POLITECNICO DI MILANO

SCUOLA DI INGEGNERIA INDUSTRIALE E
DELL'INFORMAZIONE
CORSO DI LAUREA MAGISTRALE IN INGEGNERIA GESTIONALE

ANALYSIS OF DECISIONAL METHODS FOR RENEWABLE ENERGY INVESTMENTS IN DEVELOPING COUNTRIES

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Anno Accademico 2013-2014

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ABSTRACT

Italian

La tematica energetica è, negli ultimi anni, una questione ricorrente a livello internazionale e la cui strategicità è in costante aumento. Il crescente interesse verso questo tema, senza dubbio molto complesso ed articolato, è dovuto essenzialmente al fatto che oggi l'energia rappresenta una componente essenziale per svolgere le azioni quotidiane, tanto è vero che la maggior parte delle attività esplicate nei principali settori economici hanno un collegamento, diretto o indiretto, con l'utilizzo di energia.

Alla luce di questo verrà di seguito affrontata la problematica dell'*energy investment* e della sua valutazione strategica, con una particolare attenzione verso la diffusione delle fonti di energia rinnovabile nei paesi in via di sviluppo. Infatti è proprio in questi contesti che l'*energy investment* incontra i maggiori ostacoli, dovuti principalmente alla mancanza di procedure e strumenti tecnici di valutazione completi e affidabili, con cui gli investitori possano sviluppare una macro-analisi di fattibilità a dimostrazione della sostenibilità economico-finanziaria, sociale ed ambientale dell'investimento.

Nondimeno, la mancanza di meccanismi finanziari efficaci nel ridurre il rischio di investimento porta gli interessi dei fornitori di capitale e delle istituzioni finanziarie lontano da progetti di questo tipo. Perciò è necessario sviluppare nuovi criteri di finanziamento delle tecnologie ad energia rinnovabile in paesi in via di sviluppo.

L'analisi condotta non si focalizza su un'unica area geografica, ma espande le proprie considerazioni a tutti quei paesi che mostrano contesti simili a quelli prima citati, dove quindi ci si può basare sulle medesime ipotesi per svolgere delle corrette ed esaustive valutazioni di investimento.

Il punto di vista assunto nell'analisi è quello del generico investitore, o meglio *stakeholder*, che vuole effettuare una valutazione (o pre-valutazione) di fattibilità di investimento, per definirne il potenziale non solo a livello di ritorno economico, ma considerando anche altri aspetti critici per il successo del progetto.

L'obiettivo di questo lavoro è proprio quello di fornire uno strumento, o meglio un insieme di procedure volte a guidare l'investitore ad un corretto approccio e valutazione dell'investimento in energie rinnovabili nelle zone meno sviluppate del pianeta.

ABSTRACT

English

The energy topic is, in the last years, a world-wide recurring subject and its strategic importance is constantly growing. The increasing interest towards this theme, very complex and widely structured without a doubt, is basically due to the fact that today energy represents a fundamental tool to carry out daily actions, so much so that most activities in the main economic industries have a direct or indirect link to the use of energy.

In view of this, the issue regarding the energy investment and its strategic assessment will be examined, with a particular focus on the diffusion of renewable energy (RE) sources in developing countries. That's because in this context the energy investment faces the major obstacles, principally due to the lack of procedures and reliable technical instruments; those are critical tools for stakeholders to develop a feasibility analysis in order to show the economic, financial, social and environmental sustainability of the investment.

Nonetheless, the lack of financial mechanisms able to effectively reduce the risk of investment determines the shift of the interests of financers and financial institutions away from projects of this type. As a consequence, it is necessary to develop new financial schemes for REs in developing countries.

The proposed work is not focused on a single geographic area, but enlarges its considerations to all those countries that show a similar context to the one previously mentioned, where you can make the same assumptions to carry out correct and exhaustive evaluations of investment.

The point of view assumed in the evaluation process is the one of a generic investor, or stakeholder, who wants to conduct a feasibility analysis of the investment, in order to define its potential regarding the return on investment, and also considering other key factors for the success of the project.

The ultimate aim of this work is to supply a set of procedures, or even a tool, to guide the investor to a correct approach and assessment of RE investment in developing countries.

EXECUTIVE SUMMARY

La domanda mondiale di energia è in costante aumento e le previsioni per il futuro confermano il trend attuale. Petrolio, carbone e gas naturale rappresentano i mezzi attraverso cui la crescente richiesta di energia verrà soddisfatta, a meno che le fonti di energia pulita e rinnovabile non siano rese maggiormente attrattive di quanto non lo siano oggi, in modo da rappresentare delle valide alternative alle fonti tradizionali.

Nonostante ciò, negli ultimi anni il mercato elettrico sta attraversando una radicale trasformazione in tutto il mondo [1]. Una drastica riduzione nelle emissioni di gas ad effetto serra può essere ottenuta solamente aumentando la quota delle fonti rinnovabili nel mix produttivo. Per evitare un danno catastrofico al nostro pianeta e al genere umano, è inevitabile dover prendere in considerazione delle fonti di energia sostenibile e a basso impatto ambientale.

In realtà le energie rinnovabili rappresentano già una valida alternativa alle fonti tradizionali in determinati contesti, ascrivibili principalmente ai paesi in via di sviluppo. In particolare, nelle zone rurali di questi paesi, cioè piccole aree abitate lontane dalle principali città e dalle loro infrastrutture, spesso non è possibile estendere la rete elettrica nazionale data la grande distanza che intercorre tra il più vicino punto di allacciamento e la comunità stessa, che quindi rimane " elettricamente isolata" dal resto del paese. In questi casi diventa molto interessante la tematica della **generazione distribuita**, con cui si intende la produzione di energia elettrica in unità elettriche di autoproduzione di piccole dimensioni disperse o localizzate in più punti del territorio (quindi decentralizzata) e allacciate direttamente alla rete elettrica di distribuzione, anziché centralizzata in poche grandi centrali elettriche allacciate invece alla rete elettrica di trasmissione [2].

Inoltre la crescita del prezzo dei combustibili fossili potrebbe contribuire allo sviluppo del modello di generazione distribuita, realizzando su tutto il territorio piccoli impianti di produzione vicini alle singole comunità, cosa resa possibile grazie allo sviluppo delle conoscenze tecnologiche in merito alle *smart grids* [3].

Un interesse crescente è rivolto verso questo tema da parte di diversi tipi di investitori, tra cui soprattutto istituzioni internazionali come la Banca Mondiale, che prendono in grande considerazione l'applicazione di **tecnologie ad energia rinnovabile** a contesti dove la generazione distribuita è l'unica possibilità per estendere la fornitura di energia elettrica alle zone rurali dei paesi sotto-sviluppati, garantendo nel contempo lo sviluppo socio-economico dell'area e la minimizzazione degli impatti ambientali del sistema di produzione dell'energia.

Date le condizioni tecniche, economiche, sociali ed ambientali dei contesti appena descritti, i metodi tradizionali di valutazione dell'investimento, frutto dell'esperienza maturata nei paesi sviluppati, non rappresentano più uno strumento completo e affidabile per la definizione di costi e benefici di questi progetti, perché si basano su ipotesi non più valide per le opportunità citate precedentemente [4].

C'è un ulteriore aspetto da considerare. Non solo gli schemi tradizionali molto spesso non sono allineati con i diversi interessi degli investitori, ma in più le motivazioni per lo sviluppo di energie rinnovabili nascono sempre dai governi dei rispettivi paesi in cui questa alternativa viene presa in considerazione. Per poter realizzare completamente il potenziale delle energie rinnovabili, è necessario un approccio innovativo per motivare gli investitori e diminuire gli esborsi di capitale dei governi nazionali. Dato il budget limitato a disposizione dei governi dei paesi arretrati e la grandi necessità di finanziamento per gli investimenti in energie rinnovabili, gli investitori pubblici, privati ed istituzionali hanno un ruolo fondamentale nello sviluppo delle tecnologie sostenibili. Indubbiamente, la creazione delle condizioni necessarie a rendere le energie rinnovabili attrattive per investitori e società pubbliche è una sfida impegnativa per i decisori istituzionali.

Riassumendo, il fattore di successo in questi contesti difficili si traduce per lo sviluppatore nella **personalizzazione del prodotto a tutti i livelli** (tecnologico, manageriale, organizzativo e finanziario) perché incontri le caratteristiche specifiche del paese di destinazione del progetto. Ad oggi, infatti, il progetto va ben oltre al semplice sviluppo dello specifico impianto in quanto gli aspetti più problematici risultano essere una valutazione integrata dell'investimento, nonché il reperimento di capitali per finanziare tale settore.

Tenendo conto di tutte queste considerazioni, questo lavoro ha l'obiettivo di analizzare lo stato dell'arte delle analisi di fattibilità e delle valutazioni di investimento, nonché l'applicabilità di diversi metodi decisionali per i progetti sopra citati, che potremmo sintetizzare con l'acronimo di "elettrificazione rurale attraverso tecnologie basate su fonti di energia rinnovabile". L'analisi, evidentemente supportata da documenti, articoli scientifici e pubblicazioni ricavati dalla letteratura di genere, comprende nella valutazione sia aspetti tecnico/tecnologici, come ad esempio la previsione della risorsa rinnovabile e la definizione della migliore opzione di distribuzione dell'energia, sia aspetti economico-finanziari che sono chiaramente preponderanti in una valutazione di investimento. Non ultimi, vengono inclusi nella trattazione anche aspetti sociali ed ambientali che sono cruciali per il successo di tali progetti.

Lo scopo ultimo di tale analisi non risiede solamente nella comparazione e nella discussione dell'applicabilità di tali strumenti e della loro efficacia in determinati contesti di studio, ma bensì è necessaria per poter acquisire una buona padronanza dell'argomento e poter proporre un insieme di procedure e di regole che possano guidare lo sviluppatore di progetto, o l'investitore, ad una corretto approccio alla delicata tematica della valutazione di investimento in tecnologie ad energia rinnovabile nei paesi in via di sviluppo.

Nel particolare, il capitolo uno è pensato come una sezione introduttiva per chiarire il contesto di studio e di applicazione dell'analisi condotta, sottolineando vantaggi, e nondimeno svantaggi, delle tecnologie selezionate e della loro applicazione. Viene successivamente sottolineata la diffusa importanza della teoria del "valore temporale del capitale" in tutta la trattazione, e soprattutto nell'analisi finanziaria. Infine, viene chiarita la principale opzione di generazione e di distribuzione di energia che verrà presa in considerazione.

Il capitolo due è dedicato alla trattazione delle maggiori criticità tecnico-tecnologiche che è necessario valutare. Si noti come questo argomento è stato volutamente posto al primo posto in ordine cronologico, visto che ogni successiva analisi economico-finanziaria, sociale ed ambientale sarebbe inutile senza una adeguata considerazione della fattibilità "fisica" degli impianti. Nel passato infatti molti progetti, valutati positivamente da un punto di vista economico, sono falliti a causa di un'inaccurata previsione delle performance tecniche dell'impianto. Perciò verrà dapprima esposta la tematica del *siting* o *placement* dell'impianto, vale a dire, nel caso delle energie rinnovabili, la previsione della risorsa naturale per un orizzonte temporale sufficientemente ampio. Queste considerazioni ci permettono successivamente di fare il *sizing* d'impianto, vale a dire la determinazione della taglia del sistema e perciò della sua produzione energetica generalmente annuale. Infine vengono sottolineati degli aspetti che risultano critici nei contesti che verranno studiati, e che negli schemi tradizionali non vengono generalmente considerati, cioè la pre-esistenza di infrastrutture di supporto, la disponibilità di capacità tecniche e risorse locali, nonché la capacità del sistema di accomodare future espansioni modulari per poter far fronte ad un aumento della domanda di energia.

Il capitolo tre consiste nell'analisi dei principali metodi di valutazione delle opzioni di fornitura di energia elettrica alle comunità rurali, volti a confrontare da un punto di vista tecnico-economico l'estensione della rete nazionale con una gestione decentralizzata della produzione e distribuzione dell'energia. Le metodologie esposte si basano rispettivamente sul calcolo del costo del ciclo di vita delle due opzioni e sul calcolo del costo di generazione dell'energia. Il capitolo è arricchito dal resoconto dell'esperienza nell'uso del software HOMER, un applicativo informatico per la progettazione e l'ottimizzazione di micro-reti a energia rinnovabile e sistemi distribuiti di generazione di potenza.

Nel capitolo quattro ci si soffermerà sulla revisione dell'applicazione di metodi decisionali agli investimenti in energia rinnovabile. Tutti i metodi analizzati sono basati sulla *Multi-criteria analysis,* e quindi permettono di integrare diversi punti di vista e criteri di selezione all'interno del medesimo strumento, per poter raggiungere il consenso tra tutte le parti coinvolte nel processo decisionale.

Le metodologie riportare sono le seguenti: *"VIKOR method"*, *"PROMETHEE method"*, *"SMAA-2 decision aiding tool*", *"REGIME method"* e *"Multi-criteria analysis"*. Nella parte finale del capitolo, e nondimeno nella trattazione di ogni singolo metodo, una particolare attenzione viene posta sulla discussione dell'insieme di criteri adottati nelle varie valutazioni.

Infine il capitolo cinque, volutamente inserito all'ultimo posto in ordine cronologico tra le revisioni della letteratura, espone dei significativi casi studio che mettono in luce le esperienze derivanti dall'adozione di particolari strumenti finanziari per far fronte alle varie barriere e ai rischi di progetto di volta in volta identificati. Questo capitolo perciò dà un'idea di quali siano le principali criticità finanziarie relative ai progetti di elettrificazione rurale e di quali possano essere gli strumenti efficaci nel superare queste problematiche.

Avendo acquisito una certa sensibilità sulle tematiche esposte nelle varie sezioni di questo elaborato, il capitolo sei ha l'obiettivo di proporre un personale modello iter-procedurale capace di valutare correttamente l'investimento laddove quest'ultimo debba essere effettuato in condizioni analoghe a quelle evidenziate. Il lavoro esposto non ha la presunzione di essere esaustivo di tutte le casistiche possibili in determinati contesti, e inoltre esula dalla trattazione di condizioni soggettive di contorno all'investimento che possono influenzare la scelta degli sviluppatori e dei decisori. Quelle analizzate dal presente elaborato sono delle condizioni oggettive che, se opportunamente valutate, possono portare ad una decisione corretta e consapevole.

CHAPTER 1
INTRODUCTION TO THE SUBJECT

1.1 Renewable energy investment

Recent technical developments and reductions in the cost of all major categories of RE technologies have been substantial [5]. As a consequence, the application of all renewable technologies have expanded by nearly three orders of magnitude over the past 15 years. RE technologies such as photovoltaics (PV), solar thermal, wind, and biomass are now being used successfully for both subsidized and commercial small-scale applications. Wind power is increasingly being used for large-scale commercial power generation projects.
Rising oil prices have also been a factor in the increased use of RE. As oil and gas prices increase, RE becomes more cost effective. An example of how two RE sources can displace oil and gas fuel for some typical applications is shown in Table 1.

ENERGY SOURCE	APPLICATIONS			
	Refrigeration	**Lighting**	**Pumping**	**Communication**
Photovoltaic	Small scale only. Expensive for larger scale	Appropriate	Sometimes appropriate. Expensive for large volumes or deep wells	Appropriate
Kerosene	Appropriate for small scale	Appropriate for small scale. Fire hazard	Not Appropriate	Not Appropriate
Low Pressure Gas (LPG)	Appropriate for small scale	Appropriate	Not Appropriate	Not Appropriate
Gasoline generator	Expensive	Appropriate for short duration. Expensive	Appropriate	Appropriate for short duration. Expensive
Diesel generator	Appropriate for large scale	Appropriate for large scale	Appropriate	Expensive for small applications
Small wind turbine	Appropriate for medium and small scale	Appropriate	Appropriate for some cases	Appropriate

Table 1: Comparison of energy sources and applications [USAID/Office of Energy, Environment and Technology]

According to the International Energy Agency (IEA) [6], worldwide 1.456 billion people (18% of the world's population) do not have access to electricity, of which 83% live in rural areas. In 1990 around 40% (2.2 billion) of the world's people still lacked power. Much of this increase over the past quarter century has been in India, facilitated by mass migration to slums in powered metropolitan areas. India was only 43% electrified in 1990 as opposed to about 75% in 2012. In 1979 37% of China's rural population lacked access to electricity entirely. Some 23% of people in East Java, Indonesia, a core region, also lack electricity, as surveyed in 2013.

In Sub-Saharan Africa less than 10% of the rural population has access to electricity. Worldwide electrification of rural population progresses only slowly. The IEA [6] estimates that, if current trends do not change, the number of people without electricity will rise to 1.8 billion by the year 2030. Due to high population growth, the number of people without electricity is expected to rise in Sub-Saharan Africa [7].

However, cross sector applications have been given recent attention by Multilateral Lending Agencies in order to better address the needs of the roughly 1.5 billion people who lack access to reliable energy sources. Those applications usually refer to the subject of "**Rural Electrification**", that is the challenge to bring electrical power to the remote areas of developing countries which are not served by any type of electric supply.

Among those cross-sector applications of REs can be found:

- Schools
- Project facilities and other buildings and equipment
- Community water supplies (including disinfection)
- Community refrigeration and ice-making
- Crop irrigation
- Agriculture (post harvest management/food processing)
- Livestock watering
- Roads (illuminated signs, emergency phones, street lighting, signals)
- Telecommunications and rural telephones
- Health posts and clinics

RE technologies offer commercial and operational advantages as well. These advantages are particularly important in remote areas not served by electric utility companies. Even when conventional utilities offer service, there are some advantages to RE technologies, which include:

- Modularity, providing redundancy and resilience in the event of failure of utility supply;
- Low or no fuel requirements;
- Life-cycle costs which can be less than for equivalent service from fossil fuel options;
- Hybrids (PV and/or wind plus diesel generators) which can provide 24-hour high-quality power; and
- PV and wind equipment that often require less maintenance and provide greater reliability than diesel generators in many field conditions.

Several direct and indirect savings and other economic benefits can accrue from the use of RE technologies to displace fossil fuels. Several of these are as follows:

- Fuel cost savings
- Reduction in fuel delivery costs
- Reduction of hazardous air emissions
- Reliability of power supply
- Lower operating costs
- Economies of scale
- Spillover effects from induced investments in power supply
- Waste recycling
- CO_2 emission reduction
- Carbon sequestration
- Increased salvage value of power generating equipment

Recent technical developments and reductions in the cost of all major categories of RE technologies have been substantial. The sustained drop in photovoltaic module costs, from 1980 to 2009, is shown in Figure 1. A profile of the declining cost of electricity vs deployment of US land-based wind is shown in Figure 2.

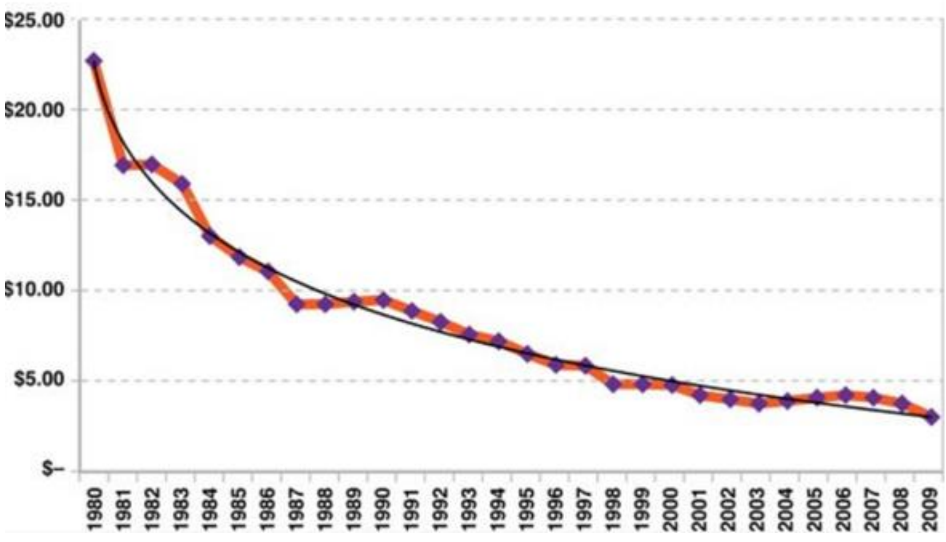

Figure 1: Solar PV modules cost per watt (1980-2009) [Homeenergyllc.com]

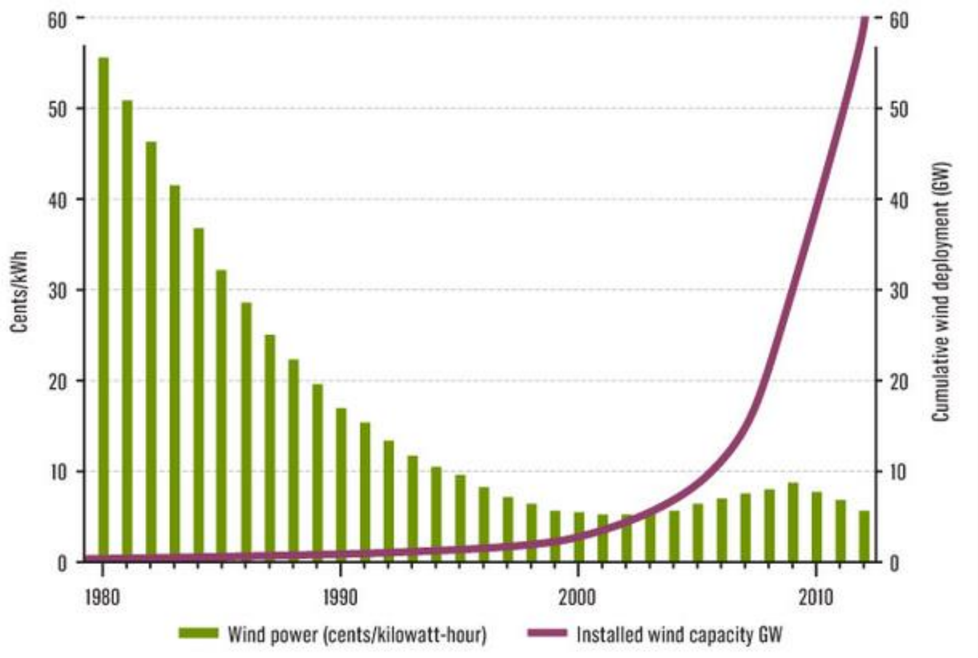

Figure 2: Cost and deployment for US land-based wind (1980-2012) [US Department of Energy]

In spite of the long-term decline in costs for installed capacity of RE technologies, and a large demand for RE in developing countries, large-scale investments remain elusive. Several factors have been identified that can improve the market potential for RE [8].

- First, there is a need to provide **grant or technical assistance funds** to identify RE programs and to conduct project preparation so that they can be incorporated within subsequent implementation loans. The resources needed for project preparation are typically one to three percent of total project costs and may not always be recovered, especially for those projects that prove to be unfeasible or fail to obtain funding. Resources for such work are often available through multilateral development banks, such as the Global Environment Facility (World Bank), bilateral grant aid, developing countries themselves, private investors and electric utilities.
- Second, market potential can be enhanced by **increasing the awareness within the energy industry** of the possibilities created by new and more cost efficient renewable technologies. This can be accomplished by providing education and training to people in the energy industry, financiers and regulators.
- Third**, structural reform** of the energy sector in many countries can provide the opportunity for commercial supply of electricity, private investment and hopefully improve the returns on RE investments.
- Finally, to ensure long-term success of a RE investment program there must be adequate **attention to the preparation and financing of the program** at the outset followed by continuous training, maintenance and support services for the life of the project . Too many promising RE projects have failed because of these services were neglected or never adequately provided for [9].

1.2 The time value of money

As regards the economical evaluation and financing phase of RE projects, we always assume the importance of the theory of the 'Time Value of Money' to calculate the financial feasibility of the investment.
Money has a value that is related to time. The purpose of investments is to set aside a sum of money now in expectation of receiving a larger sum in the future. By using the discounted cash flow approach, and assigning a value to the cost of capital, it becomes apparent that the cash flow in the early years of a project has greater value at the present time than the same amount in the later years of a project.
The discount rate is very important for a RE project analysis. The selection of a discount rate can depend on many factors. Usually the rate depends on the opportunity cost of capital, which is defined as the foregone production or potential return when capital is invested in one project rather than another. The equation to calculate the discount factor is shown below.

$$Discount\ Factor = \frac{1}{(1+i)^n}$$

i is the interest rate or cost of capital, and n are the years from project implementation.
Since RE investments are measured by the consumers' implicit discount rates, they require a high rate of return on investment, indicating high risk. These investments may appear risky to the consumer due to lack of information and resulting uncertainty. However, for society, RE is a low-risk investment that deserves a low discount rate.

1.3 Off-grid rural electrification

Electric power can be supplied in multiple ways. The term "**off-grid**" refers to not being connected to a grid, mainly used in terms of not being connected to the main or national electrical grid.
Off-grid can be stand-alone systems (SHS) or mini-grids typically to provide a smaller community with electricity supplied by RE sources or diesel generators [10].
In developing countries, rural electrification can be a very difficult task where the national grid is too far to be extended to remote areas. In such cases, off-grid electrification can be a very interesting option and gives the opportunity for practical RE applications.
There are two main types of off-grid systems [11]:

- Decentralized system, which is built by autonomous units and feed by a single source, locally based and need oriented, and it serves a restricted number of consumers.
- Distributed system, based on a number of decentralized systems, interacting through a transmission/distribution grid, so it works like a virtual power plant.

In this thesis we are going to focus on **distributed systems** based on different RE technologies, such as PV, wind, hydro-power and biomass plants. We can call this configuration a **Smart Grid,** that is an off-main grid independent micro-grid [3], with the following characteristics:

- Multiple and renewable sources: integration of natural sources to feed the load;

- Multiple components: different power units;
- Multiple customers: the system serves several consumers and different types of load.

The main advantages and disadvantages of such an hybrid RE system are as follows:

Advantages

- Energy security
- Lower energy prices in the long-term, because of the increasing efficiency and decreasing prices of RE technologies
- Flexibility and modularity
- Low maintenance and reduced environmental impact

Disadvantages

- Aleatory nature of the sources, especially solar and wind
- Storage is a mandatory component, with increasing cost, complexity and maintenance
- High dependence on weather conditions (solar, wind), with seasonality effects (hydro, wind technologies) and daily cycles effects (solar)

As a result, attention to the peak load demand and to the temporal load distribution is required.
The principal conventional alternative to an off-grid RE system is the use of small diesel generators, still generally the most economical solution when loads are concentrated and served by a centralized system. Good wind or hydro resources at a particular site may make small wind power, micro hydro, or hybrid power systems cost competitive on an annualized or life cycle basis. Also, in many communities small diesel generators may not be technically feasible due to the difficulty of providing effective operation and maintenance.
However, off-main-grid systems are often built up with diesel generation technology coupled with RE technologies-based system. This configuration is called an "Hybrid system", and is adopted in order to overtake the aleatory nature of RE sources. Pros and cons of an Hybrid system are the following:

Advantages

- High reliability and continuity of supply
- Reduction of the storage system size
- Batteries lifetime and operation costs benefit

Disadvantages

- Higher investment and maintenance costs than pure RE technologies use
- Hybrid solutions increase the complexity of the system

- The management and maintenance of different technologies is required

Note that even in projects involving thousands of households, the total megawatts of generating capacity is very small compared with traditional power projects. The decision to implement off-grid projects starts with a public policy to extend at least basic electricity services to unserved populations that are unlikely to obtain electricity connection in the foreseeable future. While many un-electrified communities are suitable for grid extension, many others are too remote from the main grids, and are more suitable for decentralized distributed power systems, including diesel, RE, and hybrid systems.

