced the king to give to Belgium his personal property, which was renamed the Belgian Congo. After decades of bad administration, the first nationalist movements led to the independence of the Republic of the Congo in 1960. Nevertheless, early disorders, especially in the eastern region, and the interventions by the UN and different world nations facilitated the accession to power of Joseph-Désiré Mobutu, who became president in 1965; he changed the name of the country to Zaire, nationalised many mining industries (always crucial for Congolese economy) and established a private domain in the footsteps of Leopold II. The rule of Mobutu, characterized by a slow but unavoidable socio-economic and political crisis, lasted more than 30 years, until exile and death, towards the end of the First Congo War (1996-97). However, the end of the dictatorship did not guarantee peace for the new Democratic Republic of the Congo, which, in 1998, experienced the Second Congo War, which involved eight African countries [43]. Despite the official end of the war in 2003, hostilities have continued, especially in the east, where armed gangs and non-governmental troops keep on spreading violence. These never-ended clashes, together with the serious national malnutrition issue and the collapse of the sanitary facilities, have fuelled the socio-economic decline in Congo: in 2018 the GNI per capita was one of the lowest in the world (US\$490 [12]), as well as the human development index (179th out of 189 countries [30]).

Because of the wars and the consequent economic and political instability described above, today, DRC is one of the countries with the lowest electricity access rate in the world, with only 19% of the population benefitting from electric services (not including the many illegal connections and informal grids) [44]; the value sharply drops to about 1% in rural areas [45].

Indeed, transmission network, in addition to being highly dysfunctional, is fragmented into three semi-isolated main sub-networks, aimed at serving the main urban agglomerates: the West network (in the area of Kinshasa), the South network (in the Katanga province) and the East network (North and South Kivu) [46], [47]. Furthermore, even if the national installed capacity is about 2.67 GW [48], the daily available power is much less, since more than half of the hydropower plants, on which the energy system rely, work under 50% of their capacity, because of aging infrastructures and lack of maintenance [49]. These numbers are even more alarming considering that the territory of DRC is, probably, the richest of the whole continent, especially in terms of mineral deposits and energy sources (oil, hydro and geothermal above all) [46].

In 1970, the government of the then Zaire established the Société Nationale d'Electricité (SNEL), a state-owned power utility with the monopoly of the power sector, from production to distribution. In the '90s, large-scale national plans for the development of electricity asset were made, but the following wars hampered their execution and led to mismanagement and degradation of the existing infrastructures [45]. However, in 2009, the first proper Energy Policy of DRC was approved [47]. The main authority within the sector is the Ministry of Energy and Hydraulic Resources (MEHR), which operates through the Unit for the Management and Coordination (UMC), responsible for the supervision and the administration of MERH's electricity and water projects, and the National Energy Commission (CNE); the National Investment Promotion Agency (ANAPI) is, then, in charge of attracting and facilitating the action of investors, including those in power sector [49].

In 2014, the government launched the Electricity Code, which removed SNEL's monopoly status and introduced two new institutions (both still inoperative): the Electricity Regulation Authority (ARE) and the National Agency for the Electrification of Rural and Peri-urban Areas (ANSER). ARE is supposed to manage the main responsibilities within the sector in terms of stakeholder disputes, fair competition, tariff systems and projects guidelines; ANSER, as its name suggests, will be the main authority as regards rural and peri-urban electrification projects [49].

Congolese electricity sector has always completely relied on the water resources of the country – the Congo River and the eastern Great Lakes: since 1970s the share of electricity produced from hydro sources has never dropped below 95% and, nowadays, it is about 99.7% [44]. Despite the revocation of the monopoly status, SNEL is still by far the most important producer in the country, considering that it owns most of the hydropower plants in the country and that the capacity of its two largest dams, Inga I (351 MW) and Inga II (1424 MW), represents almost 70% of the national installed capacity (not including the persistent maintenance problems) [45]. However, the 2014 Electricity Code was the first important step of a political and regulatory framework focused on the promotion of private investments and public-private partnerships. Since then, many independent power companies, such as Virunga SARL, EDC, SINELEC and SOKIMO, have invested in large hydro projects, also thanks to the funds coming from big international institutions like the World Bank, the African Development Bank (AfDB) and the Export-Import Banks of China and India; moreover, the MEHR launched a programme aiming at electrifying 100 rural villages through green mini-grid [49].

Despite this change, the renewable potential of the country is still largely unexploited: the Congolese average solar irradiation is 6 kWh/m²/day, making photovoltaic systems very tempting [34]; while, including eventual promising small hydro projects, the national hydro potential is estimated at around 100 GW [49].

It is precisely with the implementation of two mini-hydropower plants that two Italian NGOs, respectively SOFIA Global and Kilalo Ponte, have given their contribution within the long and complex rural electrification process in the DRC. The mini-grid installed by SOFIA Global is located in the territory of Kapanga, in the southern province of Lualaba; while Kilalo Ponte has intervened in the territory of Masisi, belonging to the unstable North Kivu province, on the border with Uganda and Rwanda, theatre of the recent wars.

2.3.1 SOFIA Salvatorian Office for International Aid

SOFIA (Salvatorian Office for International Aid) is an internationally-oriented and non-profit organization, part of the Society of the Divine Saviour (commonly known as the Salvatorians), an international and religious congregation of priests in the Roman Catholic Church engaged in apostolic activities around the world since 1881, when it was founded in Rome by Father Francis Mary of the Cross Jordan. SOFIA is relatively young, as it was established by the Salvatorians in 2008 as integral part of the General Secretariat for the Missions. Moved by Catholic social teaching, SOFIA is engaged in activities aimed at overcoming poverty, oppression and injustice in 21 countries, operating in the sectors of health, education, rural development and pastoral formation. SOFIA Global, in particular, is the office that deals with the development, coordination and evaluation of projects and international funding [50].

In the recent years, after its birth, SOFIA gave an important contribution to the development of the Democratic Republic of Congo, with the promotion of many different interventions, such as the opening of a maternity clinic in the territory of Kapanga and the launch of a secondary technical school in the city of Lubumbashi. Moreover, the Salvatorians are supporting the construction of a Sickle-Cell Disease health centre in Lubumbashi and working on the establishment of a proper university in the city of Kolwezi. However, the most interesting activity in reference to the topic of this thesis, is the green energy ELKAP project.

2.3.1.1 ELKAP Project

ELKAP, which stands for Electricity for Kapanga, is a rural electrification project which officially started in 2010 in the territory of Kapanga, located in the province of Lualaba (established in 2015 after the split of the former Katanga province), in the south-west of Congo. This area is isolated with respect to the important urban centres of the country, because of the degraded roads and the total absence of railway connections; people mainly rely on farming and fishing, and the national electric network does not serve the local communities [51].

The key-character of ELKAP is the Salvatorian Father Jaak Henkens, who had worked on the implementation of different hydro systems all around the region, throughout the 80s and the 90s, acquiring good expertise and know-how about hydropower technology. At the

beginning of the new millennium, he started reasoning on the great energy potential of Rushish Falls, 12 km away from the town of Musumba, in Kapanga territory. Finally, also thanks to the support of Moses Katumbi Chapwe, the Governor of the then Katanga province, in 2009 Father Jaak was able to attract the attention of the European Commission, which, in the context of a green energy campaign for Africa, commissioned SOFIA Global to install a mini-hydropower plant, in order to exploit the potential energy of Rushish Falls and electrify the villages nearby [51]. The project designed by Father Jaak and SOFIA provided the realisation of a diversion-channel mini-hydropower plant equipped with two cross-flow turbines. In November 2012, the two 100 kW turbines were installed and, less than two years after, the 30-km medium voltage line transmission was extended through the area of Kapanga. In September 2015 the power plant was officially inaugurated in Musumba. In the meantime, in 2013, SOFIA Global instituted ELKAP ASBL, a non-profit organisation, headquartered in Kapanga, in charge of managing the power plant, the mini-grid and the sale of electricity and promoting the socio-economic development of the territory. At the inauguration, in 2015, the connected users were already 155; at the beginning of 2019, they had rose up to 365, including 3 hospitals, 3 health centres and 5 schools. Until the end of 2020, they are expected to become about 500, distributed in five residential areas in Kapanga, with more than 720,000 kWh yearly produced. Because of the aforementioned geographical isolation of the area and the underdevelopment of the national network, the system is not grid-connected. The total investment cost of the project is 1,400,000 €, funded by the European Commission (75%) and the Katanga Province (15%) [51].

| Kapanga (SOFIA Global) | |
|--------------------------|--|
| Location | Rushish Waterfalls, Kapanga Territory, Lualaba Province (DRC) |
| Commissioning year | 2015 |
| Developers | SOFIA Global, ELKAP ASBL |
| Funders | European Commission Katanga Province |
| Management and Ownership | ELKAP ASBL |
| Investment cost | 1,400,000 € |
| Technology | Diversion channel mini-hydropower plant (2 cross flow turbines) |
| Capacity | 200 kW |
| Served Communities | 5 villages (Musumba, Kapanga, Ntita, Kashimba, Katat) |
| Connections | 272 households 35 public services 58 private businesses |

Table 14 – Main details about Kapanga project by SOFIA Global.

The two cross-flow turbines, capable of delivering 200 kW in total, have been constructed by Father Jaak with the help of local workers. In 2018, the same turbines were redesigned, in order to increase the water intake flow and, so, the generated power. The same team furthermore resorted to the use of recycled waste material for the realisation of part of the equipment, while cables and poles needed to be bought in the closer cities and transported to Kapanga [51].

During the first years of operating, the system incurred in some blackouts, especially at night time, in the dry season, and the main technical problems are related to the load controller in charge managing the power output and matching it with the load, in particular due to the high relays consumption and the difficulty in managing too many simultaneous consumption variations [52].

2.3.1.2 Method of Intervention

The vision of SOFIA Global was, specifically, “to accelerate the community development of Kapanga area, providing the population a reliable, affordable and environment-friendly electric power service” [51]. From the previous statement it’s easy to understand that the provision of electricity represents a carrier to stimulate a sustainable and comprehensive development process. That’s why the realisation of the plant and the mini-grid has been accompanied by different secondary activities, fundamental for the achievement of the complex objective.

First of all, the Salvatorians and the staff of SOFIA Global opted for the establishment, in 2013, of a local non-profit organisation, the aforementioned ELKAP ASBL, which was supposed to gradually take over the tasks of the programme and the management of the system. The team of this association is structured into a management section and a technical section and, in 2018, it counted already 24 members. The board is composed by Father Jaak as director, an assistant from SOFIA Global, two local directors and two local secretariats; while the technical team has been completely recruited on field and it is made up of four electricians, three power plant operators, six workers two sentinels and two rural community workers. All the workers, especially electricians and power plant operators, have participated to training session throughout and after the implementation phase [52].

Once established, ELKAP ASBL took on the following objectives in a long-term perspective:

- the sustainable management and maintenance of the hydropower plant and of the connected mini-grid;
- the management of the electricity sale service;
- the provision of electric energy which is clean, reliable and affordable for the different social classes present on the territory;
- the increase of local awareness about the use and the potential of electricity, which is supposed to boost other fundamental services (telecommunication, health, education and water provision);
- the design of a local development plan with the inclusion of energy and environmental values and the involvement of local stakeholders;
- the development and the solicitation of new business and social projects, through workshops, incentives and a micro-credit service.

In particular, in order to achieve at least some of these tasks, between 2016 and 2019, ELKAP ASBL has collaborated with the Irish organisation Mísean Cara in carrying out the programme “Capacity Building for Rural Development”, which specifically aimed at empowering the Kapanga community for the management of the new system, increasing their capacity and skills and strengthening their sense of identification and ownership [51].

Throughout the first years after the plant inauguration, the financial sustainability of ELKAP has represented a significant issue, and the means to achieve it, especially regarding the sale of electricity, have been discussed. Between 2015 and 2017, the board opted for the utilization of a flat tariff, which led to the usual related problems, such as uneven distribution of electricity costs between large and small customers and non-paying users insisting on not being disconnected. In 2017 the revenues were still too low compared to the operational costs and, in August, ELKAP announced the introduction of a new payment system based on consumption-related tariffs, possible through the installation of pre-paid meters. This way customers were made more aware and responsible about their consumption efficiency, leading to a reduction in wasted power and to a simplification of the service administration. Considering that the power utility SNEL has one of the lowest electricity tariffs in Africa (0.06-0.07 €/kWh in 2017 [49]), the first tariff offered by ELKAP in 2018 and ratified through a contract signed by the NGO and the customers, was 0.11 €/kWh, with a growth perspective up to 0.14 €/kWh in 2021. Thanks to this new policy, the increase of connections and the supplying contract signed with the telecommunication company Vodacom, the revenues grew by 39% in 2018. ELKAP ASBL is expected to achieve the break-even point and the consequent financial sustainability towards the end of 2020. It's important to highlight that, without relevant investments in the capacity building programme, this goal would not so quickly reachable [51], [52].

The community acceptance and the involvement of local public authorities have been possible especially due to the importance of the figure of Father Jaak and the long tradition of SOFIA Global on the territory. The successful impact of the whole programme has significantly contributed to consolidate these relationships, pushing the Salvatorians and SOFIA to replicate the project on a larger scale, in order to meet the electric demand of about 70,850 people. The project ELKAP II (or ELKAP FOR ALL) will be based on the construction of a 1.6 MW hydropower plant on Kaongweji River; the new plant will be then connected to the existing grid, which will be extended, reaching, this way, 13 new villages. The hope is that the socio-political instability, especially due to Kamwina Nsapu rebellion in the bordering provinces, would not jeopardize these plans. Indeed, to date, ELKAP is still the only example of social rural electrification project in the territory of Kapanga [50], [51].

2.3.2 Kilalo-Ponte Onlus

The association Kilalo-Ponte Onlus was formally born in Rome in 2010, from the informal group “Amici di Mweso”, composed by some people that, in 2007, took a trip in the unstable province of North Kivu (DRC), in the context of an international student project organised by the Italian Ministry of Foreign Affairs. Once back in Italy, they decided to create a bridge (*kilalo*

in swahili language) between the Roman civil society and the Congolese rural reality, with the aim of boosting the socio-economic development of the village of Mweso, in the aforementioned province. Their first project, still lasting today, consisted in a schooling programme dedicated to 300 children of Mweso, reeling from the war violence and its social consequences [53].

2.3.2.1 Project in Mweso

In 2013, thanks to the funds raised by the Italian organization Fondazione Prosolidar, Kilalo launched the plan for the electrification of Mweso in the territory of Masisi, which, at the time, was a fast-growing centre of 25,000 people, experiencing a period of economic effervescence; despite this, it was isolated from the national electric network. Since the beginning of the programme, the main partner of Kilalo has been the Comité des Agriculteurs pour le Développement Participatif (CADEP), a non-profit organisation established in Mweso in 1992 and, since then, committed to providing technical and organizational support to the initiatives undertaken by local farmers [53].

The core of the project is represented by the construction of a run-of-the-river mini-hydropower plant in Kiusha site, 7 km far from Mweso; the electricity is produced by a 100-kW pelton turbine (locally manufactured) and then transported to the centre thanks to a dedicated mini-grid, which serves also the intermediate village of Muhongozi; at the beginning of 2020, the connected users were about 75, including households, public services and private activities. The investment cost of the entire project was €182,088, of which €139,088 were paid by Prosolidar through six instalments, while CADEP and the local community were supposed to provide the remaining part. The project was interrupted in 2015, because of issues with some local farmers and due to the collapse of the Banque Internationale pour l'Afrique au Congo (BIAC), where the last Prosolidar payment was deposited. Fortunately, in 2017, the work was resumed, thanks to the repayable loan from Fondazione Prosolidar, and, after delays on the delivery of the electric cables, all the planned installations were concluded in 2018 [54].

| Mweso (Kilalo Ponte) | |
|--------------------------|--|
| Location | Kiusha, Masisi Territory, North Kivu Province (DRC) |
| Commissioning year | 2018 |
| Developers | Kilalo Ponte, CADEP |
| Funders | Fondazione Prosolidar CADEP |
| Management and Ownership | CADEP |
| Investment cost | 182,088 € |
| Technology | Run-of-the-river mini-hydropower plant |
| Capacity | 100 kW |
| Served Communities | 2 villages (Mweso, Muhongozi) |
| Connections | 75 |

Table 15 – Main details about Mweso project by Kilalo Ponte.

2.3.2.1 Method of Intervention

In the context of the electrification of Mweso, Kilalo-Ponte played the role as intermediate between CADEP and Prosolidar, in order to find the funds necessary for the realization of the project. CADEP, together with a selected local enterprise, specialized in electrical installation, was the actual developer the project, whose global objective was the socio-economic development of Mweso community, feasible through the following specific points:

- the provision of electricity to households, aiming at improving the quality of their life, with a particular focus on education and health;
- the electrification of Mweso general hospital, in order to facilitate the laboratory analysis, the utilization of diagnostic equipment, the proper storage of vaccines and blood and, in general, the hospitalisation;
- the electrification of the Institut Supérieur d'Etudes Agronomiques (ISEA) and of the Université Progressiste de Gran Lacs (UPROGL), with the consequent possibility of using modern I&T technologies;
- the acceleration of agricultural development and food industry;
- the development of new income generating activities and the boost to the revenues of small local enterprises [55].

Along the whole implementation period, CADEP has been directly responsible for the sensitization campaign addressed to the dwellers about the socio-economic opportunities that electricity could bring to a rural community, but also about the dangers and the risks related to an improper use of it [56]. The original plan provided for the described activities and the fact that, once finished the construction phase, CADEP would have taken on the whole system as

owner in charge of the management of the maintenance. To date, the sale of electricity is managed with a monthly flat-tariff system, which distinguishes users according to their type; nevertheless, Mujogo Kanyamuhanda, the executive coordinator of CADEP, expressed the intention to modernise the system, so as to move to the use of smart meters and software for customer and billing management, once new funds are found. New resources are also needed to physically reinforce the electric grid, whose fragility has already led to several blackouts and accidents.

The sustainability of the electrification project of Mweso is thus an open challenge, but it's eventually important to highlight that it is perfectly in line with the governmental strategies about combating poverty outlined in the Poverty Reduction and Growth Strategic Document (PRSP), precisely in relation to the objectives shown above [55].

2.4 Burundi

Burundi is a small country of Eastern Africa, stuck between the DRC, Tanzania and Rwanda. His contemporary history has been obviously affected by the socio-political instability and bloody conflicts inherent in the region of the Great Lakes, which led Burundi to be one of the poorest countries in the world. The thirty years following its independence, gained from Belgium in 1962, were, indeed, marked by the succession of different coups d'état led by personalities that, punctually, became protagonists of racially motivated massacres, especially against the population of Hutu ethnicity, causing the deaths of hundreds of thousands of people. The first democratic elections were held in 1993, but the assassination of the new president, a few weeks after the elections, plunged the country into a civil war that lasted until 2005, when university professor Nkurunziza was elected. Since then he has been the uninterrupted head of the Burundian government, practically establishing a dictatorship, whose characteristic violence and political tensions led to further deaths, displacements and socio-economic backwardness [57], [58]. Among the approximately 10 million inhabitants of Burundi, about 90% live in rural areas, and country's economy relies on subsistence agriculture, although, recently, the government has been pushing for the transformation and modernisation of agricultural sector [57], [59]. According to the World Bank, in 2018 Burundi was the country with the lowest GNI per capita (USD 280) among those registered [12] and the UNDP puts it at the 185th place in the HDI rank [30].

Also from an energy point of view, Burundi is one of the most backward countries in the world. Indeed, during the long civil war, the country's energy infrastructures have been almost totally destroyed and an embargo established in 1996 has further reduced the few foreign investments [60]. In 2017 only 9.3% of Burundian population had access to electricity and it is mainly concentrated in the former capital city Bujumbura, while the access value falls to less than 1.7% in rural areas [61], where the households needs are almost exclusively met by traditional biomass [60]. The weak power sector relies on hydroelectric source, represented in particular by the two large plants of Rwegura and Mugere which produce about 85% of the

national electric supply [62], with the consequent unreliability and frequent shortages characterising especially the dry season. The Ministry of Energy and Mines (MEM) is in charge of policy making and regulating the energy sector, while the Régie de Production et Distribution d'Eau et d'Electricité (REGIDESO), created in 1968, is the public utility charged with the production and distribution of water and electricity, operating and controlling most of the plants in the country (including those in Rwegura and Mugere). REGIDESO is then flanked by the Agence Burundaise de l'Electrification Rurale (ABER), which is in charge of rural electrification enhancement, managing few off-grid hydropower plants in the country. The electric tariffs are set by MEM and REGIDESO and they must be applied to all electricity sales services [62].

In recent years, the government has been engaged in policies aimed at expanding and modernising the national energy sector, mainly focusing on exploiting the high hydroelectric potential of the country. Through this process it has collaborated with international institutions and programmes, such as the EU Energy Initiative Partnership Dialogue Facility (EUEI PDF) and Sustainable Energy for All (SE4ALL), which especially contribute to improving the poor technical and management knowledge proper to local energy actors and to developing a new national energy policy more sensitive to rural electrification. The goal is also to take advantage of other renewable sources in addition to hydroelectricity, especially of solar energy, given the high average solar irradiation on Burundian territory (4-5 kWh/m²/day) [60], [62].

2.4.1 ICU Institute for University Cooperation Onlus

ICU – Institute for University Cooperation Onlus is an Italian non-profit organization established in 1966 on the initiative of some university professors aiming at supporting human and social growth in developing countries and at disseminating the concept that cooperation development represents an integral promotion of human dignity. Since its inception, ICU operated in more than 40 countries around the world through some 480 cooperation projects, mainly in the fields of education and vocational training, sanitation and healthcare, agriculture and irrigation, renewable energies and women empowerment [63].

2.4.1.1 Projects

The commitment of ICU in Burundi dates back to 2015, when, in collaboration with ABER, the Burundian agency charged of rural electrification, they intervened in order to provide affordable and reliable electricity to the rural centres of Ryarusera (Muramvya Province), Kigwena (Bururi Province), Butezi (Ruyigi Province) and Nyabikere (Karuzi Province). Nevertheless, this energy project is different from the ones previously illustrated, since the main action provided for the renovation, the commissioning and the reinforcement of four existing hydropower plants out of operation (independent of each other), supported by the rehabilitation and the extension of the respective connected distribution grids; the plant in Nyabikere was also coupled with a new PV field. Before the intervention, the Butezi and Nyabikere plants were the only two functioning, with an electricity production of 204,770 kWh/y. Considering all four installations, the project led to an overall installed power of 462,2 kW and an expected nominal annual production of 1,826,448 kWh, bringing clean electricity to almost 10,000 users, including

households, public services and productive and commercial activities, and selling the exceeding energy to REGIDESO national network. Once the action was completed, the management and the ownership of the four grid-connected mini-grid facilities remained prerogative of ABER, which was already the owner of the plants. The investment costs of the overall programme amounted to €2,8 million, of which €2 million were funded by the EU and €800,000 came from private donors [64].

| Ryarusera, Kigwena, Butezi, Nyabikere (ICU) | |
|---|--|
| Location | <ul style="list-style-type: none"> • Ryarusera, Muramvya Commune, Muramvya Province (Burundi); • Kigwena, Rumonge Commune, Bururi Province (Burundi); • Butezi, Butezi Commune, Ruyigi Province (Burundi); • Nyabikere, Nyabikere Commune, Karuzi Province (Burundi) |
| Commissioning year | 2017 |
| Developers | ICU, ABER |
| Funders | European Union Private sector |
| Management and Ownership | ABER |
| Investment cost | 2,800,000 € |
| Technology | 2 micro-hydropower plants 2 mini-hydropower plants |
| Capacity | 462,2 kW |
| Served Communities | 4 villages (Ryarusera, Kigwena, Butezi, Nyabikere) |
| Connections | 8723 households 42 public services 390 commercial activities 7 factories 400 farms Grid |

Table 16 – Main details about Ryarusera, Kigwena, Butezi and Nyabikere projects by ICU.

2.4.1.2 Method of Intervention

From a technical point of view, the programme implemented by ICU included the following interventions in the four different plants:

- Ryarusera: the disused micro-hydropower plant (30 kW) has been reopened, with the substitution of the old turbine with a new crossflow turbine; the existing connected transmission and distribution lines have been rehabilitated;
- Kigwena: the disused micro-hydropower plant (62.2 kW) has been reopened, through the installation of reconditioned Ossberger turbine; the existing transmission lines have been rehabilitated and the distribution lines extended;
- Butezi: the malfunctioning mini-hydropower plant has been restored to its nominal capacity (200 MW), with the replacement of the old hydraulic system and the installation of a new generator;
- Nyabikere: the existing mini-hydropower plant (130 kW) has been renovated with the replacement of the old hydraulic system and the installation of a new generator; the hydroelectric production has been then reinforced with the implementation of a coupled PV field, providing further 40 kW.

As part of the work carried out at the four sites, ICU has been supported by ABER and different private actors, as the local enterprises EFC and EGHE, and the Belgian JLA Hydro, which supplied and installed the new turbines. The overall result thus consists in the realisation of three purely hydropower plants and one hybrid hydro-solar power plant, each of which is equipped with its own rural mini-grid, providing clean and reliable electricity to remote areas of the territory; in addition, all four systems are connected to REGIDESO national grid, in order to sell the surplus energy. As regards electricity sale service, the tariffs offered to all rural consumers are aligned with the national ones, since, as aforementioned, the plants are managed by ABER, which is under the Ministry of Energy and Mines [63].

The energy intervention has been, then, flanked by diverse complementary activities. First of all, ICU is committed to providing intensive training to ABER's technicians and directors, through an extended capacity building programme especially focused on the management and the maintenance of the plants. The entire project has been then supported by an insistent on-field information campaign, made of sensitization meetings organised in the four rural centres, distribution of promotional material and media coverage in the press, radio and social networks. The realisation of such a complete awareness intervention has been possible thanks to the good relationships that the Italian NGO established with the involved local utilities, ABER, REGIDESO and the Ministry of Energy and Mines. The two events organised in July and October 2017 to inaugurate the plants were also attended by the Minister's assistant, the local authorities and the representatives of EU delegation to Burundi [63].

2.5 Ongoing Projects

This final section is dedicated to the synthetic treatment of Italian NGOs mini-grid projects that are in the start-up or stalled phase, because the long legal procedures have not yet been unravelled or the work has not yet been completed, in relation to expected or unforeseen reasons. In this regard, four projects have been identified in Africa: the two mentioned hydroelectric mini-grids, by CEFA under construction respectively in Ninga and Luganga (Tanzania), and two hybrid solar-diesel mini-grids designed, but not yet implemented, by AVSI and COSV partnership for rural areas of Mozambique.

2.5.1 Ninga and Luganga Projects by CEFA

After the successful intervention of Matembwe-Ikondo and taking advantage of the new opportunities that Tanzania offers to energy developers, recently CEFA decided to aim higher, by planning the realisation of two larger hydropower plants, whose mini-grids will be able to provide reliable electricity to numerous remote villages in wider rural areas of Tanzania. The first project consists in a run-of-the-river plant, built on Rufiji River, in Ninga, in the mentioned District of Njombe. It is supposed to supply an output power of 6 MW (two Francis turbines) with an expected annual energy production equal to 26,410,000 kWh, capable of satisfying the energy needs of 13 villages in the district, for a total of 3500 users, including households and activities [65]. The second run-of-the-river hydropower plant has been installed in the rural District of Iringa, more precisely in the site of Luganga: the installed power is equal to 9.9 MW (two Francis turbines) and it is expected to produce 76,030,000 kWh/y, serving the villages of Luganga, Kipera and Kiwere (about 1000 connections). Given the high nominal power of the two plants, they will be both connected to TANESCO grid, so as to derive significant gains from the sale of excess energy to the national network [66].

As illustrated in the previous section about CEFA's interventions, within the action in Ninga and Luganga the Italian NGO has inaugurated an innovative approach based on a non-profit/for-profit partnership, collaborating, in particular, with ENCO Engineering consultants (an Italian company from Belluno) and Energy and Environment Partnership Programme (EEP) of Southern and East Africa [18], [19]. Moreover, the investment costs necessary for Ninga and Luganga mini-grids (respectively €16.2 million and €25.43 million) were covered by EU and REA grants, commercial loans and partially by developer equity. Today, at the beginning of 2020, both the projects have stalled because of the continuous obstacles that arise within the Tanzanian regulatory framework concerning the independent power producer market. Once the work is completed, the ownership and management of the two functioning systems will be transferred to selected local actors [19].

2.5.2 Projects by AVSI and COSV

The last projects that will be illustrated are those still in the start-up phase, proposed by the Italian NGOs AVSI and COSV in order to contribute to the process of rural electrification in Mozambique. Both non-profit organisations have been engaged since the early 1970s in development cooperation and humanitarian aid operations in the Balkans, Sub-Saharan Africa, Latin America and the Middle-East. In particular, the beginning of the action of COSV in Mozambique dates back to 1976, while AVSI started working in the African country in 1999 [67].

In December 2017, AICS approved the initiative formulated by AVSI and COSV, organised through a temporary joint venture, which provided for the installation of two hybrid solar-diesel mini-grids, respectively in Cabo Delgado Province and Zambezia Province, in order to meet the basic needs and the energy requirements of the local population, both in the domestic environment and in the productive and commercial sector; the programme also aim at strengthening public health and education services, and, thus, promoting local socio-economic development. In both the sites, the mini-grid implementation is accompanied by sale services of individual solar systems for households living in dispersed areas, and biomass improved cooking stoves; all supported by training programmes on the use, maintenance and benefits on these modern energy systems. Furthermore, AVSI and COSV intend to focus on actions aimed at promoting women's empowerment, through the strengthening of the skills of local women entrepreneurs and the reinforcement of social and training services guaranteeing their autonomy and social affirmation (e.g. support and aggregation centres, leadership and active citizenship courses) [68].

The project “E2COM Cabo Delgado” provides for the installation of a hybrid mini-grid in the rural village of M'paka (Balama District, Cabo Delgado Province). In particular, it will be powered by a PV solar field of 200 kW, supported by a 70-kW diesel generator and a 450-kWh battery pack, for an expected yearly production of 295,000 kWh (87% solar); the distribution network will initially connect about 136 users, including households and activities, in addition to two wells and the new LED public lighting system. Moreover, exploiting the scalability of PV technology, the plant is expected to be reinforced up to 320 kW in the following years. Within this project AVSI has the role of leader, while COSV is the co-executor [67].

The two organisations will, then, manage the second project, named “MuL-ER Zambezia”, with exchanged roles, so that COSV is the main implementer and AVSI the co-developer. In the village of Namanjavira Sede (Mocuba District, Zambezia Province) the hybrid power plant is supposed to be smaller (96 kW), composed of a 60-kW solar field, a 36-kW backup generator and the support of batteries for 285 kWh; the annual energy production is expected to be about 110,800 kWh in the first year, meeting the needs of about 100 customers, one well and public lighting. Also in this case, there is the possibility of scaling-up the production, both in terms of PV panels and batteries. Finally, it is important to highlight that the project “MuL-ER Zambezia” has been designed following the steps of the Comprehensive Energy Solutions Planning (CESP) framework carefully analysed in the following homonymous chapter [69];

unfortunately, as the plant has not yet been built, it is not yet possible to assess the concrete benefits of CESP design model.

It is planned that AVSI and COSV will cooperate at all stages of the actions with FUNAE (Fundo de Energia), an administratively and financially autonomous Mozambican public institution, in charge of supporting and developing the management of energy resources. This utility is then supposed to obtain the ownership of both plants, whose operator, instead, will be selected through a call for tenders, issued by FUNAE itself. The investment cost of the two interventions, totalling €4.73 million, are borne entirely by AICS funding [67], [69].

3 Private and academic actors

As is known and already mentioned in the introduction, in order to assess the involvement of a given country in the international rural electrification sector, it is necessary that the analysis is not limited to the study of interventions by non-profit interventions, although they are generally the most active players when it comes to development cooperation; the domain of potential mini-grid developers must therefore also include actors from private and academic environment.

With regard to the identification of mini-grid projects implemented by Italian private parties, the research has been more complex and less fruitful than that of NGOs activities. It is in fact only few years that private enterprises began to invest in the process of rural electrification in SSA, and hence the number of actors involved in that area is still limited. This delay is simply and mainly due to economic reasons: private individuals basically invest in profit-making projects, and mini-grids have only recently begun to guarantee gains, since cooperation development agencies started to target private actors and to consider them eligible for funding [5]. Indeed, although the costs of renewable off-grid technologies are becoming increasingly competitive, the economic sustainability of mini-grid projects is still fundamentally dependent on subsidies and grants, which are able to cover, at least partially, the high investment cost of such interventions [5], [70].

The involvement of private investors in mini-grid projects seems to be further reduced within the Italian panorama: the results of this research showed that Absolute Energy, a company headquartered in Rome and focused on renewable energies and environmental technologies, is currently the only private Italian entity that has realised its own mini-grids in Africa. This outcome was then confirmed by the talks that the author held with key figures in Italian development cooperation, such as Carlo Tacconelli (co-founder of EnGreen Solutions, which provides technical assistance to actors engaged in rural electrification) and Matteo Leonardi (energy and environment consultant in renewables infrastructures and regulation of electricity markets). They then pointed out that there are different Italian companies simply supplying technical equipment (e.g. FIAMM batteries and ZCS inverters) or carrying out electro-mechanical installations; an example of these industrial realities that, however, cannot be considered proper project developers, is represented by SAET Padova Spa, a firm specialised in automation systems, which recently supplied a “turn-key” smart mini-grid to an isolated agricultural education campus in Rwanda. Moreover, it has been possible to identify some mini-grid companies which, from a legal point of view, are not to be considered Italian, as they are based in a foreign country (typically in an African one), but which were founded and are still run by Italian personalities: examples such as Equatorial Power (headquartered in Uganda) and Devergy (headquartered in Tanzania) will be discussed in more detail in the following sections.

Lastly, when it comes to electricity within Italian context, one cannot fail to mention the energy giant represented by ENEL. Even though they have never implemented a mini-grid system in Africa, a brief discussion will be dedicated to its vision and approach to rural electrification.

Finally, it was decided to include in this chapter also the only example, that the author was able to identify, of mini-grid projects installed by an Italian academic body; it corresponds to the hydropower system realised to electrify a Tanzanian secondary school, within the research project Energy4Growing (E4G), promoted and funded by Politecnico di Milano. The reason for the almost non-existence of mini-grids implemented by academic entities may lie in the fact that practically all Italian engineering universities are public, and the limited resources that they receive are mostly and rightly used in the fields of education and research, considering also that off-grid energy interventions require significant investment costs.

3.1 Absolute Energy S.r.l., the only private Italian developer

As previously anticipated, the only private and properly Italian company that has so far developed, as owner, mini-grid projects in Africa is Absolute Energy (AE) S.r.l. [71], an independent investment platform and principal investor focused on renewable energies and environmental technologies, headquartered in Rome and London, with local offices in Uganda, Rwanda and Kenya. Its action, driven by a 4-D vision (Decentralisation, Decarbonisation, Digitalisation and Development), develops on several fronts, such as the promotion of climate-resilient infrastructure and clean technologies, the creation of a new asset class for impactful and sustainable investments and the provision of universal energy access and productive uses of energy in developing countries. This last commitment, in particular, is addressed through the delivery of smart, flexible and distributed energy systems, based on renewable sources, downstream of a holistic approach to promote the socio-economic development and a symbiotic growth of target rural communities. Development plays, in fact, a central role within the strategy of AE, which aims to operate the so-called Water-Energy-Food (WEF) Nexus, catalysing the enhancement of a plurality of agricultural, economic and social activities for the benefit of the community and the company itself. These key concepts translate into a comprehensive and multi-partner action, which typically revolves around the implementation of a mini-grid for reliable and affordable energy supply, but also includes complementary interventions for the improvement of local health and education, the upgrading of existing businesses and the development of new ones, and the transferring of educational training to the served communities [72].

The first two mini-grid projects implemented by Absolute Energy concerned the electrification of the Ugandan islands of Kitobo and Bukasa, located in the Lake Victoria. Although the systems installed on the two islands are similar (both based on solar PV technology), the energy development programme carried out is different.

In Kitobo, AE, together with technical partners as Work System S.r.l. and SMA Group, has built a hybrid mini-grid power by 880 PV panels with an installed power of 228.8 kW and an expected yearly production of 130 MWh [73], [74]. The solar plant, which allows a reduction of around 60 tonnes of CO₂ per year, is supported by innovative vanadium redox flow batteries (VRFB) with a total capacity of 520 kWh (expensive, but extremely performing both in terms of depth of discharge and life span), and a backup diesel generator of 60 kW, ensuring the continuity of energy supply in case of extraordinary maintenance of the PV field or very high load demand [74]. The functioning of the plant is efficiently monitored thanks to the SMA Energy Meter, which collects and transmits all production and consumption data; moreover, the commercialisation of electricity is managed through a pre-paid strategy – which allows users to pay in advance via mobile-phone for the energy they are supposed to consume – and monitored by remotely connected individual smart meters [73]. The mini-grid provides energy to about 520 domestic and commercial users, ensuring a significant improvement to the standard of living of local population and to the conditions of the existing commercial activities [74]. The generated energy also powers the ice-production activity implemented on the island within the electrification programme, which allows local fishermen to store and transport fish in a simple and economical way [75]. In addition to the mentioned technical partners, AVSI, CIRPS (Inter-university Research Centre for Sustainable Development), Finafrica and Kafophan also contributed to the implementation of the project, which was co-financed by the Energy and Environment Partnership (EEP), the Rural Electrification Agency and Shell Foundation [74], [76].

For the electrification of Bukasa Island, instead, AE opted for the design of a community photovoltaic plant, for which eight buildings, with 100 kW of PV solar panels above their roofs, have been constructed. The idea is to start in each of these buildings, which also contains the mini-grid batteries, commercial activities of various kind, such as a fish processing business, a flour mill, a laundry, a bakery and an internet café, with a dual purpose: the definition of an anchor load ensuring a stable electric demand and the creation of a place of meeting and growth for the community. This way, alongside the development of economic activities and the quality of life, the electrification is also expected to increase the level of social cohesion [75]. The electrification project in Bukasa Island has been partially financed by AICS through the first profit call launched by the agency, in which AE participated [72].

| Location | Technology |
|------------------------|---|
| Kitobo Island (Uganda) | 228.8 kW PV panels 60 kW diesel generator 520 kWh vanadium flow redox batteries |
| Bukasa Island (Uganda) | 100 kW community PV panels |
| Rutenderi (Rwanda) | 50 kW PV panels 30 kW diesel generator 120 kWh storage batteries |

Table 17 – Technologies used in mini-grid projects implemented by Absolute Energy.

In May 2019, Absolute Energy inaugurated its first mini-grid in Rwanda, more specifically in the village of Rutenderi, in the district of Gatsibo, Eastern Province. The hybrid power plant, composed by a 50-kW PV solar field, a backup diesel generator of 30 kW and supported by a storage system with a capacity of 120 kWh, provides reliable and affordable electricity to 560 households, 36 local businesses and 7 social institutions, according to a rural development approach combining modern energy provision with businesses incubation and the enhancement of productive uses of electricity and clean water [77], [78]. The integrated programme for the electrification of Rutenderi has been conducted by AE also through the collaboration with different international partners, such as CIRPS, AVSI and Energy 4 Impact (E4I), a UK NGO. In particular, AVSI was selected to conduct a market assessment in the target village to help AE to confirm the financial projections and viability of the project, to review the electric tariff system and to create a more accurate local load curve [79], [80]. E4I, through its SOGER (Scaling up Off-Grid Energy in Rwanda) programme, funded by SIDA (Swedish International Development Cooperation Agency), supported the project helping AE in negotiating the acquisition of the land for the plant, conducting a research for the identification of potential smart meters suppliers and facilitating the procedures for the obtainment of the permits by the public utility EDCL (Energy Development Corporation Limited); moreover, E4I provided, through mentoring activities, expertise to support local enterprises in making their activities more profitable, taking advantage from the upcoming modern energy provision [80]. It is finally important to highlight that the action has been partially financed by the Results-Based Financing facility of the energy access partnership EnDev (Energising Development) [80].

After the successful projects implemented in the Ugandan islands and in Rutenderi, Absolute Energy is currently working on the off-grid electrification of another Rwandan village, Gatoki, in the Southern province, for which it has been long and difficult to get the needed permits from the EDCL [79], [80].

3.2 Turn-key mini-grids suppliers

As mentioned in the brief introduction to the chapter, it is necessary to highlight that, in the panorama of Italian energy companies working in the rural electrification sector in Africa, in addition to real developers of integrated mini-grid projects, there are firms dealing with the construction and the supply of turn-key mini-grid stations. Such realities generally realise small energy systems that meet the needs and requirements of their customers, covering only the installation phase of the facilities; after the completion of the work, the mini-grid is directly delivered to the customer, who is reserved the ownership and management of the station itself. This section therefore aims at illustrating the example of two Italian companies operating according to the “build-and-sell” model described above: SAET Padova Spa and Heliopolis Spa.

3.2.1 SAET Padova S.p.A.

Founded in 1956 as electromechanical enterprise, SAET Padova S.p.A. [81] has subsequently diversified its activities, also entering the dosing and weighing and industrial automation sectors, and acquiring a more complete plant vision. SAET has a long experience in the energy field, especially in the design, construction and commissioning of turn-key systems and plants for the production, transmission and distribution of electricity commissioned by energy producers, utilities and industries. Starting from more traditional energy activities, such as thermopower, hydropower and the installation of HV substations, the company has recently also been involved in the alternative resources sub-sector, with a particular focus on Waste to Energy (WTE) and hybrid mini-grids. In regard to the latter, SAET developed the so-called “Smart Rural System”, a modular and customisable system for the supply of clean, safe and sustainable energy to small settlements, based on a central control unit capable of managing variable and bidirectional energy flows from renewable resources (e.g. solar and wind), a battery storage system and one or more backup diesel generators. Being a turn-key system, this smart mini-grid is designed to best suit the needs of the client community and taking into account the eventual possibility of support by the national network; Smart Rural System can in fact work both in isolated mode and connected to the grid, thus providing an optimised and robust “plug and play” solution [82].

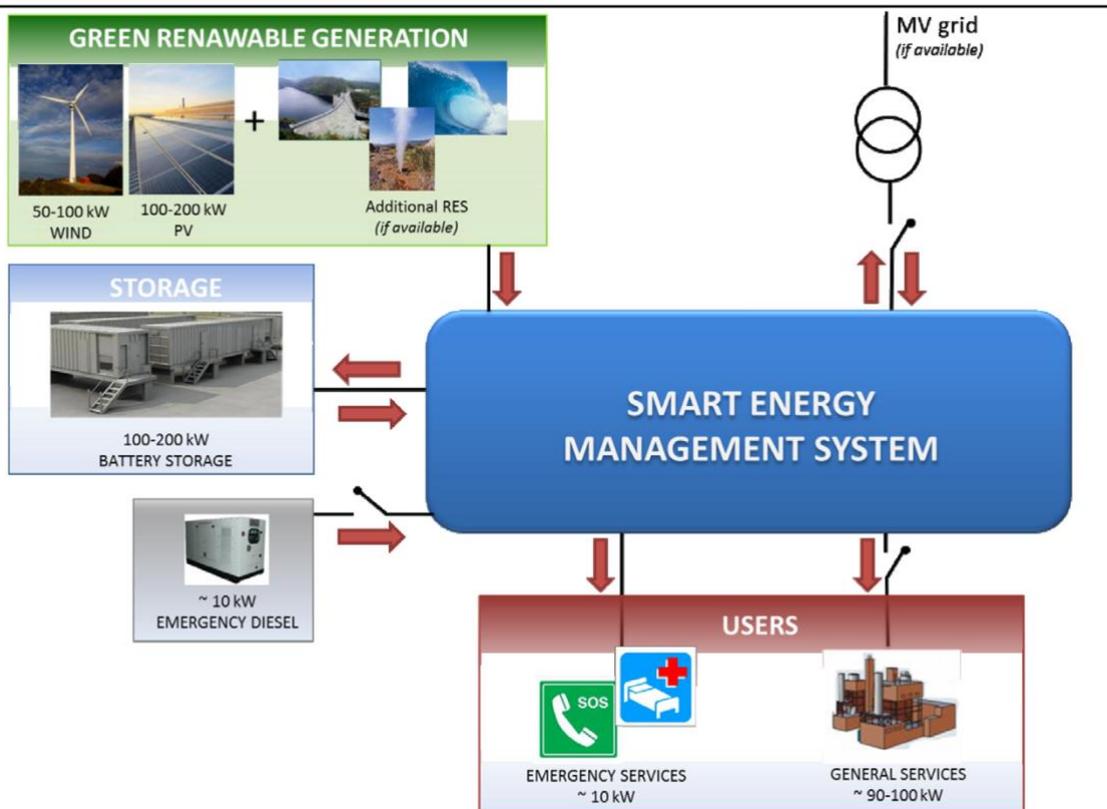


Figure 6 - Simplified layout of the Smart Rural System proposed by SAET [82].

Recently SAET partnered with Remote Group, an engineering, construction and project management firm working on the design and building of the new campus of Rwanda Institute for Conservation Agriculture (RICA) in Bugesera (Rwanda). RICA is a local institution that aims at training students on modern agricultural technologies, and SAET has been commissioned to design and install a smart mini-grid for the power supply of the isolated campus, which is currently off-grid. The most suitable energy solution identified by the Italian company consists in a hybrid system powered by a 1.8-MW PV solar field and four auxiliary diesel generators, each with an output of 400 kW, for a total installed power of 3.4 MW; the power production is then supported by a 3-MWh battery bank. The design is based on a degree of redundancy thanks to the use of two semi-busbars ensuring failure resilience, and the PV panels, the generators and the batteries are connected to the LV switchgear so as to allow an eventual system extension in response to a future load increase. The mini-grid also offers the possibility of working in two distinct modalities, islanding mode and grid mode (the grid is expected to arrive), ensuring a seamless transition between the two and a fast-dynamic response [83], [84].

SAET is also active in the proposition of “energy kiosks”, which represent a pre-electrification solution, as they consist in centres for electricity production and supply of energy services (e.g. printing service, device charging, internet connection, refrigeration systems) to people living in rural or peri-urban areas. Energy kiosks are generally powered by hybrid PV-diesel individual systems and supported by batteries, just as in the case of the smart mini-grid in Rwanda, with respect to which the installed power is significantly reduced (in the order of 20-40 kW), so as to offer the proposed energy services to a few hundred people [84].

3.2.2 Heliopolis S.p.A.

Heliopolis S.p.A. [85] was born in 2008 with the aim of developing business opportunities in the field of renewable sources and energy efficiency, planning projects in a sustainable and shared key according to the economic and social development needs of the territory. In particular, the company focuses on the design of energy infrastructures that redevelop the target areas, transforming them into places of aggregation and growth. In 2014, Heliopolis expanded its activity in Sub-Saharan Africa by acquiring the majority of the shares of a small company incorporated in Mozambique, Moçitaly Lda, which had been operating in the energy sector since 2000 through the turnkey supply of individual solar systems and mini-grids in rural areas of the country on behalf of governmental agencies, religious bodies and some private actors. Since then, Heliopolis has provided its technical and financial support to enable its Mozambican subsidiary to carry out larger photovoltaic mini-grid projects; Moçitaly, for its part, ensures representation, know-how and labour within the local context.

The main client in Mozambique is FUNAE, the aforementioned governmental agency with the mandate to promote rural electrification from renewable sources; in particular, FUNAE periodically organises public calls for tenders open to the private sector for the design/procurement/installation of mini-grids of various sizes: until 2019, Heliopolis has installed 11 solar mini-grids in Mozambique, with a total output of 590 kW.

The company is also taking part in the tenders launched as part of the BRILHO initiative, a five-year programme financed by the United Kingdom's Department for International Development (DFID) and implemented by SNV (a non-profit international development organisation) to promote and support the supply of off-grid energy solutions in Mozambique. The first phase of this project involves the design and construction of turn-key mini-grids, while, in a second phase, a private entity is selected for the management of the systems that will be realised, according to terms and modalities that are still under study. The intention is to remedy the public's shortcoming in the ordinary and extraordinary management of the power plants, considering that in Mozambique, at present, only the state is authorised to sell energy to private individuals [86].

Finally, Heliopolis is evaluating some possible acquisitions of small and medium sized EPC (Engineering, Procurement and Construction) companies, with 100% local capital, operating in Kenya and Uganda, in order to replicate the business model tested in Mozambique, but ensuring the opening to more structured markets.

3.3 Non-Italian companies founded by Italians

As already mentioned, the author decided to include within this analysis also those companies that, from a legal point of view are not to be considered as Italian, since they are headquartered in another country, but were founded and are still run by Italian actors. In particular, the identified social enterprises are Devergy, founded in Tanzania by Fabio De Pascale and Gianluca Cescon, and Equatorial Power, founded in Uganda by Riccardo Ridolfi e Dario Fallara. In the following sub-sections dedicated to them, it is interesting to note how these two companies adopt methods of intervention that, in many ways, differ from each other: Devergy has based its success (recognised by USAID [87]) on the high efficiency of its scalable and adaptive solar mini-grids; the young Equatorial Power, on the other hand, tends to adopt a more holistic approach, relying on the productive uses of electricity.

3.3.1 Devergy

In 2010, Fabio De Pascale, project manager with a background in the European Space Agency, and Gianluca Cescon, an energy engineer who had worked on technical projects in the Netherlands, founded Devergy [88], an energy services company providing smart solar mini-grid electricity to low-income communities living in rural areas off the grid. Their business idea was born during a trip around South America, but Tanzania was chosen as the headquarter for the new company, which began operations in 2012; up to now Devergy has limited itself to working in Tanzania, but the goal is to soon extend the business to other countries on the African continent.