This thesis is going to focus on and review the following subjects, regarding the RE investment in developing countries:

- Siting and other technical/technological constraints;
- Distribution mechanisms of energy, by comparing stand-alone systems over the grid extension;
- Decisional methods to evaluate the investment, with a particular attention to the criteria used to rank the alternatives;
- Financial instruments to address specific project risk and/or financial barriers;
- Finally, we are going to introduce a procedural method to guide decision makers through the subjects previously discussed.

CHAPTER 2
TECHNICAL FRAMEWORK FOR RENEWABLE ENERGY PROJECTS

2.1 Introduction

This chapter is supposed to introduce the reader to a resume of the primary assessments that a developer should make when approaching a RE investment in a developing country.

Currently, the distinctions between pre-feasibility and feasibility studies have become blurred [5]. This is due to the fact that costs for such studies have continued to increase and thus time devoted to two distinct studies is less likely, and also because there is much more accurate engineering, financial and market data available than in the past. Generally, the best source of data about a specific kind of RE project can be gleaned from comparable in-country projects. Successful projects should be carefully studied for lessons learned.

The feasibility evaluation that we propose can be initially viewed as a technical project appraisal effort. For a RE project in developing countries in particular, the study should report the evaluation of the following major items:

- Siting of the system considering its technical/technological constraints;
- Focus on the advantages of a mini-grid composed of different RE technologies, instead of basing the system on the exploitation of a single source;
- Checking for services and supporting infrastructure;
- Compatibility with future capacity expansion;
- Availability of local skills and labour.

2.2 Siting

Before any economic, social or environmental assessment of the RE investment is made, decision-makers have to take into consideration the placement of the system and its technical/technological constraints. When a RE project is evaluated, the first issue you take care of is to find the best RE sources to be exploited in the site and to minimize the possible negative impacts of the systems. Then project developers have to size the RE system, that is the assessment of how much energy the plant will produce, given the availability of the source and other factors. Although a detailed dissertation of this subject goes beyond our study, a general framework is going to be introduced.

All energies, with the exception of geothermal resources, is derived from the sun. Fossil fuels are just solar energy stored in organic material converted to hydrocarbon fuels by pressure and temperature over geologic time. Unlike hydrocarbon fuels, solar energy is pollution free and for all practical purposes, inexhaustible, as the sun will continue to shine for the next billion years or so. The principal technologies used to extract energy from the various natural processes generated from the radiant energy of the sun include:

- Solar photovoltaic
- Wind (derived from the sun's radiant heating and movement of the earth's atmosphere)
- Biomass (conversion of biological matter into energy)
- Hydropower (derived from the sun's hydrological cycle)

Most of these technologies can produce mechanical and thermal energy directly, but they are being used more frequently to produce electric power.

2.2.1 Wind Energy

As regards wind turbines, project developers have to assess the wind energy potential of the site; obviously, sites with steady high wind produce more energy during the year [12]. Two essential data are needed for the evaluation: the wind speed and the characteristic curve of the turbine, which is a function of the wind speed. The second data is supplied by the manufacturer of the turbine, while the first is to be obtained by a measuring campaign.

The measurement operation is usually done by a wind gauge (anemometer) which is installed at the height of the hub of the turbine, because the data of the characteristic curve are referred to the wind speed at this height; the interval period is extended to 2 or even 3 years in order to prevent periodicity effects and to consider the difference of the wind intensity among different years. The wind speed data is registered on an electrical junction box every 10 or 30 minutes, because this interval period is estimated to be the biggest with no significant changes from the average wind intensity.

The data from the campaign are usually represented as probability functions in order to make the best reliable forecast of the wind speed for the future years; furthermore, they are modelled in mathematical functions to extend the forecast to different spots and heights. The most used model is the Weibull probability distribution, because it best describes the variation in wind speed:

$$f = \frac{k}{A} * \left(\frac{v}{A}\right)^{k-1} * e^{\left(\frac{v}{A}\right)^k}$$

A is the scale index, k is the shape index and v is the wind speed.

The height of the measurement is a crucial factor for the wind forecast. The wind speed is not the same at different heights; it is zero km/h at the ground level, and then increases with the height from the ground; the reason of this variation is the roughness of the ground on which the wind flows, which represents the capacity of the ground to slow down the wind. The variation of the wind speed with the height is evaluated trough mathematical models, and the exponential trend is usually supposed:

$$v_h = v_0 * \left(\frac{h}{h_0}\right)^{\alpha}$$

Where v_h is the wind speed at height h, v_0 is the wind speed at height h_0 and α is the roughness index of the ground of the site.

Another future of the wind, which is used to describe and forecast weather, is the direction [13]. It is measured with a weather vane, abroad, flat blade attached to a spoke pivoted at one end. The wind impinging on the blade turns the spoke and lines up the blades in the wind direction. The wind direction is indicated by an arrow fastened to the spoke or by an electric meter remotely controlled by the weather vane. The wind direction is often indicated in terms of a 360° circular scale. On such a scale, 0° indicates the north, 90° indicates the east, 180° indicates the south, and 270° indicates the west.

Having one or more measurements, the results can be extended to the surrounding area; this operation is called 'micro-siting' and is made by specific software with different technologies, such as mass conservation, Navier-Stokes equations, etc.

Consequently, the data from the measurement and the resulting wind map are a valuable tool for assessing the availability of the wind source and therefore the siting of the system.

The next step is to determine the annual average energy produced by the turbines with the wind conditions forecasted; the energy produced with a given wind speed v_i is

$$EE(v_i) = f(v_i) * Wel_i \quad [\frac{MWh}{year}]$$

$EE(v_i)$ is the energy produced with wind speed v_i, $f(v_i)$ is the probability (wind frequency) of the wind speed v_i and Wel_i is the power produced by the turbine with the wind speed v_i (data from the characteristic curve of the turbine). The annual energy produced is the sum of the $EE(v_i)$ for any possible v_i during the year.

Finally, a wind park can also have some environmental impacts, principally on landscape, noise and fauna; these effects are to be assessed during the siting stage of the project because they can negatively influence the authorization phase.

2.2.2 Photovoltaic energy

Besides the wind source, that needs a careful site search because of the variability of the wind intensity for different spots in the same area, photovoltaic systems don't have this necessity. Once project developers decide for a particular stand-alone system in the nearby of a rural village or an isolated community, they have to check for the mean solar radiation of the site, which is a data usually available; for a precise computation you need to know the solar elevation for every hour of the day and in every period of the year; a simple choice is to check for the equivalent solar hours, that is the number of hours the plant would produce at maximum power as much as it produces at limited power during the day [12]. The equivalent solar hours are usually expressed as mean radiation values during the year for the chosen site $\left[\frac{kWh}{m^2} * day\right]$; that is the total radiation coming from the sun, but for a more precise assessment we need to know the radiation that impinges on the solar panel, that is:

$$I = I_T * \cos\Theta$$

I is the solar radiation which impinges on the fixed solar panel, I_T is the total solar radiation, and Θ is the angle between the solar radiation and the perpendicular line to the panel. I_T is computed as the sum of direct radiation, diffused radiation and reflected radiation.

These type of data are usually supplied by solar radiation maps, showing yearly solar energy reaching the surface of the earth. It is the total yearly energy-capture potential of the site that determines the economic viability of installing a power plant. As this regards, the most diffused data is the 'annual average solar energy per day impinging on the surface always facing the sun at 90°', because modules mounted on a sun-tracking structure receive this energy [13].

If the system is composed of different panels set in parallel rows, they could darken each other during the day. As a result, we need to compute the minimum tilt angle of the solar radiation with which the panel starts to be shadowed and then the percentage of losses can be evaluated.

As regards the project of the system, besides the mean solar radiation of the site, a key requirement is the electrical load that needs to be satisfied, that is the daily consumption of the demand center.

For a stand-alone system, the sizing of the system is to be done in the conditions of minimum photovoltaic energy production and with the maximum electrical load.

The estimation of equivalent solar hours, daily consumption and performance ratio are to be supposed; they are, respectively, h_{EQ}, $Load$, and ρ. The parameter ρ (performance ratio) is usually set at 80%, which considers a good panel placement and a good maintenance.

The next step is the choice of a particular solar panel; different types are available on the market, with different output powers and potentials of 12V and 24V. For example, a 180 W_p panel is chosen; the number of panels N is computed by the following equations

$$P = \frac{Load}{h_{EQ}} * \frac{1}{\rho} \quad [kW_p]$$

$$N = \frac{P}{P_{PAN}} = \frac{P}{180}$$

P is the necessary total power of the system to satisfy the load; the $Load$ is expressed in $[kWh]$; $P_{PAN} = 180\ W_p$ is the nominal power of a single panel.

As regards the energy storage system, it should be able to cover the total daily consumption for at least 3 or 4 days, considering the total absence of solar radiation.

$$C_{STO} = Load * 3\ days * \frac{1}{\eta} \quad [kWh]$$

C_{STO} is the storage capacity, η is the efficiency of the storage system. The capacity to be installed (Cap), for 24 V storage systems, is

$$Cap = \frac{C_{STO}}{V_{STO}} = \frac{C_{STO}}{24} \quad [Ah]$$

$V_{STO} = 24\ V$ is the nominal potential difference of the storage system.

Such a system, supposing a useful life of 20 years, is able to produce the following total energy E_{TOT} :

$$E_{TOT} = N * P_{PAN} * h_{EQ-anno} * \rho * 365 \quad [kWh]$$

2.2.3 Hydroelectric energy

The production of hydroelectric energy is obviously based on the availability of water on the surface of the earth; the water from rivers, lakes and aquifers can be exploited for the production of electricity, as the hydroelectric energy production depends on the availability of draining water in a natural or artificial flow with a great altitude gap. Therefore, the siting choice is not limited to natural options, but it can be extended by building dams or deviating a water flow; in fact the key factor is the availability of the source in terms of flow rate, which is to be assessed by measurement stations in the flow. In case the measurement stations are not available, other options are hydrology, rain and flow regime, assessment of catch basins, drainage and ground's geology. Moreover, it is necessary to know the flow rate's variations during the year and the gross altitude gap.

The evaluation of the flow rate is initially accomplished by searching for time series of the flow's section under study or, if not available, time series of other sections of the same flow or even next and similar flows, so that it is possible to recreate the time series of the section of interest [12].

If the flow rate's time series are not available, it can be directly measured for at least one year, in order to assess its variations during the seasons. Different techniques can be used for the measurement, such as the speed-area method, the incline-area method, etc.

Flow rate's measurements of different years of a site have to be conveniently organized, in order to be significantly represented. One way is to chronologically represent the flow rate's data on a flow rate vs time graph, the so called 'Water Graph'. An alternative way is to build the 'Flow Duration Curve'. The FDC represents, for a water flow, the time interval during which the flow rate is equal or above a certain value. The flow rate's data are sorted in a decreasing way, and Figure 3 reports an example.

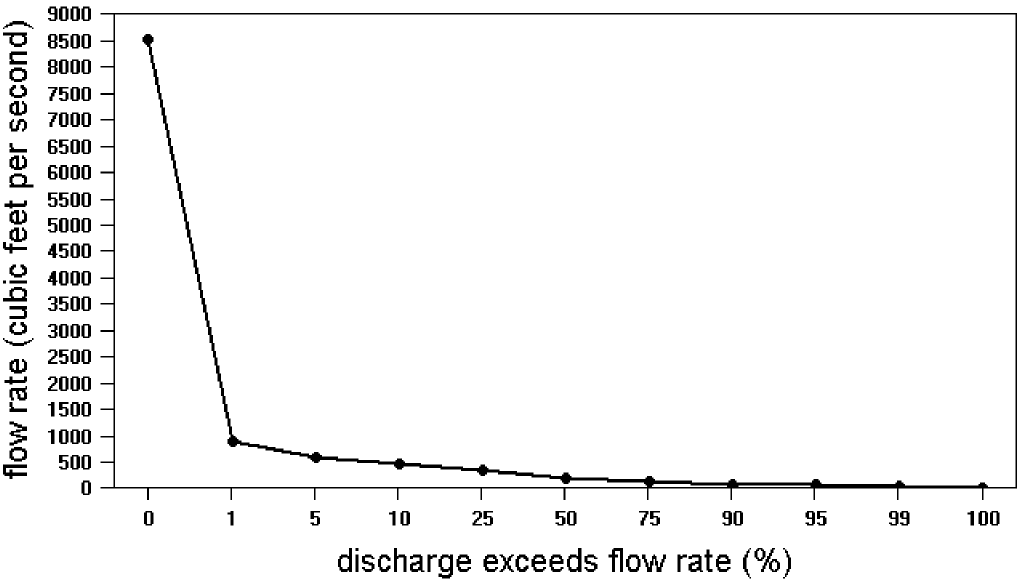

Figure 3: Example of flow duration curve

In figure 3, 'cubic feet per second' is the flow rate's unit of measure, while 'discharge exceeds flow rate' is a way to describe the percentage of time for which an observed stream-flow is greater than or equal to a defined stream-flow.

The presence of an hydropower station in a natural flow with a water derivation to produce energy would determine the complete drainage of some sections of the flow, with great damages to the water life. In order to prevent a possible disaster, the water licenses consider that a residual flow rate must be preserved.

As regards the operation of the system, the physical theory consists in the conversion of the potential energy of a water mass, which flows through an altitude gap, in mechanical energy and electrical energy in the lower part of the system, where the station is located. An hydroelectric plant can effectively supply the subsequent power P:

$$P = \eta * Q * H_n * g * \rho \quad [W]$$

η is the total efficiency of the system, Q is the flow rate in $[\frac{m^3}{s}]$, H_n is the net altitude gap in $[m]$, g is the acceleration of gravity in $\left[\frac{m}{s^2}\right]$, ρ is the water density in $[\frac{kg}{m^3}]$. This formula can be used to evaluate the power production potential of the site.

Finally, the environmental impacts are to be taken into consideration. Big basin hydropower plants have the most problems, as the dam's building implies many variations in the ecosystem of the area.

Other aspects to be considered in the project stage are the acoustic impact, visual and biological.

2.2.4 Biomass energy

The siting of a biomass energy conversion system is dependent on the availability and proximity of the source [12]. The distance from the source has to be limited, in order to minimize the transportation cost (if the distance is too much high, the system's economy can result negative) and the stock volume in the area of the plant. As a result, the optimal arrangement of the plant's area consider the farm of the biomass on site and the placement of the plant in the middle of the area.

Generally, the needed volumes require great surfaces to create warehouses, as it is necessary to guarantee some autonomy.

The forecast of the necessary surface area to produce the needed biomass consider many factors, such as the site productivity. If a steam-electricity power system is considered, the land area to produce the necessary biomass to supply the electrical power $P\ [MW_e]$ is computed with the following steps: first the electrical energy produced in one year is calculated as follows.

$$E_{el} = P * 10^3 * h * 3600 \quad [\frac{kJ_{el}}{year}]$$

In the equation, h are the equivalent operating hours of the plant in one year, while 3600 and 10^3 are unit conversion factors. Then the heat energy E that has to be supplied is determined as follows:

$$E = \frac{E_{el}}{\eta_{el}} \quad [\frac{kJ}{year}]$$

η_{el} is the electric efficiency of the system. Knowing the heat value $H\ [\frac{kJ}{kg}]$ (the weight $[kg]$being always referred to the dry biomass) you can compute the biomass consumption.

$$m_c = \frac{E}{H} = \frac{P * 10^3 * h * 3600}{\eta_{el} * H} \quad [\frac{kg}{year}]$$

Finally, knowing the annual productivity $p\ \left[\frac{tons}{hectare \times year}\right]$ of vegetable dry material, the necessary surface area A is deduced.

$$A = \frac{m_c}{p * 10^3}\ [hectar] = \frac{m_c}{p * 10^3 * 10^2}\ [km^2]$$

Modern farm techniques (Short Rotation Forestry) have maximized the plant's density per farmed hectare and tend to reduce to a couple of years or even to one year the harvest cycle of the biomass. A high number of plants per unit of area, with a short harvest cycle, allow to obtain greater productions.

Finally, the principal impacts on the environment due to the exploitation of the biomass energy are the ones connected to the greenhouse effect. Unlike one could think, it is not the exploitation of the biomass for energy production purposes that determines the growth of the carbon dioxide level: its quantity released during the decomposition stage equals the quantity absorbed during the growth of the same biomass, that is the photosynthesis process. The real cause is to be searched in the transportation of the biomass from the harvest's site to the conversion system.

Other possible emitted pollutant, depending on the technology used and on the type of the biomass, are sulfur oxides, nitrogen oxides, carbon monoxide, etc.

2.2.5 Geothermal energy

Geothermal energy is based on the exploitation of the underground heat of the earth. The search for geothermal sources starts with the dig of a well very similar to an oil well, from which the heat is extracted by a geothermal fluid [12]. The main technology, the dig of the well, is derived from the oil & gas technology. The limiting factor of the geothermal systems is the underground permeability. Without an appropriate fracture of the rocks, the necessary water flow, for the steam's production, cannot exist. That's why the research in the geothermal field looks for methods of artificial rocks' fracture (Hot Dry Rock).

In the context of study, this RE has been intentionally listed as the last because its siting is usually a very limited stage of the project; once project developers focus on a pre-existing well, they just check for its consistency and move to the sizing stage of the project. In addition, this RE source is not usually taken into consideration for rural electrification's applications, because of its scarce availability; that's why we are not going into details as regards its resource assessment and the potential output of the system.

2.2.6 Hybrid (RE) systems

RE sources are among the oldest sources of energy used and new and modern technology has enhanced and improved the use of this energy for the production of electricity as well as for the production of thermal and mechanical energy.

However, RE technologies use, and are at the same time limited by, the various forces of nature to produce energy. The sun does not shine all day, the wind does not always blow, and droughts occur. Combining renewable technologies generally increases the reliability and often the efficiency of energy production. This combined use of RE technologies is described as an **Hybrid RE system** [14].

Off-grid systems can also use fossil fueled energy; in this case, we call the plant's configuration as an **Hybrid system**. Each technology is capable of complementing or circumventing the gaps in power generation, physical limitations or economic efficiencies of the various technologies. Hybrid systems are used whenever large amounts of reliable energy are needed at all times. They are more costly and complex, but make up for this disadvantage by their reliability.

As a result, the potential site should be fit to accommodate more than one natural source, such as the combination of solar and wind. This is not a simple task because developers have to find a site with particular characteristics and conditions. One should explore all the possible combinations of renewable sources in the site and then choose the best hybrid system.

One way to choose the best option is to set an objective function which minimize the annual energy losses in the distribution system for all possible combinations of RE output power and load.

For a precise assessment of the best mix of RE technologies, the software HOMER is a very valuable tool [15]. A two week's license of the software can be downloaded for free from the internet. This software allows to describe the conditions of the potential RE sources for a site, and then, given other input parameters, it calculates the best mix of conversion systems by listing the alternatives on the basis of their

economic performance. The software will be better described in the third chapter, where it is going to be used to calculate the LCOE (Levelized Cost of Electricity) for off-grid generating systems.
Table 2 summarizes advantages and disadvantages of the different RE sources, regarding the siting of RE systems.

PROS	CONS
WIND ENERGY	
1) It is possible to fully exploit the source	1) Necessity of more than one year for the measurement campaign
	2) Difficult forecasting of the source
PHOTOVOLTAIC ENERGY	
1) It is possible to fully exploit the source	
2) Data on the source's forecasting usually available	
3) Availability of the source	
4) Low environmental impacts	
HYDROELECTRIC ENERGY	
1) Availability of the source (possibility of artificial flows)	1) Environmental impacts
BIOMASS ENERGY	
1) It is not necessary to forecast the availability of the source	1) Availability of the source
	2) Environmental impacts
GEOTHERMAL ENERGY	
1) It is not necessary to forecast the availability of the source	1) Availability of the source

Table 2: Pros and Cons of REs concerning the siting of the system

2.3 Integration of sources into a micro-grid

The assessment of a RE investment in a fast-growing country is a laborious task.
Providing energy to isolated communities and rural villages, far from the population centers, is usually accomplished by means of RE sources, when the national grid is too far to be extended. As a result, two main issues have to be faced:

- A single RE source can’t guarantee safety of supply, because it strongly depends on weather conditions and on the availability of the source.
- In a developing country, the national electric grid usually can’t connect isolated communities to the centers of energy production.

For these reasons, a single stand-alone system can’t provide electricity in a reliable way: the discontinuity of REs is a world-wide issue in the exploitation of such sources, and we have already discussed in the past section the necessity of an hybrid system. In addition, rural villages usually cannot rely on a supporting infrastructure to connect the system to the national grid, and it would be too costly to extend the grid to reach the communities.
Traditional western assessment methodology fails to reliably valuate a RE investment in these contexts, because it is based on false hypothesis for a developing country, and thus would lead to improper conclusions [4]. As we have outlined before in the chapter, the RE investment has to take into account the energy system as a whole, and thus integrate the different sources into a global framework, focusing on a new and higher level, which is the grid. As stand-alone single RE plants cannot fully satisfy the energy needs, they have to be integrated into a global system by means of interconnections, creating an **hybrid RE**

micro-grid system able to overcome the traditional issue of RE systems. Considering that RE systems show very interesting perspective for the integration into a micro-grid, they can lead the country to the development of the national energy sector, where no other options to supply electricity to rural areas are available. For example, building an energy system composed of different RE production plants, (such as wind, solar, etc…), the local community can be independent from the weather conditions of the area; moreover, the system can deliver additional (not self-consumed) energy to public buildings such as hospitals, as far as they are connected to the mini-grid. Only a self-sufficient system can effectively provide the energy service to rural villages, and thus is able to create social benefits for the local people.
As a result, the evaluation of RE projects has to evolve in a different way, analyzing the possible interconnections between different RE sources in a given area; the resulting system has to be fully independent as regards energy needs. Decision makers have to consider all the different opportunities of the investment, which should not be tied to the exploitation of a single source.

2.4 Lack of infrastructure

One of the main barriers to the development of RE systems in developing countries is the lack of supporting infrastructure. The supporting facilities such as roads, market infrastructure, households resources, training facilities, etc…, can affect the development of RE options at different extents. For example, biogas plants can get full support from existing rural infrastructure, but other renewable alternatives may not.
When evaluating the sustainability of a RE project in developed nations such as European ones, the condition of the existence of supporting services for the construction and operation phase of the project is usually taken for granted. Anyway, some RE projects, such as the ones based on wind turbines, consider the necessity of facilities (for example roads to the site) for the success of the project.
Focusing on a developing country, this issue becomes more and more important because of the very low development of services all over the nation, and especially for rural villages. Project developers can't usually rely on pre-existing infrastructure to help the development of the project or, if available, they have to check the compatibility of these facilities with the RE option.
For example, the construction process of a wind turbines' park is very complex [12]. The civil works needed are several, such as roads, drainage, dig for electric wires, etc. The transfer of the system to the site and on the site needs a project: principal limitations are radius of curvature of the route and its slope. For the assembly of the turbines, you need to have a crane.
On the other hand, it is much more easy to manage a PV or solar system. The assembly of the solar cells, which are usually ready-made, does not require the presence of particular infrastructure. The location of the cells on the roofs is very simple; in the worst case scenario, it is required to secure the cells on an incline level, in case the roof is in horizontal position.
As you can see from the examples, one particular RE source, such as wind, can require a very expensive investment not just because of the cost of the system, labor, etc… but also for the necessity of building facilities vital to the project; most of the times, in developing countries this necessity is much more

important: as most of the farms are sited close to rural areas of the country that are not linked with good roads, hence most of the costs involved with installation (especially cost of civil work, turbine transportation and road construction) are always higher than normal, when compared with cost that will be incurred if plants are to be sited in an urban terrain. Major installations always have to be carried out alongside other project work in rural communities.

Thus a great impact on the revenue account of the project is to be considered. Most of the costs related to a wind energy project are variables because of the characteristics of the chosen site: the morphology of the land affects the foundations and viability costs, while the accessibility to the site influences the transportation costs. As a result, the total cost per kW installed of a wind energy system differs significantly depending on the reference country, ranging from 1000 €/kW to 1350 €/kW [12]. Furthermore, for complex projects the components of the system aren't usually ready-made, so they have to be built in the nearby of the site; however, you cannot take for granted the presence of a cement plant near a rural village. Consequently project developers observe an additional impact on the revenue account, which is very difficult to be assessed.

A RE system, which is cheaper compared to another one, can become more expensive in case basic infrastructure are not present. Thus it is very important, when assessing the energy output potential of the sites, to primarily evaluate the presence of all the services which are needed throughout the lifetime of the project.

2.5 Compatibility with future capacity expansion

The generating capacity of a power system must be expanded to maintain an acceptable level of system reliability as energy demands increase with time [16]. The installation of different proportions and combinations of conventional and RE sources are usually viable options in a composite small isolated power system.

Anyway, without complying with capacity expansion, the system may lead to power shortage and thereby to failure. Furthermore, a non-compatible system is vulnerable to a future grid extension, because an additional rural electrification program, through grid extension, may be issued to cover the unserved energy demand, in order to guarantee the same living conditions to the people of the rural area.

Among all the RE sources, solar PV, for example, can be easily scaled up if resources are available. Other RE sources, however, may not be fit to accommodate a future capacity expansion. A biomass plant requires more and more raw material to satisfy the growing load, and either farm fields may not be able to produce more biomass or it would be too costly to buy it on the market.

2.6 Availability of local skills and resources

The lack of local skills and resources could limit the opportunity of off-grid power supply options and will cause an high cost of the system. Availably local manpower, technicians and spare parts will not only reduce the installation and operation costs but also increase the community acceptance. A biogas plant, for example, can be developed by utilizing local skills and manpower.

The skills and materials available for RE projects vary greatly, even within different localities of a given country [17]. The methods or techniques selected to manage the system will be strongly influenced by local availabilities. Any technique which relies on specialized equipment or materials imported from a distant country can't generally be considered suitable for the projects. On the other hand some materials which are routinely imported and are almost always available locally may be used in limited quantities if their prices are not prohibitive (e.g. cement, pipe, etc.). However, projects should use indigenous materials to the greatest extent possible to have a better social impact and acceptability.

Where skills are not locally available, they can frequently be taught and the upgrading of skills is another important factor to enhance the social benefits of the project.

Frequently a given country may have a relatively high level of skills and materials in and around population centers with lesser levels in the more remote regions. Since it is precisely in more remote regions that RE projects are most needed, project developers may consider to move in the direction of simplicity and labour intensity than in the direction of technical sophistication.

The presence of local resources and human capital is also crucial for a local control of the system, which is the most efficient and social-friendly management of the plant. The project itself is an opportunity to enhance job creation and involvement of the local community.

CHAPTER 3
ANALYSIS OF RURAL ELECTRIFICATION SUPPLY OPTIONS: GRID EXTENSION AND OFF-GRID

3.1 Introduction

Rural electrification can be modelled as a multifactorial task connected to a large number of variables.

One of the first issue to be resolved in RE investment's assessment is the choice regarding how to deliver electricity to rural communities. Though it is evident by many case studies that off-grid renewable energy systems can play a vital, cost-effective role to supply electricity to the rural areas, decision makers may require a computational demonstration as a tool to better evaluate this choice [18].

The grid expansion is often found nonviable over the off-grid options because of the distance of the national grid from the rural areas. Moreover, the increased cost of generation, transmission and distribution losses (technical as well as non-technical like pilferage) and the high cost of a centralized management system for small loads make supply of grid power unattractive for remote places, and in some cases impossible.