Devergy, installs small-size solar mini-grids (output between 5 and 10 kW per site), in order to serve small rural communities (no more than 400 households) that are isolated from the national grid and do not have the money necessary to purchase an individual solar home system.

The base concepts underlying the business model of this social enterprise are technological innovation, system efficiency and smart data monitoring. Solar energy is collected thanks to panels on top of solar towers, it is stored in batteries within the towers and then distributed along the target area through a short-distance DC grid (maximum 1 km length), which minimizes distribution losses. The overall service efficiency is also ensured by the dynamism with which energy production is managed, exploiting the scalability and modularity of PV units: the plant capacity is gradually upgraded following the demand of the supplied community with a short-time horizon, remedying the under/oversizing issue and continuously and optimising the generation-consumption matching, without excessive curtailments and wastes. The business model also includes Devergy's sale of modern and compatible DC electrical devices, which, in addition to ensuring a technologically efficient demand, offers auxiliary revenues contributing to the economic sustainability of the projects [5].

The entire process of production, distribution and consumption is managed through an advance energy monitoring and control system based on smart meters and GPRS gateways, coming from the partnership between Devergy and Digi International Inc., a pioneer in wireless communication [89]. This smart system is then coupled with a pre-paid pay-per-use strategy, according to which, using a mobile commerce platform such as Tigo Tanzania Pesa or Vodacom M-Pesa, users can top up their credit and choose the most suitable tariff plan among those offered, which allows for a defined amount of energy within a given time and additional consumption-based kWh; thanks to a remote customer care service, Devergy supports the consumers in selecting the offer that best suits their energy requirements [5], [89]. The company, moreover, covers almost entirely the installation costs (a fee ranging from \$6 to \$12 is charged, compared to the \$250 required for a TANESCO connection), which are then gradually recovered through energy tariffs. Lastly, O&M activities are managed by locally employed technicians, remotely supported by technical experts [87].

Given the small size of the solar plants typically implemented by Devergy, such mini-grids are not compatible with the productive uses of energy, but they aim to meet the primary domestic electrical needs, such as lighting, mobile-phone charging and the use of TV and radio. Despite the lack of the significant revenues that could come from the PUE, Devergy is cited by USAID among companies with a successful equity-funded business model, which demonstrates how financial and technological innovations could make mini-grids profitable. The initial investment capital needed by Devergy to start and expand its business has been provided by different international organisations, such as USAID, Persistent Energy Capital, DOEN Foundation and Energy Environment Partnership (EEP) Africa. The company also uses other forms of financing, such as the per-connection subsidies it receives from Tanzania's Rural Energy Agency (REA), which, in response to Devergy's success, expanded its incentive programme to include mini-grid projects (previously, only solar home systems were eligible) [87].

3.3.2 Equatorial Power

Equatorial Power (EP) [90] is a young energy start-up based in Kampala (Uganda) and founded in 2018 by the Italians Riccardo Ridolfi and Dario Fallara: the first is an energy developer and entrepreneur with a long experience in the East Africa market and a background in structured finance and investment protection; the second is specialised in the off-grid sector with a background in international relations, economy security and intelligence. Pursuing the goal of universal access to productive electricity and clean water, EP is engaged in holistic programmes for the electrification of SSA rural areas, implementing renewable off-grid and grid-connected solutions. Less than two years after its birth, EP is working on projects in Uganda, Rwanda, Tanzania and DRC, with a team of highly skilled people, half of which are local.

The holistic approach adopted by the company translates into integrated actions that involve the installations of green mini-grids, combined with the establishment of productive activities to meet urgent gaps in the agro-processing and food value-chains of target rural communities: an exemplifying intervention is the realisation of an ice production, which allows the fishermen of Lake Victoria to conserve and transport fish without having to buy expensive imported ice. This business model, with EP managing the implemented services, aims to stimulate local socio-economic development and to create productive uses of electricity that significantly contribute to the complex financial sustainability of the mini-grid. The identification of the most important local needs and the implementation of business activities aimed at alleviating them, are carried out together with EnerGrow (EG), a company based in Kampala and also co-founded by Ridolfi, focused on financing productive energy-consuming assets to foster economic development. The two companies are then planning community engagement activities, capacity building courses and programmes to promote the growth of local energy consumption, through initiatives for appliances financing and partnerships [91], [92].

In December 2019, the first hybrid mini-grid owned and managed by EP was commissioned in the rural village of Bugarula, on Idjwi Island, in the province of South Kivu (DRC): it is powered by a 20-kW solar field, coupled with a 37-kW backup diesel generator and it currently counts 300 connections, supplying them reliable electricity 24/7. As early as 2019, two other projects were due to start in Rwanda, but their launch was delayed because of sudden and unexpected changes in the local regulatory framework. Furthermore, the company, in partnership with ENGIE, is working on the electrification of Lolwe Island, located in the Ugandan portion of Lake Victoria, through the installation of a solar-diesel mini-grid and the realisation of a small industrial complex consisting of machines for water purification, ice manufacturing and basic fish processing. Still in Uganda, EP is negotiating with UMEME Ltd, the national grid operator, the design of two small hydropower plants in Rubanda and Ntungamo districts respectively, which would also provide for power purchase agreements to sell electricity to UMEME, in order to promote grid stabilisation during peak periods [90]. Thanks to the extensive working experience of Ridolfi in Uganda and his presence in the Board of UMEME, EP is committed to demonstrate that, through a holistic and cross-sectorial

approach, it is possible to foster the energy demand of remote rural areas for a potential future grid expansion [91], [92].

In addition to ENGIE, Equatorial Power is partnering with other international giants, such as Google and Shell Foundation, and the company has received funding from governments donors, including the United States, Germany and UK. When, during an interview that Ridolfi gave for the Italian newspaper La Stampa, he was asked if EP had also received donations from Italian actors, the CEO replied that, apart from the contribution of the Italian embassy in Kampala, no one showed up: “When I think of the money given to us by the British and French, I have little to rejoice in, being EP an Italian majority excellence. But there is always time: mini-grids are the last frontier of energy infrastructure, so that, in Africa alone, there is a need for investment of over 100 billion dollars in the next ten years” [91].

3.4 ENGIE Eps, a hybrid example

ENGIE Eps [93] has been operating in the sustainable energy sector since 2005, when it was founded, under the name Electro Power Systems, as a spin-off of Politecnico di Torino, specializing in efficient energy storage systems and mini-grids converting renewable sources into reliable and affordable electricity. Close to bankruptcy in 2013, a year later the company underwent a complex financial restructuring; in 2015, after being listed on the stock exchange, EPS acquired Elvi Energy (the energy and system integration division of Elvi Elettronica Vitali) and Mcm Energy Lab (a leading R&D laboratory owned by Politecnico di Milano), thus becoming an integrated energy storage group. Finally, in 2018, ENGIE, a global energy leader present in more than 70 countries, took over a majority stake of the group; today ENGIE controls 60.5% of ENGIE Eps, which, however, has maintained all R&D functions and production activities in Italy. The quality of ENGIE Eps products, fully developed on the HyESS platform (a revolutionary technology that allows integrating any renewable source with all energy storage formulas), led the company to be the world’s number one for implemented mini-grid projects implemented, with an installed capacity of 111 MW in a total of 23 countries [94].

The first mini-grid installed on the African continent by the then EPS Group dates back to 2016, when the company commissioned a new hybrid power plant in Garowe, in the Puntland State of Somalia (which has no national grid). The project, awarded one year earlier to Elvi Energy by NECSOM (National Electric Corporation of Somalia) for a total investment of around EUR 3 million, included the design, supply and installation of a turn-key hybrid solar-diesel energy production and storage plant to provide reliable electricity to about 100,000 people. Initially, the mini-grid was powered by a 1-MW photovoltaic field, 3.2 MW of conventional diesel generators and supported by a mixed lead-acid/lithium-ion storage system of about 1.4 MWh. Since, thanks to the new energy system, the inhabitants of Garowe were able to pay a 17% cheaper bill and benefit from a more reliable energy supply, there was soon an increase in electricity consumption and a growth of daily peak power of about 1.7 MW. These

results drove EPS to close a deal with NECSOM for the extension of the plant, by integrating 750 kW generated by wind turbines and upgrading the storage system by additional 400 kWh. The final configuration of the plant (1 MW of PV, 750 kW of wind, 3.2 MW of diesel and 1.8 MWh of storage) guarantees a saving of more than 1 million litres per year of diesel and 600 tonnes of CO₂ avoided, ensuring quality power supply 24/7 to 12,000 connected users [95], [96].

Over the years EPS has particularly focused on the electrification of islands around the world, through the proposition of islanded hybrid mini-grids, with the aim of reducing the high electricity costs and the negative environmental impacts due to the old and expensive diesel generators that typically power islands. The group recently started working on the implementation of two mini-grids respectively in Anjouan and Mohéli, the two smaller islands in the Union of the Comoros, located in the Indian Ocean, between Mozambique and Madagascar. The two hybrid solar-diesel generation systems will provide an overall installed power of 22 MW and, thanks also to the coupling with a series of battery storage systems distributed on the territory, they will supply affordable and reliable electricity to the approximately 400,000 inhabitants of the two islands. Unlike the case in Somalia, where EPS worked on the design and the installation of the system, which was then supplied as turn-key project to NECSOM, in the Comoros the company signed with the local government a power purchase agreement (PPA), providing that EPS will be in charge of the of the management of the plants and the electricity sale service [94], [96].

For the electrification of the target areas, from a technical point of view, ENGIE Eps generally opts for the typical solar-diesel-storage coupling, which, in some cases, as in Garowe, is integrated with the wind component: the optimal design of the diverse parts of the plant is done on the HyESS platform, while the dispatchment of the different energy flows is managed and optimised by an implemented smart energy management system [94]. It is also worth pointing out that, during the installation phase, EPS is generally committed to promoting local entrepreneurship, whose development represents an important benefit for the sustainability of the project, and to creating local participation, through sensitization and capacity building campaigns typically organised by interfacing with agencies specialised in social and environmental impacts of energy programmes.

3.5 Enel Green Power and its approach to rural electrification

Enel Green Power (EGP) S.p.a. [97] is the Enel Group company responsible for the development and the management of energy generation activities from renewable sources. EGP is present in 30 countries around the world, and, with more than 1,200 plants and a managed installed capacity of about 49 GW, it is today the leader among private operators in the global renewable energy sector; moreover, almost 48% of the more than 100 TWh produced in 2018 is zero greenhouse gas emissions [98]. The general mission of the company is, indeed, to put innovation at the service of sustainability and, to make a concrete and measurable contribution,

EGP has integrated the 17 UN Sustainable Development Goals (SDGs) into its industrial strategy [99].

EGP's core business is represented by the sale of renewable energy generated by its plants to commercial and industrial customers, with whom the company typically signs suitable and adaptable power purchase agreements (PPAs): long-term energy supply partnerships (from ten to thirty years), tailored to each customer and designed to respond actively to the normal changes occurring over the life of a firm. EGP's PPAs can, in fact, provide for the design and construction of a new renewable power plant directly on the land owned by the customer (On-site PPA), the purchase of renewable energy from an EGP plant even physically far away (Sleeved PPA), or the energy exchange through a predetermined point, usually a market hub (Virtual PPA) [100].

As far as the African continent is concerned, the commitment of EGP has mainly resulted in the construction and management of 16 renewable energy plants implemented in Morocco, Zambia and South Africa, for a total installed capacity of almost 1,500 MW, generated through wind farms (1,131.5 MW) and solar fields (357.4 MW) [97]. Unfortunately, none of these African plants may fall into the category of mini-grids described above, since they are all large-scale production centres (with an average power of about 90 MW per site), built to directly supply the national electric grid or to serve a specific industrial customer; therefore, there are no small distribution grids aimed at promoting the local socio-economic development of remote rural communities.

Nevertheless, in the past, the company tried to engage in some mini-grid projects, which though failed without effective results. In 2016, EGP began a collaboration with the US company Powerhive (PH), which planned to invest around USD 12 million (93% borne by EGP and 7% borne by Powerhive) in the electrification of a hundred isolated rural villages in Kenya, through the installation of mini-grids powered by local renewable sources [101]. However, the joint development contract between the two companies was not renewed due to a number of reasons, as very long delays in receiving the needed permits, difficulties linked to an unexpected change in Kenyan regulation, which jeopardised the definition of facilities ownership, and, finally, because the relations between EGP and PH have gradually deteriorated. As a result, the partnership collapsed without bearing fruit. In the same year, Enel collaborated with the Italian NGO Medici per l'Africa Cuamm on the electrification of St. Luke Catholic Hospital in Ethiopia and the Chiulo Hospital in Angola [102]; these projects, however, did not provide for the implementation of real mini-grids by EGP, but rather for Customer Relationship Management operations and donations for the supply of technical equipment that could integrate the pre-existing electrical systems of the two hospitals.

From what emerged from the email exchange that the author had with E. P., Head of Global Customers Operations in Enel X and previously Head of Coordination of Mini-grid Origination in Enel Green Power, for over a year EGP has no longer been involved in rural electrification projects in Africa and, above all, the company has never carried out real mini-grids installations, limiting itself only to donations and Corporate Social Responsibility activities. Finally, it is important to point out that the Enel Group, through Enel Foundation, supports the Micro Grid

Academy (MGA) [103], a vocational capacity building initiative based in Nairobi (Kenya) and promoted by RES4Africa Foundation in collaboration with local companies, universities and NGOs, with the aim of training conscious workforce in East Africa, giving them managerial, technical and practical skills to build and operate mini-grids that guarantee rural communities reliable and affordable access to renewable energy. The MGA courses, which throughout the first year (2018) trained 150 young people coming from different East Africa countries, represent a concrete response to many of the UN SDGs, as access to energy is a key factor in solving many socio-economic issues affecting Sub-Saharan Africa [104].

3.6 Energy4Growing by Politecnico di Milano

If the research process of mini-grids implemented by private Italian actors has led to the identification of a limited number of installed projects, the results are further reduced as far as the academic environment is concerned. In fact, the only mini-grid designed and built by an Italian academic institution is the one realised within Energy4Growing (E4G) [105], the initiative of a research group of the Energy Department of Politecnico di Milano, engaged since 2013 in the study of modern on-grid and off-grid solutions for the rural electrification of developing countries. E4G was selected in the first edition of Polisocial Award, a competition launched by Polimi in the academic year 2012-2013 with the aim of selecting and implementing projects related to the university, promoting the development and the enhancement of scientific research initiatives with high social impact at local, national and global level; the 23 projects selected among the 152 submitted in the first three editions of the Award were overall financed with funds amounting to €2,350,666, against which €1,553,000 were granted by Politecnico di Milano [106].

The E4G team intervened in Ngarenanyuki, in the district of Arusha (Tanzania), with the aim of designing and implementing a hybrid mini-grid capable of covering the energy needs of the local secondary school, combining renewable and conventional sources with a battery storage system ensuring the balance between power production and consumption. In particular, the implementers defined an electric grid architecture efficiently regulated and controlled through the implementation of an energy hub, an electrical panel coordinating the diverse generation sources in relation to the demand of the different loads, in order to maximise the overall system efficiency [106].

In 2013, when the project started, the main power supply of the school (which can accommodate about 200 children and has a capacity of around 400 students for daytime classes) was represented by a micro hydropower system (3.2 kW) installed few years before and equipped with a Banki turbine with integrated dampers for regulation and energy balance; the energy provision was then supplemented by few PV panels (940 W) for the classrooms and the residential and a 5-kW diesel generator, used when hydropower was unavailable. The E4G intervention included, first of all, the strengthening of the production system, through the installation of additional solar panels with an output of 3 kW, and the implementation of a lead

battery bank (12 V, 100 Ah) with a bi-directional inverter unit responsible for storing excess power in the batteries and supplying it when necessary. However, the core of the action is the implemented energy hub, a prototype designed to “intelligently” manage and integrate the energy flows between the renewable sources, the back-up diesel generator and the storage system, in order to ensure an efficient balance between the production and the consumption sides. This way, the pre-existing fragmented energy architecture has been converted into a scalable and flexible hybrid hydro-solar-diesel mini-grid, capable of satisfying the school energy needs, providing reliable and clean electricity[105], [107].

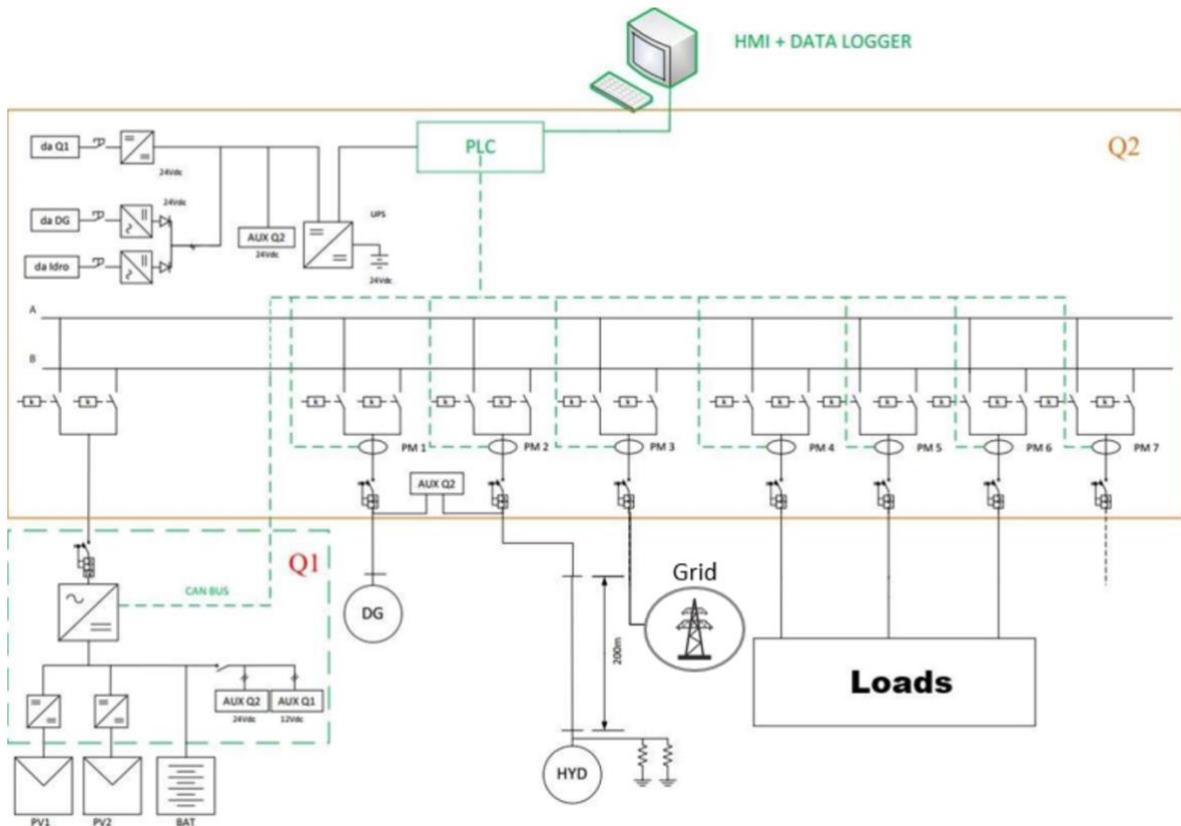


Figure 7 - Electrical layout of the hybrid mini-grid implemented in Ngarenanyuki school [107].

The overall action took place throughout different phases, starting with a first on-site data collection campaign in May 2014, during which an advanced measurement system was installed; these data were then used to optimise the redesign of the energy hub and to verify, by means of appropriate numerical simulations, the energy management logistics developed by the work team. After a second measurement campaign, the system was built and tested in the laboratory and finally installed on site, where it was activated in spring 2015. Nevertheless, the installation of the equipment did not represent the conclusion of the project, as it has been followed by an intense and continuous monitoring phase through a satellite system activated ad hoc, which ensures the interaction between the mini-grid and the laboratories of Politecnico, in order to correct control logistics, solve operational issues and establish a strong cooperation relationship. It should also be noted that, in December 2015, TANESCO extended the national grid to the

project area, providing a connection to Ngarenanyuki school; the team, therefore, intervened to adapt the working logic of the energy hub, so as to maximise the exploitation of local renewable sources and minimise the purchase of energy from TANESCO, which guarantees the school to operate in stand-alone mode. It is then important to highlight that, in addition to the technical activities, the programme has been involved, from the outset, in involving the local community in the decision-making process, in order to create a sense of ownership of the plant. Moreover, capacity courses have been organised to train the local users responsible for the management, the control and the maintenance of the system [106].

Within the Energy4Growing initiative, Politecnico di Milano, with Professor Marco Merlo as reference person, acted as coordinator of the project, providing the scientific expertise and structuring the collaborative network that involved several partners, ranging from private enterprises (ELVI S.p.a., EnergyTeam s.r.l., Contact Phoenix S.p.a., Sironi Batterie s.r.l., IREM s.r.l.), to non-profit organizations (Istituto OIKOS Onlus) and other local and international academic institutions (Dar Es Salaam Institute of Technology, Arusha Technical College, Nelson Mandela African Institution of Science and Technology, Norwegian University of Science and Technology, University of Applied Sciences and Arts of Southern Switzerland) [106], [107].

All data, information and updates on the progress of the project are openly and freely available on the Energy4Growing website and on the Facebook page dedicated to the initiative.

4 Comprehensive Energy Solutions Planning (CESP)

As it shines through from the previous chapters, the provision of electricity to developing realities must be thought of as a means, not as an end, since modern energy represents one of the fundamental drivers to the socio-economic development of local communities. If in developed countries the presence of a reliable electric service is taken for granted, on the contrary, for people living in remote rural areas of developing countries, the access to basic home appliances and electric productive devices gains more importance, as it boosts an intricate improvement process which concerns the different spheres of human life: health, education, comfort, entertainment and economic productivity. As professor Ignacio J. Pérez-Arriaga highlights, “electricity is an indispensable component of everybody’s life” [70].

The conception of energy as enabling factor for an inclusive and sustainable development should be the objective around which every rural electrification programme rotates. Scrolling the pages before, it can be seen that this key idea is ingrained enough in the action of non-profit actors, which, moved by a social intent and supported by adequate techno-economic expertise, have undertaken to contribute to the resolution of the energy problem in rural areas around the world. On the other hand, private implementers, led by the profit motive, often loose this holistic and multi-dimensional approach, which requires significant resources, not only from the economic point of view.

It is then worth emphasizing how the adoption of a comprehensive method since the original design phase of a rural mini-grid project is crucial in contributing to the achievement of the specific energy objective. In fact, the implementation of a decentralised system for electricity provision and commercialization still shows important vulnerabilities, especially in relation to its complex cost recovery. The establishment of a holistic programme, composed by complementary activities touching interconnected dimensions of a target community, significantly help in mitigating the risk of failure, thanks to the realisation of an autonomous sustainable system.

This chapter aims at presenting the Comprehensive Energy Solutions Planning (CESP) framework, elaborated by the Sustainable Energy Systems Analysis and Modelling (SESAM) research group from Politecnico di Milano. The proposed framework defines the guidelines of the planning phases that energy access interventions should follow, in order to efficiently ensure long-term and sustainable impacts. In particular, through a meticulous analysis of the different design steps, the framework aspires to go beyond the techno-economic approach traditionally used in developing countries, with the intention of including the socio-cultural and political features that so intensively affect African rural realities, and resulting in the proposition of a comprehensive and integrated design study.

The importance of such a holistic approach is already clear to part of the sector literature, which, in recent years, has proposed few frameworks such as the ones contained in “EnergyPlus Guidelines: Planning for Improved Energy and Productive Uses of Energy” by the United Nations Development Programme [108], or in “Energy Access and Electricity planning” from ESMAP environment [109]. Taking concepts and inspiration from works like those just mentioned, CESP framework outlines a simple and linear work path made of six consequential steps, covering and analysing in detail all the different phases which should constitute an appropriate energy action planning.

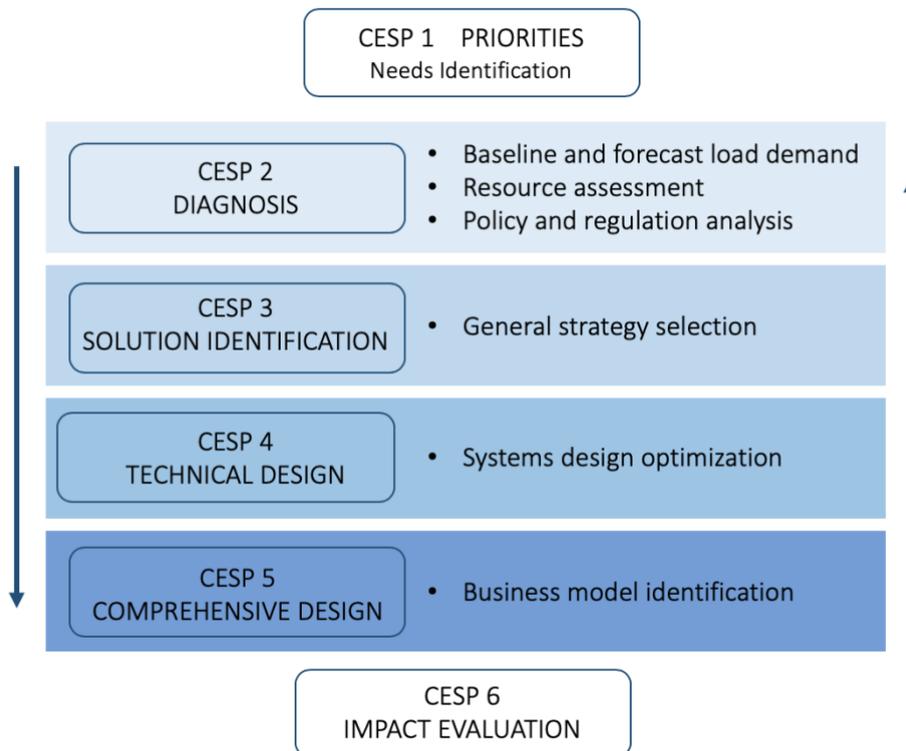


Figure 8 - Essential diagram of Comprehensive Energy Solutions Planning (CESP).

As it is possible to see from diagram in Figure 8, the design framework suggested is composed by the following steps:

- Priorities (CESP 1): the whole project planning must start from the identification of the most urgent local needs that target beneficiaries express and that are not in the form of technical availability of energy;
- Diagnosis (CESP 2): in the second phase, firstly, the assessed needs are translated into the load demand that the upcoming electric system will have to satisfy; this activity is then accompanied by a careful analysis of locally available energy resources and of the policy and regulatory framework which could affect the success of the project;
- Solution Identification (CESP3): from the data collected in the previous phases, the implementers have to outline a general strategy, identifying the areas of intervention and the potential stakeholders;

- Technical Design (CESP 4): through the utilization of engineering models, the different components of the electric system are designed and optimised, in order to get a reliable and cost-effective solution;
- Comprehensive design (CESP 5): here a complete management and business model is defined, with the outline of the complementary activities that need to be implemented to support the sustainability of the project;
- Impact Evaluation (CESP 6): lastly, it is fundamental to assess the long-term impact that the overall programme is expected to have on the beneficiaries and the surrounding environment.

As the side arrows in the diagram suggest, the phases from the second to the fifth need to be retraced through an iterative process, in order to ensure the achievement of an optimal result. Through this repeated and accurate step-by-step design strategy, it is finally possible to set an integrated energy solution tailored to the local community urgencies, with the aim of supplying affordable and reliable electricity and boosting a stable process of socio-economic development, through the sustainable exploitation of local resources.

The objective of this work consists in the proposition of a CESP framework focused on the planning of mini-grid projects, with the support of engineering modelling tools from Polimi environment and the addition of practical hints derived from successful case studies. The hope is to provide a framework which might be useful to all the actors engaged in the complex task of electrifying the remote rural areas of Sub-Saharan Africa, with particular intent to spur the commitment of Italian private enterprises.

The work takes its cue from the “Engineering and Cooperation for Development” classes taught by Professor Emanuela Colombo (Politecnico di Milano) [110] and the doctoral thesis of Jacopo Barbieri, from the Department of Architecture, Built Environment and Construction Engineering of Polimi [111].

4.1 CESP 1: Priorities

The starting concept from which this whole framework takes its origin, consists in the idea that an appropriate and successful rural electrification programme must be consumer-driven. It means that, once selected the target area, in the very first phase of the project design, implementers have to conduct a meticulous analysis for the identification of the most important necessities manifested by the local community and the potential beneficiaries. In this context, confining the research to the purely energy needs would be a serious mistake, as it is essential to extend the gaze also to those economic opportunities and socio-cultural weaknesses that could be boosted or improved by the implementation of a reliable energy system. This fundamental care is strictly connected to the aforementioned concept that energy provision must not be seen as the final objective of the intervention, but it should be the thought as the enabling factor triggering a wider and sustainable development process.

In order to obtain a comprehensive result, the needs assessment must be conducted on different levels, so as to cover the diverse dimensions of the target society. In particular, it is fundamental to evaluate the necessities:

- at household level, in terms of lighting, cooking, domestic appliances and in relation to entertainment, information and communication (e.g. radio, TV and mobile phones charging);
- at community level, with infrastructural aspects as water pumping and street lighting, but also including the improvement of crucial services such as health (clinics and hospitals) and education (schools and after-dark study); it is then important to consider the potential positive implications on environmental preservation and social issues as gender equality, women empowerment and digital divide;
- at productive level, where the main role is realistically covered by agriculture, especially in terms of techniques and technologies modernisation, to overcome the limiting subsistence activity; also rural industry and artisanal and commercial activities, with the use of ICT and mechanical appliances, would significantly benefit from the arrival of electricity.

Indeed, in order to be effective and realistic, the phase of needs identification has to be carried out on the field, by using means as surveys, consultations and interviews directly addressed to the potential beneficiaries of the intervention. Cooperating with local authorities and key personalities is essential to facilitate the data collection and encourage the engagement of the community; the organization of awareness programmes and information meetings have a strong importance in this sense, and they help in laying the groundwork for the establishment of a robust relationship between implementers and local people, which represents a necessary prerequisite for the success of the overall action.

The needs assessment phase could also be exploited as opportunity to start exploring the possible productive use of energy (PUE) and the potentiality of the abovementioned Water-Energy-Food (WEF) Nexus application. These activities, more detailed in the following sections, represent effective factors in order to reinforce the sustainability of the energy programme and achieve its desired integrated result.

It is worth highlighting that, tendentially, NGOs pay more attention to the conduction of efficient consumer-driven interventions. This is obviously due to the social mission that naturally underlies their action; furthermore, many times, the effectiveness of their activities for needs identification is favoured by the extensive experience gained in the territory, which ensures the existence of an already solid relationship with the local community. Suffice it to look at the projects implemented by the Italian organisations, previously treated.

For example, CEFA has been engaged in Tanzania since 1976 and they initially decided to intervene to alleviate the livelihood and food security issues afflicting the District of Njombe; once contextualized these urgent local needs, CEFA realised the necessity of a reliable electricity service as enabler for their mitigation. SOFIA Global similarly acted in DRC, where Father Jaak Henkens, active in the area for many years, has represented a fundamental bridge with the people of Kapanga for the comprehension of their real necessities.

4.2 CESP 2: Diagnosis

In the second phase of CESP framework, the essentially engineering side of the analysis starts to emerge. Indeed, the Diagnosis is closely consequential to the Priorities section, since, here, the information previously collected are used and modelled in order to define the inputs necessary for the following techno-economic design, core of the study. This data modelling is then accompanied by a focus on the local policy and regulations that concern the intervention areas and might affect the action. The Diagnosis phase can thus be divided into three sub-sections summarised as follows:

- the definition of the local baseline load demand (starting from the previous needs evaluation) and of a realistic prediction of its evolution after the advent of modern energy;
- the assessment of the amounts and types of energy resources used in the target area, of those available on the market and of local renewables potentialities;
- the analysis of regional and national policy and regulatory frameworks, with particular attention energy barriers and opportunities.

4.2.1 Baseline and Forecast Load Demand

With regard to the complex task of designing a system aiming at electrifying a target rural area, one of the most important but, at the same time, challenging steps is represented by the definition of a realistic long-term load demand and its evolution throughout the years.

The essentiality of a proper load prevision is clearly connected to the techno-economic success of the project: indeed, wrong calculations, assumptions or projections in this sense, may lead to the choice of inappropriate solutions, inadequate sizing of the system components, shortages and failure of cost recovery (already very complex for off-grid projects). All these eventualities could thus result in the concretization of negative impacts on the local community [112]. On the contrary, a reliable engineering prediction significantly helps in the design of a quality system and in the achievement of the overall programme sustainability [113].

As aforementioned, the assessment of rural energy and power consumption is as important as intricate, and its criticality is related to many factors, which do not only concern purely technical aspects. The first difficulties derive from the complexity and reliability of the time-extended needs identification phase and the translation of those necessities into energy demand. It is then even more challenging to predict evolution scenarios that realistically simulate how the electric consumption of beneficiaries will change with the implementation of the new energy service, especially because it is fundamental to take into account the strong influence that the triggered socio-economic dynamics have on electricity utilization [113]. These complexities generate a parametric uncertainty, which could lead to inaccurate calculations and a non-optimised technical design [114].

The aim of this section consists in the proposition of a practical scheme of the useful passages for the generation of reliable load profiles describing the power consumption of users in remote rural areas. Three main steps have been identified:

- the translation of assessed needs into electric loads and their integration with data collected in electrified similar villages;
- the conceptualisation of users' habits evolution with the use of System Dynamics models;
- the generation of accurate load profiles thanks to the use of modelling tools.

Data Integration – As stated in the introduction to the chapter, the analysis of this work is focused on mini-grid projects, intended to provide electricity to remote rural areas of Sub-Saharan Africa. This contextualization needs to be mentioned in this passage, since it highlights the fact that most of this kind of interventions are carried out in rural realities that are totally un-electrified, aspect that further increases the parametric uncertainty and complicates the collection of reliable data. In these cases, the identified most effective bottom-up strategy begins with the integration of assessed needs information with the analysis of nearby villages that show characteristics similar to the target area and that have been recently electrified. This starting step allows to get quantitative data about used electric appliances and modified habits that realistically resemble the evolution expected in the considered communities [115].

System Dynamics – In order to conduct a more comprehensive study of the potential future scenarios, the obtained material is then developed through the conceptualisation of the multi-dimension dynamics that are predicted to be triggered by the electricity provision and of their feedbacks on the electric consumption itself. This formulation can be done resorting to the use of a System Dynamics (SD) modelling framework, which helps to outline the non-linear cause-effect interrelations between the electricity demand and the main economic and social variables affected by the energy programme [116].

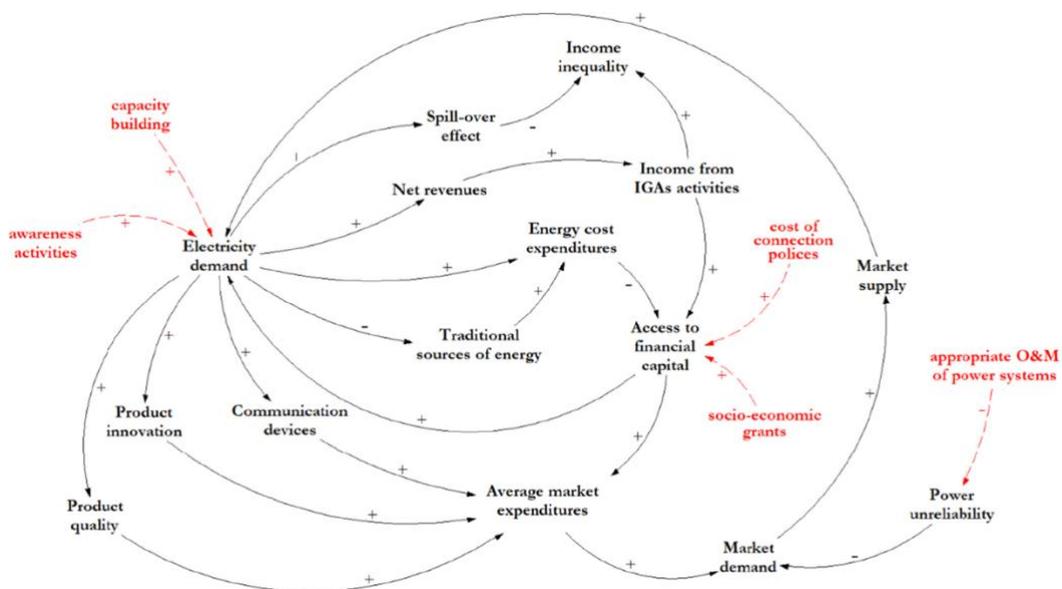


Figure 9 - Example of a causal-loop diagram representing the interrelations between electricity demand and household economy [113].

In particular, Riva et al. [113] proposed a study of the electricity-development nexus, which analyses the causalities between electricity demand and six other dimensions, three of which are economic (income generating activities, market production and household economy), while the

other three are social (health, education and people habits). The interrelations between electricity demand and each of these different dimensions can be represented through the utilization of causal-loop diagrams, in which other intermediate linked variables appear. Each link has a polarity, which can be positive (“+”), meaning that an increase of the independent variable (at the tail of the arrow) leads to an increase of the dependent variable (at the head of the tail), or negative (“-“), with the opposite effect. Moreover, every loop in the diagram can be identified as reinforcing (“R”) or balancing (“B”). Eventually, it is possible to introduce exogenous factors, usually indicated in red.

These diagrams, which can be realised thanks to software as Vensim, simplify the comprehension of electricity-development nexus, which then can be more deepened through the use of additional computer aided modelling methods [113], [116].

Load Modelling Tools – The final step for the definition of the load demand needs to be operated through bottom-up stochastic modelling approaches. These are based on microscopic data as the ones gathered and developed through the previous passages and, thanks to their stochastic nature, they are capable of managing parametric uncertainty, generating different load profiles out from the same given inputs [117]. This mathematical procedure is followed by different engineering software structured over a specific algorithm.

The first modelling tool proposed here is LoadProGen (“Load Profile Generator”), based on MATLAB and elaborated by Mandelli et al. [117] for the formulation of daily load profiles for off-grid consumers in rural areas of developing countries. It requires, as inputs, the users’ classes, the number of users and appliances for each user class and the functioning time and windows of each appliance; the last two parameters, in particular, help to model the habits of the different users. Furthermore, the uncertainty intrinsic to the utilization of the different appliances is considered, with the possibility of introducing functioning random parameters for each of them. After the elaboration of the inputs, according to an iterative process, the software firstly computes the peak power and the load profile of each user, then it aggregates the different obtained daily profiles, in order to get the final one.

The SESAM Group from Polimi have recently proposed an enhancement of the bottom-up stochastic tool, which aims at generating high-resolution multi-energy load profiles for the analysis of energy systems implemented in remote areas: its name is RAMP, which stands for “Remote-Areas Multi-energy systems load Profiles” [118]. It is based on input data of the same type of those required by LoadProGen, but it is implemented in a Python environment and it offers a higher degree of stochasticity. RAMP works on the basis of three main modelling layers: the user types (households, commercial activities and public services categories can be further detailed), the users identified for each type and the appliances used by each user of each type, with the possibility of defining several optional attributes for the appliances themselves (e.g. the weekly frequency of use). The implemented algorithm is capable of computing the estimated load of all the single users, which are then aggregated for the generation of the overall daily profile. In particular, RAMP, in order to consider the unpredictability of people habits, guarantees the reproduction of a series of different load curves, according to a multiple-run procedure.

Finally, it is important to highlight that both the proposed tools, LoadProGen and RAMP, are open-source, customizable and context-adaptable.

Case Studies – Thanks to the long-standing collaboration between Politecnico di Milano and the Italian NGO CEFA, the validity of some of the models shown in this section have had the opportunity to be tested through their application to specific case studies.

In particular, collected data about the implementation of the described hydropower plant in Ikondo (Tanzania) allowed the calibration of the System Dynamics model, which, in the same context, has been also soft-linked with LoadProGen, in order to test the functioning of the modelling tool [116].

LoadProGen has been recently used also for the prediction of the load profiles related to the electric consumption of the 13 villages that will be electrified by the new 6-MW mini-grid in Ninga (Tanzania). In this case, the locally gathered data have been integrated with those collected in two nearby similar villages that, two years before, have been reached by TANESCO national grid. Then, with LoadProGen, the implementers forecasted three potential scenarios, respectively characterised by the electrification of 30%, 50% and 70% of the households in the village. The load curve obtained by the average of the three scenarios resulted significantly lower and differently shaped from the one estimated by the engineering firm in charge of the feasibility study. The comparison of the two curves (Figure 10) showed that the firm had overestimated the electric consumption of machinery used by productive activities and, thus, the LoadProGen resizing led to an increase of the predicted surplus energy saleable to TANESCO, making the business plan more profitable and attractive [115].

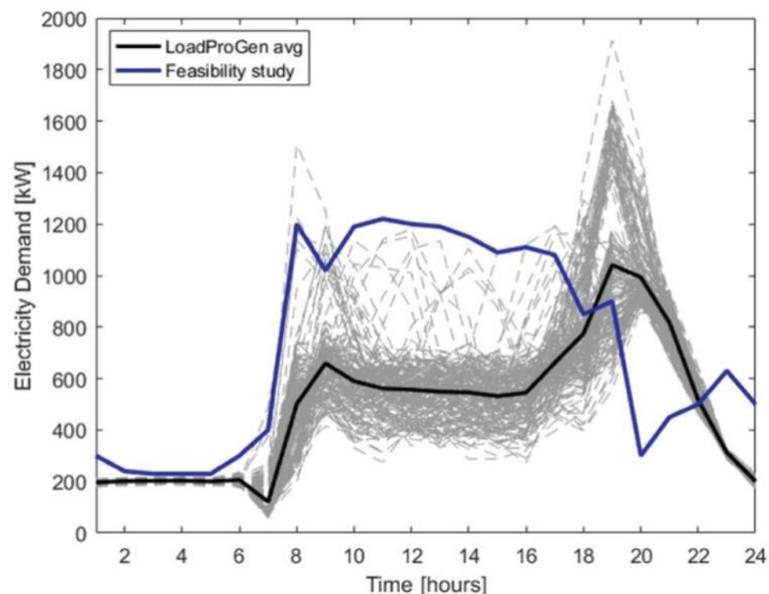


Figure 10 - Comparison between the load curve predicted by the feasibility study and the one computed with LoadProGen for the Ninga SHPP [115].

Eventually, RAMP has been tested against the measured empirical data from the hybrid micro-grid implemented in the village of El Espino (Bolivia) where, in 2015, 60 kW of PV panels, 464 kWh of battery storage and a 58 kW diesel generator were installed in order to

provide reliable and affordable electricity to 128 households, a hospital, a school and the public lighting. After identifying 8 user types among the target area and setting all the required inputs about users and appliances, the aggregated load profile was generated through RAMP and, as it is possible to see from Figure 11, it consistently approximates the curve obtained from the measured data (maximum 2.9% error for the peak load). Within the same study, the authors also demonstrated the better performance of RAMP with respect to LoadProGen (which, in particular, overestimated the peak load), especially thanks to the higher degree of stochasticity and the possibility of defining precise duty-cycles for selected appliances (e.g. fridges) [118].

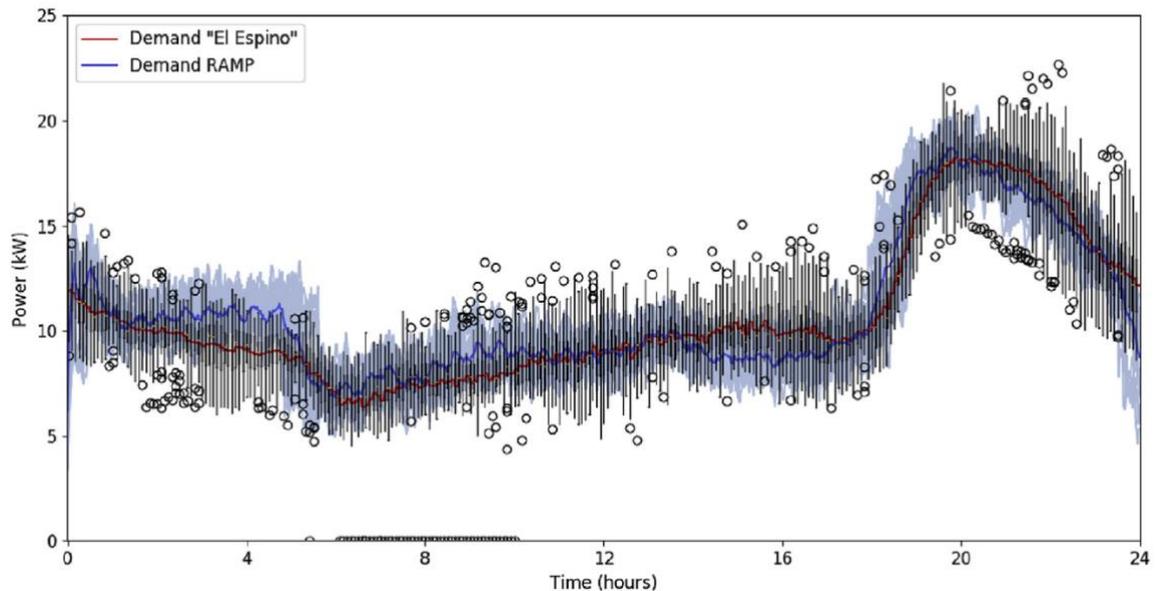


Figure 11 - Comparison between measured data (weekdays November 2016) and the load profile generated with RAMP [118].

4.2.2 Resource assessment

The second step of the Diagnosis phase consists in a careful study of the energy resources landscape that the target area offers. This analysis needs to be performed with a high degree of detail, in order to identify all the energy opportunities that can be exploited, but also to investigate the subtle connected socio-economic dynamics that the upcoming electric service might affect. Actually, an accurate resource assessment is essentially developed through the formulation of two consequential scenarios:

- a framework of the amounts and kinds of the energy sources utilized before the intervention, with particular attention to the related drivers and to the specific activities and sectors in which the different resources find application;
- the evaluation of the resources that the new mini-grid, giving priority to the locally available renewables, could potentially exploit, and the shock that the implemented project will cause on the pre-action energy system.

The framework of the energy network existing before the arrival of the mini-grid electric provision can be represented with a Sankey diagram that outline and quantify (in terms of energy

measures) the connections between the exploited resources, the drivers in which they are attracted (domestic, commercial or public) and, finally, the specific services that benefit from their utilization. This passage is particularly challenging for un-electrified rural areas, because of the complex on-field gathering of energy data; its accuracy depends on the width of the approaches used in order to overcome this barrier. Indeed, according to the considered source and service, diverse collection methods need to be applied, such as questionnaires, surveys, interviews, consultations, direct measurements and observations. Moreover, collected data often need to be further elaborated, in order to get the desired quantitative values: for example, firewood power consumption has to be computed starting from the consumed mass, then converted through the use of the firewood heating value, taken from literature [119].

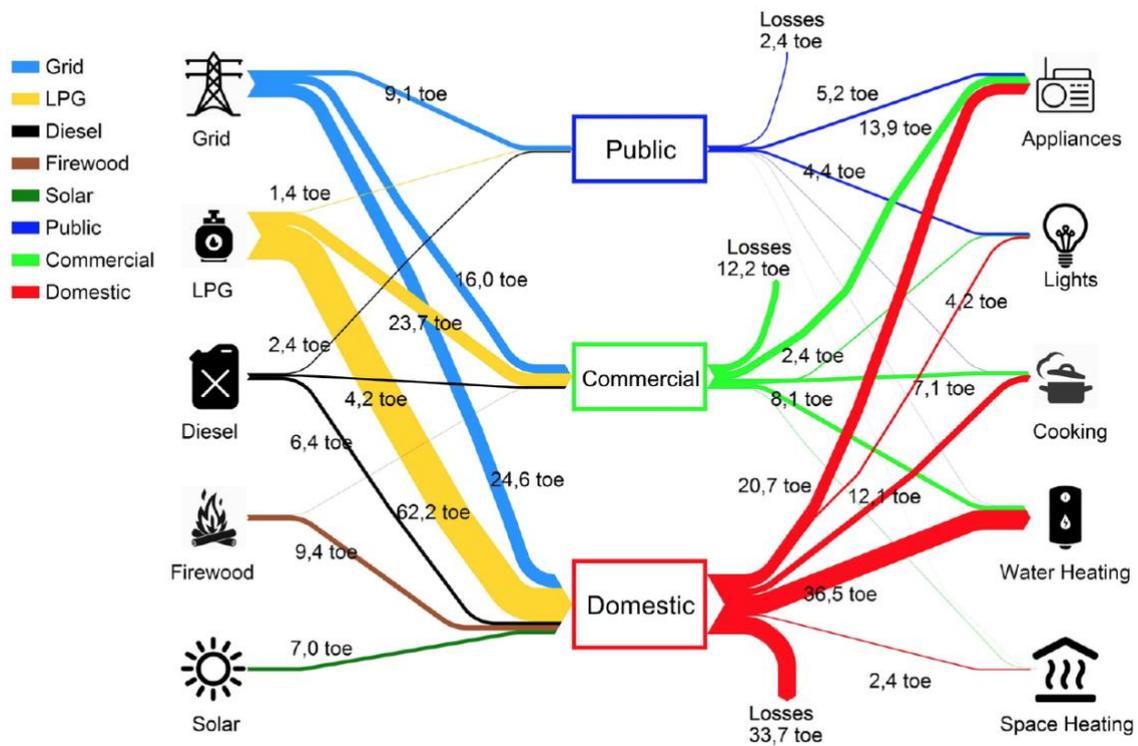


Figure 12 - Example of a Sankey diagram describing the energy resources framework of a village in Chile [119].