The investment required for extending the grid depends on the distance of the load center from the existing grid point. The cost of delivered electricity depends on the load factor, transmission and distribution losses and cost of electricity generation. Hence, low load factors, long distribution lines, low load densities and associated high transmission and distribution losses make many of the rural electrification programs through conventional grid extension economically unattractive.

Another reason why to analyze this choice is that national or regional utility companies have often structured their grid-extension plan without excluding villages which might have potential for off-grid supply. Therefore, for the long term sustainability of the investment, it is required to know whether the off-grid system will be vulnerable to a future grid extension.

As a result, in this chapter we are going to report and discuss the results of some significant methodologies of assessment of these options. The reviewed methods are based on either the LCC (Life Cycle Cost) analysis or LCOE (Levelized Cost of Electricity) methodology, which allow to compare the present financial values of the two alternatives (off grid and grid extension).

3.2 Levelised cost of electricity methodology

Following the general framework from [19], a standardized approach is proposed for decision making concerning the extension of electricity services to rural areas.

This approach first determines whether the supply provision should be grid expansion or off-grid on the basis of levelized cost of delivered electricity. We are going to show the procedures for determining the cost of delivered electricity for both grid and off-grid options and for finding the critical line length (or circuit-km, which is the line length in km required for extending the grid electricity services) for grid expansion against different off-grid alternatives.

3.2.1 Delivered cost of electricity through grid extension

The viability of grid extension depends on a number of factors such as distance to the load, anticipated load, distribution losses etc. Checking of the viability of grid expansion can be done by comparing the costs of delivered electricity against the off-grid supply costs. At any location, the costs of delivered electricity from the grid is composed of three components: cost of generation at the bus-bar of the generation plant, cost of transmission and cost of distribution to the clients' meter.

Cost of generation at the plant bus bar

The levelized cost of energy generation is the preferred tool to compare different power generation technologies of unequal economic life, capital cost, efficiencies (or heat rates), and fuel costs.

The levelized cost of electricity generation ($LCOE_g$) can be calculated according to the formulae presented below:

$$LCOE_g = \frac{\sum_{i=1}^{m}\left[CRF_i * I_i + E_i * \Phi_i^{HR} * C_i^{FC} + \beta_i * I_i\right]}{\sum_{i=1}^{m} E_i}$$

Here *i* represents the power generating plant (1,2,….,m), *m* is the total number of power generating plants serving to the central grid, E_i is the annual electricity output at the bus bar (kWh) of plant *i* which can be obtained as:

$$E_i = P_i * \mu_i^{CF} * (1 - s_i) * 8760$$

s_i is the fraction of generated power consumed by the auxiliaries of plant *i*, μ_i^{CF} is the plant capacity factor, which is the ratio of actual output of a power plant over a period of time and its potential output if it had operated at a full nameplate capacity the entire time, and P_i is the rated capacity of the generator unit *i* in kW.

CRF_i is the capital recovery factor which is the ratio of a constant annuity to the present value of receiving that annuity for plant *i* of life *t* years and can be calculated as:

$CRF_i = \frac{r*(1+r)^{t_i}}{(1+r)^{t_i}-1}$,

Here *r* is the rate of interest.

I_i is the capital cost of plant i measured in (US$/kW), Φ_i^{HR} is the heat rate of the plant measured in (MJ/kWh), C_i^{FC} is the fuel cost (US$/MJ), and β_i is the fraction of the capital cost for annual operation and maintenance of plant i.

Cost of transmission of electricity

The power grid transports electric power from the generators to the low voltage distribution sub-stations. Cost of power transmission is associated with capital cost, operation and maintenance cost, and technical losses and depends on the specific power system configuration. The path travelled by electricity through the transmission network is very difficult to trace in a large national electricity transmission network. ESMAP [20] has summarized the levelized cost of power transmission $(LCOE_t)$ for four power generation configurations on developing countries perspective.

	Large Scale	Small Scale	Mini-grid	Off-grid
Typical generator size (kW)	50-300 MW	5-50 MW	5-250 kW	0,3-5,0 kW
Transmission costs	0,25 US$/kWh (100 km circuit)	0,5 US$/kWh (20 km circuit)	None	None

Table 3: LCOE of power transmission [ESMAP 2007]

Transmission and distribution (T&D) losses

In developing countries, the losses in electric power output from generator to customer can vary from 10% in well designed and maintained power grid to 25% or more in ordinary power grid. The transmission and distribution losses $(L_{T\&D})$ estimated by ESMAP [20] for few developing countries can be used as the main reference tool.

Country	T&D Losses (%)
India	26
Philippines	13
Vietnam	11
Tunisia	12
Zimbabwe	15
Kenya	17

Table 4: Transmission and distribution losses [ESMAP; data referring to 2004]

Cost of distribution of electricity

The cost of electricity distribution mainly depends on line length (circuit-km) of the distribution conductors and the size and number of distribution equipment installed. The distribution lines consist of a wide range of configurations: 3-phase 1 kV to 20 kV medium voltage feeders and 1- or 3-phase 110 V, 220 V, and 440 V low voltage circuits.

However, the single-phase configuration has been developed as a suitable configuration to serve the dispersed settlement of rural areas. The levelized cost of electricity distribution can be calculated by using the equation presented below:

$$LCOE_d = \frac{\left[\frac{C_T * P_{PL}}{p_f} + x_d * (a_{11} * C_{11} + a_{2w} * C_{2w} + a_{4w} * C_{4w})\right] * (CRF_d + \beta_d)}{8760 * P_{PL} * \psi^{LF}}$$

Here $LCOE_d$ is the levelized cost of electricity distribution in US$/kWh, p_f is the power factor of transformers, C_T (US$/kVA) is the unit capital cost of distribution transformers, x_d (km) is the total length of the electricity distribution line (circuit-km), C_{11} (US$/km) the unit cost of 11 kV distribution line, C_{4w} (US$/km) the unit cost of 3-phase 400 V line, C_{2w} (US$/km) the unit cost of single-phase 230 V line; a_{11}, a_{4w} and a_{2w} are the percent fractions of total length (circuit-km) for 11 kV, 400 V and 230 V circuits, respectively; β_d is the fraction of the total capital cost of distribution system towards annual operation and maintenance, P_{PL} (kW) is the anticipated load in the village for which the distribution system has to be designed, and ψ^{LF} (%) is the load factor (LF, which is the ratio of average load to the anticipated load of a power system over a period of time) in the village or cluster of villages to be served by the new distribution network.

Cost of delivered electricity

The estimated total cost of delivered electricity $LCOE_{dl}$ (US$/kWh) by extending the grid to the remote villages can be estimated by summing up its components using the following expression

$$LCOE_{dl} = \frac{LCOE_g}{(1 - L_{T\&D})} + LCOE_t + LCOE_d$$

3.2.2 Cost of electricity from off-grid options

Introduction

The cost of electricity delivered from off-grid options $(LCOE_{dg})$ in the rural areas has been widely studied and reported in the literature.

Nonetheless, in this section a different approach is going to be discussed. We have assessed how to calculate the $LCOE_{dg}$ through the HOMER software [15]. HOMER is a computer model that simplifies the task of designing hybrid renewable micro-grids. HOMER manages optimization and sensitivity analysis algorithms which allow to evaluate the economic and technical feasibility of a large number of technology options and to account for variations in technology costs and energy resource availability [21].

As a result, this tool calculates not only the principal economic parameters of an off-grid system, including LCOE, but also gives the possibility to design the best solution in terms of technology options, and to understand the impacts of different variables on the overall performance of the plant through the sensitivity analysis.

An HOMER's application to the village of Sicud, Philippines is going to be discussed [22]. A detailed application, including the comparison with the grid expansion, can be accessed at [23].

Sicud is a small village in Palawan, Philippines. This analysis investigates the options for providing electricity to the village using wind, solar, or diesel power. The results show the impact of different assumptions about the wind resource, fuel price, and required system reliability. The following data to calculate the results have been obtained from [22].

Data input

- Solar Resource

  The solar resource data used in the analysis is an actual imported file. Data input are:

  - latitude(9°0' north), longitude(0°0' east) and time zone(GMT Iceland, Uk, Ireland and West Africa)
  - 12 values of radiation for each month of the year, or the clearness index for each month of the year.

  HOMER uses these data to synthesize hourly data for a whole year. HOMER also uses the latitude value to calculate the average daily radiation from the clearness index and vice versa.

- Wind Resource

  As for the solar source, wind hourly data can be synthetized from 12 monthly values, a Weibull K value and other parameters. Anemometer height set at 10 m. In this analysis, the wind file was generated using HOMER's wind data generator. The daily profile is based upon one day of measurements taken on site. Other entered parameters are typical for the region.

  You can change the scaled annual average to examine the effect of higher or lower wind speeds on the feasibility of system designs. It was set to 3 m/s, given an annual average of 3.937 m/s.

- Primary Load

  HOMER's load data generator was used to generate the load profile of a whole year. Daily profile shape is based on educated guesswork. Typically, small village residential load profiles peak in the evening. It is important to try to get a good estimate of the peak load because this will affect the size of the generator and the inverter. Data input are:

  - 24 values of hourly load of a typical day; HOMER then replicates the profile throughout the year
  - load type: AC
  - scaled annual average for the sensitivity analysis: baseline data are scaled up or down to the scaled annual average value

Now the component inputs are going to be showed, which describe technology options, component costs (initial capital, replacement and O&M), and the sizes and numbers of each component that HOMER will use for the simulations.

- PV system

  Price and lifetime data are based on feasibility report. Performance data are commonly used defaults. Data input are:

  - size: 1 kW

- capital and replacement costs: 6900$; O&M cost: 0 $/year
- sizes to consider: 1-2-3-4-5-6-8-10 [kW]
- lifetime: 25 years
- slope: 9 degrees, set by default equal to the latitude from the solar resource input window

- WTG (Wind Turbine Generator)

  Data input:

  For a generic 10 kW generator:

  - quantity 1, capital cost 27000 $, replacement cost 23000 $, O&M cost 300 $/year; quantity 2, capital cost 50000 $, replacement cost 43000 $, O&M 350 $/year
  - sizes(quantities) to consider: 0,1,2
  - lifetime: 15 years

  For a generic 3 kW generator:

  - quantity 1,capital cost 11000 $, replacement cost 7000 $, O&M cost 200 $/year
  - quantity 2,capital cost 20000 $, replacement cost 12000 $, O&M cost 375 $/year
  - quantity: 0,1,2,3
  - lifetime: 15 years

The power curves are generic. Price data are based on information in the feasibility report and manufacturer cost data for wind turbines of these sizes. Note that the marginal cost of additional turbines is somewhat less than the cost of the first turbine. This reflects cost savings involved in shipping, installing and maintaining multiple wind turbines. This highlights HOMER's ability to use arbitrary cost curves for the components.

- Generator

  Data input:

  - size 5 kW, Capital cost 6500 $, Replacement cost 5500 $, O&M cost 0.2 $/hour (not including fuel costs)
  - sizes to consider: 0 and 8 kW
  - lifetime: 15000 operating hours

  Price and performance data are based on typical default values used by the analysts. The initial cost is 20% higher than the replacement cost to account for ancillary equipment such as controllers, fuel tanks, etc, that would not need to be replaced (HOMER assumes that the cost and generator size are related linearly, i.e., that the installation cost of hardware is $1,500 for 1 kilowatt worth of diesel generation, $3,000 for 2 kilowatts, $4,500 for 3 kilowatts, etc. Analysts can define a non-linear cost curve to account for quantity discounts and economies of scale by adding values that do not follow this linear pattern).

  For this size of load, the lowest cost system typically includes a fossil fuel generator. A zero size is included so that HOMER will consider all-RE systems. Typical design practice mandates that the diesel is to be sized to cover the largest anticipated load. In this case the peak hourly load is 4.5 kW. A 5 kW diesel is considered in order to ensure an adequate safety margin.

- Diesel Price

  Data input are:

  - 0,2 $/L
  - prices to consider: 0,2-0,4 $/L

- Batteries

  Data input are:

  - battery type: Surrette 6CS25P
  - quantity 1, Capital cost 1200 $, Replacement cost 1100$, O&M cost 50$/year
  - sizes to consider(quantities): 0,4,8,12,16,20,40

  20% added to initial cost to account for purchase of wires, racks, etc...

- Inverter

  A converter is required for systems in which DC components serve an AC load or vice-versa.

  Data input are:

  - size 10 kW, Capital cost 12500 $, Replacement cost 12500 $, O&M cost 100$/year
  - sizes: 0,2,4,6,8 kW
  - lifetime: 20 years
  - efficiency: 90%

  The report listed a 10 kW inverter as costing PHP 500,000. This seems a little high. For other sized inverters it was assumed a cost of $1250/kW (PHP 50,000/kW). Performance data inputs are default values used by the analysts.

- Economics

  The 8% real interest rate represents a typical commercial rate. The 20 years project lifetime is from the feasibility report. Typical project lifetimes are 20 – 30 years. The $6000 system fixed capital costs is from the feasibility report. It represents balance of system and distribution system costs that cannot be allocated to a specific component.

- Constraints

  - maximum annual capacity shortage: 0% (to consider 0, 5 and 10 %)
  - minimum renewable fraction: 0%

- Sensitivity analysis

  - diesel price: from 0,2 to 1 $/L
  - average wind speed: from 3 to 7 m/s

<u>Results</u>

The three best solutions are shown in table 5.

	PV MODULES	WIND TURBINES		GENERATOR	BATTERIES	
RANK	PV [kW]	G10 [kW]	G3 [kW]	Diesel [kW]	S6CS25P [num]	Converter [kW]
1				8	4	2
2	1			8	4	2
3			1	8	4	2

Table 5: HOMER's three best configurations

	COSTS			
RANK	Capital [$]	Operating [$/year]	Tot NPC [$]	COE [$/kWh]
1	19800	4325	65973	0.484
2	26700	3947	68836	0.505
3	30800	4559	79464	0.583

Table 6 : HOMER's economical ranking of alternatives

In table 6, the NPC represents the Net Present Cost of the system. Whether the $LCOE_{dg}$, necessary to compare the off-grid option over the grid extension, is the COE calculated by HOMER.

Beyond a diesel price of 0.6 $/L, the second best solution becomes the first best. Beyond an average wind speed of 6.5 m/s, the third best solution becomes the first best. The third best solution results to be the first best also beyond 0.6 $/L and 5 m/s, simultaneously.

3.2.3 Critical or breakeven line length for grid extension

The critical grid extension line length can be determined by comparing between the electricity supply costs by grid extension and off-grid options. The breakeven line length (circuit-km) is the length beyond which a stand-alone or mini-grid system has a lower cost of electricity delivered than that of the grid extension. If the site requires less line length (circuit-km) than the critical length then the grid extension appears to be more cost effective than the off-grid options. If the site, on the other hand, requires more circuit-km than the critical length then off-grid supply options would be economically preferable. The levelized cost of delivered electricity for off-grid systems are independent of the grid extension distance whereas the levelized cost for grid expansion fairly linearly increases with the increase of grid circuit-km.

The critical line length (or breakeven length) x_c (km) can be calculated for *n* different off-grid alternatives using the following equation

$$\frac{LCOE_g}{(1-L_{T\&D})} + LCOE_t + \frac{\left[\frac{C_T * P_{PL}}{p_f} + x_c * (a_{11} * C_{11} + a_{2w} * C_{2w} + a_{4w} * C_{4w})\right] * (CRF_d + \beta_d)}{8760 * P_{PL} * \psi^{LF}} = LCOE_{dg,j}$$

For $j=1,\dots,n$ where *j* stands for off-grid option among *n* different alternatives. If you calculate the $LCOE_{dg,j}$ with the HOMER software, *j* stands for the best alternatives selected by the software. The equation shows that the delivered cost of electricity varies with the anticipated load to line length ratios $\frac{P_{PL}}{x_d}$ for a local setting.

3.3 Life cycle cost analysis

In [24], the author compares the financial costs of providing centralized photovoltaic generating system of various capacities, to satisfy different load requirements, in a remote village in Nigeria to the cost of grid extension over a distance of 1.8 km. Comparison is also made with the centralized diesel generator power supply option, but we are not going to discuss this part of the paper.

For all the systems, the initial capital costs and the life cycle costs over a 20-year life cycle are reported. Sensitivity analysis was performed using variations in module costs, diesel fuel prices and grid extension distance.

The life-cycle-cost (LCC) methodology has been used as the present-worth technique. The systems have been compared based on the services they provide rather than the classical utility approach of cost per kWh.

The life-cycle costing of the alternatives is given by:

$$LCC = C_{pw} + M_{pw} + R_{pw} + E_{pw} - S_{pw}$$

The components $C_{pw}, M_{pw}, R_{pw}, E_{pw}, S_{pw}$ represent the 'present worth' values of the capital, maintenance, repair, energy costs and salvage value, respectively. The local cost of the PV system components were deduced from quotations of local suppliers while the cost of the grid was obtained from the National Electric Power Authority.

The discount rate of 5% used in the analysis is based on the average inflation rate in Nigeria (1970–1993) of 20%, and a maximum interest rate of 25%. An exchange rate of 84 was used to convert the costs in local currency to US$.

For the PV systems, installation was assumed to be 5% of the panel costs. The operation and maintenance (O&M) costs in the centralized systems include the costs for annual inspection ($500) and wages for three system operators working for 8 hours each per day on a wage of $25/month. The repairs/replacement costs (R/R) of the systems include the costs of replacing solar batteries every 5 years and of rebuilding inverters and controllers every 10 years at approximately 50% of the initial cost. The salvage value is 20% of the capital cost, excluding installation.

The local cost of the 185 $mm^2 \times LPE$ high tension (33 kV) cables at 33.45 $\frac{\$}{m}$ gives a total cables cost per km of grid extension of $100\,\$ \times 10^3$. Cable cost constitutes 90% of the cost of components for grid extension per km. The cost of transportation and installation are estimated to be 20% of the materials cost.

Grid extensions have no moving parts and therefore require little or no maintenance. An allowance of 1% of the capital cost is made for maintenance. Replacement cost is assumed to be negligible while the energy cost was derived from the total load rating (in kWh) and the tariff which is equivalent to 1.2 $\frac{cents}{KWh}$.

3.4 Life cycle cost detailed analysis

In this section we are going to discuss an analysis aimed at choosing between off-grid solar photovoltaic, biomass gasifier based power generation and conventional grid extension for remote village electrification [25]. The model provides a relation between RE systems and the economical distance limit (EDL) from the existing grid point, based on life cycle cost (LCC) analysis, where the LCC of energy for RE systems and grid extension will match. The EDL is defined as the distance where the LCC of energy (Rs/kWh or US$/kWh) of the RE systems matches the LCC of energy from grid extension. The LCC of energy feed to the village is arrived at by considering grid availability and operating hours of the RE systems.

The analysis is designed to predict the capacity of the RE systems and corresponding optimal economical distance. The study also addresses sensitivity analysis of the critical parameters.

The LCC of energy generated at the end point (Rs/kWh or US$/kWh) is used to compare the options.

An exact and fair comparison between RE systems and the conventional power grid is rendered difficult by the different operating situations. As the type and character of input energy is dissimilar, cost and availability of input energy differs with time and geographic region, technological maturity and operating constraints. All these have a significant impact on the result of economic analysis.

All these calculations are made using a discount factor of 12%. The baseline year of all the costs reported in this study is 2009–2010.

3.4.1 Life cycle cost of energy from biomass gasification and solar photovoltaic systems

The costs of delivered energy from the biomass gasification and solar photovoltaic systems are calculated by the life cycle cost (LCC) analysis method. The LCC is calculated by considering the capital cost, fuel cost for the entire project life, present worth value of the operation and maintenance cost, component replacement cost etc., and also the total carbon trading benefits in the entire system life. The LCC of energy for each option is calculated by dividing the total LCC of the system by the total energy output in the system's life.

The LCC values for different capacities of photovoltaic systems and biomass gasification systems are calculated by using the following relations:

$$LCC_{PV} = \frac{C_{PV} + C_B + (C_{PV} + C_B) \times \beta \times P(d,n) + C_R \times P(d,n_1) - C_C \times P(d,n)}{L \times h \times n}$$

$$C_C = L \times h \times n \times C$$

C_{PV} and C_B are the capital costs of the photovoltaic system, excluding the battery, and the battery respectively, β is the fraction of capital cost for annual operation and maintenance of the system, C_R is the component replacement cost, h is the annual operation hours, n_1 and n are the life of a specific component and the complete system, d is the discount rate, P is the present worth factor and C_C is the annual carbon benefit. L is the system capacity and C is the carbon emission benefit.

$$LCC_{BG} = \frac{C_G + C_E + (C_F + C_M) \times P(d,n) + C_R \times P(d,n_1) - C_C \times P(d,n)}{L \times h \times n}$$

$$C_C = S_C \times f_{con} \times h \times f_C$$

$$C_M = S_C \times h \times m_C$$

$$C_C = L \times h \times n \times C$$

C_G and C_E are the capital costs of the gasifier system and engine, L is the gasification system capacity (kW), h is the annual operation hours, n and n_1 are the life of the complete system and of a specific component and, d is the discount rate, P is the present worth factor. C_F is the annual fuel cost, C_M is the annual maintenance cost, C_R is the component replacement cost and C_C is the annual carbon benefit. S_C is the gasifier rating (kg), f_{con} is the fuel consumption (kg/h), f_C is the unit fuel cost, m_C is the maintenance cost of the system and C is the carbon emission benefit.

3.4.2 Life cycle cost of grid extension

The grid extension cost depends on the distance of the village/load center from the existing grid, cost of distribution transformer and operation and maintenance cost of the grid line along with the transformer.

The cost of delivered electricity at the village or load center depends on the cost of unit power generation (electricity cost at existing grid point), transmission and distribution losses, load demand and grid availability. So, the life cycle cost of grid extension depends on life cycle cost of electricity generation at the village load center, capital cost for grid line depending on the distance of the village load center from the existing grid point, cost of distribution transformer and operation and maintenance cost. The expression for calculation of LCC of energy (Rs/kWh or US$/kWh) for grid extension can be written as:

$$LCC_{GE} = \frac{LCC_{gen} + LCC_{grid} \times X}{L \times h \times n}$$

$$LCC_{gen} = t_{gen} \times L \times h \times \left(\frac{1}{1 - \delta_{t\&d}}\right) \times P$$

$$LCC_{grid} = C_{grid} + C_t + (C_{grid} + C_t) \times \beta \times P$$

$$P = \frac{(1+d)^n - 1}{d \times (1+d)^n}$$

LCC_{GE}, LCC_{gen} and LCC_{grid} are the life cycle cost for grid extension, electricity generation and grid line (cable/conductor and transformer) cost respectively, X is the distance from the village load center to the existing grid point. L is the load demand, h is the annual operation hours, d is the discount rate and n is the life of the project. t_{gen} is the electricity generation cost, $\delta_{t\&d}$ is the transmission and distribution losses, P is the present worth factor, C_{grid} is the grid line cost, C_t is the distribution transformer cost, β is the fraction of capital cost for operation and maintenance of the grid.

3.4.3 Economical distance limit

The economical distance limit (EDL) is calculated by considering the life cycle cost of the RE system and the distance at which this cost and the life cycle cost of grid extension match; this is similar to break even analysis. The following expression is used for the calculation:

$$\frac{LCC_{gen} + LCC_{grid} \times EDL}{L \times h \times n} - LCC_{PV/BG} = 0$$

EDL values are calculated for different capacities of RE systems and for various operation hours of the RE systems at various grid availability hours.

3.5 Comparison and conclusions for grid approach

The three case studies that have been displayed are based on either LCCA (Life Cycle Cost Analysis) or LCOE (Levelized Cost of Electricity) methodology. These two approaches are very similar to each other; the LCOE is the price at which electricity must be generated from a specific source to break even over the lifetime of the project [26], so it is the necessary price for the electricity to be sold over the lifetime of the project in order to repay the initial investment.

LCCA is a tool to determine the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or system, when each is equally appropriate to be implemented on technical grounds [27]. So LCC and LCOE are very similar and can be seen as an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, etc.

In [24], the authors calculated LCC for the different alternatives following its definition, while in [25] a different approach is followed: the LCC of energy for each option is calculated by dividing the total LCC of the system by the total energy output in the system's life. Consequently, the LCC becomes very similar to the LCOE; the difference is that in the LCCA all the costs occurring in the lifetime of the project are usually added, such as replacement costs of components, or even differential earnings such as carbon benefits , while in the LCOE approach the comparison is just based on the cost of electricity generation.

In our opinion both the approaches are valuable; the very best solution is to use the LCCA tool by listing all the different costs of the project; the level of detail used to describe the costs should be the one used in [19], where the LCOE is computed very precisely by dividing the total LCOE cost of grid extension into generation cost, transmission cost and distribution cost. Moreover, the use of the HOMER software allows to have a good result for the LCOE of the off grid option. The software can be used to compared directly the cost of grid extension with the cost of a stand-alone system, and the sensitivity analysis can be used to assess which parameters are critical to determine this choice.

Going into details, in [24] the LCC is calculated accounting for the present worth values of the capital, maintenance, repair, energy costs and salvage value. The costs are not excessively investigated, but this can also be an advantage because data for the calculation of the results should be available to decision makers. On the opposite, in [19] the computation of the LCOE requires specific data which may not be available, especially in rural communities. Anyway, if you suppose to have all the necessary information, the final results are much more precise than the ones proposed in [24] .

Finally, the method proposed in [25] has the same pros and cons of the one shown in [19] , so it is very precise but specific data are needed. One could choose upon one of these two methods looking at the best choice between an LCOE method and an LCC analysis, considering which factors (costs) are more likely to be critical in the choice.

3.6 Technical instruments for an optimal decisional approach

In the next chapter we are going to analyze and discuss some significant documents from the literature, which show the application of decisional methods to RE investment. Consequently, we are going to shift from the dissertation of technical and physical subjects to economic and financial evaluations, which are the core of our analysis.

As chapter two and three are meant to provide the reader with an analysis of the possible instruments to address both technological constraints and energy distribution mechanisms of RE projects, with a particular focus on the issues raising from fast-growing countries, now we are going to discuss the management of the decisional process regarding economic as well as social and environmental aspects of the investment.

The aim of the next section is to gain awareness about the state of the art of RE investment’s evaluation and highlight pros and cons of every method.

CHAPTER 4
DECISIONAL METHODS FOR RENEWABLE ENERGY INVESTMENT

4.1 Introduction

The latest literature on RE investment in developing countries analyze the multiple factors that affect the success of the project, although the most part of the scientific documents are focused on the exploitation of a single source and do not embrace the concept of the integration of the REs into an hybrid system [28].

The central idea of these studies is that decision-making has to take into consideration several conflicting objectives because of the increasingly complex social, economic, technological and environmental factors that are present. Different group of decision-makers become involved in the process, each group bringing along different criteria and points of view, which must be resolved within a framework of understanding and mutual compromise.

Because of the complexity of energy planning and energy projects, **Multi-Criteria analysis** is used as a valuable tool in the decision-making process.

We have reviewed a lot of methods of this kind from various scientific articles [29] [30] [31] [32], but only the most significant are going to be analyzed in order to find pros and cons of every framework; in particular the criteria of assessment of the alternatives are going to be discussed, considering that the context of application of our study is a developing country, where the best way to provide electricity to rural villages and isolated communities is through off-grid plants, so that distributed RE systems are perfectly fit to the case. Whereas any extension of the grid would be too costly because of the distance of these villages to the main cities of the country. A new framework is necessary for these contexts; for further reading, the reader can refer to [33].