Once defined the framework of the energy system supplying the target area, it is necessary to start evaluating the resources that, through their exploitation, would determine the system evolution towards a more affordable and sustainable direction. Given the purpose of CESP analysis, the assessment must prioritise locally available renewable sources; this assumption has even more reason to be fixed as Sub-Saharan Africa shows significant potentialities in terms of solar, wind and hydro energy. For each of the considered renewable sources, it is fundamental to keep into account their proximity to the community, their ease of access and their adequacy to the computed load profile and to the mini-grid system that is intended to be implemented. In particular, in addition to on-field measurements, reliable data about renewables' availability can be checked in local meteorological or airport stations, international GIS databases (e.g. PVGIS [120] and IRENA global atlas [121]) and national GIS databases.

As already mentioned, a mini-grid that distributes electricity produced from both conventional and non-conventional sources could offer a more reliable service with respect to a totally renewable power system, especially because of the unpredictability of renewables' generation. This is the main reason why it is usually highly suggested to maintain the utilization of one or more back-up diesel generators, which ensure a reliable base energy provision. Eventually, while evaluating the selection of certain resources, it is important to assess and verify the opinion and the acceptance of the local community, together with the socio-economic consequences that the planned energy shock might have on local dynamics: for example, the total elimination of traditional sources, as kerosene or diesel, could highly affect the business of eventual local providers. In this sense, it is always essential to keep in mind the comprehensive philosophy that stands at the basis of adequate rural electrification programmes.

4.2.3 Policy and Regulation Analysis

The last part of the diagnostic study is focused on the attentive inspection of the policy and regulatory framework ruling the specific context within which the developers operate. Indeed, politics and regulation highly affect the feasibility of rural electrification programmes and this influence is further heightened for those energy projects that aim at the realisation of a more integrated socio-economic development action. For these reasons, implementers need to be very adept at working within the national and regional regulatory guidelines and at identifying financial aid that the local framework eventually offers. This cleverness becomes even more decisive for the success of mini-grid project, whose cost recovery process is particularly challenging and, thus, it would significantly benefit from the presence of any kind of risk mitigation solution.

First of all, the existence of a solid political stability in the country of intervention represents an important starting point for off-grid electrification programmes: relatively stable politics is often reflected on the realisation of a robust regulatory environment, which is a key factor for the attraction of private sector actors. On the contrary, the occurrence of sudden and unexpected political “revolutions” generally affects the stability of national electrification strategies, whose continuous changes of direction (e.g. in terms of taxation and licenses) do not give economic guarantees to anyone who would like to invest in the energy sector [122]. Unfortunately, throughout the last century, almost all the African countries experienced civil wars, whose aftermath are still perceived in today's national politics. As mentioned in the previous chapter, Tanzania, which gained independence through a peaceful process, is nowadays one of the most politically stable countries in the continent and, consequently, also one of the most energy developed in Sub-Saharan area [13].

Assumed these barriers, implementers need to be capable of navigating the complex and often incomplete frameworks that regulate local off-grid electrification. This lack of clarity concerns, first of all, the licensing fees and permitting procedures, which usually vary according to the type and the size of the energy project (for example, in Tanzania, mini-grids up to 100 kW do not require licenses [123]) and whose release generally requires long time and money. Off-grid implementers then have to be attentive about tariff regulations, which could follow

two main approaches: the imposition of a uniform national tariff, usually too low for the sustainability of mini-grids and, thus, sometimes, accompanied by sufficient viability gap funding; or, alternatively, the openness to the autonomous definition of tariffs high enough to cover the significant mini-grids' costs [122]. Countries as Tanzania, Kenya, Rwanda and Madagascar already give the possibility of setting cost-reflective tariffs, which, before being applied, need to be reviewed by the regulator [123]. Eventually, a significant risk that mini-grid developers have to consider in the design phase is represented by the untimely expansion of the national grid to the target area (generally, the shorter the distance between the mini-grid and the national grid, the higher the risk). In this regard, it would be important that African national grid operators published their future plans ahead of time, but very few of them do so (e.g. Tanzania and Namibia) [123]. Because of this high uncertainty, mini-grid implementers, in advance of the installation, should agree with the operator a compensation mechanism that mitigates the risk related to the main grid arrival and that, in that case, would cover the costs of the mini-grid, allowing a return of investment [122], [123]. A useful tip in this respect is to build AC mini-grids that are compatible with the national network, in order to ensure the interconnection and a certain level of financial sustainability, in the case of grid arrival [122].

4.3 CESP 3: Solution Identification

The Solution Identification phase, the third one of the proposed linear planning framework, represents a linking step allowing to gradually move from the previous sections of context analysis and data elaboration, to the actual techno-economic design described in the next passages. In particular, here it is important to exploit all the gathered information and the realised models in order to structure a general action strategy, tailored to the target community and its identified needs. The outlined broad scheme will then be technically elaborated through the system sizing phase and the proposition of an effective management and business model.

First of all, it is necessary to define the macro-areas on which the implementers intend to intervene. From an energy point of view, assumed the main rural electrification intention of the action, the designers have to decide whether or not to supplement the installation of the electricity system with a side intervention in the field of thermal energy, which, in rural Sub-Saharan Africa, finds its application almost exclusively in relation to the cooking activity (heating and cooling might be also considered in the context of few productive usages). In fact, still about 900 million people in SSA rely on the use of traditional biomass, such as wood and charcoal, for cooking; its inefficient and incomplete combustion, also related to the inadequate used technologies, lead to excessive levels of domestic pollution, which still cause the untimely death of hundreds of thousands people every year [124]. In addition to health consequences, it is important to take into account also the pressure of wood collection on natural resources and the long time spent, especially by women and children, for this activity [110]. In the event that these issues appeared particularly urgent during the needs identification phase in the target area, the implementers might consider the proposition of a complementary intervention aiming at

the improvement of access of modern thermal energy for domestic use; this action, in particular, could be realised through the provision of more efficient technologies (improved biomass stoves) and/or encouraging the utilization of less pollutant non-solid fuels (modern fuel stoves). In relation to the electrification intent, the most interesting modern fuel cooking solution is represented by the induction stove, which is the most efficient technology (up to 90% [110]) and it does not produce emissions at domestic level; on the contrary its electric power absorption is particularly high. In case of mini-grid installations, thus, the introduction of induction stoves is recommended only if the upcoming electric system is already thought to power other electricity-intensive appliances: their connection to small mini-grids aiming at fulfilling only community basic needs, would entail enormous additional investment and the system sizing would become too complex. Alternative non-electric modern solutions are solar, liquid fuel or gas stoves, which, though, do not directly affect the design of the electric system [110].

As regards the electrification strategy to adopt, the first distinctive structural choice needs to be done between following a top-down on-grid approach, entailing the national grid extension, or opting for a bottom-up off-grid solution, with the installation of independent electric systems; a third eventual alternative consists in the proposition of a hybrid project, which materializes with the realisation of a mini-grid connected to the national network. The two main discriminating parameters that have to guide the designers in this choice, are the distance separating the target area from the main grid and the population density of the beneficiary community: starting from these two factors it is generally possible to identify the least-cost approach among the three ones mentioned above [111].

The grid extension (top-down), the most obvious solution in the traditional Western mentality, today, usually, is not the most cost-effective option for the electrification of remote rural communities of Sub-Saharan Africa, which, basically are scarcely populated and very distant from the underdeveloped national grid. Considering, then, the reduced ability to pay and the low energy consumption that often characterize the dwellers of African rural areas, the high infrastructural costs for the extension are rarely justified [5]. These mostly economic reasons, added to the inefficiency and the frequent blackouts occurring in the SSA national electric networks, make off-grid solutions particularly attractive for the projects of rural electrification.

The bottom-up off-grid approach, in turn, could entail the implementation of a mini-grid or the installation of individual systems. The latter, which include especially photovoltaic devices as pico-solar systems and plug-and-play solar home systems, are optimal to ensure access to electricity to extremely disperse communities, whose interconnection would be too expensive [5].

Given the topic of this work, major attention will be paid to the analysis of mini-grid possibilities, which, as abovementioned, include also the third hybrid approach, represented by grid-connected distribution systems. Micro-grids can be classified as decentralized or distributed. The former ones refer to technologies constituted by one single conversion unit, exploiting the energy produced from one single source and supplying it to multiple, similar or different, consumers, through an autonomous distribution network. In contrast, the power

provided by distributed mini-grids is generated by more than one decentralized conversion unit, which can rely on multiple different energy sources; these units are then interconnected through a distribution grid serving a single or several users. The result of this solution is a virtual power plant, composed by various real generation stations, coordinated by a centralized control brain, communicating with each of the unit [9].

| Mini-grids Taxonomy | Decentralized | Distributed |
|--------------------------------|----------------------|--------------------|
| Conversion units | Single | Multiple |
| Energy Sources | Single | Single or Multiple |
| Centralized Control | No | Yes |
| Consumers | Multiple | Single or Multiple |
| Possibility of Grid Connection | Yes | Yes |

Table 18 – Decentralized and distributed mini-grids taxonomy.

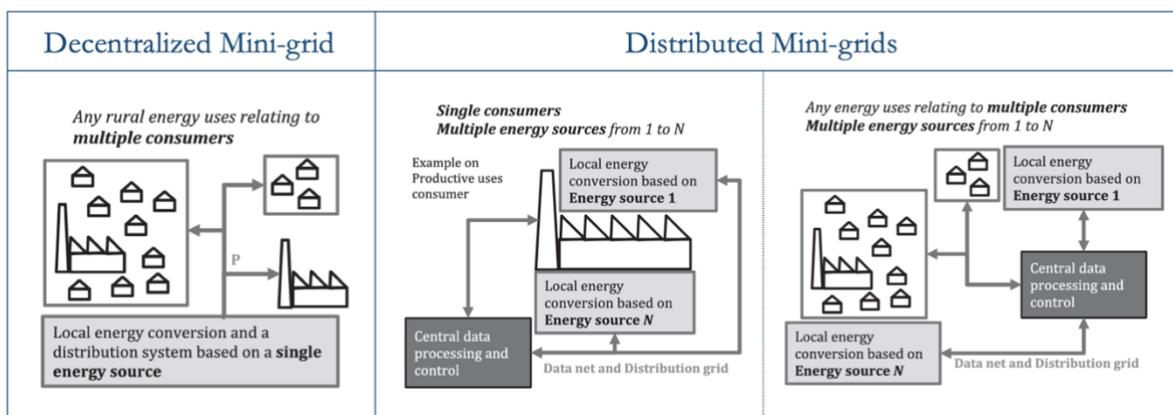


Figure 13 – Graphic representation of decentralized and distributed mini-grids [9].

As repeatedly stressed, one of the fixed points of a proper comprehensive and sustainable rural energy programme consists in the exploitation of locally available renewable resources (solar, wind, hydro), which are basically preferred to the conventional fossil fuels. Nevertheless, given the renewables' intrinsic unpredictability, non-conventional mini-grids need to be supported by storage systems (batteries are the most common), in order to ensure a more dispatchable electricity provision. In the case of distributed micro-grids, a less expensive but reliable solution is represented by the support of diesel generators to the renewable production: resorting to the recovery and renovation of the used generators that can be found in the area, is an even more economical and sustainable option.

Most of the renewable technologies adaptable to mini-grid systems require significant capital investments but reduced operating expenditures, and the levelized cost of electricity (LCOE) of them all have experienced significant declines in recent years. This improvement is especially true for on-shore wind and photovoltaic technologies, whose weighted-average LCOE

respectively fell to USD 0.056/kWh and USD 0.085/kWh, getting closer and closer to the already competitive value of hydropower plants (USD 0.047/kWh) [125]. Among these, PV source is particularly attractive in SSA in relation to its obvious abundance and its minor site-specificity with respect to wind and hydro sources [5]. It is then necessary to highlight that bio-energy based technologies are not suitable for rural electrification projects, especially due to the complexity of biomass supply chain and the minimum plant size that makes electricity production economically feasible [9].

As concerns the distribution system, the choice between direct current (DC) or alternative current (AC) is mainly related to the loads that the mini-grid is expected to serve (especially valid if the programme entails the sale of specific appliances): for example, a small decentralized micro-grid aiming at satisfying domestic basic needs, as lighting and charging, is better to be designed with a DC bus line. Nevertheless, DC protection devices are expensive and the connection of usually cheap AC appliances to a DC grid requires the implementation of additional inverters. Moreover, it is important to consider the eventual connection of the mini-grid to the national network, which would certainly result much simpler and cheaper with an AC bus line [5].

Eventually, within the strategy selection phase, the implementers have to identify the stakeholders that could be involved in the project. This search must not be restricted to the only potential technical partners, but it has to include also all the actors that might be affected by the different dimensions of the programme: providers, consultants, local authorities and institutions, community key personalities, academic figures etc. The multi-stakeholder approach, in fact, represents an essential requirement for the implementation of a proper comprehensive rural electrification programme, whose feasibility is inevitably subjected to non-technical factors, as local politics and regulations, economic and cultural framework and social acceptance.

4.4 CESP 4: Technical Design

The fourth step of CESP framework represents the engineering core of the mini-grid planning process, as, in this phase, implementers resort to the utilization of high-resolution sizing tools, aiming at designing and dimensioning an optimised energy system that is capable of properly satisfying the computed load demand through a cost-effective solution, fundamental prerequisite for the techno-economic feasibility of the project.

In relation to the forecast load profile generation, within CESP 2, there was talk of the parametric uncertainty associated to the long-term demand prediction as one of the most challenging barriers in mini-grids modelling: it is easy to understand that the obtainment of an adequate mini-grid design is strictly dependent on the precision and the appropriateness of the calculations used for the prevision of the local power consumption, which certainly represents the main input variable to the system dimensioning process. Here, in the Technical Design, implementers have to deal with the structural uncertainty related to the mathematical

formulation adopted for the representation and the sizing of the micro-grid components, whose modelling is usually too simplified to accurately reproduce their real behaviour, often due to the limited available data [114]. Moreover, it is necessary to take into account the epistemic uncertainty of the available energy models with respect to socio-economic parameters, which, most of the times, are treated in an imprecise or subjective manner within the formulation; examples of these factors are the costs of fuels and technologies, the maximum acceptable land occupation for the system installation or the long-term learning curves of a certain technology [126].

In recent years, many software tools and models have been developed to mitigate the complexities inherent in the technical design and optimisation of hybrid energy systems; they typically minimise the costs of investment and/or operation and try to maximise the share of renewable sources exploited [127]. According to the categorisation of Turcotte et al. [128], sizing and simulation tools for hybrid energy systems can be classified as:

- prefeasibility tools: implemented as spreadsheets for a rough sizing of the system, these tools are used in order to understand if the identified solution is adequate for the specific target context; they are often supported also by an economic and financial study; an example is RETscreen, developed by the Ministry of Natural Resources of Canada,
- sizing tools: compiled software that, given the energy requirements and other input parameters, define the optimal size of the different components of the system, according to a specific optimisation function (e.g. minimisation of the life-cycle cost); HOMER® is the most famous and used sizing tool;
- simulation tools: compiled software working in the opposite way to sizing tools, since the user has to specify the nature and the size of the different components and the tool returns a detailed analysis of the system behaviour, with a certain time resolution; HYBRID 2, developed by the Renewable Energy Resource Laboratory of the University of Massachusetts, is an example;
- open architecture tools: sizing or simulation software that give to the user the possibility of modifying the operating algorithms and the interactions among the system components; an example is represented by TRNSYS (Transient Energy System Simulation Programme), developed in 1975 by the University of Wisconsin and University of Colorado (USA).

An energy system modelling tool, in order to provide accurate and comparable results, should offer a wide range of technological options and a high spatial and temporal resolution, capable of responding to the fluctuations of load demand and renewables availability; moreover, in order to give a concrete contribution to the universal electricity access goal, it must be transparent and provided of a high level of adaptability to user- and context-specific needs [110]. In particular, the last two requirements are ensured only by open-source models, which, thus, can be freely used, modified and shared by anyone, for any purpose. For example, HOMER®, the most widely adopted tool for the dimensioning of off-grid systems, guarantees highly valid technical results, but, being a closed-code model, it does not give the possibility to the user of customising the involved parameters and formulations, limiting the adaptability of the software

to specific contexts [129]. The open and free availability of energy system design tools is essential to improve the quality of research, to create a more effective collaboration between dedicated engineering and politics, to increase the R&D productivity and efficiency (given the limited funds) and, finally, to enhance the influence of electrification studies on social debates. Fortunately, these concepts are starting to be understood and, recently, many universities and research institutions are proposing open and free modelling software [130].

For the technical design and sizing of mini-grids, this work focuses on MicroGridsPy [114], a tool that ensures that essential requirements mentioned in the premises, open nature included. MicroGridsPy is an open-source modelling framework developed by Sergio Balderrama and Sylvain Quoilin, from the University of Liege (Belgium), specifically conceived to optimise the complex dimensioning process of rural mini-grids and licensed under the European Union Public License (EUPL); moreover, the SESAM Group from Polimi have worked on specific expansions and applications of the software. It is implemented in Python, using the Pyomo library and its code is freely accessible at GitHub repository [131].

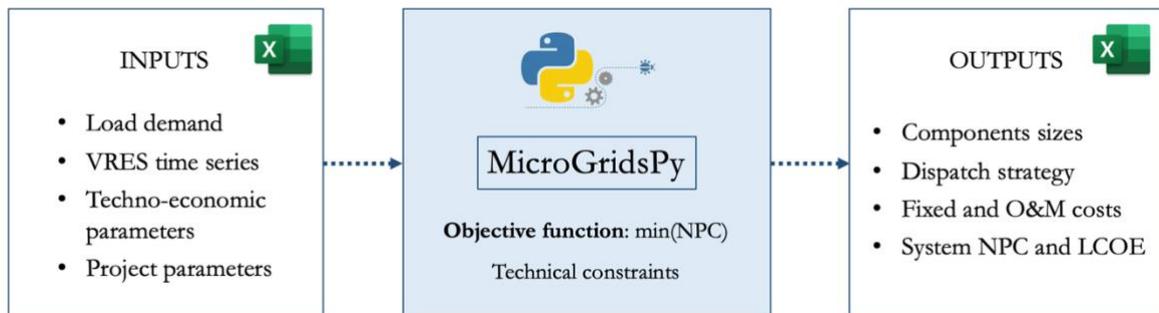


Figure 14 - Schematisation of MicroGridsPy architecture. Author's elaboration based on [47].

MicroGridsPy operates the cost-optimal sizing of batteries, diesel or other-fuel gensets and renewable technologies, offering also the cost-optimal solution for the dispatch of the considered different sources and returning the LCOE of the optimised system; in particular, the objective function, driving the implemented algorithm, is represented by the minimisation of the net present cost (NPC) calculated over the lifetime of the project.

The inputs that the software requires as Excel files are the following:

- the yearly load profile, generated in the Diagnosis phase, with a one-hour resolution (i.e. 8760 time-steps);
- the Variable Renewable Energy Sources (VRES) time series, for each of the renewable technology units, with a one-hour resolution and site- and model-specificity (Renewables.ninja offers reliable and adequate data concerning photovoltaic and wind technologies [132]);
- techno-economic parameters about the different components composing the system, such as efficiencies, capacities, charge/discharge rates, investment and O&M costs;
- detailed parameters regarding the nature and the economic management of the specific project, such as the lifetime and the applied discount rate.

The mathematical formulation running the software is then subjected to technical constraints as the overall energy balance, the generation limitations of the different technologies, the battery charge/discharge range and the accepted lost load. The tool, finally, returns the following Excel outputs:

- the cost-optimal size of all the involved renewable, fossil-fuel and storage components;
- the cost-optimal dispatch strategy, represented by one-hour resolution time series of the electricity generated or stored by the different technologies;
- the fixed and variable costs associated to each system component;
- the minimised NPC and LCOE of the overall system calculated over the project lifetime.

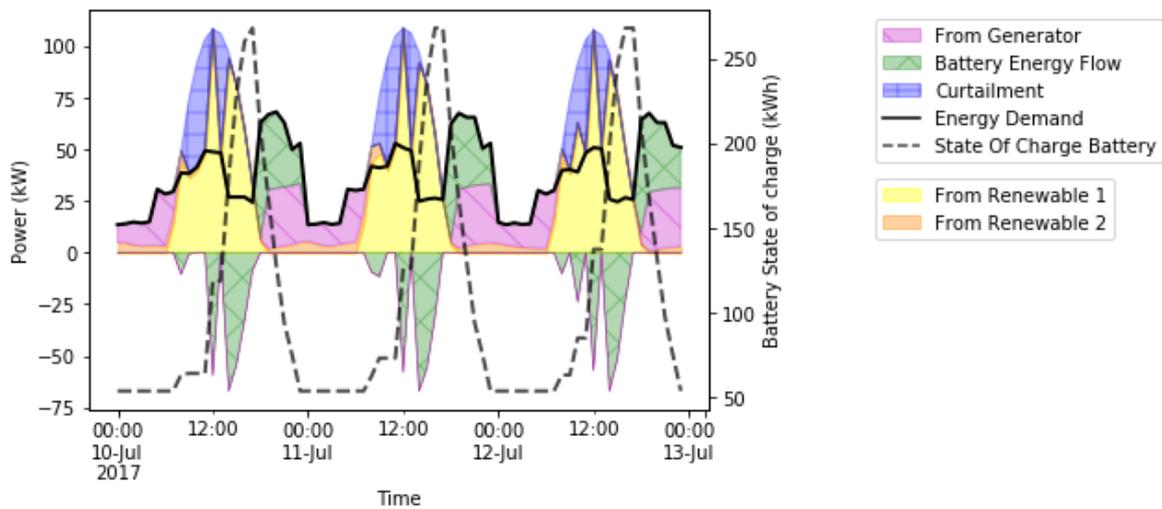


Figure 15 - Example of optimised generation and storage time series produced by MicroGridsPy.

Within the baseline version of MicroGridsPy, the complex optimisation problem is faced through the use of linear programming (LP), which allows to find the absolute optimal solution in a deterministic way. The main drawback of this optimisation process is represented by the impossibility of modelling non-linear or discontinuous system features. This disadvantage drove the developers to elaborate an alternative version of the software, based on mixed-integer linear programming (MILP), which ensures a better approximation of non-linear models, while reducing the computational efficiency. This release operates a two-stage stochastic optimisation process that allows to simultaneously consider multiple load demand scenarios: it determines the optimum value of the first-stage variables (the rated capacities of the different technologies, i.e. their sizes) under the uncertainty generated by the stochastic second-stage variables (the energy flows from the different components, i.e. the dispatch strategy) in each scenario. The new objective function consists in the minimisation of the weighted average of the NPCs of the different scenarios (weights are assigned according to the estimated probability of occurrence of each scenario). Giving the possibility of taking into account diverse input energy profiles, the two-stage optimisation guarantees to embrace the high parametric uncertainty associated to the predicted load demand of rural communities, identifying the least-cost solution capable of satisfying all the potential demand scenarios and, thus, leading to a more robust system configuration [114], [133].

The two-stage stochastic version of MicroGridsPy can be particularly well coupled with RAMP, the bottom-up stochastic load profile generation tool described in the CESP Diagnosis section, which allows to simulate different load scenarios, the inputs required by MicroGridsPy. This coupling has been tested by Stevanato et al. [133] to design the mini-grid in the Bolivian village of El Espino, where the designer considered a range of four scenarios, differing according to degree of transition to e-cooking; the designed and optimised mini-grid can satisfy all the predicted load scenarios, ensuring enough adaptability to each of them without significant economic differences.

In 2019, the developers from the University of Liege together with the members of SESAM Group, proposed a further development of the software that would ensure even more accurate and reliable results [129]. On the basis of the existing MicroGridsPy, they built a multi-year capacity-expansion optimisation model, named MicroGridsPy-CX, which receives, as inputs, non-linearly time-evolving load demand series and enables the expansion of the system capacity, in response to the demand changes. This advanced feature is particularly useful to design mini-grids for the energy provision to un-electrified rural villages, whose load demand, in the first years after electrification, is characterised by significant growth rates difficult to predict. In particular, MicroGridsPy-CX is based on:

- multi-year formulation, which allows to adopt demand time series and parameters evolving throughout the project lifetime, so that all the time-dependent variables of the problem are, now, functional to the specific year too; this is a preliminary condition for the following feature;
- multi-step capacity-expansion logic, which translates into the possibility of postponing the installation of part of technologies capacities (e.g. PV panels, battery units) to later years, according to the demand evolution; this way, all the variables that are functions of components capacity become dependent also on the decision steps in which the timeline is divided.

Thanks to this tool, it is possible to reduce the significant initial capital costs, which generally represent a challenging barrier to mini-grid projects, and to make O&M costs proportional to the capacity expanding throughout the years. It is then important to highlight that MicroGridsPy-CX still works with the two-stage stochastic optimisation, which allows to consider as inputs multiple load scenarios.

The novel features of MicroGridsPy-CX have been applied to re-design an existing hybrid solar-wind mini-grid installed by a private enterprise in the Andes, on the border between Bolivia and Chile. After a field campaign and direct measurements conducted in 2018, the designers obtained the village load demand of the first year, from which they then developed three different scenarios describing the local energy outlook evolution in the following years: the first scenario (D1) provides a growth of 4% after the first year and 1.2% in each of the following years; the second one (D2) follows the more optimistic electricity access growth proposed by ESMAP [134]; the third one (ST) is a stochastic intermediate scenario between the first two, in turn made of ten diverse predictions with equal probability of occurrence.

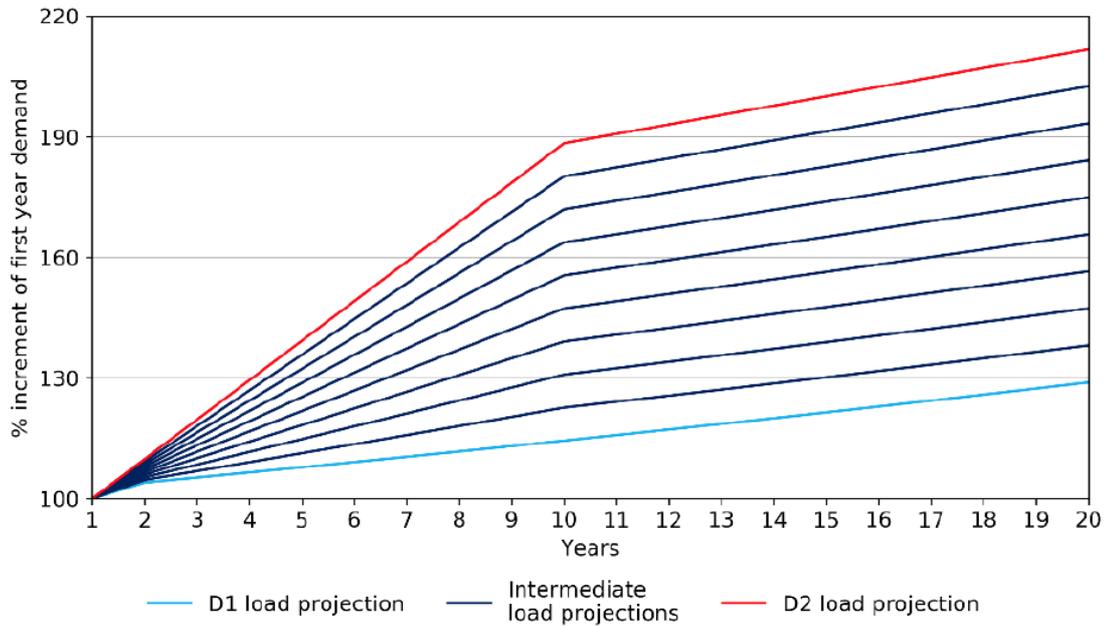


Figure 16 – Load demand projected evolution according to three different scenarios [129].

The study of the application of MicroGridsPy-CX to the Andean mini-grid showed that the adoption of a multi-year formulation, alone, ensures, with respect to the fixed-demand version, a 15.2% reduction in the total investment costs, averaged over the different scenarios; also the NPC is much lower in all the diverse projections (Figure 17A). The project economy is, then, further improved adding the capacity-expansion feature, which lead to the decrease of the investment costs, O&M costs and NPC; moreover, Figure 17B shows that the higher the number of decision steps, the greater the reduction of NPC values.

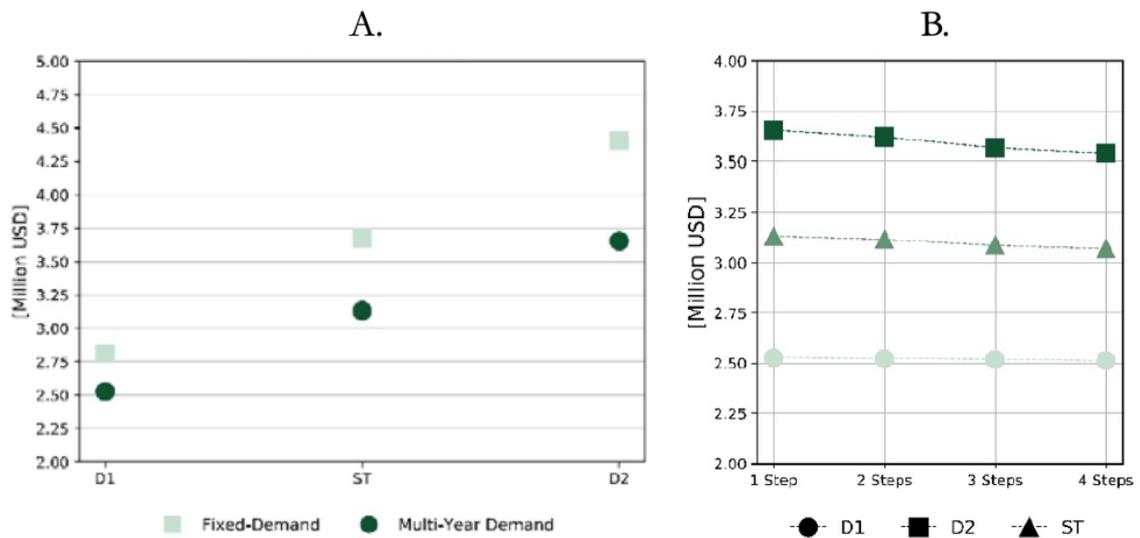


Figure 17 - NPC reduction with the only multi-year formulation (A) and with the addition of the capacity-expansion logic (B) [129].

Eventually it is necessary to note that MicroGridsPy-CX still relies on linear programming (LP), so that non-linear parameters are simplistically modelled through non-integer values, since multi-integer linear programming (MILP) is not yet transferred to this software version. The implementation of MILP formulation within MicroGridsPy-CX would lead to a further development of the modelling optimisation process, ensuring even more robust configuration and even more realistic results [129].

4.5 CESP 5: Comprehensive Design

All the work done in the first four steps of CESP planning, from the extended on-field needs assessment through to the technical design and optimisation of the electric system, has little chance of success, unless particular attention and resources are paid to the Comprehensive Design of the overall energy project, fifth phase of the proposed framework. Indeed, in CESP 5, the implementers must address the issue of identifying an effective business and management model, which is able to ensure the multi-dimension sustainability of the whole electrification programme, starting from the economic one. In this design phase, in particular, it is fundamental to define a fruitful strategy for the sale of electricity and to organise a comprehensive and detailed framework of all the interconnected activities and partnerships that are essential to foster and accelerate the socio-economic development of the target rural community. These complementary interventions could also represent important resources to economically support the energy commercialisation service in the expensive maintenance of the realised infrastructures and the proposition of further developments throughout the project lifetime.

4.5.1 Business model classification

Scientific literature still lacks adequate and precise business models that can widely tailor mini-grid projects, which stand out among the other electrification solutions due to their pronounced dependence on the specific context and community in which they are applied [123]. However, mini-grids business models can be easily classified according to the ownership structure of the system (community, private, public utility, hybrid) and to the operating methods typically adopted within each of these structures, in relation to the nature and the purpose of the main actors involved.

In the **community ownership model**, the community itself or a local NGO owns and manages the power plant and the distribution infrastructures. This approach is usually adopted by non-profit actors, who tend to follow a build-short operate-transfer business model, which provides, after the installation, a short period of direct management of the mini-grid. During this temporary phase the NGO is committed to training, through capacity building programmes, the local technical operators selected for the system maintenance and the staff that will manage the electricity commercialisation and all the connected administrative affairs; when the implementers believe that the community is ready to take over the techno-economic management of the mini-grid, they proceed with the ownership transfer to the association or

cooperative established specifically for the aforesaid tasks. Many of the existing mini-grids fall into the community ownership category, since European and American NGOs have been always engaged in the process of electrification of Sub-Saharan remote rural areas. Given their nature, all non-profit interventions heavily rely on grants provided by international cooperation institutions, without which the developers would be absolutely unable to cover the significant capital costs that mini-grids entail; with regard to operating costs, mostly, when local regulations allow, NGOs set a tariff plan that could economically sustain the expenditure necessary for system O&M; eventual profits are generally reinvested in the programme [5].

According to the **private company model**, the project is implemented and then managed by private actors investing in it. In fact, private enterprises typically are directly responsible for all the aspects and the phases of the electrification programme, as they build a mini-grid, of which they maintain both ownership and management (build-own-manage business model). This approach certainly tends to give less importance to the engagement of local communities with respect to the previous one, as it does not provide for the transfer of system administration. The involvement of private investors in rural electrification process has been emerging in recent years, especially since cooperation development agencies began to open their funding calls, previously reserved to non-profit organisations, also to private players; these grants, indeed, significantly facilitate the economic profitability of energy projects, increasing their attractiveness. Private actors are, obviously, more attentive to the proposition of a profitable tariff strategy that could guarantee an efficient return of investment, always taking into account the willingness-to-pay of the target community [123].

The **public utility model**, as the name suggests, provides for the presence of a utility owning and managing all the aspect of the mini-grid project. Public entities generally opt for a build-own-outsource business model, since, after the mini-grid has been built, they issue a call to select the actor that will be in charge of the management of the system maintenance and the sale of electricity, while the power generation and distribution infrastructures will remain public-owned. Despite the public funding they significantly rely on, these public actions often prove to be unsuccessful, from both a technical and financial point of view, since they usually charge low uniform national tariffs, use expensive diesel as main energy source, disregard the system maintenance and do not adopt a comprehensive approach, overlooking the importance of involving the concerned local communities. All these factors result in the unsustainability of public off-grid electrification projects [111], [123].

Finally, it is possible to mention **hybrid models**, which seem to represent a promising alternative, aiming at exploiting the most successful features of each of the above approaches. In particular, public/private partnerships involve different actors in building, owning and managing the power plant and the connected mini-grid. This asset, which is generally applied to larger projects, is typically supported by public grants or subsidies, and the involvement of private actors may be limited to the system management or it could be extended to the installation phase as well [123]; the Nigerian Energy Support Program has then pushed for a further hybrid solution, according to which the distribution network is owned and installed by

public utilities, while the generation assets are owned and installed by private players, who are also in charge of the infrastructures maintenance and the electricity sale service [135].

Eventually, it is important to highlight that the mini-grid projects proposed within the ownership models just described can be differentiated according to the services provided. In fact, rural electrification projects could be limited to provide the electricity supply service, or they may adopt a more comprehensive and integrated approach, as the one recommended by the CESP framework. This wider approach can be implemented on more levels, from the simple provision of other energy-related products or services to interventions in sectors different from the energy one, but still connected to it (e.g. WEF Nexus). As already mentioned, non-profit organisations are the ones who most often choose a more holistic approach [5].

4.5.2 Hints for the sustainability of mini-grid projects

This sub-section will address the complex task of pointing out different solutions that can be adopted within a mini-grid project, in order to increase the chances of success of a rural electrification programme that is not limited to the enhancement of the local energy sector, but is capable of promoting a sustainable process of socio-economic development in the target community. For the achievement of such an ambitious goal, it is necessary to set a comprehensive design that entails interventions of different nature, from a technical, economic and social point of view.

The hints here presented, moreover, aim at increasing the bankability of mini-grid projects, in order to make them more economically attractive and involve more closely the private sector, whose contribution can be decisive in bringing modern energy to remote rural areas of Sub-Saharan Africa. In this connection, the definition of an effective and credible value proposition is important in relation to both potential investors and future consumers, and it has to be complete with marketing, pricing and risk reduction strategies.

As repeatedly stressed, one of the most challenging barriers to the deployment of hybrid mini-grids is represented by the high capital costs that still characterise renewable sources technologies and that inevitably require the presence of grants for the economic sustainability of these projects. Nevertheless, to overcome such complexities, recently, some companies have focused on less capital-intensive technologies, as distributed **scalable mini-grids**. An example is represented by Devergy [88], a private energy service company installing in Tanzania small-size solar mini-grids with outputs in a range between 5 and 10 kW per site, coupled with distribution grids that, individually, do not exceed one kilometre in length, ensuring high-efficiency provision. Given their size, such systems aim at satisfying the basic needs of the target community, but they are designed in order to take advantage of the scalability of PV fields and to be managed in a dynamic way: the company gradually upgrades the system capacity accurately following the local energy demand with a short-term horizon, in order to avoid excessive curtailments and always have an optimised power generation [5].

It is clear that investing in efficient technologies represents a winning strategy; nevertheless, it is important that this high efficiency is inherent to all the aspects of the electric system and is

not limited to production and distribution phases. In this sense, the installation of **smart meters** ensures a well-structured and efficient data collection and management, with the consequent elimination of the costs associated with meter reading and the improvement of customer assistance and control. Moreover, in recent years, smart meters have become more affordable and their higher cost than traditional meters is justified by their performance and by the high-potential solutions that they offer, as the Pay-As-You-Go (PAYG) model and the Demand Side Management (DSM). The **PAYG** system assumes that customers pre-pay only the electricity that they are expected to consume, and these payments can be done through mobile-phones; besides reducing the billing costs, PAYG model also eliminates the risk of non-payment, which is typically high among rural consumers without a fixed income. An example of smart metering implementation is provided by the project realised by the Italian NGO COOPI in Sierra Leone: they resorted to the installation of SparkMeter system [42], which offers comprehensive metering solution, coupling a hardware architecture, made of a base station and users' meters, with software application (ThunderCloud) which manages data and monitors the overall system functioning.

DSM, instead, is defined as a combination of strategies and technologies helping in modifying the shape and size of the users load curve, in order to optimise the matching between power production and consumption and reduce the waste of energy; for example, peak clipping, the reduction of the maximum load occurring at peak time, can be done through the application of a differentiated-tariff scheme or defining a priority scheduling among the different loads [123]. An overall reduction of the load curve could be then achieved promoting the utilization of high efficiency appliances (e.g. lightbulbs), which represents another effective DSM strategy that must be supported by information campaigns to discourage dwellers from using cheap inefficient technologies [5].

The aforementioned **high-efficiency electrical appliances** could bring another advantage: their sale, indeed, could be entailed in the business model to guarantee some extra revenues and to ensure that consumers use safe appliances compatible with the mini-grid design. The sale service usually concerns DC appliances for lighting and charging purpose or refrigeration systems, but the commercialisation strategy must be accurately studied, assuring that the market is big enough to provide a net gain and evaluating the presence of eventual local competitors, whose business exclusion could generate social tension in the community.

Indeed, it is important to identify stable revenue streams capable of sustaining the operating costs of the system, especially in the piloting phase of a mini-grid project, when domestic users generally do not ensure significant and constant consumption. In this regard, implementers should particularly focus on **productive uses of electricity** (PUE) [136], defined as those uses that increase the income or productivity of the target community; within the context of rural Sub-Saharan Africa, PUE can be mainly found in the agro-processing value chain (e.g. irrigation and milling), but also in business activities, as carpentry, tailoring and welding. In fact, as already mentioned, the promotion of PUE is primarily aimed at supporting energy provision in the intent to boost local social and economic development: through targeted measures implementers have to encourage productive and business activities to exploit the upcoming

electricity to increase incomes and employment and decrease workload. At the same time, promoting PUE could decisively contribute to the enhancement of local energy demand, thus ensuring the presence of more stable and consistent revenues for the mini-grid project and boosting the economic sustainability of the electrification programme. This reasoning is much strengthened in relation to the realisation of PUE primary objective, i.e. provided that the profitability of productive and commercial consumers is improved by the electricity provision.

The fostering of productive uses of electricity could thus be aimed also at the creation of **anchor clients**, with whom it is possible to sign electricity supply contracts, ensuring to the mini-grid stable and guaranteed income [122]. This is what CEFA did in the Tanzanian village of Matembwe, by setting up a poultry hatchery and an animal feed factory, managed by the same utility operating the electric system: this way the Italian NGO intervened alleviating the nutritional issues of the community and, at the same time, they established solid customers essential for the sustainability of the mini-grid. However, anchor clients could also be identified among the realities already present in the target area; the most common ones are telecommunication companies and mobile towers, which exploit the rapid expansion that mobile networks are experiencing in recent years in SSA [5]: the aforementioned COOPI, for example, within its mini-grid project in Sierra Leone, signed a supply contract with Africell and Sierratel, two telecommunication companies operating in the considered territory. Lastly, also national grids could represent important anchor clients, as long as the mini-grid energy production exceeds the local demand and surplus electricity is sold to the grid operator. Generally, this solution, which entails significant costs and long bureaucratic procedures, is adopted by larger projects, capable of offering high amounts of surplus energy [123]. The mini-grids installed by CEFA and ACRA in Tanzania are all connected to TANESCO grid and ACRA's Lugarawa project (1.7 MW), in particular, is expected to get important revenues from the sale of electricity to the network.

As highlighted few paragraphs above, agro-processing sector, being the essential chain on which rural SSA relies, represents also the most urgent and valuable PUE, for implementers, to focus on, in order to foster and enhance the fruitful bond between energy and food production.; intervening, then, on the third indispensable element, water provision, the **Water-Energy-Food (WEF) Nexus** model is outlined. It is an innovative holistic approach aiming at providing access to the three vital resources necessary to fight poverty and trigger a sustainable and comprehensive development process. The WEF Nexus model provides for an integrated management of water, energy and food, and its effectiveness derives from the strong interconnection existing between these three resources: access to modern energy ensures pumping and treatment of water, whose provision is crucial to crops irrigation and, thus, to food production; at the same time, energy is also needed within the food supply chain. From this causal scheme it is easy to note that energy has the role of key enabler for the other related services, which, all together, are capable of promoting a process of transformational engagement, defined by the World Bank as the change that “improves fundamentally the lives of the poor and disadvantaged people” [137].

The evaluation of WEF Nexus approach has been assessed through its application to the Ikondo-Matembwe mini-grid project implemented by CEFA in Tanzania, where the Italian NGO established MVC Ltd, an integrated company managing the electric system, diverse agro-processing activities and the water provision service. The benefits of the proposed model arose from the comparison between the sole energy implementation and the integrated WEF Nexus approach. In particular, it came out that the energy project's net present value (ENPV) is USD 5,940,652, with a 16% internal rate of return (IRR) and a 3.1 benefit-cost ratio (BCR); on the other side, the simultaneous implementation of the three WEF components lead to an ENPV equal too USD 12,479,239, a 22.57% IRR and a 4.5 BCR, showing a net success of the model thanks to the exploitation of the interdependence between water, energy and food [21].

Finally, in the comprehensive design, it is essential to outline all the complementary **social activities and interventions** that need to be planned in order to engage the local community within the different phases of the electrification programme and to achieve the project sustainability. Indeed, the creation of a strong direct relationship with local stakeholders since the beginning of the project design, in addition to promoting social development, could significantly contribute to solidify the positive impacts of the programme. During the implementation phase it is important to organise awareness campaigns and workshops aimed at finding social acceptance and informing dwellers about the potentialities and the risks coming from electricity provision; the involvement of local authorities and key personalities could facilitate the achievement of this task. Furthermore, non-profit organisations, which typically adopt a business model providing for the transfer of the system management to the target community, spend significant resources in training local candidates through time-extended capacity building programmes, both during and after the system installation. These are just a couple of examples of complementary social activities, which may also include business incubation, microcredit services and women empowerment programmes. In order to guarantee stable and effective impacts from such interventions, it is fundamental to preliminarily identify their potential outcomes, adequately select the stakeholders that need to be involved in each of them and accurately schedule their implementation within the phases of the programme [5].

It is true that complementary activities entail relevant expenses, but implementers should consider them as positive investments, given the socio-economic benefits that they are expected to generate, if precisely planned. This is valid also for private investors, considering that, recently, many international cooperation institutions require social interventions to be included in the business model of the project, in order for it to be eligible for funding [5].

4.6 CESP 6: Impact Evaluation

The last step of CESP analysis has to be devoted to the assessment of the impacts that the electrification intervention is expected to generate, a task that often proves to be insidious. UNDP specifically define impacts as the “positive and negative long-term effects on identifiable population groups produced by a development intervention, directly or indirectly, intended or

unintended” [138]. This complex characterisation often leads energy projects implementers to dedicate little attention to the definition of an adequate impact evaluation within the project design, also due to the lack of reliable data and the scarce importance given to the use of participatory approaches [139]. Furthermore, though literature offers different propositions for the impact evaluation, it still lacks a structured, comprehensive and adaptable framework evaluating the cross-sectorial and long-term sustainability of off-grid electrification programmes [140]. Most of the organisations and institutions operating in the cooperation and development sector, in fact, tend simplistically to verify that a specific project meets the five evaluation criteria set by the Development Assistance Committee of the Organisation for Economic Cooperation and Development (DAC-OECD): relevance, effectiveness, efficiency, sustainability, impact [141]. These properties are then generally measured along the different steps of the Results Chain elaborated by the DAC-OECD, which starts from the project inputs and ends with its impacts, dwelling on the analysis of the implemented activities and the resulting outputs and outcomes. Instead, the general interest has recently focused more on the final wider impacts generated by development programmes, which must not be confused with the direct results of the intervention, especially because of their extension in time, space and sphere of influence [139].

Once these assumptions have been made, it is important to define the features that should characterise an accurate evaluation study of the impacts produced by a rural electrification programme, in order to capture the capillarity and the profound influence of such interventions. A proper holistic impact evaluation framework has to be:

- People-oriented, assessing the project performance and its consequences from the point of view of the local community;
- Multi-dimensional, considering all the economic, socio-cultural, institutional environmental and technological changes induced by the project;
- Extended in time and space, in order to evaluate the effectiveness of the long-term and sustainable development process triggered;
- Open and customisable, allowing its diffusion and its adaptability to any technology, site, context and scenario;
- Quantitative, in order to develop results that give the possibility of comparison between different projects.

4.6.1 Impact Evaluation Framework (IEF)

Recently, Colombo et al. [139] proposed an impact evaluation methodology specifically designed in order to address electrification projects in developing countries, trying to respect all the above mentioned features. In particular, the resulting Impact Evaluation Framework (IEF) takes its cue from the Sustainable Livelihoods Framework (SLF) elaborated by the British Department for International Development (DfID) and the Institute for Development Studies (IDS): it is a people-oriented and context-specific framework, based on the concept of Sustainable Livelihoods and aimed at analysing the impacts on the Livelihood Assets, which are

usually divided into five interconnected community capitals (natural, physical, human, social and financial) [142].

The IEF, which can be applied both to urban and rural energy interventions, is built around the idea that project impacts can be measured “as the changes of target community livelihoods”, comparing the local scenario before the action (ex-ante) with the one that is expected to be after the action (ex-post). Its hierarchical structure is based on the mentioned five capitals and the evaluation analysis then develops according to five further steps, resulting in a six-module framework, featured below.

1. **Comprehensive hierarchy** – Each of the livelihoods capitals is characterised through few standardised dimensions, which, in turn, are divided into specific indicators. It is important to highlight that the hierarchy has been constructed from capitals through dimensions to indicators (top-down approach), while its customization has to follow an inverse bottom-up approach, in order to properly adapt the framework to the target context.

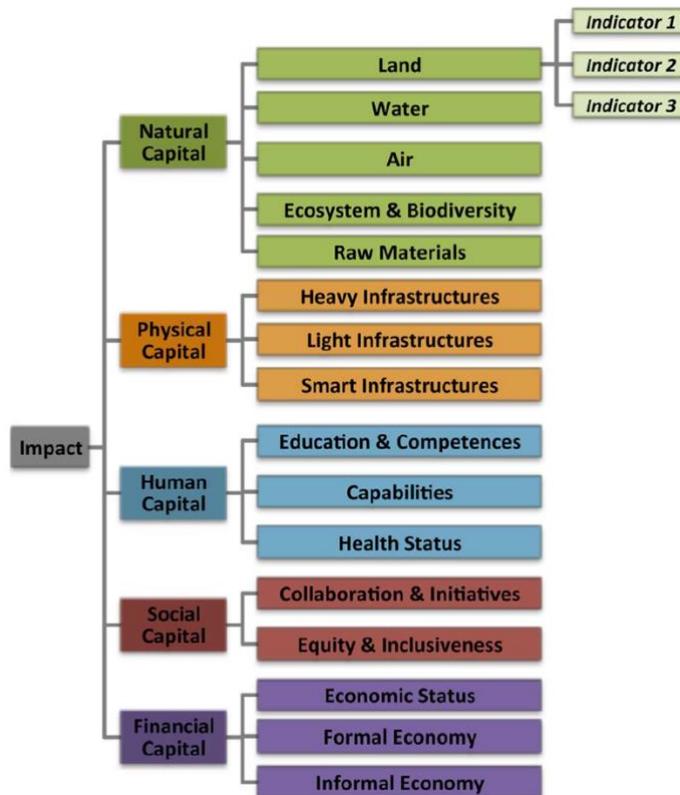


Figure 18 - Typical hierarchy structure of Impact Evaluation Framework [139].