The key representative decision makers for this type of investment are non-governmental organizations (NGOs), private investors, local communities and the national government of the country. Given the variety of decision makers involved in the process, multiple objectives are going to be present. Anyway, the main concern is always to guarantee the financial sustainability of the investment.

4.2 Compromise Ranking method (VIKOR method)

4.2.1 Introduction

The Compromise Ranking method, also known as the VIKOR method, introduces the Multi-Criteria ranking index based on the particular measure of "closeness" to the "ideal" solution. In [34], the method is applied in the selection of a RE project corresponding to the Renewable Energy Plan launched by the Spanish government. The method is combined with the Analytical Hierarchy Process method for weighting the importance of different criteria, which allows decision-makers to assign these values based on their preferences.

The VIKOR method, which was developed as an alternative to ELECTRE [29], is based on an aggregating function representing "closeness to the ideal" which originates in the compromise programming method. In order to eliminate the units of criterion function, the VIKOR method uses linear normalization and the normalized values do not depend on the evaluation unit of a criterion. As regards the aggregating function, the VIKOR method introduces an aggregating function representing the distance from the ideal solution, considering the relative importance of all criteria, and a balance between total and individual satisfaction of decision makers.

The alternatives selected for the RE project are 13, which include wind, hydroelectric, solar, biomass and bio-fuels plants. The designed systems are evaluated according to the following criteria, which are simultaneously going to be discussed:

- *Power [kW]*
- *Investment Ratio [€/kW]*
- *Implementation Period [Years]*
- *Operating Hours [Hours/Year]*
- *Useful Life [Years]*
- *O&M costs [€/kWh]*

Those are suitable attributes to evaluate the overall economic/financial performance of a RE plant; as a result, putting together these indicators, a potential investor could gain some information on the net present value of the investment.

- *Tons of CO_2 avoided [tCO_2/Year]:* this criterion is able to assess the environmental benefit of a RE plant, compared to a traditional one.

In the chosen set of indicators, an important emphasis is put on both financial and technical parameters; furthermore, *"Tons of CO_2 avoided"* allows to highlight the benefit of a RE plant, compared to a traditional one; however, socio-economic impacts on the population haven't been considered, not representing the preferences of stakeholders such as local authorities, non-governmental organizations etc.

Within the VIKOR method, the various *j* alternatives are denoted as a_1, a_2,….,a_j. For alternative a_j the rating of the *i*th aspect is denoted by f_{ij}, i.e., f_{ij} is the value of the *i*th criterion function for the alternative a_j; *n* is the number of criteria. The compromise ranking algorithm VIKOR has the following four steps:

4.2.2 Step 1

Determine the best f_i^* and the worst f_i^- values of all criterion functions, *i=1,2,….,n.* Consider that the *i*th function can represent a benefit or a cost.

4.2.3 Step 2

Compute the values S_j and R_j, *j=1,2,…,J* by the relations

$$S_j = \sum_{i=1}^{n} w_i * (f_i^* - f_{ij})/(f_i^* - f_i^-)$$

$$R_j = \max_i [w_i * (f_i^* - f_{ij})/(f_i^* - f_i^-)]$$

Where w_i are the weights of criteria, expressing the decision maker's preference as the relative importance of the criteria. In the RE Plan launched by the Spanish government three stakeholders are involved: the government who subsidizes the project, the banks that contribute with private funds and the development companies. It is these stakeholders who act as the decision-makers, that must choose the most suitable RE project and who must, therefore, determine their preferences for weighting the importance of different criteria. The weights of relative importance of the attributes may be assigned using AHP (Analytical Hierarchy Process), including a procedure to check for the consistency in the decision-maker's comparisons.

4.2.4 Step 3

Compute the values Q_i, by the relation

$$Q_i = v * \frac{S_j - S^*}{S^- - S^*} + (1 - v) * (R_j - R^*)/(R^- - R^*)$$

Where $S^* = \min_j S_j$; $S^- = \max_j S_j$; $R^* = \min_j R_j$; $R^- = \max_j R_j$ and *v* is introduced as a weight for the strategy of maximum group utility, whereas $(1 - v)$ is the weight of the individual regret. Parameter *v* can take any value from 0 to 1.

4.2.5 Step 4

Rank the alternatives, sorting by the values *S*,*R*, and *Q* in decreasing order. The results are three ranking lists. Propose as a compromise solution the alternative $A^{(1)}$, which is the best ranked by the measure *Q* (minimum), if the following two conditions are satisfied:

a. Acceptable advantage: $Q(A^{(1)}) - Q(A^{(2)}) \geq DQ$, where $DQ = \frac{1}{J-1}$ and $A^{(2)}$ is the alternative with second position on the ranking list by Q;

b. Acceptable stability in decision-making. The alternative $A^{(1)}$ must also be the best ranked by S or/and R. This compromise solution is stable within a decision-making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or "by consensus" ($v \approx 0.5$), or with veto ($v < 0.5$).

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

c. Alternative $A^{(1)}$ and $A^{(2)}$ if only condition b is not satisfied, or

d. Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if condition a is not satisfied. $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum *n* (the positions of these alternatives are "in closeness").

4.3 PROMETHEE method

4.3.1 Introduction

In [35], an integrated, dynamic framework is developed for achieving group consensus in RE projects based on PROMETHEE 2 outranking method. The framework employs an iterative structure to promote mutual compromise among decision makers and facilitate group decision-making. It consists in the formulation of different alternatives (RE conversion systems) which are evaluated by the decision makers according to different criteria; these data lead to a decision matrix, which is the input to the MCDA (Multi-Criteria Decision Aid) method. In outranking methods the preference elicitation, mainly through the decision makers' assignment of weights to each criterion, is accomplished. In case of group disagreement a sensitivity analysis, including the sensitivity of a ranking to changes in the data and/or to the modification of weights, may be promoted through the iterative loop procedure.

4.3.2 Case study

The proposed framework is tested in a case study concerning the exploitation of a geothermal resource, located in the island of Chios, Greece.

Four groups of decision makers were identified: local authorities, potential investors, central government, and public pressure groups (non-governmental organizations and local media). Those can also be considered coherent stakeholders for our context of study, as RE projects in developing countries are usually promoted by international organizations (such as the World Bank) or central governments (and sometimes also private investors) which try to bring together the conflicting needs expressed by non-governmental organizations, local authorities and other stakeholders involved in the process.

Furthermore, four scenarios were chosen, considering different level of exploitation of the geothermal resource.

Finally, five criteria, crucial to the success of the project, were taken into account:

- *Conventional energy saved* [toe/year]: this parameter is relevant when it is possible to deliver electricity in an alternative and traditional way, such as a carbon plant. Considering the context of application of our study, this attribute doesn't have a great importance in the evaluation of the performance of the RE investment; remote villages usually do not have access to electricity, so the villagers don't gain any energy saving.

- *Return on investment* [yearly earnings/ initial investment]: this is a traditional parameter to assess the financial sustainability of an investment, so it suits the situation under analysis.
- *Number of jobs created*: it is important to evaluate the socio-economic impact of the investment on the economy of the populations who live in the nearby of the new plant; as far as the system needs work labor to operate and maintain, the relevant positive effect on the socio-economic conditions of the rural poor must be assessed.
- *Environmental pressure*: qualitative criteria, which was later transformed into quantitative using an impact scale with a range of 1-10. Aspects like air quality, generated wastes, water quality, and aesthetic nuance were incorporated in the overall environmental pressure index. This parameter is important to extend the evaluation of the RE investment to an additional field, which is the environmental one. RE conversion system, nonetheless, have some impacts on the environment and on the quality of life of the nearby population.
- *Entrepreneurial risk of investment*: as environmental pressure, this qualitative index was translated into a 1 to 10 impact scale. Experience from geothermal projects led the analysts to break down the risk of investment to distinct characteristics: new product, new technology, future changes, and initial investment. The values allocated for the entrepreneurial risk index reflect past experience in Greece and elsewhere from similar projects. Considering the present situation, RE systems have reached a considerable technological maturity, so the only parameters which should be considered in a new application are future changes and initial investment, while new product and new technology aren't relevant.

The set of criteria is to be considered complete because it embraces the three main spheres (meanings) of RE investment sustainability: financial, environmental and social. However, the framework should be more detailed and, for example, consider the presence/absence of local know-how, thus considering the possible difficulties in the operation and maintenance.

PROMETHEE 2 technique performs a pair-wise comparison of alternatives in order to rank them according to a number of criteria. If $V_i(A)$ is the value of criterion i of alternative A, then the difference D_i between alternatives A and B is calculated:

$$D_i(A) = V_i(A) - V_i(B)$$

To render the differences in the evaluation between two alternatives meaningful, the PROMETHEE method utilizes two thresholds, which are considered constant and traditionally are decision makers-dependent. These thresholds are: $p_i[V_i(A)]$ threshold of strict preference for criterion value V_i of alternative A, $q_i[V_i(A)]$ threshold of indifference for criterion value V_i of alternative A. The preference index, $P_i(A, B)$, describing the positive arguments of criterion *i* supporting the assumption that action A is "at least good as" action B, is then defined for the case of linear preference:

$P_i(A,B) = 0$ when $D_i(A,B) \leq q_i[V_i(B)]$,

$P_i(A,B) = 1$ when $D_i(A,B) \geq p_i[V_i(B)]$,

$P_i(A,B) = \frac{V_i(A)-V_i(B)-q_i[V_i(B)]}{p_i[V_i(B)]-q_i[V_i(B)]}$ when $q_i[V_i(B)] < D_i(A,B) < p_i[V_i(B)]$.

For the preference threshold p_i a value equal to the difference between the maximum and the minimum for each criterion divided by *n*, the number of scenarios, is adopted in the present framework.

$$P_i = \left(\frac{l}{n}\right) * [V_{max,i} - V_{min,i}]$$

For simplicity reasons the indifference threshold was taken equal to zero in all cases, which tallies with the technical nature of the energy project.

In a new application, these values should be fixed according to the real decision makers' attitudes and preferences, not following this simplified way.

The decision maker assigns a set of weights , $W = (W_1, W_2, \ldots., W_n)$ to the *n* criteria and an outranking degree over ail criteria is calculated:

$$\prod(A,B) = \sum_i W_i * P_i(A,B) / \sum_i W_i$$

In PROMETHEE positive and negative flows, used for ranking the alternatives, are defined as:

$$\Phi^+(A) = \sum_{b/\alpha} \prod(A,B)/(n-1)$$

$$\Phi^-(A) = \sum_{b \neq \alpha} \prod(B,A)/(n-1)$$

The net flow $\Phi(A)$ for each alternative, i.e., the difference between positive and negative flows, was used for the final complete ranking of all alternatives:

$$\Phi(A) = \Phi^+(A) - \Phi^-(A)$$

Since the project was in its initial phase, it was not possible to bring all decision makers together and employ a formal procedure for extracting their preference regarding weight attributes. Therefore, weight factors reflecting the analysts' previous experience and their insights from their involvement in the initial stages of the project were adopted. This is a coherent choice for a possible new application and it also fits our context of study, as far as in the evaluation phase of a RE investment not all the decision makers' preferences on the attributes can be systematically collected.

Given the ranking of the scenarios for every decision maker, a sensitivity analysis is needed in order to promote a better understanding among decision makers who may want to modify their initial preferences moving towards group consensus. The final result is a possible compromise solution which tries to fit the different expectations of the stakeholders.

4.4 SMAA-2 Multi-criteria decision aiding tool

4.4.1 Introduction

The paper [19] presents a standardized approach for decision making concerning the extension of electricity services to rural areas. This approach first determines whether the supply provision should be grid expansion or off-grid on the basis of levelized cost of delivered electricity. If the grid expansion is found nonviable over off-grid options then a multi-criteria decision aiding tool, SMAA-2 (Stochastic Multi-criteria Acceptability Analysis), will evaluate off-grid technologies by aggregating 24 criteria values.
The first part of the paper has been analyzed in the previous chapter, where we have compared different methods to evaluate the advantage of off-grid solutions over the grid expansion.
In SMAA, uncertain or imprecise criteria and preference information are represented by suitable (joint) probability distributions $f_x(x)$ and $f_w(w)$. Probability distributions allow very flexible modelling of different kinds of inaccurate, uncertain ,imprecise, or partially missing information. Based on stochastic x and *w*, SMAA identifies the sets of favourable rank weights $W_i^r(x) = \{w€W: rank\ (i, x, w) = r\}$ for each alternative *i* and rank *r*. The favourable rank weights are those that, given a particular stochastic outcome for criteria, place an alternative to the *r*th rank. SMAA characterizes the favourable rank weights in terms of two descriptive measures: their relative size and midpoint (centre of gravity).

4.4.2 Rank acceptability index

The relative size of W_i^r is the rank b_i^r acceptability index, and it describes the variety of weights that place alternative *i* on rank *r*. The most acceptable alternatives are those with high acceptability for the best ranks. The rank acceptability indices are within the range [0,1], where 0 indicates that the alternative will never obtain a given rank and 1 indicates that it will obtain the given rank always with any choice of weights. The rank acceptability index is computed as the expected volume of W_i^r divided by the volume of the set of all feasible weights *W*.

$$b_i^r = E\left[Vol\left(W_i^r(x)\right)\right]/Vol(W)$$

In particular, the first rank acceptability index b_i^1 describes the variety of weights that make the alternative *i* most preferred. Nonzero (first rank) acceptability indices identify efficient alternatives, i.e. those that can potentially be the most preferred ones.

4.4.3 Central weight factor

The center of gravity of W_i^1 is the w_i^c central weight vector and it characterizes typical weights that make an alternative most preferred. The central weight vectors are defined only for the efficient alternatives. The central weight vectors of different alternatives can be presented to the decision makers in order to help them understand how different weights correspond to different choices. The central weight vector is computed as:

$$w_i^c = E[w: w \in W_i^r(x)]$$

4.4.4 Confidence factor

The confidence factor p_i^c is defined as the probability for an alternative to be the preferred one with the preferences expressed by its central weight vector. It coincides with the first ranking acceptability index subject to precise preference information: $w = w_i^c$.

4.4.5 Case study

The presented approach has been applied to the rural village of Char-Lokman, Laxmipur in Bangladesh to support the choice of how to provide electricity to this village. Among the selected 24 criteria, values for 10 criteria are taken from national and international reports. The remaining 14 criteria are qualitative in nature and have been scored on an ordinal scale from decision makers view by consulting with decision makers from Laxmipur Rural Electric Cooperative (LREC), representing reasonably all the major stakeholders. The different criteria selected are as follows:

- *Capacity utilization factor*: it depends on both resource availability and connected demand characteristics. This is an important factor to be included in any assessment of RE investment projects, because the quantity of energy produced, and therefore the potential earnings, are crucial characteristic to determine the financial sustainability of the investment.
- *Compatibility with future capacity expansion*: the generating system should have the ability to accommodate the growing demand for long term sustainability. Solar PV, for example, can be easily scaled up if resources are available. It is important to preserve the possibility to exploit the growing energy demand of the rural population, as you can grant a better sustainability of the investment.
- *Compatibility with existing infrastructure*: pre-existing rural infrastructure (such as roads, household resources) supports the development of the RE option.
- *Availability of local skills and resources*: availably local manpower, technicians and spare parts will not only reduce the installation and operation costs but also increase the community acceptance.
- *Weather and climate condition dependence*: weather dependence decreases the reliability of the energy system and also causes requirement of larger storage system, which increases system costs. For biogas plants, this criterion doesn’t represent an important factor.
- *Annual resource availability duration*: renewable resources are not usually available throughout all 8760 h of the year.
- *Capital cost*

- *Annual O&M costs(fixed*)
- *Lifespan of the system*
- *Learning rate*: percentage decrease of per unit production cost for every doubling of cumulative production volume. RE plants in rural villages should perform an important learning rate as long as they get used to the system.
- *Current market share*
- *Dependence on fossil fuels*
- *Public and political acceptance*: for successful implementation of an off-grid system, it should fit well into the socio-cultural context of the society.
- *Scope for local employment*: employing local people reduces the system's installation and operation costs. Local employment plays a role to improve socio-economics of the local community and thus increase the acceptability.
- *Public awareness and willingness*: public awareness is very crucial for rural energy projects. If the public is found unsupportive, the system may face many local challenges like thieving, damaging, tampering etc.
- *Conflict with other applications*: the availability of natural resources cannot be restricted by other applications.
- *Lifecycle GHG (Green House Gases) emissions*: this indicator may be important to compare a RE system to a traditional one, and thus evaluate the GHG emissions reduction.
- *Local environmental impact*: negative impact on the local community can make the system unacceptable. For RE projects, this is an important task, i.e. small hydro-power plants can cause disturbance to the aquatic faunal populations.
- *Land requirement and acquisition*: this may provoke public resistance. Land acquisition for development projects in many cases are very challenging and time consuming. RE projects may require to handle this task.
- *Emphasis on use of resources*: policy incentives for using local resources reduce the administrative costs and attract the investor. Also, collection of resources might be easy if uses of local resources for energy applications are encouraged.
- *Opportunity for private participation*: private participation brings financial competitiveness and reduces inefficiency and corruption. Alternatives with the possibility of private investment can increase the financial sustainability of the system.
- *Tax incentives*: financial incentives that a system may achieve from the governments. Tax incentives cause a reduction of costs and attract investment.
- *Degree of local ownership*: renewable based electrification systems are often theoretically owned by initial fund provider, but physically owned by the end users. Private ownership practice of the system reduces maintenance cost, overcomes tampering, reduces overuse and maximizes benefits.

- *Interference with other utilities*: the off-grid system should not interfere with the utility infrastructure of the locality. Installation of micro-hydropower plant , for example, may require relocation of water supply wells and pipes. This could lead to a significant increase in costs of the system.

The set of indicators spreads across all the aspects of sustainability, however some criteria should be added in order to test the financial sustainability of investment, i.e. NVP, comparing capital cost to predicted earnings.

The SMAA simulation is performed without preference information from the decision makers. The rank acceptability indices indicate how widely acceptable each alternative may be. Alternatives with high acceptability for the best ranks are the most immediate candidates to be considered by the decision makers. However, the decision makers need to see whether they agree with the central weights of the most acceptable candidate, and if not, consider the next most acceptable solution. The confidence factors are based on a kind of sensitivity or robustness analysis. The confidence factors can be used to see if the criteria information is accurate enough for making an informed decision. If the confidence factor is low, it indicates that the alternative cannot be reliably considered as the most preferred one.

4.5 The REGIME method

4.5.1 Introduction

In [36], the authors initially evaluate the theoretical potential derivate from REs exploitation, related to area disposable in the region under analysis; then criteria to determinate the RE source and the degree of its exploitation are selected, aiming at the maximum penetration of REs in an energy mix. The process to select criteria for best exploitation of REs in a region needs the following requirements:

- Compatibility with environmental and ecological constraints;
- Compatibility with economic, political, legislative and financial situation at a regional level;
- Compatibility with the local socio-economic conditions;
- Consistence with the technical conditions of the area under consideration and technology of the REs facilities.

A list of the evaluation criteria is proposed:

<u>Economic criteria</u>

- *Investment cost*
- *Net present value*
- *Operation and maintenance cost*
- *Payback period*
- *Fuel cost*
- *Service life*

Environmental criteria

- *Greenhouse gas emission reduction*
- *Land use*
- *Visual impact*

Social criteria

- *Social acceptability*
- *Job creation*
- *Social benefits*

Technical-technological criteria

- *Efficiency*
- *Safety*
- *Availability*
- *Reliability*

The proposed methodology is based on the REGIME method. REGIME is a MCDA(Multi-criteria decision analysis) qualitative method based on the possibility of partial compensation among the different criteria which affect the evaluation of the various policy alternatives. MCDA qualitative methods are used when some or all data are not available in quantitative terms, and qualitative criteria and measurements must be applied. Moreover, qualitative information is transformed into quantitative in order to be analyzed more easily. It is a concordance analysis, meaning that it is based on pairwise comparison between alternatives according to some chosen criteria in order to establish a rank between them. REGIME uses an impact matrix and a set of weights as input. The first gives information about the impact of the alternatives in relation to the chosen criteria. The weights express the (politically determined) relative importance of the criteria. The impact matrix indicates the performance of each alternative according to each of the chosen criteria.

Pairwise comparison between the set of alternatives according to each criterion are carried out. For each pair of alternatives i and *j*, the criteria are selected, for which alternative i is better or equal to alternative *j*. The set of these criteria is called the criteria concordance set. Then, the alternatives i and *j* are ranked by means of the concordance index C_{ij}, that is, the sum of the weights attached to the criteria according to which alternative *i* is better or equal to alternative *j*. Then the concordance index C_{ji} is calculated, which is obtained by summing up the weights of the criteria according to which alternative *j* is better or equal to alternative *i*. Finally, the net concordance index is calculated subtracting C_{ji} from C_{ij} ($iij = C_{ij} - C_{ji}$), which is positive if alternative i is preferred to alternative *j*.

Since sometimes it is not possible to obtain a complete ranking of the alternatives using only *iij*'s sign, a performance indicator p_{ij} is formulated for the criterion *i* with respect to the criterion *j*, which indicates the probability that an alternative *i* is preferred to another one, that is, that the net concordance index is positive:

$p_{ij} = prob(iij > 0)$. Using the performance indicator, an aggregate probability index can be defined, which indicates the performance score. Therefore an aggregate probability measure is defined , which represents the performance score:

$$p_i = \frac{1}{I-1} * \sum_{j \neq i} p_{ij}$$

Where I is the number of chosen alternatives, p_{ij} and p_i are estimated using a specific probability distribution of the set of feasible weights.

4.5.2 Case study

The proposed method has been tested on a regional level in a case study at Thassos, Greece.

Following a multi-criteria approach, the first step to be taken is the definition of alternatives, which are the relevant potential REs of wind, biomass, PV and alternative combinations of wind-biomass, wind-PV, wind-biomass-PV.

The second step is the definition of the evaluation criteria on the basis of which the alternatives will be evaluated.

- *Economic benefits for the region:* expression of the economic progress made in the region by REs exploitation.
- *Employment in the energy sector*: increase of employment during construction and operation period of REs facilities.
- *Creation of development*: the role of the energy systems as development poles of the greater region.
- *Land used:* land used for REs facilities.
- *Social acceptability:* opinion about the REs development by the local population.
- *Environmental quality:* impact on the environmental quality.
- *Visual impacts*
- *Impacts on flora-fauna*
- CO_2,SO_2,NO_x *emissions*
- *Efficiency:* useful energy obtained from energy source.
- *Safety:* public safety.
- *Availability:* guarantee of the energy supply.

From the point of view of a potential generic investor, too much emphasis is put on the environmental performance of the system, while there is no indicators that assess the financial sustainability of the project. However, criteria such as *Availability* and *Efficiency* are properly included, as the technological characteristics of the system provide constraints in the supply of the energy output; as a result, you can determine whether the needs (i.e. energy demand) of the local populations are satisfied. Moreover, including socio-economic criteria in the framework enables to assess the positive welfare impacts on the local populations, improving the overall judgment on the project, from any point of view.

The third step is the definition of alternatives' scores with respect to each evaluation criteria; the result is an impact matrix, whose elements reflect the benefit of each alternative REs with respect to each criterion. The benefit matrix is the main input into the REGIME multiple-criteria evaluation method.

The fourth step is the weighting of each criterion to express their relative importance. Moreover, the priorities of the alternatives are considered: alternatives are divided into groups, each one having a priority towards one of these criteria's kinds: social criteria, economic criteria, environmental criteria and technical-technological criteria, reflecting the relative importance of each group according to socio-economic factors, high potential of energy resources, environmental issues of the island and technical-technological relative to energy sources.

The fifth step is the comparison of each pair of alternatives on the basis of the evaluation criteria, which finally leads to the selection of the most proper alternative in the final step.

4.6 Application of MCA (Multi-criteria analysis)

4.6.1 Introduction

The main objective of this section is to examine how to incorporate socio-environmental considerations into project assessment models and the Multi-criteria analysis is applied to the case study of Sri Lankan hydropower projects as an illustrative example [37].

The three main sustainable development indicators considered in the paper are the *economic costs of power generation* (average generation costs per year), *ecological costs of biodiversity loss* (estimated biodiversity index values per year), and *social costs of resettlement* (number of resettled people per year). These indicators are selected as a key representative indicator for each aspect of sustainability since they often pose the most significant impacts when conducting hydropower project assessment in Sri Lanka.

4.6.2 Economic indicator

The economic objective of the selected hydropower schemes is to generate additional kilowatt-hours (kWh) of electricity to meet the growing demand for power in Sri Lanka. The usual economic indicator in power project evaluation is the maximization of net present value (NPV). However, in the proposed study, minimizing average generation costs per unit of generation will be used as the main economic indicator instead of NPVs. This selection is based on the assumption that the total benefit per unit generated is the same for all projects under comparison.

Such an indicator is not enough to give a complete view of the financial sustainability of the project, especially for RE projects in fast-growing countries where the potential investor faces a great variety of economic issues. Moreover, the assumption on the equality of benefits is very strong. As a result, additional financial indicators should be included in a new application.

4.6.3 Environmental indicator

The study applies the existing Biodiversity Index (BDI) values per year as the environmental indicator. The total BDI value associated with site *I*, is defined as

$$E_i = \sum_j w_j * A_{ij}$$

Where E_i is the BDI value associated with site *i*, A_{ij} is the ha (hectare area) of ecosystem of type *j* at site *i*, and w_j is relative biodiversity value of type *j*.

Since E_i would tend to be correlated with reservoir size (i.e., land area inundated and energy storage capacity), two further scaled indices may be defined as follows:

$$F_i = \frac{E_i}{\sum A_{ij}} = \frac{E_i}{Tot\ land\ area\ affected\ at\ site\ i}$$

$$G_i = \frac{E_i}{Hydroelectric\ energy\ generated\ per\ year\ at\ site\ i}$$

Thus, F_i is the average BDI value per hectare of affected land, and G_i is the average BDI value per unit of energy produced per year. These formulae are applied to each hydro project site under consideration in the study, to determine the BDI values per year.

These indicators are suitable to give a synthetic view on the ecological impact of an energy conversion system, allowing the decision-makers to include the preservation of the environment as a constraint in a new application.

4.6.4 Social indicator

Communities that are affected by dam projects often face severe hardships. Thus, effective planning to prevent the destruction of the local socio-economic system is essential. Hence, an important social objective is to minimize the number of people resettled as a result of dam construction, which is used as the social indicator of sustainable energy development in the study.

This indicator is specific for hydro-power projects, so it does not fit an overall assessment of a generic RE project.

In order to visualize the trade-off among the three sustainability indicators, they are incorporated into one equation. The equation to represent the best-fit plane formed by the three sustainability indicators can be expressed in the *(x, y, z)* plane as

$$Ax + By + Cz - D = 0$$

Where *A*, *B*, *C*, *D* are coefficients that give the best-fit plane through the data. Since planes with different values of *D* are all parallel, they all pass the same gradient. Thus, an arbitrary, non-zero value of *D* may be chosen to solve the equation (setting *D=0* leading to a trivial solution). The value of *D* for every *(x, y, z)* data point can be set equal, because all the points are assumed to lie on the same best-fit plane.

4.6.5 Case study

Applying the above equation to the Sri Lankan hydropower case, *(x, y, z)* are respectively the variables *electricity supply cost, number of people resettled* and *biodiversity loss.* The three variables are weighted inversely by the amount of electricity generated. This scaling removes impacts of project size and makes them directly comparable. Moreover, you can note that the units for each parameter are different; thus, a natural logarithm of each parameter is computed.

Finally, the analysis treats the three sustainability indicators in an equal manner, i.e., the same weights are allocated.

Applying the proposed method on our context under study, one could find some limitations, such as over simplification by condensing complex and highly complicated information into a single equation. Thus, there is a danger of placing too much emphasis on certain indicators based on the equation result.

Furthermore, it is more realistic to allocate different weights to the indicators, reflecting the importance given by the decision makers to each kind of criterion. Finally, setting a benchmark coefficient or threshold levels could help achieve accordingly effective decisions with appropriate socio-environmental goals.

4.7 Comparison of decisional methods

The **VIKOR method**, applied to RE investment, may not be simple to understand for decision makers. The formulae of indicators *S*,*R* and *Q*, used to rank the alternatives, do not show an immediate meaning.

On the other hand, the method used to calculate the weights of criteria, Analytical Hierarchy Process (AHP), is very suitable to RE investment. This tool allows decision makers to express only the relative importance of different criteria, which is something that they should know, because this is the expression of their preferences regarding the primary goals of the investment. For example, a private investor would give a greater importance to an economic/financial criteria in respect to an environmental one, while Non-Governamental Organizations (NGOs) would assign the greatest weight to social criteria in respect to a financial one. As a result, different decision makers could give different relative importance to the same criteria; however, AHP allows to set a parameter (v) which makes the strategy move from maximum group utility to a veto solution (when the preference of a single decision maker is considered critical), with intermediate solutions alike (by consensus).

In our opinion, the set of criteria used to rank the alternatives is not relevant: a potential investor can have only a generic overview on the financial performance of the investment and does not have information about its risk. Moreover, the set does not focus on the other fields of the sustainability (environmental and social); technical constraints and efficiency performances are not highlighted.

The **PROMETHEE method**, otherwise, has a significant set of criteria, because the preferences of different decision makers are expressed. Also, the set is not enough detailed, because you have just one criteria for each kind of assessment (economical, environmental,…).
As regards the method, it is easy and ready to understand; in particular, the values of the thresholds, if possible, should be assigned following decision makers' opinions, in order to have a better ranking of the alternatives.
In the set of weights, decision makers have to express absolute values regarding every criteria; considering that this operation is made in the initial phase of the project, decision makers may be forced to assign wrong values or, in the worst case scenario, they don't have the necessary information to do it. Nevertheless, the method finally considers a sensitivity analysis to give to decision makers the possibility to modify their initial preferences. As a result, you can evaluate subjective uncertainty originated from decision makers' evolving preferences, ignorance, lack of sufficient time for the necessary interviews, and increased problem complexity; it is also possible to try to move to group consensus, taking into consideration the different expectations of the stakeholders.

The **SMAA-2 method**, like and even more than the VIKOR method, is not easily understandable by all decision makers, because the calculations of the performance indicators are based on the statistics theory.
The main advantage of this method, in respect to the other ones, is that decision makers are not supposed to express the preference information for the simulation; it is the method that shows them which are the proper weights to obtain one of the possible ranking of alternatives, and they can discuss the central weight factors of the most acceptable candidate, and then consider the next most acceptable solution if they do not agree with the proposed values. Furthermore, the confidence factor is a very important tool as it indicates if the best ranked alternative can be reliably considered as the most preferred one.
The set of criteria is both significant for all the aspects of sustainability and complete; some financial parameters could be added to give a detailed overview of the economic performance of the investment. However, decision makers may not have the sufficient information to calculate all the parameters.

The **REGIME method** is not difficult to understand but it is not very precise in the ranking of alternatives; it is a relatively easy method to use, provided that one can have access to user-friendly software. However, it presents the same difficulties of the other MCDA methods: the determination of alternatives, criteria and weights entails a high degree of subjectivity although at the same time this subjectivity can also be made more explicit by the same implementation of the method.
Along with other methods like PROMETHEE and VIKOR, the most important difficulty is the determination of the weights, because it is very difficult to reach a consensus among the stakeholders and it is mainly a political problem rather than a technical one.
The set of criteria used in the case study of Thassos, Greece is not sufficient to evaluate the financial performance of the investment.

Nonetheless, similarly to the other MCDA methods, REGIME is a useful instrument to support a policy process, that is the assessment of the sustainability of alternative policy options. It offers a structure that helps to gather information on the different impacts of alternative policies. Using the method, the ranking process becomes easy. In fact, the criteria used in the analysis can represent and include aspects from the three dimensions of sustainability, that is, the environmental, the social and the economic one. As all MCDA methods, REGIME helps to structure the evaluation process and the information gathering.
The most important advantage of REGIME is that it can use different types of information. This flexibility is very important with RE investments in developing countries, where there is complexity and many data are not available in quantitative terms.

The last case study, with the **application of MCA**, is focused on the integration of social and environmental aspects in the assessment process; in our opinion, too little concern is put on the economic performance of the project; without a clear evaluation of the financial sustainability of the investment, no stakeholders will put money on these projects. Having set the same weights for the three aspects of sustainability, equation's results could led decision makers to choose alternatives which are financially non-viable. So once again we have assessed the difficulties in choosing the proper weights for the criteria.
The MCA is especially powerful when quantifying the trade-offs that must be made between conflicting objectives which are difficult to compare directly. The proposed method in this paper assesses projects in a holistic manner, so it should be used as a complementary tool to the existing single criteria approaches (environment (e.g., EIA), finance (e.g., NPV) and social (e.g., SIA)).
The advantage of the MCA is its ability to provide a range of feasible alternatives instead of one 'best' solution. Furthermore, we can assess alternatives with different objectives and varied costs and benefits.
This is the case even when economic evaluation is difficult.
The MCA incorporates various project stakeholders' opinions into the ranking of alternatives in a systematic way, while integrating risk levels, uncertainty and valuation.

4.8 Proposition of a significant set of criteria

Having reviewed all these methods and their criteria, we are going to propose a set of criteria which is supposed to summarize all the dimensions of sustainability (economic, social, environmental, technical and policy/regulation) [38]; also, the set is meant to be a user-friendly tool for decision makers, so it is not redundant and it does not require very detailed data for the assessment.
However, we are not expecting to represent the preferences of all the possible stakeholders involved throughout the lifetime of the project; moreover, some aspects of sustainability may not be included in the set.
Table 7 shows the proposed set of criteria.

ECONOMIC dimension	SOCIAL dimension	ENVIRONMENTAL dimension	TECHNICAL dimension	POLICY/REGULATION dimension
NPV	Social Acceptability	Local Environmental Impact	Efficiency	Land Requirement and Acquisition
Learnig Rate	Scope for Local Employment	Lifecycle Greenhouse Gas Emissions	Availability	Opportunity for Private Participation
Entrepreneurial Risk of Investment	Creation of Development			Tax Incentives

Table 7: Proposed set of criteria

4.8.1 Economic dimension

As previously stated, the economic/financial performance is always the most important dimension of sustainability of the investment. Without a sufficient return on investment, no one would be willing to participate in the program and the project would never start. Regardless who is the major stakeholder in the investment, the primary assessment is always to be made in the economic/financial field. We are suggesting the following criteria:

- **NPV**: net present value of all the benefits and costs occurring throughout the lifetime of the project; so this indicator resumes both the benefits (revenue and other income) of the project and its costs (investment cost, annual operation and maintenance); so it gives a complete overview on the financial performance of the investment.
- **Learning Rate**: percentage decrease of per unit production cost for every doubling of cumulative production volume. RE plants in rural village should perform an important learning rate as long as they get used to the system.
- **Entrepreneurial Risk of Investment:** qualitative index which resumes the risk of investment, which is a crucial factor for RE projects in developing countries. In order to assign a value, analysts should refer to past experience with similar projects in the same country. Also, the index should be translated into a quantitative scale.

4.8.2 Social dimension

In a RE investment, it is important to evaluate both social benefits and "costs". The values of all the criteria are the expression of the relative importance of the alternatives in respect to the criteria. We have selected the following criteria:

- **Social Acceptability**: it resumes the opinion about the REs development by the local population. Any development project, which conflicts whit the interests of the local people, may provoke resistance. Some REs have experienced very supportive responses from the local people, while other not. For example, the solar PV system already gets wide acceptance from people of all walk of life.

- **Scope for Local Employment**: local employment plays a role to improve socio-economics of the local community and thus increase the acceptability of the system.
- **Creation of Development:** the project may be a supportive initiative for the rural electrification of the country, and thus be a source of economic development; for example, some productive activities may grow because of the availability of electric power delivered by a RE system.

4.8.3 Environmental dimension

As it is for the social dimension, it is important to include both environmental benefits and "costs". The values for this criteria are the expression of relative importance of the alternatives in respect to the criteria itself. The following criteria have been considered critical to evaluate the environmental impact of a RE system:

- **Local Environmental Impact:** negative impacts on the local flora-fauna can make the project unviable;
- **Lifecycle GHG Emission:** it is the lifecycle production quantity of GHG per unit energy production by the system. Options with less GHG emissions are better for the environment. The indicator can represent a measure of environmental benefit if a comparison with a traditional fossil fuel system is made, thus calculating GHG emissions reduction.

4.8.4 Technical dimension

Standard and significant indexes for an assessment of the technical/technological performance of the system are:

- **Efficiency**: measure of the useful energy obtained from the energy source. For a RE system, having a greater efficiency means that the plant has a minor dependence on weather conditions.
- **Availability**: measure of the availability of the RE source, and it can be estimated in different ways. It can be estimated as the duration (in hours) of the year when the resource is available to meet at least the minimum demands. Those resources, which have higher availability durations, can serve longer periods of the year. Data are to be obtained from local climate database.

4.8.5 Policy/regulation dimension

As it is for social and environmental criteria, the values are the expression of the relative importance of the alternatives in respect to the criteria. We have selected the following:

- **Land Requirement and Acquisition**: if the off-grid system requires substantial land area, public resistance should be expected. Those alternatives which require no extra land must enjoy the privilege over other alternatives that require land. Solar PV do not require any remarkable land.

- **Opportunity for Private Participation**: private participation is crucial for the financial sustainability of the investment. Alternatives with a greater possibilities of private investment have to be preferred.
- **Tax Incentives**: some RE systems may attract a greater interest from the local government than others; that's a consequence of the economic/social development and environmental safeguard that a RE investment brings with it. Projects with the major probability to attract financial incentives are to be preferred, as they cause a reduction of costs and attract investment.

CHAPTER 5
FINANCIAL ANALYSIS OF SIGNIFICANT RENEWABLE PROJECTS IN DEVELOPING COUNTRIES

5.1 Introduction

Although every RE project is unique, there are some factors that always have a strong influence on project success [39]. To begin with, the lender will be interested in the commercial viability of the proposed project. The market analysis and strategy for providing a service that the local consumer is both willing and capable of paying is crucial. Second, the assessment of risks and their mitigation is essential. Risk mitigation requires mobilizing support from governments, multilateral and bilateral financiers, as well as guarantee and insurance arrangements with parties involved in construction and operation of the project. A prerequisite for satisfactory risk mitigation is a suitable ownership structure, and the evidence of effective risk management is a comprehensive security package.

Lastly, political commitment to the proposed investment is another essential element. Experience shows that energy projects require an enabling environment, unambiguous government policies, and co-ordination between government ministries and their agencies. This means that successful RE projects are more feasible in countries where the government adopts clear procedures and limited intervention in the energy market. In addition, project developers should always try to establish reliable relationships with local authorities.

As a result, new financing mechanism have to be tested to help the large-scale deployment of REs [40].

In this chapter we are going to discuss some case studies setting out the experience of renewable project barriers and risks being addressed by specific financial instruments or intermediaries [41].

A number of multilateral, bilateral and private sector programs have emerged in recent years specifically to foster investments in RE projects. Specifically, the multilateral development banks are aware of the need to take action to redirect energy sector investments toward more sustainable development. For example, the World Bank has established the Asia Alternative Energy Unit (ASTAE), which is chartered to develop only RE and energy efficiency projects. Since its inception, ASTAE has helped the World Bank lend over US$500 million for RE projects in the Asia region [42]. The International Finance Corporation (IFC) has recently launched a US$100 million Renewable Energy and Energy Efficiency Fund (REEF) which is designed to invest in private sector projects [43]. The Asian Development Bank recently approved a US$100 million loan to the Indian Renewable Energy Development Agency (IREDA) for biomass cogeneration projects in India [44]. These and other examples suggest that the multilateral development banks are increasing their level of financial support for RE projects.

The point of view proposed is that of the **World Bank** [41], a United Nations international financial institution that provides loans to developing countries for capital programs. The World Bank can act both as a source of debt financing, mainly through the International Development Association (IDA) [45], or grant financing, through Global Environment Facility (GEF) [46].

IDA is the part of the World Bank that helps the world's poorest countries. Established in 1960, IDA aims to reduce poverty by providing loans (called "credits") and grants for programs that boost economic growth, reduce inequalities, and improve people's living conditions.

The GEF has become an important source of grant financing especially for RE projects. For further reading, refer to [47]. One of its institutional mandates is to support projects that help reduce greenhouse gas emissions. As a result, many RE projects are targeted by the GEF in order to improve the competitiveness of these projects relative to conventional fossil fueled energy projects.

The World Bank, as a multilateral development agency, supports RE projects with several types of service, among which feasibility studies/assistance for project development, debt financing, investment co-financing, loan guarantees, partial risk guarantee/political risk insurance, technical assistance and training, etc.

By analyzing experiences with financial instruments to scale up RE technologies, we are going to identify financial instruments that can be used to overcome specified project risks and barriers; otherwise, this chapter of the thesis can also be used to identify project risks and barriers that have been addressed by a specific financial instrument in the past.

As a result, our analysis is intended to assist policymakers (or other stakeholders) in low-income countries in identifying how to apply financial instruments funded from different types of sources to support the scaling-up of commercially proven RE technologies.

We are going to discuss the following financial barriers/project risks to RE investment in low income countries:

- **High and uncertain project development costs**: RE technologies projects are particularly vulnerable to changes in the regulatory framework. Their lack of cost competitiveness means that these projects are generally dependent on a supportive regulatory framework to proceed, including commitments to pay premium prices, priority access to electricity grids including support for the necessary infrastructure investments and guarantees of purchases of their output. Severe problems for project viability can arise where the regulatory framework changes.
- **Lack of equity finance**: while large numbers of RE technologies project developers exist, there are only limited numbers of large-scale project sponsors, particularly among those operating in low-income countries, with the ability and willingness to fund RE technologies projects on a corporate finance basis. RE technologies projects are generally smaller than conventional generation projects and this is reflected in the size of developers. The high risks of investment in many low income countries, whether inside or outside the energy sector, will also tend to deter many large energy companies based in more developed economies leading to a lack of equity.

- **Lack of long-term financing**: RE technologies are generally characterized by high up-front capital costs and low ongoing operating costs, due to the nature of the technologies concerned. This implies a need for RE technologies projects to be able to access long-term funding. Such long-term financing is often difficult or even impossible to obtain in many low income countries. This may be partly due to regulatory or other restrictions on long-term bank lending. In the smallest developing countries, the major financing barrier may simply be a lack of capital market funds.
- **Lack of project financing**: in a project finance basis, the security for the loan comes from future project cash flows and where little or no up-front collateral is required, although there will still be a need for a share of the project to be funded from equity. RE technologies projects are more exposed to the limited availability of project financing than most conventional technologies, as the share of capital costs in their total cost is much greater.
- **Small scale of projects**: the small-scale of many RE technology projects creates significant problems in obtaining private financing. Economies of scale in due diligence are significant and many larger financial institutions will be unwilling to consider small projects.
- **Weak banking sector**: the weak local banking sector is characterized by limited access to financing, short loan maturities, and high interest rates.

The financial instruments used to address project risks and financial barriers are:

- **Individual guarantees:** an individual guarantee covers a portion of the losses to the financier (for loans, this would typically be unpaid principal and collection costs, but not necessarily unpaid interest) if specified events occur. A guarantee would not cover all potential losses as doing so would obviously remove the incentives on the financier to conduct proper due diligence or to seek to recover unpaid amounts. Guarantees might take the form of either a pari-passu or subordinated guarantee. The difference between the two lies in the treatment of unpaid sums that may be subsequently recovered. Under a pari-passu guarantee, recovered monies are shared in a pre-agreed ratio between the financier and the guarantor while, under a subordinated guarantee, the recovered monies are first used to repay the financier and only after this are any remaining amounts used to repay the guarantor.
- **Liquidity guarantee**: liquidity guarantee is where the guarantor is guaranteeing that the guaranteed entity has sufficient funds to meet its obligations. For example, hydro projects may have very volatile revenues depending on rainfall in the year. In these cases, a liquidity guarantee can provide assurance that the project will be able to service its debts in dry years.
- **Partial risk guarantee/Political risk insurance**: political risk insurance or a partial risk guarantee are offered by a number of multilateral institutions and bilateral credit agencies within the World Bank Group. Such a guarantee will typically cover the risk that a project defaults due to the actions of government or public sector agencies. These might include, for example,

expropriation or a breach of contract that cannot be relieved by other means, regulatory actions that have severe economic impacts on the project or limits on currency convertibility.

- **Senior debt**: senior debt provided from public sources, whether in the form of a project loan or credit line, will take its place among the first creditors to be repaid from a project. It is primarily used to reduce the costs of the project, by providing concessionary funds which may be blended with more expensive commercial funding, and to offer longer-term debt than may be available in local financial markets.
- **Payment against outputs**: payments against outputs are going to be discussed in the form of Output-Based Aid (OBA). OBA specifically refers to delivering outputs for low-income consumers. For the energy sector, OBA is typically used to increase access to energy services by the poor, by helping cover the difference between the full cost of supply and the affordable price to poor households.
- **Aggregation**: a major barrier to lending to small-scale projects is that of the associated transaction costs. These will rule out many RE technology projects from the commercial financing market, even if they are otherwise attractive. Aggregation of projects is one way to overcome this barrier. Various forms of aggregation can be used. One approach is to adopt standard project specifications and agreements so that each individual project can be rapidly appraised at low cost. For example, Sri Lanka have adopted standard power purchase agreements and tariffs for small hydro projects, avoiding the need for these to be reviewed for each new project.
- **Micro financing**: one mechanism that has been pursued is to channel funds through Micro-Financing Institutions (MFIs) to provide loans to households, either directly or via the equipment supplier, who can then use this to pay for at least part of the capital costs of RE technology systems.
- **Commercial Financial Institutions (CFIs**): public financing is used to provide a credit line or guarantee for a Commercial Financial institution (CFI). The CFI is then responsible for providing funds to RE technologies project companies, whether as grants, loans or guarantees. The CFI might supplement the public funds with complementary funding from its own resources or blend public and its own funds into a single loan. The CFI is responsible for due diligence, following procedures and processes approved by the public financing agency.
- **Concessionary financing:** a concessionary loan is a loan bearing no interest or a rate of interest that is below the average cost. It is used to bring down the cost of capital and attract private investment. This instrument can additionally be employed as an incentive to successfully improve utility efficiency, sector governance, or both. A senior debt can be used as a provider of concessionary financing, too.

- **Public guarantee fund**: it is a source of financing where the government of the country makes available subsidies to private companies to make their projects profitable, and thus attract private sector investment. Subsidies are usually allocated only to projects with a positive social return.

The case studies which have been reviewed do not always report homogeneous data, that is some performance indicators may be shown in some case studies, while in others may not [41]. That' s because chapter five is a supporting section to give a generic view of financial aspects and issues raising from RE projects in developing countries, and the data from the literature are not critical for the goals of our work.
Having all the data available, and then showing them in an uniform way in the studies, the chapter would have been redundant and it would not be integrated with the other sections of the thesis.

5.2 Nepal - Power Development project

Source: World Bank
Barriers: Lack of long term financing and availability of equity
Financial Instrument: Project loan (Senior debt)
Amount: Original IDA (World Bank) fund of US$35 million
Results: Partial

5.2.1 Introduction

Nepal faced a large and growing need for investment in its power sector [48]. The required investment was beyond the capacity of the government and donor agencies. The availability of private-sector debt and equity for hydropower projects was constrained, the debt that was available was of an insufficient maturity, and private investors were uncomfortable with investing in first-of-a-kind projects.
This project aimed to increase the flow of private investment in small and medium hydropower plants through the creation of a Power Development Fund (PDF), which provides long term financing to private investors, leveraging debt (and developer's equity) financing from the local capital markets. The project also aimed to reduce costs of new plants by implementing improved international competitive tendering processes. The project became effective in March 2004.
Under this credit operation, the Power Development Fund would finance small hydro schemes with an aggregate capacity of about 10 MW and one medium-sized scheme of about 30 MW. The US$35 million from IDA credit was expected to leverage financing from other sources, i.e., developers' equity and commercial banks, of about US$40 million.
The Power Development Fund would be set up and owned by the government while the administrative management of the fund would be carried out under contract by a local commercial bank (the Fund Administrator). The fund would provide long-term financing to small and medium hydropower projects, initially using money advanced by the World Bank (IDA). Other donor institutions would be invited to

contribute over time. This donor involvement would be leveraged to attract private lenders and project developers. The government would form a Power Development Fund Board which would approve loans from the fund.

5.2.2 Global indicators

GLOBAL INDICATORS	
Definition	**Value**
Progress towards Achievement of PDO	Unsatisfactory
Overall Implementation Progress (IP)	Unsatisfactory
Overall Risk Rating	High

Table 8: PD project's global indicators [2010]

In Table 8, PDO refers to "Project Development Objective".

5.2.3 Project Development Objective indicators

- Number of additional rural households with access to electricity generated by micro-hydro schemes: 71813, given the initial goal of 74000
- Increased generation capacity (MW): 53.4, given the initial goal of 46.4
- Total kW capacity of new micro-hydro village schemes (off-grid): 7, given the initial goal of 8.02

5.2.4 Results

The financial instrument, regarding the context of study, has not performed well. In January 2008 a proposal to restructure was submitted. Due to the political unrest in Nepal the project had rated as unsatisfactory and only a quarter of funds had been dispersed. Under the restructuring the unutilized funding would be redirected to rural electrification. The Power Development Fund would remain but without funds. The November 2010 Implementation Status and Results Report stated progress as unsatisfactory [49].

The main reason of the failure of the project is Nepal's political unrest; potential investors perceive a greater investment risk for projects in such unstable countries and consequently they are not willing to invest. Investors did not trust in the stability of the fund, which was set up and owned by the government.

For these reasons, we can say that the financial instrument did not perform well because of the mismatch with the context of application. It is crucial for the success of RE projects that the central government guarantees stability of political and social conditions.

In table 9, the different financial disbursement paid over time are detailed.

FINANCIAL DISBURSEMENTS (XDR million)						
IDA fund	Original	Revised	Cancelled	Disbursed	Undisbursed	% disbursed
IDA-37660	36,8	32,5	4,3	22,37	10,13	69%
IDA-46370	49,6	28,51	21,09	26,51	2	93%
IDA-H0390	18,4	17	1,4	16,76	0,24	99%
IDA-H5060	10,5	9,01	1,49	8,77	0,24	97%

Table 9: PD project's financial disbursements [World Bank REFINe tool, 2010]

5.3 Bangladesh - Solar Home program on credit sales

Source: World Bank

Barriers: High initial costs and lack of long term credit

Financial Instrument: Output based-aid (Soft loan to refinance customer loan and subsidy to buy down purchase price)

Amount: US$492,98 million (Credit) + US$8,2 million (Global Environmental Facility grant)

Results: Overall

5.3.1 Introduction

The Rural Electrification and Renewable Energy Development (RERED) is a global rural electrification program funded by IDA (World Bank), which became effective in December 2002 [50]. One of the components of the RERED implemented in Bangladesh is the development and implementation of solar home system (SHS) for rural off grid households. The solar home project is managed and administered by the Bangladesh Infrastructure Development Company (IDCOL) and involves the following activities:

- developing consumer awareness of SHS and their potential for rural lighting;
- selection of Participating Organizations (POs) who will be eligible for initial business set up assistance, IDCOL loans and GEF (Global Environmental Facility) grants;
- establishing standards to be met for equipment;
- providing refinancing of loans of POs to their customers (up to 80%);
- providing the GEF financed grant (commencing at US$90 per system and declining over the duration of the project to US$50 per system);
- supervising the activities of POs and coordinating activities among participants (POs, suppliers, and customers).

The preparatory stage of the project showed that the high initial costs to customers and the inability of the majority of rural households to meet this expense in the short term, combined with the lack of available credit with longer term and lower interest is the main barrier to SHS sales.

To address the barriers identified, the financing and subsidy mechanism under this project is focused on two main components:

- **Output based aid** (funded by GEF), used to provide the subsidy element by buying down the purchase price of the SHS system. The grant is released after IDCOL has verified that the SHS has been appropriately installed and is in working order. The size of this output based aid is provided on a reducing basis to the POs, with the objectives of reducing initial cost of sales and some of the POs start up costs, which in turn will lower the SHS price to customers.

- **IDA credits** (to be used in an output based manner), used to provide soft loans to the POs on 10-year maturity term with 2-year grace period at 6% per annum interest rate. The POs are only refinanced at this attractive rate after IDCOL has verified that the SHS has been appropriately installed and is in working order. This mechanism is then used by the POs to refinance 80% of the credit sales to customers.

In addition, GEF and other institutions have provided a project preparatory grant, which is used for initial activities performed by IDCOL, such as assistance to POs in terms of personnel training in SHS installation and maintenance, business planning and development, and consumer awareness program including advertisements, SHS installation demonstrations, and several SHS pilot set ups.

Under the project, the POs would provide a one-stop-shop to customers, by sourcing the SHS technologies and equipment, installing the SHS, maintaining the SHS after sale, and most importantly providing customers with access to loans for credit sales. The PO can be any registered entity (private firms, non-governmental organizations or micro-finance institutions, or other community organization). However, the POs must satisfy criteria set by IDCOL, such as good business record, good recovery rate and previous record of micro-financing activities.

The POs are selected by calling for invitation issued periodically by IDCOL, who then provides grants and refinancing, set technical specification for solar equipment, develop publicity materials, provide training, and monitor the PO's performance.

POs are allowed to set up their own terms for customer lending and credit sales, although they must comply with IDCOL guidelines. Typically, the credit sale terms involves a customer down payment of 15% of total costs, and loan with flat interest rates of between 6% and 15% to be paid over 3 years.

5.3.2 Global indicators

GLOBAL INDICATORS	
Definition	**Value**
Outcomes	Satisfactory
GEO Outcomes	Satisfactory
Risk to Development Outcome	Moderate
Risk to GEO Outcome	Moderate
Bank Performance	Satisfactory
Borrower Performance	Satisfactory

Table 10: SH program's global indicators [2013]

In Table 10, GEO stands for "Global Environmental Objective".

5.3.3 Project Development Objective indicators

- Number of SHS installed: 1231720, given the initial goal of 994000

- Number of mini grid installed: 3, given the initial goal of 4
- Number of connections to the grid: 656802, given the initial number of 700000

5.3.4 Results

The project has been successful, shown by the significant increase in the number of SHS sold and installed since the project started in 2002 [51].

Key factors contributing to the success of the projects are:

- The ability to develop existing non-governmental organizations and micro-finance institutions to operate as SHS vendors: the existing organizations and institutions have the knowledge and experience in providing financial services to rural communities and the selection process ensures that they have good collection history and are strong enough to develop a credit line.
- Strong incentives to go out and offer micro credit when a credible output based aid package is put in place.
- The initial marketing and customer awareness, because it is important to establish a market for SHS. This was achieved by developing customers confidence and awareness of the advantages and benefits of SHS.