2. **Indicators selection** – Except for some mandatory alerts (complementing indicators of general validity), the user has to fulfil the third level of the structure with freely selected indicators, which must be Objectively Verifiable Indicators (OVIs), SMART (specific, measurable, available, relevant, time-bound) and independent of each other. It is certainly essential that the selected indicators are accurately chosen according to the project context, site and technologies.

3. **Data input and normalisation** – According to the re-scaling method, indicators are normalised in a common range between 1 (corresponding to the worst performance) and 9 (corresponding to the best performance); this way the data referring to the different indicators become consistent, dimensionless and comparable one to each other. Re-scaled values are then further normalised so that the sum of their components is equal to 1 and each component shows the percentage with which once scenario (ex-ante or ex-post) is better than the other one.
4. **Weights assignment** – The user sets the priorities among the different elements in the structures, through qualitative pairwise comparisons. In particular, “importance scores” are assigned to indicators with respect to their dimension, to dimensions with respect to their capital and, lastly, to each capital; this process leads to the definition of three groups of pairwise comparison matrices, one for indicators, one for dimensions and one for capitals.
5. **Aggregation** – According to the Analytic Hierarchy Process (AHP) methodology [143], normalised and weighted values are then aggregated, in order to get the two comparable scenarios, ex-ante and ex-post. In particular, this procedure starts from the indicators level and, through a bottom-up path, it climbs the hierarchy up to the capitals.
6. **Impact evaluation** – The results obtained after the previous step can be finally used in order to assess the global impact that is expected to be generated by the energy project. Among the many outputs of the analysis, the most meaningful are the General Impact Scores, which shows the overall effect (positive or negative) that the intervention may have on the community, and the Radar Diagram representing the ex-ante and ex-post impact scores for each capital.

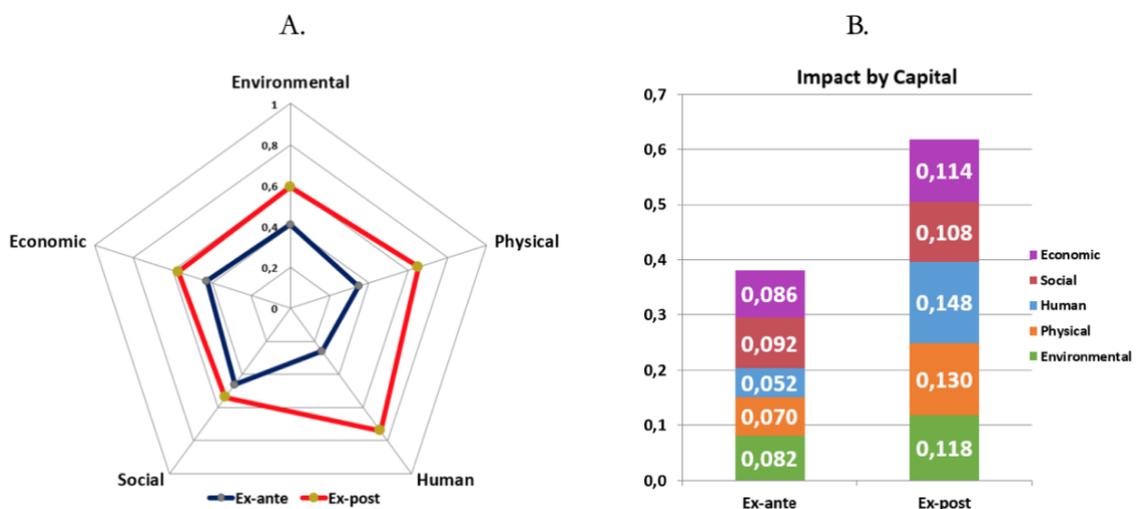


Figure 19 - Radar Diagram with the impact scores of the five capitals (A) and shares of the General Impact Score among capitals (B) [12].

As shown throughout the previous six passages, the IEF consists in an engineering tool that, as long as it is supported by reliable data, provides a flexible and customisable instrument offering, however, standardised and comparable results. Managing to match these two

fundamental requirements, IEF could significantly contribute to the enhancement of the impact evaluation phase within the design of electrification projects.

Ceci et al. [23] recently applied the IEF to the analysed hydroelectric mini-grid project implemented by Fondazione ACRA in Mawengi (Tanzania); actually, they proposed an improved IEF, which limits the user's subjectivity and revises some names and definitions of the comprehensive hierarchy (e.g. Environmental capital, instead of Natural capital). That work was not part of the mini-grid design project, as it was conducted after the system implementation and its aim consisted in verifying the validity of the reviewed IEF. Nevertheless, it also helped the Italian NGO to better characterise the overestimated evaluation previously made. Such detailed results about the effective impact of ACRA's action are particularly important within their relations with donors and stakeholders; moreover, their dissemination may increase the attractiveness of the project towards potential future investors.

4.7 CESP applications

After having analysed in detail the different subsequent phases of the Comprehensive Energy Solutions Planning framework, it is possible to propose a couple of illustrative cases in which the author has applied a synthetic CESP version for the design and sizing of hybrid mini-grids for the electrification of two rural villages, one in Mozambique and the other in Tanzania. As highlighted in the previous sections, following the guidelines and steps defined in the CESP framework allows to carefully plan integrated off-grid solutions that, through the exploitation of local renewable sources and the adoption of a holistic multi-sectorial approach, are capable of meeting the energy needs of the target communities and promoting local socio-economic development. The delineation of a complete and detailed CESP planning requires time, resources and, above all, an insisted presence of the developers in the field. The latter, in particular, should not be limited to the implementation phase of the project, but, as already stressed, it needs to be continuous and extended over time: above all, it is necessary that, before the installation, developers conduct a careful direct assessment of local needs, carrying out local people engagement activities, in order to realise a project tailored to the target community.

Despite these fundamental prerequisites, clearly difficult to completely fulfil here, it has been possible to carry out a mini-grid design path focused on the more technical CESP phases, crucial for the precise dimensioning of the implemented system. In particular, the proposed applications are developed according to the three following linked steps:

- the definition of the type and order of magnitude of the electrical appliances that are realistically used in the selected village, to outline its average power consumption, also considering that the implementation of a reliable and affordable energy supply may lead to an increase in local demand;
- the calculation of the daily and annual load curves thanks to the use of RAMP, the aforementioned bottom-up stochastic tool developed by SESAM Group that allows to

generate high-resolution multi-energy load profiles for the analysis of energy systems implemented in remote rural areas;

- the technical design and sizing of an off-grid plant able to meet the identified energy needs, using MicroGridsPy, the open-source modelling tool specifically conceived to optimise the dimensioning process of hybrid mini-grids, offering the cost-optimal solution for the target context, in terms of installed technologies and dispatch strategy.

The two rural villages selected for the application of this synthetic CESP framework are Namanjavira Sede (Mozambique) and Kitole (Tanzania), two communities which are still unelectrified, but are part of the electrification projects of two Italian NGOs, respectively COSV and CEFA. Thanks to this aspect and to the collaborative experiences between the two organizations and the SESAM Group from Polimi, it has been possible to view interviews and questionnaires conducted in the two villages, in order to get the minimum information necessary to carry out a realistic study about the electrical appliances owned and used by local dwellers. However, given the mentioned limitations in terms of time and resources, this work is not intended to define detailed strategies for the electrification of the considered villages, but rather to illustrate the applicability of the technical phases of CESP framework, showing their validity and the complementarity of the used modelling tools, RAMP and MicroGridsPy. Finally, it is important to point out that different assumptions were made in the two case studies: with regard to the intervention in Namanjavira Sede, the mini-grid is supposed to serve domestic users only; in the design of the mini-grid for the village of Kitole, on the other hand, the power consumption of some income-generating activities and those of a health centre and a school were also included. This diversification obviously resulted in differently shaped load profiles, leading to different analysis outcomes.

4.7.1 Namanjavira Sede, Mozambique

Namanjavira Sede is a rural village in the Mozambican Province of Zambezia, more precisely in the District of Mocuba. Zambezia is one of the most densely populated provinces in the country (48.7 inh./km²), 70.5% of the population live below the poverty line and 93% reside in rural areas [69]. The conception of such data is further aggravated by considering the energy framework in Mozambique, according to which, for example, in 2017 only 2.18% of rural population had access to electricity [144]. Given the prohibitive costs of extending the national grid and the great potential in terms of renewable resources (solar above all), the Mozambican government has recently shown the willingness to invest on off-grid systems; nevertheless, such investments are struggling to materialise, mainly due to unclear legislation and the fact that currently, in Mozambique, only the state is allowed to sell energy.

Within this context, is located Namanjavira Sede, the target village with a population of 25840 inhabitants (2017), divided into about 5500 households, mainly engaged in subsistence farming and livestock farming. The considered area is 60 km far away from the national grid and therefore not included in the extension projects of EDM (Energia de Moçambique), the energy public utility. In the past, Namanjavira Sede was equipped with a diesel mini-grid, which

ran for three hours a day, but only supplied about 50 users; however, such system has been inactive for some years, especially due to a lack of funds for the maintenance and the purchase of fuel [69].

As already mentioned, Namanjavira Sede has been selected by the Italian NGO COSV as one of the beneficiary sites for the rural electrification programme (Ilumina) in collaboration with AVSI, which aims to increase the access to modern energy within the rural areas of Zambezia and Cabo Delgado provinces. The SESAM Group of Politecnico di Milano has been also involved in this project, in particular carrying out interviews and questionnaires in the villages benefiting from Ilumina programme: the objective of this fundamental priority activity was to outline the socio-economic framework characterising the target area and the energy habits of its inhabitants. In the village of Namanjavira Sede 545 households, about 10% of the total, were interviewed and the results of this survey were fundamental for the author to delineate an overview of the electrical appliances used by the villagers. In particular, the investigation revealed that:

- the vast majority of the respondents (342 out of 545, about 63%) own only a radio and/or a mobile phone;
- televisions (29), stereos (26) and light bulbs (only 33 in the whole village) follow radios and mobile phones, in quantitative terms;
- the framework of the electrical appliances owned by the interviewees is then completed by the presence of 4 fans, 3 personal computers and very few other household appliances, such as 2 fridges and 2 kettles;
- 30% of the inhabitants interviewed (163 out of 545) do not own any electrical devices.

It was therefore necessary to model the local potential consumption starting from these data and according to the input parameters required by RAMP to calculate the load demand. This stochastic tool implemented on a Python environment, in fact, works on the basis of three main modelling layers: the definition of the *User types*, the number of individual *Users* associated to each user type, and the number and nature of *Appliances* owned by each of those users.

On the basis of the previous survey results, it has been possible to define the three-layer structure for this specific case study, in which the designed mini-grid is supposed to meet only household energy needs. The domestic users were thus divided into four income-based categories according to the appliances they owned; the number of users identified in each income-based category was defined taking into account that the surveyed households represent about 10% of those in the whole village and that the implementation of a reliable and affordable electricity supply service may drive consumers to buy new appliances, with a consequent growth in local power consumption and a reduction in the population without devices. Table 19 shows the four income-based *User types*, with the number of individual households identified in each of them and the appliances owned by their users.

| User Types | Number of Users | Electric Appliances |
|---------------------------------------|-----------------|--|
| High-Income households (HI) | 55 | 4 phone chargers, 1 radio, 1 TV, 1 stereo, 7 indoor bulbs, 2 outdoor lights, 1 fridge, 1 fan, 1 kettle |
| Higher-Middle-Income households (HMI) | 110 | 3 phone chargers, 1 radio, 1 TV, 1 stereo, 4 indoor bulbs, 1 outdoor light, 1 fan |
| Lower-Middle-Income households (LMI) | 260 | 2 phone chargers, 1 radio, 1 TV, 2 indoor bulbs |
| Low-Income households (LI) | 3540 | 1 phone charger, 1 radio, 1 indoor bulb |

Table 19 – Framework of Users Types and appliances used in Namanjavira Sede.

As required by RAMP, it is necessary that each of the identified appliances is detailed in terms of power consumption, average and minimum daily usage time, number and extension of its daily functioning windows and the percentage random variability over the appliance usage time and over the starting and ending times of its functioning windows. It is also possible to further characterise the framework, for example, stating whether all the appliances of the same kind are always switched on together, indicating if the considered appliance usage is associated with weekdays or weekends and setting the probability that the appliance is everyday included in the mix of devices that the user actually uses. Finally, there is the possibility to model the duty cycles of those appliances (e.g. fridges) working in this mode.

All this information needed to be set in a file that represents the only input to the software. Once received it, RAMP, through its three-layer structure, independently models the behaviour of each ijk^{th} *Appliance*, so as to define the load profile of each ij^{th} *User* of each i^{th} *User type*. All the independent *Users* profiles are then aggregated by the software in a total daily load curve, uniquely generated at each model run; multiple model runs generate different total daily profiles, reproducing the inherent randomness and unpredictability of users' habits. Figure 20 shows the daily curves generated with a one-minute resolution by RAMP regarding the power consumption of households in Namanjavira Sede: in particular, it is possible to distinguish the 365 curves independently generated for each day of the year (light blue) from the average daily profile resulting from them (dark blue).

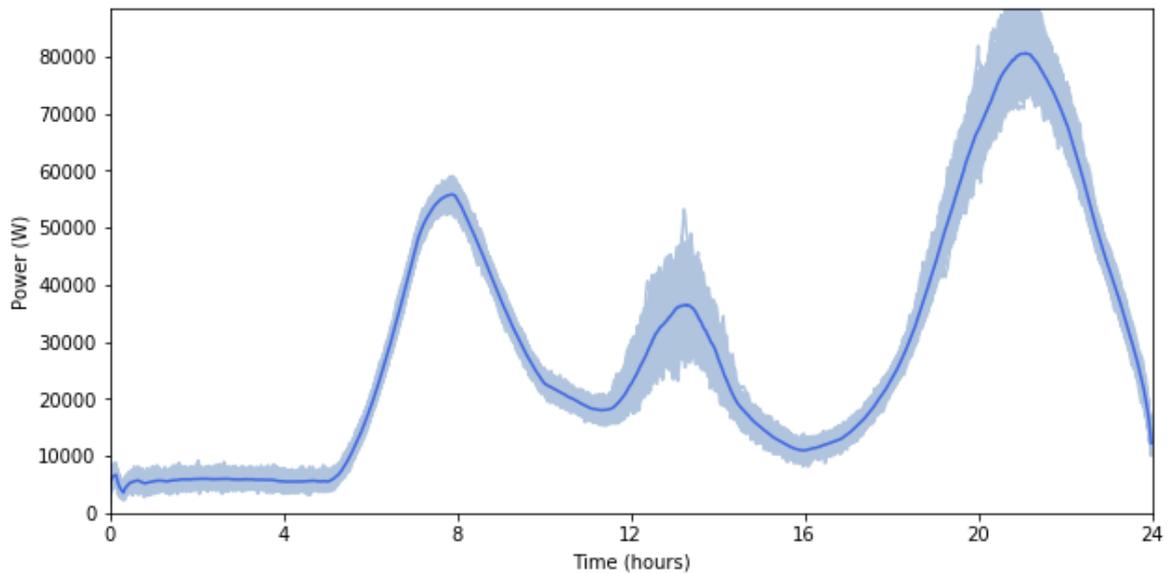


Figure 20 - Daily load curves of Namanjavira Sede households, generated by RAMP.

The load curve represented in Figure 20 follows the typical profile of household power consumption: a global peak, ranging from 70 and 90 kW and mainly due to domestic lighting, stands out in the evening hours; there are also two local peaks respectively in the early morning hours (50-60 kW), when the population wakes up, and at lunchtime (30-50 kW); the absence of work activities taken into account in the study inevitably resulted in a significant lowering of the curves in the late morning and afternoon hours. From the figure it is also easy to note that the consideration of domestic uses only, albeit divided into four different categories, led to the definition of total daily curves not too dissimilar too each other, therefore characterised by a reduced overall variability.

RAMP also returned a file.csv containing the 525,600 power values that the village domestic demand takes in every minute of the year. Once converted the minute values into hourly values, this file represented one of the inputs needed to run MicroGridsPy and carry out the actual dimensioning process of the mini-grid for Namanjavira Sede. As mentioned in the section about the CESP Technical Design phase, in addition to the one-hour resolution yearly load profile of the target village, MicroGridsPy required in input another Excel file with the one-hour resolution VRES time series for each of the renewable technology units considered (PV and wind), specifically referred to Namanjavira Sede and obtained from Renewables.ninja [132]. Finally, it was necessary to define the characteristic features of the project and the techno-economic parameters regarding the different components of the system. Table 20 lists the parameters concerning the project in Namanjavira Sede and the technologies that are supposed to be implemented.

| Project and techno-economic parameters (Namanjavira Sede) | | |
|---|-------------------------------------|-------|
| Project | Project lifetime [y] | 20 |
| | Discount rate [%] | 11.07 |
| Li-ion Batteries | Investment cost [USD/Wh] | 0.35 |
| | Electronic investment cost [USD/Wh] | 0.275 |
| | O&M cost [% of inv. cost] | 5 |
| | Round-trip efficiency [%] | 97.5 |
| | Depth of discharge [%] | 80 |
| | Max. charge/discharge time [h] | 3 |
| | Lifetime [equivalent full cycles] | 7500 |
| | Initial SOC [%] | 100 |
| PV panels | Inverter Efficiency [%] | 96 |
| | Investment cost [USD/Wh] | 1.7 |
| | O&M cost [% of inv. cost] | 2 |
| | Lifetime [years] | 20 |
| Wind | Investment cost [USD/Wh] | 2.4 |
| | O&M cost [% of inv. cost] | 5 |
| | Lifetime [years] | 20 |
| Diesel generator | Investment cost [USD/Wh] | 1.1 |
| | O&M cost [% of inv. cost] | 3 |
| | Lifetime [years] | 20 |
| | Efficiency [%] | 30 |
| | Diesel LHV [Wh/L] | 9840 |
| | Diesel cost [USD/L] | 0.83 |

Table 20 – Project and techno-economic parameters about Namanjavira Sede mini-grid.

With regard to project details, a 20-year life expectancy has been assumed for the mini-grid and, therefore, the discount rate is equal to the 20-year treasury rate in Mozambique (11.07% in January 2020 [145]). Furthermore, for the storage system in Namanjavira Sede, the author opted for the implementation of lithium-ion batteries, which, together with lead-acid batteries, are currently the only ones suitable for small off-grid applications: compared to the latter, Li-ion

batteries are more expensive, but also more efficient and more durable (the techno-economic data used in the application were taken from IRENA report “Electricity storage and renewables: costs and market to 2030” [146] and the “Comparative study of techno-economics of lithium-ion and lead-acid batteries in mini-grids in Sub-Saharan Africa” by USAID and NREL partnership [147]). The techno-economic parameters concerning photovoltaic, wind and diesel technologies, on the other hand, were taken from the “Sustainable Energy Handbook” published by the European Commission [148]. Finally, the diesel cost reported in Table 20 refers to April 2020 for the Mozambican market.

Set the inputs required by MicroGridsPy, the modelling tool implemented on Python and using the Pyomo library operated the cost-optimal sizing of lithium-ion batteries, diesel gensets and renewable technologies, returning a hybrid mini-grid layout that minimises the net present cost (NPC) of the system calculated over the project lifetime. Specifically, the power production is ensured by an 85 kW PV solar field coupled with 31.5 kW diesel generation, for a total installed power of 116.5 kW; a Li-ion battery storage system, with a nominal capacity of 187.5 kWh, is also planned to be installed to store the excess solar energy produced during the day. Scrolling through the technical data of the mini-grid designed for Namanjavira Sede in Table 21, it is immediately noticeable the absence of the wind component among the installed technologies: the low wind potential of the target area and the higher costs of this renewable technology compared to the other two considered, in fact, led the software and its optimisation process to exclude its installation.

| Mini-Grid Technical Data (Namanjavira Sede) | |
|--|---------|
| PV nominal capacity [kW] | 85 |
| Diesel generator nominal capacity [kW] | 31.5 |
| Li-ion batteries nominal capacity [kWh] | 187.5 |
| Renewable penetration [%] | 53.2 |
| Yearly curtailment [%] | 1.99 |
| Mini-Grid Economic Data (Namanjavira Sede) | |
| PV investment [USD] | 144,369 |
| Diesel generator investment [USD] | 34,646 |
| Li-ion batteries investment [USD] | 65,608 |
| Total investment [USD] | 244,623 |
| NPC [USD] | 578,003 |
| LCOE [USD/kWh] | 0.29 |

Table 21 – Technical and economic data about the dimensioned mini-grid in Namanjavira Sede.

Investment Costs (Namanjavira Sede)

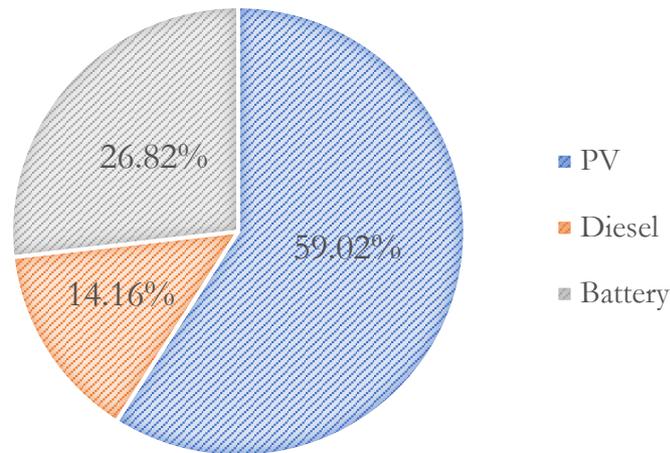


Figure 21 - Investment costs share of the mini-grid in Namanjavira Sede.

In terms of costs, the total investment needed to build the hybrid mini-grid of Namanjavira Sede equals USD 244,623, of which approximately 59% is due to the solar field, almost 27% to diesel generators and 14% to the storage system; the NPC of the entire system is calculated at USD 578,003. The optimisation process operated by MicroGridsPy returns a particularly low LCOE, equal to USD 0.29 per kWh. According to the Rocky Mountain Institute (RMI) the best-run hybrid solar-diesel mini-grids, in 2018, had an LCOE of at least USD 0.60 per kWh, but their analysis showed that this value could be reduced to USD 0.23 per kWh by 2020, as a result of several factors (PV technology cost reduction most of all) [149]. Now that it is 2020, the value calculated by the modelling tool for this case study is very close to the target set by the RMI, mainly due to the actual continuous cost reduction of PV technology and Li-ion batteries. The high interest rate at which cash flows are discounted (11.07%), due to the weak economy of Mozambique, has certainly also contributed to the definition of a low LCOE.

MicroGridsPy offered also the cost-optimal solution for the dispatch of the selected energy technologies throughout the different phases of day and night. From the graph in Figure 22, it is possible and obvious to note that, during the day, the main power source is represented by the implemented solar field (yellow dotted line), which, in part, directly feeds the demand of the village (green continuous line), in part, with the excess energy produced, recharges the installed batteries (red dotted line). The 80-kW evening peak, on the other hand, is met jointly by the energy stored during the day in the batteries and by the diesel generators (light blue dotted line); the latter then continue to deliver the little energy required during the night and the energy needed to meet the local morning peak, to whose fulfilment the first daily solar generation also contributes. This strategy guarantees a very low curtailment of the produced solar energy (1.99% in the whole year) and a renewable penetration of 53.2%.

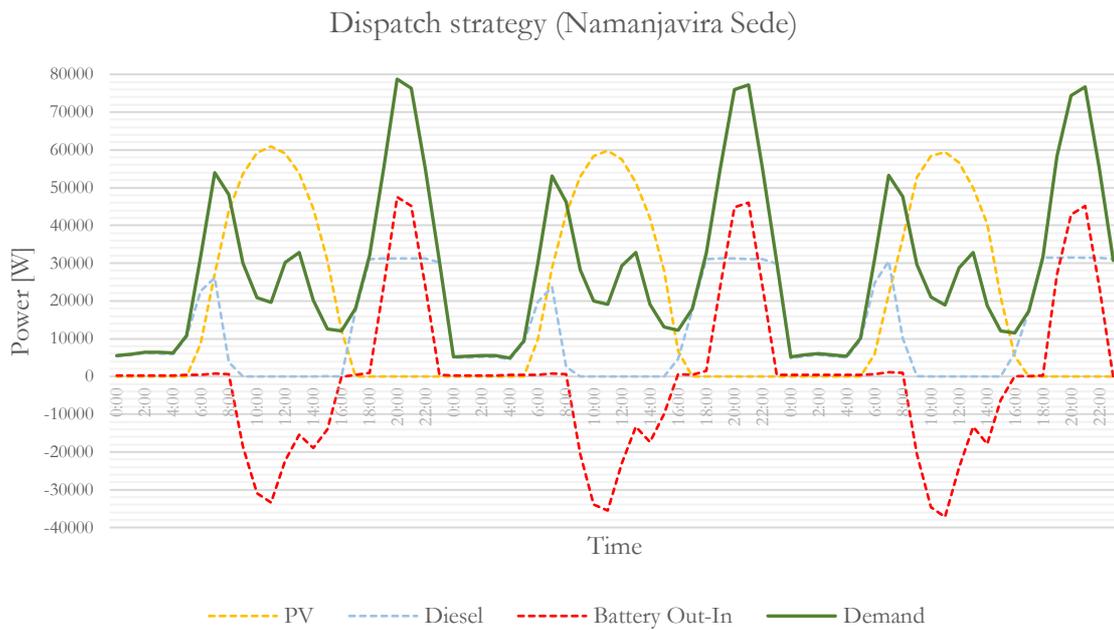


Figure 22 - Outlook of the energy dispatch of the mini-grid in Namanjavira Sede (6th-8th of June).

4.7.2 Kitole, Tanzania

The second rural village selected for this CESP application is Kitole, a small community in the District of Njombe, in Tanzania. As already mentioned in section 3.1, Tanzania has the advantage over the vast majority of other African countries that it has not experienced any civil war since its independence, a factor that has always guaranteed greater socio-political stability, the results of which are visible in the economic development of recent years. This growth has also been reflected in the energy sector, so much so that the percentage of the population in Tanzania with access to electricity has increased from 14.8% in 2010, to 32.8% in 2017; in the rural areas of the country, the figure for access to electricity has risen from 2.52% to 16.76% [16]. Although these values are high compared to the average in Sub-Saharan Africa, too many people in rural Tanzania still have no access to modern energy, especially considering that the country's renewable off-grid potential is still under-exploited.

Most of the inhabitants of Njombe District rely on subsistence agriculture and 67% of the households in the district has a farming activity: bean, tea and maize crops are the most widespread in the area [21]. This strict dependence also applies to Kitole, which is inhabited by about 1320 people (201 households) and which is not far from Matembwe and Ikondo, the two villages where CEFA has realised the hydroelectric mini-grids analysed in the chapter dedicated to the study of the projects of Italian NGOs [18]. Kitole is still unelectrified, but there is the possibility that it will be included in CEFA's electrification programme, which covers the entire rural area between the two mini-grids of Matembwe and Ikondo, interconnected in 2011.

Assuming that, for geographical reasons or due to insufficient hydropower to electrify all the villages in the area, Kitole cannot be connected to the existing distribution network, in this

section the author carried out a study to design a small-sized mini-grid specifically for the considered rural village. The approach adopted in this case study is the same as for the village of Namanjavira Sede, therefore made up of three main steps: the definition of the framework of the electrical appliances used in the village, the calculation of the load curve with the help of RAMP, and the sizing of the mini-grid carried out with MicroGridsPy. The main difference from the application for the Mozambican centre lies in the fact that, in the case of Kitole, the implemented mini-grid is supposed to meet not only the domestic energy needs, but also those of some local productive uses and public services.

In this case too, the author had the opportunity to refer to field studies in order to model the power consumption of the inhabitants of Kitole. Fabrizio Colombelli, former student of Politecnico di Milano, in 2019 carried out a master thesis focused on CEFA's aforementioned rural projects in the Region of Njombe [18]; within that study he conducted the assessment of the energy requirements of some villages, including Kitole itself, which was then selected for the CESP application in this work. In particular, Colombelli interviewed 15 of the 201 households present in the village and 8 work activities, including a carpentry, two bars, a milling machine and a tailor shop. This investigation highlighted the use of few electrical appliances by the local population, showing that the most recurring devices are indoor and outdoor lights (respectively owned by 65% and 40% of the respondents), followed by radios (50%), phone chargers (30%) and TVs (4%).

Based on the results of the survey, the local electricity consumption framework was defined according to the three-layer structure required by RAMP. Following the same logic used for the case of Namanjavira Sede, the domestic users were divided into three income-based categories, while, as regards business activities, some literature-based assumptions were made on the type and power of the appliances they potentially use. Finally, it was supposed to meet also the demand of an equipped health centre and school, whose presence in the village was hypothesized in order to have a more complex and detailed energy framework.

| User Types | Number of Users | Electric Appliances |
|-------------------------------|-----------------|--|
| High-Income households (HI) | 10 | 4 phone chargers, 1 radio, 1 TV, 1 stereo, 6 indoor bulbs, 2 outdoor lights, 1 washing-machine |
| Middle-Income households (MI) | 40 | 3 phone chargers, 1 radio, 4 indoor bulbs, 2 outdoor light |
| Low-Income households (LI) | 130 | 2 phone charger, 1 radio, 2 indoor bulbs |
| Tailor shop | 1 | 2 tailor machines |
| Carpentry | 1 | 2 drillers, 1 jigsaw, 1 planer, 1 welding machine |
| Bars | 2 | 1 fridge, 1 freezer, 1 kettle, 1 mixer |
| Milling activity | 1 | 1 milling machine |
| Health centre | 1 | 12 indoor bulbs, 1 outdoor light, 8 phone chargers, 3 fridges, 2 PCs, 1 mixer |
| School | 1 | 8 indoor bulbs, 6 outdoor bulbs, 5 phone chargers, 18 PCs, 1 printer, 1 fridge, 1 TV, 1 DVD player, 1 stereo |

Table 22 – Framework of Users Types and appliances used in Kitole.

All the appliances listed Table 22 above have been characterised in detail, according to the realistic energy habits of the users and setting all the mentioned specific features required by RAMP. Once completed the input file with all the information about *User Types*, *Users* and *Appliances*, the software aggregated the independent profiles of the individual users, processing the 365 daily load curves in light blue in Figure 23; the dark blue profile represents the average load curve of all Kitole users.

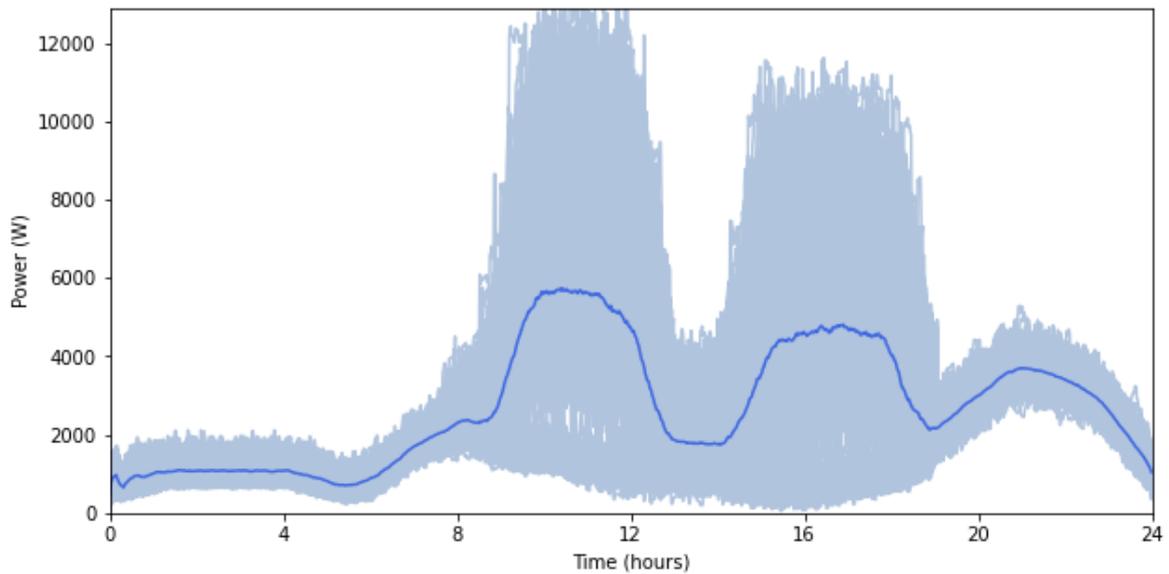


Figure 23 - Daily load curves of Kitole users, generated by RAMP.

The curve just obtained is very different from the one elaborated for the village of Namanjavira Sede, both in terms of size and shape. The two peaks of the average profile are around 5-6 kW and are mainly determined by the productive uses of electricity (the milling machine and the carpentry tools have a particularly high consumption); for the same reason, these peaks occur in the morning and afternoon working hours; a local evening peak of about 4 kW is also evident, obviously due to domestic users, mainly in relation to the indoor lighting of the houses. It is important to point out that the dark blue curve is the average load profile resulting from weekdays, when the activities are operational, and weekends, when the village demand is only due to the households and the health centre: consumption in the two different types of days is therefore very different, and, as the light blue curves show, the power peaks on working days can also exceed 12 kW. The substantial profile diversity due to the weekdays-weekends binomial and the consideration of nine different *Users types* inevitably led to a much greater consumption variability over the year with respect to the case of Namanjavira Sede.

Fortunately, the high variability of Kitole's consumption is not a problem for MicroGridsPy, which receives as input the day-by-day annual demand processed by RAMP, with a one-hour resolution. For this application too, it was necessary to fill an input Excel file with the solar and wind time series referred to the area of Kitole and downloaded from Renewables.ninja. Finally, Table 23 shows the techno-economic parameters, required as input by the software, concerning the project and the different technologies that are supposed to compose the generation and storage system for the village.

| Project and techno-economic parameters (Kitole) | | |
|---|-------------------------------------|-------|
| Project | Project lifetime [y] | 20 |
| | Discount rate [%] | 15.85 |
| Li-ion Batteries | Investment cost [USD/Wh] | 0.35 |
| | Electronic investment cost [USD/Wh] | 0.275 |
| | O&M cost [% of inv. cost] | 5 |
| | Round-trip efficiency [%] | 97.5 |
| | Depth of discharge [%] | 80 |
| | Max. charge/discharge time [h] | 3 |
| | Lifetime [equivalent full cycles] | 7500 |
| | Initial SOC [%] | 100 |
| PV panels | Inverter Efficiency [%] | 96 |
| | Investment cost [USD/Wh] | 1.7 |
| | O&M cost [% of inv. cost] | 2 |
| | Lifetime [years] | 20 |
| Wind | Investment cost [USD/Wh] | 2.4 |
| | O&M cost [% of inv. cost] | 5 |
| | Lifetime [years] | 20 |
| Diesel generator | Investment cost [USD/Wh] | 1.1 |
| | O&M cost [% of inv. cost] | 3 |
| | Lifetime [years] | 20 |
| | Efficiency [%] | 30 |
| | Diesel LHV [Wh/L] | 9840 |
| | Diesel cost [USD/L] | 0.86 |

Table 23 – Project and techno-economic parameters about Kitole mini-grid.

The differences with respect to the parameters set for the project of Namanjavira Sede are represented by the discount rate, here obviously equal to the Tanzanian 20-year treasury bond (15.85% [150]), and by the diesel cost (USD 0.86 per litre in Tanzania in April 2020). Also for the mini-grid of Kitole the author opted for the installation of lithium-ion batteries, preferred to lead-acid batteries for their performance.

Received the necessary inputs, MicroGridsPy, according to its optimisation logic, processed the data, thus dimensioning a small-sized hybrid mini-grid, powered by 10 kW of PV panels and a 2.7-kW diesel generator, and supported by a Li-ion storage system with a capacity of 18.3 kWh. It is easy to note that, given the lower energy demand, the sizes of the different components, and consequently the related costs, are significantly reduced compared to the mini-grid sized for Namanjavira Sede. Nevertheless, the general plant layout is very similar, with the exclusion, also in this case, of wind technology, expensive and not adequately exploitable in the target area.

| Mini-Grid Technical Data (Kitole) | |
|--|--------|
| PV nominal capacity [kW] | 10 |
| Diesel generator nominal capacity [kW] | 2.7 |
| Li-ion batteries nominal capacity [kWh] | 18.3 |
| Renewable penetration [%] | 62.3 |
| Yearly curtailment [%] | 7.3 |
| Mini-Grid Economic Data (Kitole) | |
| PV investment [USD] | 17,124 |
| Diesel generator investment [USD] | 2,937 |
| Li-ion batteries investment [USD] | 6,402 |
| Total investment [USD] | 26,463 |
| NPC [USD] | 48,261 |
| LCOE [USD/kWh] | 0.34 |

Table 24 – Technical and economic data about the dimensioned mini-grid in Kitole.

Investment Costs (Kitole)

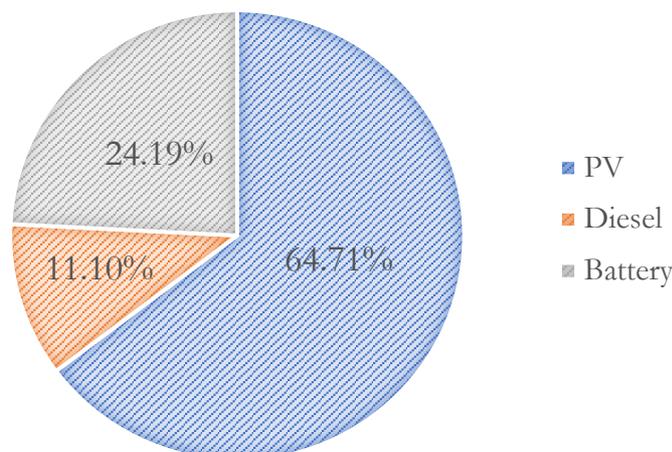


Figure 24 - Investment costs share of the mini-grid in Kitole.

The total investment required for the realisation of this hybrid mini-grid is USD 26,463, shared by the three main technologies according to the diagram in Figure 24: the necessary expenditure for the solar field (USD 17,124) represents almost 64% of the total investment, followed by the cost of Li-ion batteries (24.19%) and the cost of the diesel generator (11.1%). As already stressed, the objective function of MicroGridsPy is the minimization of the mini-grid NPC, which, for this system, corresponds to USD 48,261. The last important figure is the LCOE, equal to USD 0.34 per kWh and thus higher than that calculated for the mini-grid in Namanjavira Sede: today, in fact, the LCOE of PV technology is still higher than that of diesel production, and, in Kitole's mini-grid, the ratio between the solar nominal capacity and the diesel nominal capacity is higher compared to the plant of Namanjavira Sede.

Analysing Figure 25, it appears that the optimal dispatch strategy generated by MicroGridsPy for the mini-grid of Kitole is slightly more complex than in Namanjavira Sede: during the two daily peaks (in the morning and in the afternoon) all three technologies (PV panels, batteries and generator) simultaneously contribute to meet the high energy demand of the village (around 9.5 kW in these three exemplifying days); the evening peak and the low night demand are fulfilled by the generator and the energy left inside the batteries; while there are only few hours of the day (8:00-9:00 and 12:00-14:00) in which the solar panels provide electricity directly to the users without the contribution of the other two technologies. According to the installed capacities and this strategy, the energy supply service of Kitole would be characterised by a yearly renewable penetration of 62.3% and an annual solar curtailment of 7.3%.

Dispatch strategy (Kitole)

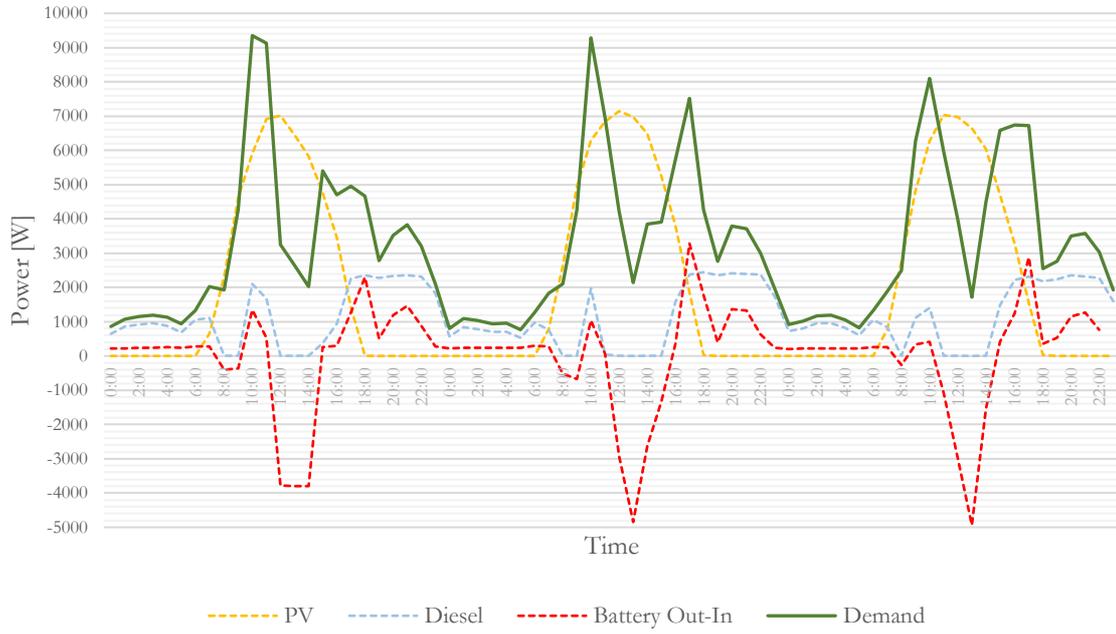


Figure 25 - Outlook of the energy dispatch of the mini-grid in Kitole (6th-8th of June).

Conclusions

On the basis of the work done for the considered research and the different projects and context analysed, several conclusions have been reached.

A first reasoning should be devoted to mini-grid technology in general, which is the common thread of the thesis, and to its application for the electrification of rural areas in developing countries. As mentioned in the introductory chapter, these off-grid systems, typically powered by local renewable sources, represent a suitable solution for the provision of electricity in poorly inhabited remote rural areas. However, mini-grids have not yet reached their full maturity and affirmation. In fact, despite the costs of renewable-based technologies have been greatly reduced in recent years, the total investment required to build a mini-grid is still high and the cost recovery is still long, mainly due to the low and unstable energy demand that generally characterises rural communities.

This trend is confirmed by the analysis of Italian projects carried out within the thesis, according to which the implementation of almost all the considered interventions has been strictly dependent on the grants received from public institutions and/or international agencies. Such reasoning is taken for granted for non-profit organisations, which do not have private equity and therefore rely on donations, but it also applies to the studied private companies, among which the only exception is ENGIE Eps, which, since it was acquired by the French energy giant, can count on the financing of the holding company.

Another important barrier to investments in the mini-grid market, which has emerged in the treatment of the various projects, is represented by the unclear and unreliable policies that typically govern the energy sectors in Sub-Saharan African. This problem particularly affects the countries of Central Africa, such as DRC, Uganda and Burundi, which come from a particularly bloody and turbulent recent history that does not yet guarantee the socio-political stability fundamental for the definition of reliable energy regulations and the attraction of foreign investments.

The issues just highlighted have certainly contributed to limiting the Italian commitment in mini-grid projects in Africa, which, as shown in the thesis, is particularly reduced and mainly led by non-profit organisations, while there are very few private actors involved.

However, it is important to point out that the approach adopted by the different Italian organizations and companies identified is generally moving towards the same direction. With the exception of private turn-key mini-grid providers, in fact, all the other players are not limited to the installation of energy systems only, but also engage in complementary activities aimed at promoting local socio-economic development and supporting the difficult economic sustainability of mini-grid projects. This cross-sectorial method of intervention is mainly pursued by NGOs, but, as shown in Chapter 3, private companies have also started to work in a more integrated perspective.

The Comprehensive Energy Solutions Planning (CESP) proposed and deeply analysed in Chapter 4 aims precisely to provide guidelines to carry out holistic energy access interventions guaranteeing sustainable and long-term impacts. The examples reported in the text and the applications in Section 4.7 show how the step-by-step CESP methodology, appropriately conducted and supported by precise modelling tools, could contribute to the enhancement of mini-grids design and sizing process, increasing their cost-effectiveness and providing a reliable and affordable provision service to the target community.

A final consideration must be made regarding a factor that concerns the recent politics of our country. By signing Agenda 2030, Italy took on the goal to reach, by 2030, the target for an official development assistance (ODA) to gross national income (GNI) ratio of 0.7%, and, in accordance with this objective, the value grew rapidly from 0.14% in 2012 to 0.3% in 2017. This achievement was certainly an important milestone for Italy, which, however, in 2017 was still ranked 13th among OECD-Dac countries, considering that countries such as Sweden and Norway have ratios higher than 1% [151]. Nevertheless, the prospects for further growth of the ratio dropped in 2018, when Italy's ODA/GNI ratio fell to 0.24%, with a 21.3% decrease from the year before, corresponding to a cut of more than €860 million in international development assistance funds [151]. The crisis that will inevitably follow the COVID-19 pandemic will lead affected countries to concentrate their economic efforts on their territory, further reducing the Italian public funds for international development assistance, and therefore for mini-grid projects.

List of Abbreviations

A4D – Agriculture for Development
ABER – Agence Burundaise d’Electrification Rurale
AE – Absolute Energy
AHP – Analytic hierarchy process
AICS – Italian Agency for Development Cooperation
ANAPI – National Investment Promotion Agency
BCR – Benefit/cost ratio
BIAC – Banque Internationale pour l’Afrique au Congo
BVC – Bomalang’ombe Village Company
CADEP – Comité des Agriculteurs pour le Développement Participatif
CAST – Church Alliance for Social Transformation
CESP – Comprehensive Energy Solutions Planning
CIRPS – Inter-university Research Centre for Sustainable Development
CNE – National Energy Commission
DAC-OECD – Development Assistance Committee of the Organisation for Economic Cooperation and Development
DFID – Department for International Development
DSM – Demand side management
E4G – Energy4Growing
E4I – Energy for Impact
EDCL – Energy Development Corporation Limited
EDSA – Electricity Distribution and Supply Authority
EEP – Energy Environment Partnership
EFO – Energy for Opportunity
EG – EnerGrow
EGP – Enel Green power
EGTC – Electricity Generation and Transmission Company
EnDev – Energising Development
ENPV – Energy project’s net present value
EP – Equatorial Power
EPC – Engineering, procurement and construction
ESMAP – Energy Sector Management Assistance Programme
EUEI-PDF – European Union Energy Initiative Partnership Dialogue Facility
EUPL – European Union Public License
EWRC – Energy and Water Regulatory Commission
EWURA – Energy and Water Utilities Regulatory Authority
FP – Fundacion Paraguaya

FUNAE – Fundo de Energia
 GDP – Gross domestic product
 GIS – Geographic information system
 GNI – Gross national income
 HDI – Human development index
 IDS – Institute for Development Studies
 IEF – Impact evaluation framework
 IRENA – International Renewable Energy Agency
 IRR – Internal rate of return
 ISEA – Institut Supérieur d’Etudes Agronomiques
 LCOE – Levelized cost of electricity
 LP – Linear programming
 MAFFS – Ministry of Agriculture Forestry and Food Security
 MEHR – Ministry of Energy and Hydraulic Resources
 MEM – Ministry of Energy and Minerals (Tanzania)
 MEM – Ministry of Energy and Mines (Burundi)
 MGA – Micro Grid Academy
 MILP – Mixed-integer linear programming
 MVC – Matembwe Village Company
 NDO – Njombe Development Office
 NECSOM – National Electric Corporation of Somalia
 NGO – Non-governmental organisation
 NPC – Net present cost
 NPFPP – Non-profit/for-profit partnership
 O&M – Operation and maintenance
 OSC – Organizzazione della società civile
 OVI – Objectively verifiable indicator
 PAYG – Pay-as-you-go
 PH – Powerhive
 PPA – Power purchase agreement
 PRESSD-SL – Promoting Renewable Energy Services for Social Development in Sierra Leone
 PUE – Productive use of electricity
 RAMP – Remote-Areas Multi-energy systems load Profiles
 REA – Rural Energy Agency
 REF – Rural Energy Fund
 REGIDESO – Régie de Production et Distribution d’Eau et d’Electricité
 RICA – Rwanda Institute for Conservation Agriculture
 RMI – Rocky Mountain Institute
 RREP – Rural Renewable Energy Project
 SD – System Dynamics
 SDG – Sustainable Development Goal

SE4ALL – Sustainable Energy for All
SESAM – Sustainable Energy Systems Analysis and Modelling
SHIPO – Southern Highlands Participatory Organisation
SIDA – Swedish International Development Cooperation Agency
SLF – Sustainable livelihoods framework
SME – Small-medium enterprise
SNEL – Société Nationale d’Electricité
SOGER – Scaling up Off-grid Energy in Rwanda
SSA – Sub-Saharan Africa
STEP-RES – Socio-technical-ecological Evaluation of Potential Renewable Energy Systems
TANESCO – Tanzania Electric Supply Company
UMC – Unit for the Management and Coordination
UNDP – United Nations Development Programme
UNIDO – United Nations Industrial Development Office
UNOPS – United Nations Office for Project Services
UPROGL – Université Progressiste de Gran Lacs
USAID – United States Agency for International Development
VRES – Variable renewable energy sources
VRFB – Vanadium redox flow battery
WEF – Water-energy-food
WHH – Welthungerhilfe

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