The main lessons learned gained from the project's experience are [51]:

- **Culture of microfinance leads to greater trust and larger up-take**: the well-established outreach of micro finance institutions and non-governmental organizations in Bangladesh contributed to large-scale reach and greater uptake of SHSs. This was one of the major factors contributing to the success of the IDCOL model. The institutional set-up and historical presence of many POs allowed for cost-effective and efficient outreach, while the familiarity of rural consumers with institutions and organizations lead to a greater amount of trust of the project POs and resulted in larger consumer up-take of SHS. The establishment of a public private partnership , such as that created under the project, sets a best practice example for other programs worldwide of how access can successfully be achieved through a cost-share model.
- **Poor households are willing to pay for energy services**: by employing a microfinance model, the RERED project demonstrated that even low-income rural households were willing and able to pay for SHSs in order to have access to improved lighting services. Providing only a minimal subsidy per SHS and leveraging micro finance institutions services for regularized payment plans allowed poor rural households to purchase critical infrastructure services.
- **Consumer buy-back schemes reduce the perception of risk and increase uptake of SHS**: at the beginning of the project, there were concerns over up-take among rural households, particularly due to the risk that the SHSs might become unnecessary if the households received grid electrification. In order to reduce the household's purchase risk, the POs offered to buy back any SHS in the case the

grid arrived to the community. In most places, even where the grid did reach, consumers chose not to sell back their SHS. POs felt that this increased the initial uptake of SHS.

- **It is crucial to establish quality assurance of product performance at the beginning of a project, and quality monitoring and enforcement among POs is essential**: the need for quality assurance for SHS was determined early in the RERED project and led IDCOL to adopt quality assurance mechanisms to ensure product performance. A testing lab should be established soon after the project begins to monitor quality and do random spot checks to ensure quality products throughout. In addition, it is critical that the quality monitoring does not stop at design and is enforced throughout the project. In the case of IDCOL, constant enforcement of technical standards and performance on the POs was critical to maintaining high-quality systems.
- **Selling systems on credit can be important for system maintenance**: in addition to the traditional benefits of selling on credit, such as greater affordability for consumers, payment collection also offers another benefit: after-sales service. IDCOL has found that consumers that do not have working systems are less likely to pay, and when POs have to go to the households to collect payments, they are able to provide after-sales and maintenance service at that time.
  Employing financing systems in SHS programs may actually help to increase the maintenance and upkeep of the systems.
- **Flexibility to adapt to the changing market needs is crucial to the success of a project**: as the project evolves, technology changes will occur; in the case of RERED, technology advancements reduced the cost and increased the efficiency of SHS, like introduction of LED bulbs helped to reduce costs of SHS. Project Technical Standards Committees should have the flexibility to update the technical standards to permit the use of improved and new components.

Table 11 shows how the success of the program has allowed IDCOL to gradually reduce the amount of subsidy per SHS paid out over time, without causing a financial loss to the POs and to the customers. The financial instrument does gain benefit from the technological innovation of the SHS system, thanks to a very efficient and effective economical management of the project.

SHS Cost			
Year	SHS (Number)	Subsidy/SHS($)	IDCOL loan share(%)
2003	10038	90	68%
2004	19297	80	68%
2005	26558	60	68%
2006	36936	50	68%
2007	68899	50	68%
2008	95843	46,5	68%
2009	166139	45	68%
2010	304742	32	68%
2011	450214	28	68%
2012	552415	25	60%

Table 11: SHS cost for IDCOL [World Bank REFINe tool, 2013]

Table 12 displays the financial disbursements of different stakeholders; data of the appraisal estimate refer to 2011, while data of actual disbursement refer to June, 2013.

DISBURSEMENTS			
Source	Appraisal Estimate (US$ million)	Actual Disbursement (US$ million)	% of the estimate
Borrower	96,34	136,28	141%
Local Communities	167,08	137,12	82%
IDA (World Bank)	492,98	462,86	94%
GEF	8,2	8,19	100%

Table 12: SH program's financial disbursements [World Bank REFINe tool, 2013]

5.4 Rwanda - Advance Market Commitments (AMCs) project

Source: World Bank

Barriers: High up front capital costs

Financial instrument: Advance market commitments (Micro-financing)

Amount: US$10 million over 5 years

Results: Partial

5.4.1 Introduction

The pilot Advance Market Commitments (AMCs) project in Rwanda was part of a work program on AMC for low carbon technologies [52]. The pilot AMC in Rwanda aims to demonstrate the wider potential of market-pull approaches to supporting low carbon development, and to catalyse private sector investment in RE projects such as biogas and off-grid micro-hydropower.

The main barrier to the development of biogas and hydro power projects in Rwanda was demand uncertainty. AMCs are defined as "temporary intervention to make revenues from markets more lucrative and more certain in order to accelerate investment" and for the pilot project in Rwanda it was in the form of short term cash incentives.

The AMC consists of one funding pot, to which biogas and hydro developers can access according to differentiated incentive criteria. The disbursement of funding and associated monitoring will be done by local banks after a competitive tender process.

For biogas projects, it was anticipated that the AMC incentive will take the form of a yearly cash incentive on commissioning of the installation and for up to three years thereafter on condition that it is fully functioning. Developers will need to demonstrate that each installation delivers biogas to a school or other community installation, and that a bilateral contract exists for the provision of biogas. For micro hydro projects, the incentive could be paid in four instalments over three years according to some combination of the total number of household connections, the number of new connections added, and the power drawn per connection.

Project is still on-going, not much information was found on the results to date. Anyway, this is an example of the use of a different micro-financing mechanism to address the lack of equity finance, specifically caused by high up front capital costs, in RE projects.

5.5 Bolivia - Decentralized Energy for Rural Transformation program

Source: World Bank

Barriers: Low affordability and willingness to pay

Financial Instrument: Medium-term service contract awarded through competitive tender for lowest level of subsidy (output based)

Amount: US$ 15 million

Results: Partial

5.5.1 Introduction

The Decentralized Energy for Rural Transformation Program (ERTIC/IDTR) started in late 2003, with an objective to increase access in rural areas to electricity, information and communication services, by using innovative, decentralized public-private business models. This program includes output-based subsidies for medium-term service contracts aimed at SHS market development, that are competitively tendered [53].

The Medium-term Service Contract (MSC) is a new model for PV market development that balances providers' wish to minimize risk exposure with the government's desire to maximize control. In all service areas, exclusive access to project subsidies ends four years after installation, at which time users and suppliers may "graduate" to open competition.

The MSC is awarded to local or international private companies through a competitive tender process. To minimize subsidies that the government must pay private providers, each MSC area was awarded to the qualified bidder promising to service the largest number of users at a given total subsidy per area, with well-defined and ambitious performance indicators. Price caps were set to prevent monopoly pricing, while minimum user requirements per area were fixed to prevent excessive unit subsidies.

The SHS was installed and serviced by the qualified private sector operators, who would work via networks of local micro-enterprises installing systems, selling spare parts and appliances, implementing after sales maintenance services, answering additional service calls, and developing their local markets via promotion and training.

The subsidies provided by the project would facilitate an accelerated sustainable market development, allow a positive return for operators (in spite of the very low user density in rural Bolivia) and close the affordability gap between rural users' willingness to pay and SHS costs. The types of subsidies provided are:

- **Direct up-front Output Based Aid** (OBA) customer subsidies on the initial investment cost, paid to the supplier on the basis of actual installations;
- **OBA service quality subsidies**, paid to supplier against installation and service performance targets;
- **OBA market development service subsidies**, paid to the supplier against training of local technicians, yearly visits, users training, etc.;
- **Indirect market development subsidies**, in case of aggressive overall promotion activities, support to the formulation of business development strategies, training and/or technical assistance.

The ERTIC program and the Medium Term Service Contracts are financed by the IDA of the World Bank. Locally, the program is technically coordinated by the Program Coordination Unit (UCP) of the Ministry of Electricity and Alternative Energies of the government. The World Bank has provided technical support, promoted capacity building and is responsible of coordinating the payments of output-based subsidies.

The performances shown in table 13 refer to intermediate results, which are the only available information.

5.5.2 Global indicators

GLOBAL INDICATORS	
Definition	**Value**
Progress towards Achievement of PDO	Moderately satisfactory
Overall Implementation Progress (IP)	Moderately satisfactory
Overall Risk Rating	n/a

Table 13: ERTIC program's intermediate global indicators [2011]

5.5.3 Project Development Objective indicators

- Number of equivalent PV systems installed: 10174, given the initial goal of 10000
- Number of new productive users of electricity under the PV solar home systems: 256, in respect to the end target of 100
- Establishment of a financing mechanism for sustainable rural electricity coverage expansion: completed

5.5.4 Results

In 2005, 14 MSCs were successfully bid out to private service providers to minimize the subsidies paid against an ambitious set of provider obligations [54]. The tender resulted in a 25-percent gain in number of new users. After an initial delay, implementation started in July 2006, and more than 1,000 SHS were installed by december.

We cannot draw final conclusions because only intermediate results are available. As far as intermediate global and Project Development Objective indicators suggest, we can say that, as it is for the Solar Home Program on credit sales of Bangladesh, subsidies in the form of Output-based aid are a valuable tool to solve the barrier of low affordability and willingness to pay of the customer, in order to guarantee the sustainability of the investment to the end user. Furthermore, it is critical to allocate the funds by a competitive tender process, in order to minimize the cost associated to subsidies.

Finally, if you want to reach the project goals and deliver the best service to the customer, the allocation of the subsidy must also be based on performance objectives properly defined.

5.6 Sri Lanka - Renewable Energy program

Source: World Bank

Barriers: Lack of financing

Financial Instrument: Aggregation in the development of standard project agreements for small hydro plants and standard conditions for on-lending of project loans to developers

Amount: US$115 million (credit) + US$8 million (GEF grant)

Results: Overall

5.6.1 Introduction

The Sri Lanka Renewable Energy Program is a World Bank and Global Environmental Facility (GEF) assisted program through two investment projects, the Energy Services Delivery (ESD) project from 1997 till 2002 and the subsequent Renewable Energy for Rural Economic Development (RERED) project [55].

The principal objective of the program is promoting the provision by the private sector, non-governmental organizations and cooperatives of grid-connected and off-grid energy services using environmentally sustainable RE technologies. The program supports the provision of electricity and socioeconomic improvements in rural areas through:

- solar PV, hydro, wind and biomass RE technologies;
- credit financing through private participating credit institutions;
- grant mechanisms for off-grid systems;
- technical assistance for income generation and social service delivery improvements based on villages’ access to electricity;
- technical assistance to promote energy efficiency, development of carbon trading mechanisms and integration of renewables into government policy, provincial council development strategies and sector reform initiatives.

GEF made available co-financing grant funds for off-grid sub-project developers who have signed a sub-loan agreement with a Participating Credit Institution (PCI). The grant funds are used to co-finance the initial cost of equipment installed through the program and are available to sub-loan beneficiaries.

The co-financing grants are released on a reimbursement basis, after the installation of the off-grid system, and are on a reducing basis. Portions of this grant is also used to provide technical advisory services to assist off-grid project developers with their business plans, project promotion and preparation, compliance with technical standards and consumer protections.

For the stand-alone solar hole system (SHS), the program provides consumer credit delivery mechanism, in which the program encourages micro-finance institutions (MFIs) involvements. Those institutions are more suitable to provide consumer credit to rural communities. Initially, the program turned to MFIs to access term loans from PCIs in order to provide the necessary consumer credit. However, this created another layer of credit delivery process and increased the interest rates. Therefore, the program was modified to allow MFIs to apply to become PCIs, and hence will be able to provide consumer credit to SHS vendors or developers, or even end-users.

The GEF fund was utilized in several different disbursement channels, as shown in the flow of funds' diagram of figure 4.

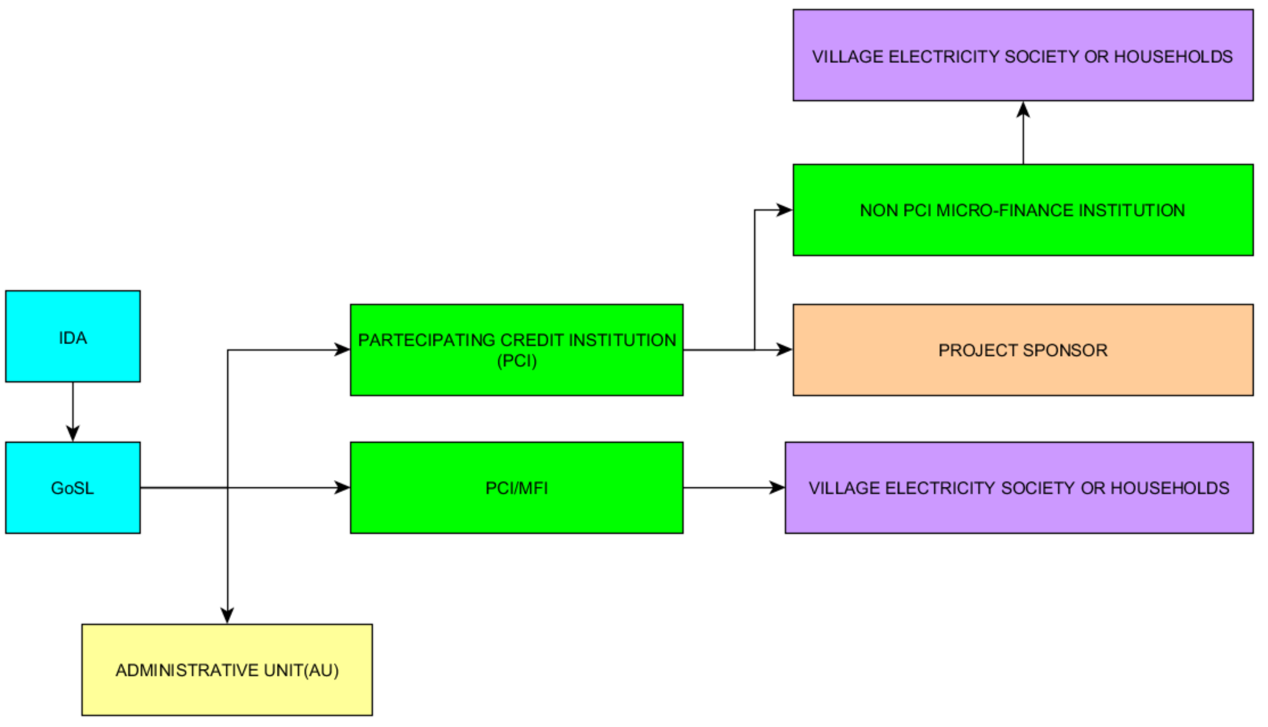

Figure 4: Flow of funds' diagram [World Bank REFINe tool, 2012]

In Figure 4, GoSL stands for "Government of Sri Lanka".

Private investors or developers are eligible to apply for funding under the program by submitting a private investment proposal. Proposals are evaluated for credit worthiness by the Participating Credit Institution

(PCI) which lend to qualifying projects on a medium- or long- term basis. The PCI can then apply to RERED to refinance up to 80% of the sub-loan.

Under the credit facility of the program, the government of Sri Lanka on lends the proceeds to eligible Participating Credit Institutions (PCIs), which in turn on-lend these proceeds, along with complementary financing from their own resources, to eligible sub-borrowers. These may include commercial banks, project developers, equipment vendors, community electricity cooperatives and end-users.

At the start of the program, there were only 1 mini hydro developer, 2-3 fledgling solar dealers and 1-2 village hydro developers. By the end of 2004, there were over 40 mini hydro companies backed by about 20 active developers, 10 registered solar companies, 22 registered village hydro developers and 12 village hydro equipment suppliers.

The availability of long term financing contributed to the significant increase in mini hydro installed capacity from about 1 MW in 1997 to nearly 70 MW in 2004 through 30 sub-projects. A further 38 projects with a total capacity of 39 MW has been approved by PCIs and at various stages of completion. The cost of development has decreased through the experience, enabling more project developments.

Through the co-financing grants, the program has supported the installation of 810 kW village hydro systems serving around 3,800 households. A total of 79 systems were implemented at the end of 2004, with a further 38 projects being approved and at various stages of completion.

The SHS industry has grown significantly since the start of the program, from only 2-3 small operations selling 20-30 SHS per month in 1998, to 11 companies and 125 rural outlets with an annual sale of around 1,500 SHS per month at the end of 2004.

Several factors contributed to the success of this program:

- **Significant technical assistance** was provided throughout the program, right from the start. This includes advice to the government on policies that would enable and promote RE projects, capacity building for project developers, MFIs and PCIs, vendors and in rural communities, advice on technical specifications of the technologies, and on business planning and development for project developers.
- **The technology and new systems were introduced through market principles**. The structure of the subsidies and grants also allows the market to adjust. This ensures the sustainability of the industry even after the program is completed.
- **The program allows some flexibility in project design** to allow different approaches and changes as and when required. This allows the program to be tailored to suit the local context, needs and capabilities.

5.6.2 Global indicators

GLOBAL INDICATORS	
Definition	**Value**
Outcomes	Satisfactory
GEO Outcomes	Satisfactory
Risk to Development Outcome	Low or negligible
Risk to GEO Outcome	Low or negligible
Bank Performance	Satisfactory
Borrower Performance	Satisfactory

Table 14: SLRE program's global indicators [2012]

In Table 14, GEO stands for Global Environmental Objective.

5.6.3 Project Development Objective indicators

- Small scale renewable grid connected power generation capacity installed:178.8 MW, in respect to the end target of 166 MW
- Increase in income generating activities in communities that gain access to electricity (measured in number of households, small/medium enterprises and public institutions): 742, given the end target of 1500

5.6.4 Financial efficiency

The financial performance of the project can be summarized on the basis of the applications of the program [56].

- **Grid connected mini hydro**: The financial analysis of the representative 2.5 MW mini hydro plant shows a Financial Internal Rate of Return (FIRR) of 17 percent against a FIRR of 21 percent calculated at appraisal. The FIRR varies substantially from sub-project to sub-project depending on site characteristics, which determine investment cost and plant factor. The financial analysis used the flat rate 20-year tariff, approved by the regulator, which was applicable in 2010.
- **Solar Home Systems**: The FIRR for the representative 40 Wp SHS was 12 percent compared to 7 percent estimated at appraisal. While the 12 percent is comparable to interest that is paid on a fixed deposit savings account, it would be considered a low return on an investment that a poor household with few savings would expect. However given the poorer quality of services from kerosene lighting, the expenses and difficulties of transporting batteries for recharging, a household would expect to give the SHS services a higher value than merely its financial returns.
- **Village hydro**: The FIRR for the 7.5 kW representative sub-project is 50 percent. The high FIRR is due to the significant reduction in investment costs due to grants provided, which reduce the investment cost to US$704/kW (compared to a SHS of over US$9,000/kW after grant). Without investment subsidies, the FIRR would drop to 13 percent. Even more so than in the case of an SHS,

the level of services provided by the village hydro plant is much greater than that of the alternative (kerosene lighting, dry cell batteries, battery charging, etc.) For example, in the representative sub-project evaluated, a household could potentially use nearly 60 kWh per month given the generation potential of the village hydro scheme (compared to 5.5 kWh per month from a 40 Wp SHS).

5.6.5 Results

The main lessons learned from project's experience are [56]:

- **Long-term involvement is very important.** As previously mentioned, RERED (and the additional finance) were a follow-up to the ESD project and this string of continuity in engagement with the country covers a period of more than 14 years. Implementation of ESD started slowly largely because different stakeholders had to grow into their respective roles and start-up problems had to be resolved. These start-up problems did not happen in RERED. The procedures and systems set-up during ESD were, with minor modifications, also used for RERED. The long project period enabled building trust and good relationships between the administrative unit and the various stakeholders. It also provided sufficient time to convince PCIs that the risk of lending for grid-connected RE sub-projects was manageable. Policies established under ESD could be monitored under RERED and emerging problems could be addressed. A much shorter duration of the project would have substantially increased the risk to the sustainability of the results. Long-term involvement also enables the identification of problems that usually occur much later, sometimes after several years. The off-grid PV component was considered a success at the end of ESD, and so with minor modifications, this component was continued under RERED. It took almost four years after the start of RERED for problems to surface. A number of factors contributed to the problems encountered, these were: (a) there was no mechanism to address vendors not honoring after sales and warrantee obligations as they stopped providing after sales and warrantee services because of bankruptcy or because business was becoming non-profitable in a small and dispersed market; (b) dissatisfied end-users stopped repayment of SHS loans to PCIs who in turn began repossessing the PV modules, and the re-sales of these would not cover the outstanding balance because the price of new modules was reducing significantly over time; (d) a shrinking market due to expansion of the grid at a faster pace than assumed; (e) PCIs were providing fewer loans with, as a consequence, further shrinking of the market.

  These developments show that design issues may become apparent years after project closure and it was because of RERED that these could at the least be monitored and salvage efforts be made. In projects with shorter durations, such problems would only be identified after an evaluation is carried out several years from completion. More importantly, in a rapidly saturating market, businesses must be agile to adopt and be responsive to new market conditions: what works where electrification rate is low will not be viable in areas where electricity coverage is high.

- **A quality implementing body is vital.** The quality of the implementing agency is vital to the success of any project. The implementing body needs to have ownership, authority and the responsibility to be flexible in addressing arising problems. The implementing agency should be able to function independently and solve issues on its own, while knowing when to involve the government and the World Bank where appropriate. Another key aspect was in building trust among key beneficiaries and stakeholders. The implementing body must have adequate staffing and the right skill mix to carry out the various tasks. It must also be able to devote sufficient time to the project.
- **Private sector market growth should be carefully managed where possible.** The provision of off-grid electricity using SHS depended on private vendors, and the village hydro component depended on private village hydro developers. These private sector parties enter into this business only when profit is to be made. In some isolated cases, this has led to participation of unqualified and/or undesirable private entities, which were drawn by the grants on offer. However, many of the unqualified/undesirable entities were not strictly private sector, but small non-governmental organizations or community-based organizations. The private sector 'businesses' that engaged in village hydro to expressly earn a profit were, on the whole, fine. The real problems arose towards the end of ESD when a large number of new developers were trained (in hindsight inadequately) in order to scale up village hydro development. Some village hydro developers lacked the required technical and community development skills, causing frustration among Village Electricity Consumer Societies (VECS), PCIs and the Administrative Unit (AU). The AU addressed this problem by introducing a pre-qualification process for all village hydro developers and also equipment suppliers. This may have reduced the number of developers but it substantially improved the quality and reduce conflicts otherwise. When SHS sales grew steeply (2003 to 2005) a large number of SHS vendors entered the market as entry barriers were low, which later became overcrowded and resulted in declining margins for each vendor. As the growth rate slowed down, the market was less profitable, causing vendors to go bankrupt or cease operations. In both cases, after sales services and warrantee obligations were often not honored. In hindsight, it would have been better to manage the growth phase more carefully to assure sustainability of after sales and warrantee services.

  On the other hand, there are factors beyond the control of project as managing such growth can often be complex and difficult to control. Where possible, the implementation would have been easier with a smaller number of pre-qualified SHS vendors. One disadvantage is that prices and services would need to be regulated by an appropriate body in the country as having fewer vendors might lead to monopolizing power in some areas. Introducing more stringent entry requirements such as the provision of guarantees and/or performance bonds may have also helped address this problem.
- **Stakeholder consultation throughout the project cycle**. Implementation of RERED confirmed the importance of maintaining an ongoing dialogue with the main stakeholders and beneficiaries. The

administrative unit maintained this dialogue through regular meetings and visits and actively supported the strengthening of stakeholder groups such as the Federation of Electricity Consumer Societies and other technology associations. Consultations strengthened trust and understanding of problems and constraints amongst the various stakeholder groups.

- **Risk analysis should be carried out also during implementation.** An analysis of the risk to achieving the project development and global environmental objectives should be carried out also during implementation and not only during preparation. External experts, not involved in the implementation of the project, should preferable carry out this assessment. That way, it is possible to identify new risks, assess the risks of emerging problems, and take appropriate action.
- **Performance based incentives work well.** The project provided performance-based incentives to selected village hydro developers. This provided an incentive to developers to help communities develop village hydro schemes. The developers would identify the village, mobilize the community and establish contacts with appropriate financing institutions, many of whom were not participating in RERED. Payment of developers by the project was based on achieving clearly defined milestones. This minimized the risk to the project and reduced the workload of the implementing agency.

  The development of grid-connected RE sub-projects was based on a similar principle where the project did not need to identify the opportunities but rather only evaluate those proposed by the developers. Subsidies to SHS vendors were also performance-based depending on proven sales of SHS. On the other hand, no grants were given to grid-connected project developers.
- **World Bank involvement added credibility.** The World Bank not only brings financial resources, knowledge and staff expertise, but through its participation in the project, it also brings credibility among stakeholders and beneficiaries. This was of particular importance for the participating commercial banks involved in RERED as it made them more willing to consider lending for RE initiatives.

5.7 Philippines - Leyte-Luzon Geothermal Power Plant project

Source: World Bank
Barriers: Lack of long term financing
Financial Instrument: Partial Credit Guarantee
Amount: US$30 million
Results: Overall

5.7.1 Introduction

The Leyte-Luzon geothermal power plant project was implemented in 1994 by the National Power Corporation (NPC), the Philippine National Oil Company (PNOC), and the Electricity Development Corporation (EDC) [57].

The main goals of the project are:

- Satisfy the growing energy demand of Luzon by means of geothermal technologies, with minor environmental impacts in respect to a carbon plant.
- Strengthening of the energy sector by implementing the institutional and financial improvements recommended in the Energy Sector Plan (ESP).
- Supporting the growing participation of the private sector in the power generation, and facilitate it by extending the national grid.
- Reinforcing NPC's capacity to evaluate social and environmental impacts.
- Introducing a co-financing operation which is common in the Philippines.
- Ensuring financial sustainability for NPC and PNOC-EDC in the investment program.

In order to reach these objectives, the World Bank provided a grant (from GEF), which reduced the cost of the project and made it more financial attractive to investors to use geothermal energy instead of coal.
The grant was used as partial credit guarantee, which was aimed to help the government access long term financing on the international capital market and to expand loan tenor.
The NPC raised around US$1,300 million in project finance through a 15 years' bond issue on the international capital market. The World Bank provided a partial credit guarantee to the bond issue structured as a put option for principal repayment at maturity. It allowed bondholders to present or "put" their bonds to the World Bank at maturity for payment of principal.
With the support of the guarantee program, NPC was able to get a bond with a 15 year maturity, which was greater than the longest maturity previously attained by an issue from Philippine sovereign entity (10 years). The 15 year maturity was obtained at the favourable pricing of 2.5% over the yield of US treasury of the same maturity.
In particular, the World Bank established two financial performance's objectives:

- For NPC, a minimum 8% Rate of Return on net fixed assets, and a minimum Debt Service Coverage Ratio (DSCR) of 1,3;
- For PNOC-EDC, a maximum Debt to Equity Ratio of 70/30, a Current Ratio of at least 1 and a minimum DSCR of 1,25.

5.7.2 Global indicators

GLOBAL INDICATORS	
Definition	**Value**
Outcomes	Unsatisfactory
Sustainability	Unlikely
Institutional Development Impact	Modest
Bank Performance	Satisfactory
Borrower Performance	Satisfactory

Table 15: LLGPP project's global indicators [2000]

5.7.3 Project Development Objective indicators

- Installation of 440 MW geothermal energy plants: Satisfactory
- Increase private sector participation in the generation of energy, and in particular access to Build Operate-Transfer (BOT) contracts with private sector companies, in order to guarantee the construction of the plant: Satisfactory
- Ensure financial sustainability for PNOC-EDC in the investment program: Satisfactory.

The PDO indicators show good results, as the initial project objectives have been partially reached, considering that [58]:

- 338 MW from geothermal energy have been installed, in respect to the initial goal of 440 MW.
- 51% of the total financing has been granted from the private sector. Furthermore, NPC had for the first time access to the international bond market, preparing the ground for possible long-term commercial loans in this market. Finally, three Build-Operate-Transfer (BOT) contracts have been signed for the construction of the plants.
- PNOC-EDC always had a great financial stability during the project, thanks to a considerable increase in turnover from energy sales, an increase in the assets' value and a minor dependency for the energy supply.

In spite of these results, the overall project performance rated as unsatisfactory, because of two main reasons:

- NPC did not resolve its unstable financial situation and the objective of strengthening the financial stability of all the actors involved in the project was not reached.
- The great cost to reach the development goals was a relevant factor contributing to this situation, and consequently project's NPV rated as negative.

Table 16 shows the project financing, summarized by the different financing plans of the project. Data of estimate refer to 1994, while actual disbursements refer to 2000.

PROJECT FNANCING			
Source	**Estimate[US$ million]**	**Actual Disbursement[US$ million]**	**% of estimate**
IBRD-PNOC	114	55,2	48%
NPC	113	99,2	88%
IBRD Energy Sector loan-PNOC	13,1	8,5	65%
IBRD Transimission Grid Project- PNOC		14,4	
JEMIX-PNOC	114	55,7	49%
NPC	56	53,7	96%
BOT Contract	620,4	577,6	93%
ECO-Bond-NPC	100	100	100%
BITS Grant-NPC	39	46	118%
GET Grant-PONC	15	15,7	105%
NPC	15	15,5	103%
Internal cash generation(PNOC)	92	132,1	144%
Internal cash generation(NPC)	41,9	143,7	343%
Total Financing	1333,4	1317,3	99%

Table 16: LLGPP project financing [World Bank REFINe tool, 2000]

5.7.4 Results

The main lessons learned from project experience are [58]:

- **BOT financing**, in respect to other financial instruments made available by the World Bank to PNOC-EDC, **is very expensive**. Furthermore, the 10 years BOT maturity is shorter than the plants' useful life (25 years); consequently, for a long period of time, you have a financial gap which is to be managed by bridge financing and a cautious financial management.
- For BOT projects, during the contract phase, **all the elements regarding the loan should be clearly identified**, avoiding ambiguity and default of the contracting party.
- **Partial Credit guarantee by the World Bank was a success**, considering that the bond issue reached the initial goals. This long-term financing allowed the government to unlock investment in geothermal plants, and to delay the debt repayment over time at a later stage, once turnover from electric energy sales is available and public energy companies have reached a greater financial stability.

5.8 Chile - Rural Electrification program

Source: World Bank
Barriers : Lack of private sector investment
Financial Instrument : Public Guarantee Fund
Amount: US$ 150 million
Results: Overall

5.8.1 Introduction

In Chile in the early 1990s, nearly 240,000 rural households, which is more than 1 million people, or almost half the rural population, had no access to any source of electricity [59]. By contrast, 97 percent of urban households had electricity supply. The lack of access was concentrated in a few regions where most of the rural population lives. It affected mainly lower-income families, since the wealthier could usually afford to install generators or pay for extension of the distribution grid.
To increase rural access to electricity, Chile launched a Rural Electrification program in 1994. Like many rural electrification projects, the program addressed these challenges:

- how to ensure sustainability of the electrification projects;
- how to avoid politicization and corruption of the process (and subsidy delivery mechanism);
- how to develop ways to deliver service to isolated communities;
- how to involve the private sector.

The program set up a special fund to competitively allocate a one-time direct subsidy to private electricity distribution companies to cover part of their investment costs in rural electrification projects. Operating costs have to be financed with tariff charges set by the regulatory authority. Bids are conducted annually.

To apply for a subsidy, companies present their projects to the regional governments, which allocate the funds to those scoring best on several objective criteria: cost-benefit analysis, amount of investment covered by the companies, and social impact. The central government allocates the subsidy funds to the regions on the basis of two criteria: how much progress a region made in rural electrification in the previous year and how many households still lack electricity. Regional governments also allocate their own resources to the program.

The designers of the rural electrification program set out to devise a scheme that would promote private investment, stimulate competition, and take into account the structural reforms in the power industry and the decentralization of the national administration. They built the program around four central principles:

- **Decentralized decision-making:** to ensure appropriate technology choices, promote local commitment and sustainability, and fit the new decentralized structure, the program designers decided that the regional governments would identify needs, choose the solutions, and participate in the decisions on the allocation of central funds. To involve local communities, the program would require that projects be requested by organizations rather than individuals. But the central government would provide economic resources and technical assistance and help to coordinate the institutions involved in the program. It would also provide the criteria and tools for evaluating projects to ensure coherent decisions and efficient allocation of investment resources.
- **Joint financing**: to ensure sustainability, all participants (the state, the electricity companies and the users) would contribute to the funding of investment projects. The state's participation was needed because rural electrification projects usually are unprofitable for electric utilities, as a result of low electricity consumption, the distance from distribution centers, and the dispersion of dwellings. But state subsidies would be allocated only to projects with a positive social return. The state's contribution, delivered through the special fund, would also cover expenditures related to managing the overall program. The state would not own or operate any facility built under the rural electrification program, but that would be the role of private investors. The aim was to make rural electrifications projects an attractive business opportunity for electric utilities. Companies would be required to invest their own resources to increase their commitment to the success of projects. Users would contribute both at the investment phase of projects, to increase their commitment to projects and to help extend the resources for rural electrification, and during the operation of projects, to support adequate service and maintenance.
- **Competition**: to reduce the risk of politicization, minimize project costs, and encourage innovation, competition would be used at as many levels and stages as possible: among projects proposed by different rural communities, among distribution companies interested in supplying these communities, and among regions requesting funds from the central government. In the first two

cases decisions on the allocation of investment funds would be made at the regional level, and in the third case by the central government. The rules for deciding among competing projects would be transparent and stable and established by the central government. They would consider the average cost required to provide a certain quality of service, the local electricity needs, and the sustainability of proposed solutions. Priority would be given to zones showing the capacity to implement the program. Zones with high poverty and low community involvement, where sustainability is more likely to be a problem (particularly where self-generation is used), would initially require more institutional assistance.

- **Appropriate Technologies:** for solutions to rural electrification needs, the program would consider not only extension of the existing distribution grids but also other technological alternatives, like PV solutions, hybrid systems, small hydroelectric power stations, and experimental solutions based on wind power and biomass systems.

The Rural Electrification Program (Programa de Electrificaciòn Rural, PER) was launched in 1994 to carry out the new rural electrification policy.

And the goals were set: supply electricity to 100 percent of electrifiable rural dwellings within ten years and reach 75 percent coverage by 2000. To reach 75 percent coverage by 2000, it was estimated that the state would have to invest about US$150 million, which would allow electrification of roughly 110,000 rural dwellings. This estimate covers subsidies from the special fund and resources allocated by regional governments. The private sector would have to invest a similar amount. Users would also need to contribute.

The responsibility for financing the projects is split up as follows:

- Users have to cover the costs of the in-house wiring, the electric meter, and the coupling to the grid. These expenditures, nearly 10 percent of the costs of each project, are initially financed by the distribution company and repaid by the users over time. Once the project is operating, the users have to pay the regulated tariffs.
- The distribution company is required to invest at least the amount calculated using a formula set by the government, to avoid such risks as “goldplating”. The company also must operate the projects once they are built.
- The state has to provide a subsidy for the investment costs that is no more than the (negative) net present value of the project, which in any case has to be smaller than the total investment.

In order to reach the project goals, a separate fund was created in 1995 to provide additional resources. Grants from international organizations have also been used in the program.

5.8.2 Results

The rural electrification program had a significant impact. It has not only greatly improved coverage but has also changed the way things are done in the field. It has shown that it is possible to achieve rural electrification, usually thought to be possible only by the state, in a competitive environment dominated by private companies, and that competition results in better use of resources and better results. The program has also helped to broaden the technologies used in these projects, though grid extension has been the predominant approach used. And by the end of 1999 the program had reached the coverage and investment goals originally set for 2000.

- **Coverage**. The program has greatly increased the number of rural dwellings electrified each year as well as the coverage of the electricity system. It has achieved the best results in the regions that started with the lowest coverage and that have the largest rural populations.
- **Investment**. The state has contributed the most funding to the program, investing US$ 112 million in rural electrification in 1995–99, something less than what was estimated at the beginning of the program. That has meant more than doubling its average investment over the previous years. As the private sector has increased its investment in rural electrification, however, the state's share has declined (from 70 percent in 1992 to 61 percent in 1999). Private investment in the program has totaled US$ 60 million.
- **Performance of participants.** Users have participated in identifying and defining the projects, helping to establish the needs and priorities in each region, and in financing the investments. Companies have helped define the projects, invested resources, and undertaken the commercial risk, and continue to own and manage the installations. The most successful companies have created or strengthened special units for rural electrification. Regional governments have managed the program well. The central government has ensured proper design and implementation of projects, clear rules (for example, for allocating funds), well defined responsibilities, and incentives to promote efficient decisions, all essential for success.
- **Use of alternative technologies.** Most of the projects have involved extension of the grid, a solution that usually means a lower cost per connected dwelling and a higher quality of service (the reader should consider that this project was implemented in the 1990s, when costs of RE technologies were much more higher than today's costs). But several projects have relied on alternative technologies, primarily one-house photovoltaic systems. These systems have been installed in isolated areas in the northern part of the country (for nearly 1,000 dwellings), which has some of the strongest solar radiation. The nonconventional technologies generally provide electricity at a higher cost and poorer quality (lower voltage, fewer hours of service). But they have been an attractive alternative where extending the grid is too costly because of the distance from the existing grid or the high dispersion of dwellings. Both these causes have increased the marginal cost of rural electrification in Chile. In 1995 the average state subsidy per dwelling amounted to US$ 1,080; in 1999 it reached US$ 1,510. This outcome is nevertheless consistent with the program's goal of maximizing rural electricity coverage within budget constraints, which mandates first implementing the projects with the highest impact per unit of investment. At the same time, however, it allows a growing role for

nonconventional technologies in rural electrification projects, as improvements in these technologies reduce their costs and make them increasingly competitive with conventional solutions.

- **Role of markets.** An innovative aspect of the program has been its promotion of rural electrification in a competitive environment dominated by private companies. It has successfully introduced competition at several levels: among communities, for financing for their projects; among distribution companies, for implementation of their projects; and among regions, for the funds provided by the central government.

  The participation of private distribution companies has been critical to the program's success. From the companies' perspective, rural electrification is a long-term business and riskier than traditional distribution. Customer payments, even with generally low default rates, are usually small, while operating and maintenance costs are high compared with those for urban distribution. Companies expect consumption to increase gradually, as users realize the potential of electricity for income-generating activities. But given the lack of exclusive distribution rights, companies have seen participation in rural electrification as a strategic move to protect the existing distribution area and discourage entry by competitors.

5.9 Laos - Rural Electrification project (first phase)

Source: World Bank
Barriers: Lack of equity finance
Financial Instrument: Concessionary Financing
Amount: US$10 million (IDA grant) + US$3,75 million (GEF grant) + US$9,42 million (Australian Agency for International Development grant co-financing)
Results: Overall

5.9.1 Introduction

Rural electrification had registered a remarkable achievement in the socio-economic development of Laos People's Democratic Republic (PDR), with household connections increased from about 16 percent in 1995 to 46 percent in 2004 [60]. However, as electrification moved to increasingly remote areas, on-grid electrification became less viable, which led the government of Laos to promote off-grid models, with emphasis on renewable technologies.

The government set an ambitious goal of electrifying 90 percent of the households by 2020 (70 percent by 2010 and 80 percent by 2015), and increasing hydropower exports to neighboring countries. Meeting these objectives would require financing from sources other than the traditional concessionary lenders. Novel financing models for non-traditional public and private financiers would need to be identified and the regulatory framework adapted to suit.

IDA's (International Development Agency) added value was three-fold: leverage, concessionary financing and global knowledge. Prior to the Rural Electrification project phase one (REP I), IDA had long-term engagement in rural electrification in Laos through the Southern Provinces Electrification Project (closed in December 1994), Provincial Grid Integration Project (closed in June 1999), and Southern Provinces Rural Electrification Project (closed in December 2004). Concessionary lending terms such as IDA were vital for electrification, which requires capital subsidies to achieve social objectives. IDA's continued association with rural electrification was necessary for successful implementation of the rural electrification program. As in the previous projects, GEF (Global Environment Facility)-funded technical assistance and investment activities under REP I were considered vital to increasing the contribution of RE and energy efficiency in the overall development of the power sector. IDA's ability to bring global knowledge to sector reform activities added value beyond the provision of grants. The ability to play this role derived from the deep knowledge of the Lao power sector that IDA had gained and the relationship that had developed with government of Laos and the Electricite du Laos (EdL) state corporation over the previous decade, which merited continuation.

5.9.2 Global indicators

GLOBAL INDICATORS	
Definition	**Value**
Outcomes	Satisfactory
GEO outcomes	Satisfactory
Risk to Development Outcome	Moderate
Risk to GEO outcome	Moderate
Bank Performance	Satisfactory
Borrower Performance	Moderately satisfactory

Table 17: RE project's global indicators [2013]

In Table 17, GEO stands for "Global Environmental Objective".

5.9.3 Project Development Objective indicators

- Number of villages and households electrified: 671 villages (original target 540) and 66879 households (original target 65250).
- Implementation status of the Sustainability Action Plan: Satisfactory; implementation of the Financial Sustainability Action Plan was largely achieved except for the continued government payment arrears that could not be prevented due to insufficient budget allocations.

5.9.4 Intermediate Outcome indicators

- Financial performance: Rate of return on revaluated asset (RRRA), Debt service coverage ratio (DSCR), Self-financing ratio (SFR), Accounts receivable (AR) :

Original Targets

- RRRA> 4%
- DSCR> 1.5 times
- SFR> 30%
- AR< 2 months

Achieved Targets

- RRRA= 1%
- DSCR= 1.26 times
- SFR= 6%
- AR= 2.2 months

Baseline values refer to 2004.

Targets were not met mainly due to spin-off of Electricite du Laos' (EdL) generation assets (and subsequent changes of baseline values for measuring these indicators). Before the spin-off of EdL in late 2009 when the baseline values were comparable with those at appraisal, the first three indicators were largely met [61].

5.9.5 Results

The lessons learned and key factors contributing to the extraordinary progress in national electrification in Laos are summarized below [61].

- **Government of Laos has played an irreplaceable role** in terms of making unwavering commitment, getting the policies right and staying the course. The government set clear targets for electricity access and developed an institutional framework and financing and monitoring mechanisms to ensure the achievement of the target in a timely and effective manner.
- **Electricite du Laos has been a key and keen facilitator** and front line partner in implementing grid extension and roll-out programs, and making them successful with effective leadership, sound planning, and efficient operations.
- Striking a workable **balance among financing, subsidy and tariff policies** by providing necessary state subsidies to rural electrification and at the same time maintaining the commercial viability of Electricite du Laos with cost-recovery tariffs.
- Complementing grid extension with **off-grid options** for remote rural areas where the grid cannot reach in the short term.
- **Leverage and concessionary financing revealed effective tools** in the rural context of Laos. Those financial instruments allowed to increase private investors commitment in the project, by reducing the perception of risk in this type of operation.
- Another key factor for the success of the project was the **IDA's deep knowledge** and its past experience in similar projects in the country.

5.10 Laos - Nam Theun 2 Hydroelectric project

Source: World Bank
Barriers: High exposure to regulatory risk
Financial Instrument: Partial risk guarantee, political risk guarantee, export credit support
Amount: Total base project costs US$1.25 billion plus US$200 million contingency
Results: n\a

5.10.1 Introduction

The Nam Theun 2 Hydroelectric project, or NT2, is an industrial and development investment owned by private shareholders and the Lao government, backed by commercial lenders and international financial institutions [62]. The project is jointly implemented by the Nam Theun 2 Power Company (NTPC) and the government of Lao People's Democratic Republic (PDR) and supported by financing from 27 parties including the World Bank and Asian Development Bank.

A total of US$1.45 billion equivalent (excluding bonding facilities) in US dollars and Thai Baht has been committed by the various financing partners to fund the base project cost of US$1.25 billion, plus an additional US$200 million for contingencies.

The NT2 includes the development, construction, and operation of :

- a 1,070-megawatt trans-basin diversion power plant on the Nam Theun River;
- a 450-square kilometer (km^2) reservoir on the Nakai Plateau;
- a 39-meter-high dam northwest of the plateau;
- a powerhouse 350 meters below the plateau;
- a regulating pond below the powerhouse;
- a 27-kilometer (km) channel from the regulating pond to the Xe Bang Fai River Basin, also a tributary of the Mekong river.

The plant would sell most of its production to Thailand, generating a secure, long-term flow of revenue for the Republic of Lao. This revenue would be an important source of funding for the government's efforts to sustain economic development based on its National Growth and Poverty Eradication Strategy and reduce poverty in Laos.

The US$ senior debt facilities include political risk guarantees, export credit agency support and direct loans from a number of multilateral and bilateral development agencies.

Nine international commercial banks (ANZ, BNP Paribas, BOTM, Calyon, Fortis Bank, ING, KBC, SG and Standard Chartered) and seven Thai commercial banks (Bangkok Bank, Bank of Ayudhya, Kasikornbank, Krung Thai Bank, Siam City Bank, Siam Commercial Bank and Thai Military Bank) are providing long term loans to NTPC. In addition to senior loans facilities, shareholders complete the project financing by contributing equity pro-rata their respective participation in NTPC. The equity contribution is financed by means of loans, grants and other financing from institutions including the Asian Development Bank, European Investment Bank and the World Bank.

The World Bank Group’s financial support consists of:

- a US$42 million IDA partial risk guarantee;
- a US$20 million IDA grant for NTSEP (Nam Theun 2 Social and Environment Project, which finances a part of the government’s equity in the project to be used for management of environmental and social impacts and independent monitoring and evaluation of the NT2 project);
- US$91 million in Multilateral Investment Agency Guarantee (MIGA) guarantees;

Asian Development Bank (ADB) supported the project through:

- a US$20 million public sector loan to the government of Lao to help fund its purchase of equity in NTPC;
- a US$50 million private sector loan directly to NTPC;
- a US$50 million political risk guarantee to NTPC.

The Nam Theun 2 Power Company limited (NTPC) is responsible to develop the project on a build-own-operate-transfer (BOOT) basis with a concession period of 31 years, of which the operating period is 25 years. The project will be transferred to the government of Lao free of charge at the end of the concession period.

5.10.2 Results

The NT2 began commercial export of electricity in March 2010, and agreed an official commercial operations date of April 30 with its main customer, the Electricity Generating Authority of Thailand. It also supplies around 20% of peak Lao demand electricity. The NT2 was officially inaugurated in December 2010. Project is still on-going and results are not available [63].

5.11 Uganda - West Nile Rural Electrification program

Source: World Bank

Barriers: Lack of long term debt financing

Financial Instrument: Two-step financing backed by liquidity guarantee (Bullet repayment of initial 8-year loan with new 7-year loan with amortization payments on the two loans profiled to match a 15-year loan. Liquidity guarantee of funds for new 7-year loan)

Amount: n/a

Results: Partial

5.11.1 Introduction

The government of Uganda has set the rural electrification as one of the main priorities and key to poverty alleviation [64]. However, one of the challenges to increase the rural electrification was the replacement of the conventional government-led rural electrification, with a private sector-led, commercially oriented program. While there was government willingness to pursue the rural electrification through this program, there were no institutional capacity and appropriate institutional framework to lead such program. In addition, there was a lack of (local) financing options necessary to attract private sector to develop such projects. The existing loans in Uganda were limited by the national banking regulation to longest maturity of eight years. However, this maturity makes them inadequate for most of the RE financing needs.

Under the West Nile Rural Electrification project, the World Bank has devised a means to circumvent this restriction through the use of a liquidity guarantee and a two-step financing mechanism.

A commercial lender, in this case Barclays Bank, makes an eight-year loan to the West Nile Rural Electrification Company (WENRECO) which holds a 20-year concession to operate a 1.5 MW thermal generator and construct a new 3.5 MW hydro generator. The amortisation profile of the loan is calculated as if it has a term of 15 years, but with a bullet payment of the outstanding principal at the end of the loan term. At the end of the eight year term, Barclays extends a new seven-year loan to the borrower, with a principal equal to the outstanding principal on the original eight-year loan. The new seven-year loan is then repaid under the same amortization schedule as previously applied. The effect is to create an amortization profile for the borrower equivalent to a 15-year loan while ensuring repayment of the first loan in full to Barclays after eight-years.

This arrangement creates a liquidity risk for Barclays in that repayment of the initial eight-year loan is dependent on Barclays having sufficient available funds to lend to the borrower at the end of this first loan's term, as the borrower is reliant on this second loan to repay the outstanding principal on the first loan. The liquidity guarantee offered by the World Bank gets around this. For a guarantee fee, the World Bank agrees to provide the necessary funds to make the second seven-year loan in the event that Barclays is unable to do so. The cost of the guarantee fee is passed to the end borrower in the form of an increased interest charge. The liquidity guarantee, therefore, offers a low-cost means of extending the term of the loan to the RE developer from eight years to 15 years. The same arrangement could be applied where other restrictions (e.g., internal credit policies) prevent loans being extended to the term lengths necessary for RE projects to be viable.

Even with this guarantee, however, the resulting commercial loan represents only 10% of the project cost. However, if successful, it can be expected that the mechanism can be extended in future.

5.11.2 Results

Since the start of its concession, the West Nile Rural Electrification Company (WENRECO) has experienced persistent cash flow difficulties. These led to suspension of work on the hydro plant in 2008 and, in march 2009, to the shutdown of the operations of the thermal generator [65]. WENRECO blamed these difficulties on delays in the payments of government subsidies that cover 60% of the project costs, non-payment of electricity bills and failure to implement tax exemptions.

The government blamed the problems on poor management while the regulator drew attention to an overshoot of costs for the mini-hydro project and the failure of the main fuel supplier to meet its commitments. In april 2009, a new arrangement was reported to have been reached whereby the government would pay for fuel costs for the thermal plant. The most recent reports are that reconstruction on the hydro project finally resumed in august 2010 following the appointment of a new contractor and the taking of a 10% stake by the government, with the project expected to commission by end-2011. No recent results are available.

5.12 Resume

Private investors usually perceive a great financial risk in RE technologies investment. The Leyte-Luzon geothermal power plant project's experience shows that individual guarantees are a great tool to target the lack of long term financing of such projects. The grant reduces the perception of risk for private investors, which are more financially attractive by this type of investment. The government also can access a debt with a longer maturity, so the repayments of initial capital are delayed over time.

The same issue, that is the lack of long term financing and equity finance, was targeted in a different way, which is concessionary financing, in two different projects: the Laos Rural Electrification project (first phase) and the Power Development project of Nepal.

In the case of Nepal, a senior debt, in the form of a Power Development Fund (PDF), was establish to reduce the costs of the project, by providing concessionary funds which are cheaper than commercial funding, and to offer longer-term debt than may be available in local financial markets.

Nonetheless, during the implementation of the project Nepal faced a period of severe political unrest and the result was that only a quarter of the fund was dispersed and the project rated as unsatisfactory. In our opinion, such a risk should have been considered during the design phase of the project, and it could have been addressed with a political risk guarantee. Moreover, an important issue for RE technologies projects is that they are particularly vulnerable to changes in the regulatory framework. Their lack of cost competitiveness means that these projects are generally dependent on a supportive regulatory framework to proceed, including commitments to pay premium prices, priority access to electricity grids including support for the necessary infrastructure investments and guarantees of purchases of their output. Severe problems for project viability can arise where the regulatory framework changes.

That was the most important problem to be resolved in the Nam Theun 2 Project of Laos, and it was addressed mainly by partial risk guarantee and political risk guarantee.

In the West Nile Rural Electrification Program of Uganda, the short maturity of loans, limited by the national banking regulation, was an important limiting factor to the development of a private sector-led rural electrification. The World Bank tried to solve this issue by developing a very interesting mechanism, based on the provision of a liquidity guarantee to the lender bank. This grant is meant to allow the private sector to access loans with a longer maturity. Unfortunately, due to cash flow difficulties, the operations were shut down in 2009 and we are not able to discuss any further result.

RE technologies are also characterized by a high share of the capital cost in their total costs; as a result, RE technologies projects are more exposed to the limited availability of project financing than most conventional technologies.

A result-based financing mechanism was used in the Decentralized Energy for Rural Transformation program (ERTIC/IDTR) of Bolivia to overpass this problem. The subsidies provided by the project were mainly meant to allow a positive return for operators (in spite of the very low user density in rural Bolivia) and to make the final user able to pay the SHS costs. No final results are available to be discussed.

However, a similar approach was followed in the Solar Home program of Bangladesh, where an output-based aid tool, to buy down the purchase price of the SHS system, was combined with a micro-financing operation, in the form of soft loans to the Participating Organizations (POs) on a 10-year maturity. The final ratings of the projects were satisfactory and we can say that the project was a success. Another micro-financing operation was carried on in the Advanced Market Commitments project for rural energy of Uganda, in the form of short term cash incentives. No information about the project's performance are available.

Focusing on another financial barrier, which is the small-scale of many RE technology projects, significant problems in obtaining private financing are to be faced. The Sri Lanka Renewable Energy program, an assisted program by the World Bank and the GEF (Global Environmental Facility), has the goal to obtain private sector participation in RE projects by the aggregation of more than one project. Aggregation is meant in the form of development of standard project agreements for small hydro plants and standard conditions for on-lending of project loans to developers.

In the same project, and to solve the same financial barrier of the small scale of the projects, public financing was raised and delivered through a financial intermediary, namely a CFI (Commercial Financial Institution), which was responsible for providing funds to RE project companies and for due diligence, following procedures and processes approved by the public financing agency. The CFI can also supplement the public funds with complementary funding from its own resources or blend public and its own funds into a single loan.

Finally, the Chilean Rural Electrification program is the only example of direct public lead of the type of investment under analysis. Anyway, it shows how the public guarantee fund is a compromise to attract private sector investment.

CHAPTER 6
A GUIDE TO PROPERLY EVALUATE RENEWABLE ENERGY INVESTMENTS IN DEVELOPING COUNTRIES

6.1 Introduction

There are many opportunities for commercial applications of REs to support rural social and economic development [66].

In this section our contribution consists of exploring the use of RE options for off-grid communities and giving the best practice in approaching such an investment. It reflects the current commitments of many national and/or provincial governments to substantially expand their rural electrification programs [5].

As the rural energy services enterprise reflects a relatively new approach to the use of RE technologies to provide basic electricity services to rural communities, the reader will need to make assumptions about the business approach and its financial requirements.

We are not expecting to provide a complete decisional method to drive RE investment in developing countries. Our aim is to create a simple investment 'handbook' for potential investors (both institutional and private) where the investment would be carried out in similar conditions. The handbook is composed of chronological steps to be taken during the feasibility analysis, which are supposed to guide the developer trough the initial phase of a long-term investment program.

Obviously, our focus is on those objective factors for which a rational decision maker is able to take the best choice; for example, a stand-alone system is not likely to be chosen where the existing grid is the least-cost option to provide electricity to isolated communities.

However, a developer, in the decisional process, can be influenced also by subjective factors which may lead to non-efficient solutions; for example, a non-economically viable electrification project can be implemented because of the political pressure of public authorities. In our work, we are not focusing on those attributes. The inspiration for our work obviously comes out from the reviewed literature too.

6.2 Technical assessment

Many RE investments have failed because of the lack of a properly-conducted analysis of the technical/technological feasibility of the power generating system. Investors should take into great consideration this issue: although a system may be economically feasible, you may not take for granted the availability of all the conditions necessary to build and operate a RE plant throughout the lifetime of the project, especially in a developing country where traditional western assessment's methodology fails to be a

reliable tool for the evaluation and decisional process. For a complete dissertation of the subject, we address the reader to the second chapter.
The first issue a project developer should take care of is the siting, or placement, of the system. As shown in chapter 2, every RE demands for particular conditions to properly operate and generate the necessary output. Projects developers are supposed to select the technically feasible systems, by calculating the availability of the sources on the site and the potential output of the plants. As a result, developers may immediately exclude some RE technologies which are not technically fit to the site under analysis. On the other hand, the selected RE technologies can be considered for additional analysis. A summary of advantages and disadvantages of the RE sources is reported in Table 2.
As far as a single RE source usually can't reliably guarantee the safety of supply, because of its dependence to the weather conditions and other factors difficult to be forecasted, we suggest project developers and stakeholders to take into consideration the realization of an hybrid system. Furthermore, the different systems should be integrated into a mini-grid able both to accommodate the energy demand and deliver the excess electricity (generated power which is not self-consumed) to other centers of demand connected to the grid.
Another important concern, regarding this phase of the assessment, is the existence of supporting infrastructure able to serve builders and operators of the systems during the time horizon of the project. Otherwise developed nations, developing countries do not always guarantee the right conditions, especially as regards the construction phase of the project. As shown in chapter 2, the lack of the right conditions, regarding the supporting infrastructure, can lead to a different economical ranking of alternatives selected for a site, because the process to design and build the necessary services can be very long and costly.
We are going to make an example for a wind turbine system with some data to clarify this subject.
The construction process of a wind turbines park is very complex. The civil works needed are several, such as roads, drainage, dig for electric wires, etc. The transfer of the system to the site and on the site needs a project: principal limitations are radius of curvature of the route and its slope [12].
For a developed nation, civil works for a 20 MW wind park account roughly for 3,6% on the total investment cost. Assuming an initial cost of €21 million , the resulting cost of the civil work is €756000 . This cost is to be considered and well managed, but it is not so relevant as well as other costs [67].
Otherwise, if we consider a 50 kW wind turbine system, the civil works account from 10% to 15% on the total initial cost. That is, if we assume an investment cost of €350000 , a resulting value range from €35000 to €52500 . This is a very significant impact on the revenue account that has to be considered [67].
As regards developing countries, we are considering small generating systems; furthermore, in these countries wind turbines may require to be placed in a remote site where no connection roads are present. Those sites are very far from the main cities and its facilities, so the impact of the civil works' cost on the initial investment raises to 20% or even to 25%. The resulting infrastructure's cost, for the same 50 kW system, ranges from €70000 to €87500.

As a consequence, project developers have to address this issue in the early phase of the project; such a concern may prevent the most economical alternative to become more and more costly over time, because of the necessity to build the surrounding infrastructure.
Finally, an important issue to consider in the early stage of the project is the availability of local skills and labour, as well as the compatibility of the system with future capacity expansion. Workforce and technicians are needed to build, operate and maintain the system. While considering a possible future increase of the energy demand, the system should be able to accommodate this growing request, by expanding its capacity through the addition of further modules on the same system.

6.3 Energy supply

In many developing countries an immediate opportunity for practical RE applications is off-grid electrification [68]. Most of the technologies involved (PV, small hydro, small wind power, renewable hybrid, etc…) are the least-cost options for sites far from the main grid .
The reader should note that the decision to implement off- grid projects usually starts with a public policy to extend at least basic electricity services to unserved populations that are unlikely to obtain electricity connection in the foreseeable future. While many un-electrified communities are suitable for grid extension, many others are too remote from the main grids, and are more suitable for decentralized distributed power systems, including diesel, RE, and hybrid systems.
However, a developer or a generic stakeholder may require an effective demonstration of the economic advantage of a stand-alone system over the grid extension. Moreover, if we assume that an off-grid option is chosen to be implemented, project developers may want to check for the long term sustainability of the off-grid system, as it is required to know whether it will be vulnerable to a future grid extension. That's because national or regional utility companies have often structured their grid-extension plan without excluding villages which might have potential for off-grid supply.
A simple way to calculate a 'break even value' between the two alternatives (off-grid vs grid expansion) is the calculation of a 'critical line length' for the conjunction of the rural community to the national grid; it represents the least grid line-lenght extension beyond which the off-grid option becomes more economically attractive then the grid expansion.
We are going to propose a possible calculation of the critical line length by basing our assumptions on the approach shown in [19], combined with our way to calculate the off-grid option, which is through the HOMER software. For further details, the reader can go back to chapter 3. The reader is also free to use a different approach for the calculation of the LCOE of the stand-alone option.
Among the different approaches reviewed from the literature, we have chosen for this one because of the very detailed calculation of all the parameters, as our main concern is to calculate an appropriate LCOE of grid extension to be compared with the alternative. The main disadvantage of this choice is that detailed data are needed to calculate all the parameters, and those may not be available in a rural context of a developing country.

Furthermore, to calculate the LCOE of the off-grid option, we have selected the HOMER software because of its great flexibility to adapt to different contexts and situations. The software allows to enter very detailed parameters which in turn allow the analyst to describe the conditions of the context in the best way. The alternatives are ranked by means of different economical parameters, allowing to compare the selected solutions on different levels, and the LCOE of the options is also displayed.
Finally, the sensitivity analysis allows to define the critical parameters over the results, and check for the results' variability based on a range of possible data inputs. Not all the data may be reliable and definitive, so this part of the software is very important.
In order to calculate the LCOE, costs data of all the components of the selected systems have to be available. Stakeholders need to calculate a rough estimate of the market to be served [66], in order to define the generating capacity of the systems and all the components that are needed to satisfy the energy demand.
An example of these calculation is presented below:

- Number of communities to be served: 1000 off-grid communities;
- Market of each community:
    - Households, mainly for lighting: about 200 households on average.
    - Public service centers: one school and one health clinic per community.
    - Economically productive applications: two per community, each requiring 1.0 kW_e on average.

Those data should be sufficient to calculate the energy demand. Consequently, developers can compute the generating capacity of the systems and all the components needed to satisfy that demand, with their associated costs.
Analysts can now calculate the critical line length with the following equation:

$$\frac{LCOE_g}{(1-L_{T\&D})}+LCOE_t+\frac{\left[\frac{C_T*P_{PL}}{p_f}+x_c*(a_{11}*C_{11}+a_{2w}*C_{2w}+a_{4w}*C_{4w})\right]*(CRF_d+\beta_d)}{8760*P_{PL}*\psi^{LF}}=LCOE_{dg}$$

$LCOE_{dg}$ is the cost of electricity of the stand-alone system from HOMER's results that you select to be compared with the grid extension. x_c is the critical line length, and it is only dependent on the cost of distribution of electricity through grid extension. All the other parameters have been widely explained in chapter three.
Once off-grid systems both technically feasible and cost effective, in respect to the grid extension option, are selected, decision makers can continue their analysis by investigating the economic and financial aspects of their project.

6.4 Economic evaluation

Once you have selected the feasible RE technologies and check for their convenience over the grid extension, some assumptions are to be made in order to calculate detailed investment requirements.

Traditionally, the appraisal process was undertaken in order to rank projects on a systematic basis. Over time, the process has become more sector-focused, allowing data generated during the feasibility study to feed back into the design process. This allows projects to be structured so as to maximize potential financial and economic return. Our aim in this section is to subject the pre-selected investments to a systematic process of capital appraisal with two goals in mind:

1) Ensure that investments are not made in projects that earn less than the cost of capital (generally expressed as a minimum rate of return).
2) Provide a basis for the calculations of mainly profitability indicators, or social and environmental ones, that will be necessary to have an estimate of the necessary budget and further for the implementation of a selected decisional method. This step can be seen as a pre-selection or rejection of projects by ranking them in order of profitability or social and environmental benefits.

A very important step in any economic evaluation is to project the cash flow. The cash flow of a project is the difference between the money generated (revenue) and ongoing costs (expenses) of the project.

As regards the revenue and costs stream, the assumption made on the market and on generating capacities for the calculation of the $LCOE_{dg}$ are still effective.

These assumptions may be modest, since many communities will have other service needs (water supply, public lighting, telecommunications/rural telephones, etc.) that also require electricity, and there is likely to be more than one or two economically productive applications per community that would benefit from a RE-based electricity supply.

As a component of the revenue stream, assume an end-use customers willingness and ability to pay; moreover, assume a specific price of electricity sold to consumers, with a minimum value equal the $LCOE_{dg}$, calculated trough the HOMER software or in other ways. Finally, assume the discount rate (capital cost) and the project duration.

All the data have been defined to calculate the investment requirements. Analysts need to present the coverage per phase and the estimated minimum investment costs for each phase. A sample to calculate the investment requirements of the model project is presented in table 18.

Phase	Number of communities	Households	Public centers	Productive systems	Investment cost in US$ million	Duration in years
1	200	50000	500	500	40	1
2	300	65000	650	650	30	3
3	500	85000	850	850	30	2
Total	1000	200000	2000	2000	100	4

Table 18: Investment requirements for the model project

The project will be carried out in three phases over a period of 4 - 7 years, with the second and third phases overlapping. As the unit costs decline, each succeeding phase will cover more communities than the previous phase.

The estimated investment cost is the economic cost of installed equipment only and does not include duties and taxes. Expenditures for project design and management and technical assistance will increase the financial requirements of an actual project.

The total required investment in US$ million is the sum of the investment costs for all the phases of the project, and it represent an estimate of the budget needed to start and conduct the project. The results show a total required investment of US$100 million.

Furthermore, a set of analytical tools are presented to assess the financial and economic viability of a proposed investment. These tools are to be used as economic criteria to rank the alternatives in the decisional method, too.

Some of the analytical tools, related to the above mentioned point 2, include:

- Benefit-Cost Ratio
- Net Present Value (or Discounted Cash Flow)
- Internal Rate of Return
- Least Cost Planning
- Payback Period
- Sensitivity Analysis

The **Benefit-Cost Ratio (BCR)** is the ratio between discounted total benefits and costs. Thus if discounted total benefits are 120 and discounted total costs are 100 the benefit-cost ratio is 1.2. For a project to be acceptable, the ratio must have a value of 1 or greater. Among mutually exclusive projects, the rule is to choose the project with the highest benefit-cost ratio. The disadvantages of the BCR is that it is especially sensitive to the choice of the discount rate, and can provide incorrect analysis if the size or scale of the various projects being compared is great.

The **Net Present Value (NPV)** approach (also referred to as discounted cash flow approach) uses the time value of money to convert a stream of annual cash flow generated by a project to a single value at a chosen discount rate. This approach also allows to incorporate income tax implications and other cash flows that may vary from year to year. The discounted cash flow or net present value method takes a spread of cash flow over a period of time and “discounts” the cash flow to yield the cumulative present value.
When comparing alternative investment opportunities, the NPV is a useful tool. As might be expected, when comparing alternative investments, the project with the highest cumulative NPV is the most attractive one. The only serious limitation with this approach is that it should not be used to compare projects with unequal time spans.

The **Internal Rate of Return (IRR)** and the net present value approach are very similar. As outlined, the NPV determines today’s values of future cash flows at a given discount rate. On the contrary, in the IRR approach one seeks to determine that discount rate (or interest rate) at which the cumulative net present value of the project is equal to zero. This means that the cumulative NPV of all project costs would exactly equal the cumulative NPV of all project benefits if both are discounted at the internal rate of return.

In the private sector, this computed **Financial Internal Rate of Return (FIRR)** is compared to the company’s actual cost of capital. If the FIRR exceeds the company’s cost of capital, the project is considered to be financially attractive. The higher the IRR compared to the cost of capital, the more attractive the project. On the other hand, if the IRR is less than the company’s cost of capital, then the project is not considered to be financially attractive. For projects financed in whole or in part by the public sector, the discounted cash flow may need to be adjusted to account for social benefits or economic distortions such as taxes and subsidies, economic premium for foreign exchange earnings that accrue from the project or employment benefits. The resulting statistic would be the **Economic Internal Rate of Return (EIRR)** and would be compared with the country’s social opportunity cost of capital. If the EIRR exceeds the social opportunity cost of capital the project would provide economic benefits to the society.

The **Least-Cost Analysis** method is used to determine the most efficient way (the least cost) of performing a given task to reach a specified objective or set of benefits measured in terms other than money. For example, the objective might be to supply a fixed quantity of potable drinking water to a village. The examination of alternatives might entail wind pumping, run-of-river offtake, impoundment, etc. One would calculate all costs, capital and recurrent, to achieve the objective, apply economic adjustments and discount the resulting stream of costs for each alternative examined. The one with the lowest NPV would be the one most efficient (least cost).

Payback Period is the easiest and most basic measure of financial attractiveness of a project. The payback period reflects the length of time required for a project’s cumulative revenues to return its investment through the annual (non-discounted) cash flow. A more attractive investment is one with a shorter payback period. In development settings, however, there is little reason to assume that projects with short pay back periods are superior investments. Also, the criterion has a bias against long gestation projects such as RE.

Sensitivity Analysis refers to the testing of key variables in the cash flow pro-forma to determine the sensitivity of the project's NPV to changes in these variables. For example, in a RE project proposal, one may increase fuel costs or fuel transport costs, remove import restrictions on solar panels, lower labor costs, increase land acquisition by different rates to determine the corresponding impact on the NPV. It is useful to test a variable in the cash flow pro-forma that appears to offer significant risk or probability of occurring. The analysis becomes another useful tool when combined with others to improve the decision making process.

Table 19 illustrates, in very simple format, how each of the various tools are calculated. Costs and benefits are expressed in US$ million. In the analysis we only consider the investment cost, and we account for annual costs by considering "benefits", which are the difference of annual revenue and annual costs.
Once assumed a 10% discount rate, a four-year project duration, an initial investment of 100 US$ million calculated before, as well as the benefits shown in the table, we have obtained the reported values.

Year	Cost	Benefit	Discount Factor	Discounted Cost	Discounted Benefit	Discounted Net Benefit
0	100	0	1	100	0	-100
1		30	0,909	0,00	27,3	27,3
2		40	0,826	0,00	33,1	33,1
3		50	0,751	0,00	37,6	37,6
4		50	0,683	0,00	34,2	34,2
				100	132,0	32,0

Table 19: Sample calculation of BCR, NPV, Discounted Cash Flow and IRR

The various discount factors of every year are calculated, as shown in chapter 1, as:

$$Discount\ Factor = \frac{1}{(1+10\%)^n}$$

n is the value of the year.

- **Benefit-Cost Ratio** is $\frac{Discounted\ Benefit}{Discounted\ Cost} = \frac{132}{100} = 1.32$
- **Net Present Value** is $Discounted\ Benefit - Discounted\ Cost = 132 - 100 = 32\ US\$\ million$
- **Discounted Cash Flow** is the final $Net\ Discounted\ Benefit = 32\ US\$\ million$
- **Internal Rate of Return** is that $Discount\ Rate$ that makes the $Discounted\ Cash\ Flow = 0$ at the end of the project, which is $IRR = 23\%$

- **Payback Period** occurs early in year 3 when benefits begin to exceed 100 US$ million, which is the initial investment

6.5 Decisional methods and criteria of assessment

While each tool is sufficient to provide data needed to make efficient decisions, **Multi-criteria analysis** (combining one or more tools with other project data and benefits) can be helpful in evaluating future financial performance. For example, other criteria might include the distribution of benefits, ease and speed of implementation and replicability, as well as social and environmental criteria, that might be combined with one of the quantifiable tools illustrated above.

In the fourth chapter we have presented some valuable multi-criteria decisional methods that can be adopted by project developers or other stakeholders in the decisional process; we have also highlighted pros and cons of every method and compared them, but we are not going to suggest the use of any of these methods.

Furthermore, we have suggested a significant set of criteria that should be selected to properly evaluate the RE investment by taking into consideration all the dimensions of sustainability. Table 6 shows the set.

In this section we suggest which dimension, and thus which criteria, should be preferred in order to privilege the interests of a given type of investor. In our opinion, a crucial factor for the success of the investment is to guarantee the accomplishments of the goals of the major stakeholder of the project. Anyway, once again we are going to underline the importance of taking into consideration the economic dimension of the project, as to guarantee the feasibility of the investment.

First, an assumption is to be made. As there are different types of investors that approach RE investments in developing countries, or even more there are different investors that contribute to a single RE investment, decision makers have to assume which is the key representative of the investors, in order to focus on and protect its interests. The “key users” identified are divided in respect to the source of financing:

- Equity financing
    - **Project developers**. A project developer initiates the project idea and usually invests the upfront capital that is necessary to develop a project from a concept to an actual project. The project developer usually leverages up-front capital inputs for a larger equity stake in the project.
    - **Venture capitalists**. The venture capitalist specializes in investing in new companies. Because venture capitalists join companies in their earliest and riskiest stages, they expect to earn unusually high returns.
    - **Equity fund investors**. Equity funds provide investment capital in a project in return for a share of the equity of the project. The expected return on equity is generally two or more times greater than return on debt. In return for the higher expected yield, equity investors bear the greatest risks and have rights to distributions from the project only after all other financial and tax obligations are met.

- **Equipment suppliers**. Reliable, experienced RE equipment supply companies often construct, install and operate RE systems and some will offer equipment financing. In addition to turnkey system delivery and operation, the RE technology vendor may offer favorable financing terms.
- **Regional development banks**. Regional development banks include the Asian Development Bank (ADB), Inter-American Development Bank (IDB) and International Finance Corporation (IFC), and others. They not only provide debt financing, but can also provide minority equity financing.
- **Institutional and individual investors**. These are organizations or individuals willing to invest in projects on an equity basis expecting to earn high returns on their investments.

- Debt Financing
    - **International and national commercial banks**
    - **Others**, such as Multilateral Development Banks (MDBs) and the International Finance Corporation (IFC), international and national commercial banks, debt/equity investment funds, equipment suppliers, and private investors.
- Grant Financing
    - **Global Environment Facility (GEF)**, which has already been introduced in chapter 5.
    - **International and bilateral development agencies**. Many international and bilateral development agencies such as the United Nations Development Programme (UNDP), the Netherlands Ministry of Development Cooperation (DGIS), Danish Development Assistance Agency (DANIDA), etc., can and do provide grant assistance for RE projects.
    - **Foundations.** A number of philanthropic agencies such as the Ford Foundation and the Rockefeller Foundation have, on occasion, provided grant funds for RE projects in order to demonstrate environmental and social benefits.
    - **National and local agencies.** In a number of countries, support for RE projects can also be obtained from national and local agencies. India is a good example. In India there is a national Ministry for Non-Conventional Energy Sources (MNES) as well as State Renewable Energy Development Agencies (SREDA).

As we are not going to be as specific as to give wrong advices, we are going to categorize the investment's preferences in respect to the source of financing. That's because every investor can have different interests towards different projects. Anyway, the usual preferences are as following:

- Equity and debt financing sources have the major interests in the **Economic** and **Policy/regulation** dimensions of sustainability, as they are willing to invest only if they can earn great returns with a limited risk of investment. The economic criteria proposed in Table 7 give a detailed description of the financial performance of the investment, while equity/debt investors may call for policy/regulation criteria in order to gain insurance on the political risk of investment [69].

Technical/technological parameters should also be proposed to this type of investors, in order to demonstrate the technical feasibility of the project.

- Grant financing sources participate in the RE projects mainly because of their interest in the **Social** and **Environmental** dimensions of the investment. Multilateral Development Agencies undertake RE investments to improve the socio-economic conditions of the rural communities and/or to promote clean energy sources such as renewables.

Finally, we want to remember how multi-criteria decisional methods usually allow the analyst to weight the different criteria, and thus it is possible to express the relative importance of the dimensions of sustainability.

6.6 Financial analysis

As it was widely explained in chapter 5, we have reviewed case studies from the literature about the use of specific financial instruments. The principal point of view is that of a multilateral development bank, the World Bank, which can act as a source of different types of financing (such as equity or grant financing). As a result, the cases reviewed resume the financing approach of different types of investors.

In this chapter, we have first assessed the investment requirements and its profitability through the lifetime of the project; then we have introduced the reader to the use of a decisional method, and to the choice of its criteria, to rank the pre-selected alternatives by taking into account the different points of view of the investors involved in the process. Analysts are now supposed to determine how to finance the total budget. Depending on the entity of the initial costs, different types of financing may be necessary.

As it was necessary, both on a technical and economical level, to deliver an integrated approach for the RE investment, it is now necessary to tailor the financial stage of the analysis to the context under study. We want to provide the reader with a customized financial tool to address and mitigate the risk of RE investment in developing countries. **Financial structuring** is the means of allocating the risks and returns of a project among the various project participants. The basic principle is that the expected returns to a given investor should be commensurate with the risks the investor is willing to take. Risk adverse investors are provided with low but more assured returns while risk taking investors are provided with the opportunity to earn higher but less assured returns [70]. While a wide variety of instruments can be used to finance RE projects, the following three categories characterized the major types:

- **Equity**. High risk financing that expects high returns. An equity investment can be made in support of a specific project or equity funds can be provided to the company carrying out the project. Equity investors maintain the right to get involved in the decision making process of the project or company in order to protect their investment.
- **Debt**. Medium risk with modest expected returns. In contrast to equity investors, lenders who provide debt financing to a project do not own shares in the project. They provide capital for the purpose of earning interest. Because lenders must be repaid before distributions can be made to

shareholders, lenders bear less risk than equity holders. For this reason, potential return to lenders is limited to risk-adjusted market interest rates.

- **Grants**. No expected returns. Governmental and international organizations offer grants (donations) to promote environmental and development policies. RE projects are often eligible for these funds.

Of course each of the above types of investment capital are usually combined to capitalize the initial investment.

Anyway, we are not presuming to give an exhaustive framework for all the types of investors, as well as for all the possible environments in which investors may act, occurring in a RE investment. Our main contribution is to recommend the proper financial instrument depending on the most significant project risk/financial barrier identified by decision makers.

- Nepal's Power Development project experience shows the necessity to investigate the political stability of the country and, in the case of assessment of a particular political risk, the best financial instrument to address this issue is a **political risk guarantee.** The project was not a success because this risk was not properly assessed and taken into consideration. In the Laos Nam Theun 2 hydroelectric project the instrument was used to address the high exposure to regulatory risk.
- Nepal's Power Development project experience is also significant to understand how a **senior debt** should be used whenever lack of long-term and/or project financing is the main financial barrier identified. In the case of Nepal, it was not a success because the most significant barrier was the regulatory risk.
- **Micro financing**, in the form of an **output-based aid**, can be used when project developers find difficulties in accessing equity finance and long-term credit. Bangladesh Solar Home program experience is significant to understand the effectiveness of this instrument in such a case.
- **Micro financing**, in the form of **advanced market commitments**, can be considered when the lack of equity finance is mainly caused by high up front capital costs. Unfortunately, we can' t discuss the results of Rwanda Advanced Market Commitments for Rural Energy project, and thus draw appropriate conclusions, because exhaustive information is not available.
- A result-based financing, such as **payment against outputs**, is very useful when the lack of project financing is due to the low affordability and willingness to pay of the consumers. It helps to cover the difference between the cost of supply and the affordable price to poor households. Bolivian Decentralized Energy for Rural Transformation program experience shows good (but not optimal) results in using this type of financing.
- **Aggregation**, in various forms, is useful to overtake a lack of financing due to the small scale of projects. Sri Lanka Renewable Energy project shows the success of the instrument.
- Individual guarantees, in the form of **partial credit guarantees**, are to be used to target the lack of long term financing. In the Leyte-Luzon Geothermal Power Plant project, this mechanism was the main facilitator to attract the international capital market. Nonetheless, this was a very expensive

instrument for the promoter, the World Bank, and that's why the overall performance of the project rated as unsatisfactory. Anyway, the mechanism is able to solve the financial barrier highlighted.

- **Concessionary financing** should be used to address the lack of equity finance. It is a valuable tool to leverage private investors commitment in the project, by lowering the cost of capital and reducing the perception of risk in this type of operation. Laos Rural Electrification project experience is a successful example of the use of such a mechanism.
- **Liquidity guarantees** should address the lack of long term debt financing. In particular, the Uganda West Nile Rural Electrification program's two-step financing backed by liquidity guarantee is a very interesting financial mechanism. It consists of a bullet repayment of initial 8-year loan with new 7-year loan with amortization payments on the two loans profiled to match a 15-year loan. The liquidity guarantee of funds are established for the new 7-year loan.
  Even with this guarantee, however, the resulting commercial loan represents only 10% of the project cost. However, if successful, it can be expected that the mechanism can be extended in future.
- **Public guarantee fund** is a very effective tool to address the lack of private sector investment. Chilean Rural Electrification program is a great demonstration of the above statement. Anyway, this mechanism involves the direct participation and lead of the state into the project.

Table 20 summarizes the financial instruments reviewed, in respect to the project risk/financial barrier addressed.

		FINANCIAL INSTRUMENTS									
		Senior Debt	Output-Based Aid	Advanced Market Commitments	Payment Against Outputs	Aggregation	Partial Credit Guarantee	Concessionary Financing	Partial/Political Risk Guarantee	Public Guarantee Fund	Liquidity Guarantee
FINANCIAL BARRIERS	Lack of long-term financing	X					X				X
	Lack of project financing	X			X						
	Lack of equity finance		X	X				X		X	
	Small scale of projects					X					
	Exposure to regulatory risk								X		
	Political Risk								X		

Table 20: Optimal financial instrument

Anyway, further considerations are necessary. In order to increase the diffusion rate, the investment environment and hence the risk/return profiles of private investors need to be further improved via government action.
Whether or not an appropriate return on investment to a specific risk is demonstrated by economic evaluations and/or decisional methods, private investments will not be raised if un-ambiguous legislative rules are not appropriately defined. That's because developing countries usually don't provide the same legal instruments of developed nations, and either for private investors the main goal is always the safeguard of their assets.
Two recent studies [70] [71] show that improving the investment environment by reducing the investment risks can attract new private investments and lead to lower financing costs and thereby substantially lower electricity generation costs. Thus, it is necessary that public authorities establish an enabling legal infrastructure and ensure a predictable business environment to support the investment.
As we mentioned in the fifth chapter and in this section, **policy risk** is one of the main barriers in which investors occur while managing RE investments in developing countries. Policy risk can be defined as the risk that a government will opportunistically alter policies to expropriate an investing firm's profits or assets.
The UNDP [70] defines two ways of de-risking renewable energy investments:

- Financial instruments (e.g., guarantees or risk insurance);
- Policy instruments (e.g., technology standards or improved energy legislation).

Financial derisking instruments, among which the ones mentioned before, do not seek to directly address the underlying barrier but, instead, function by transferring the risks that investors face to public actors, such as the government or development banks. Loans, guarantees and political risk insurance financed by the World Bank, and already discussed, are an example of such instruments.
Hence, it is necessary to define **policy derisking instruments** which address and attempt to remove the underlying barriers that are the root causes of risks (quality policy design to reduce the risk of policy reversal, streamlining of licensing processes, etc.).
Other than for financial instruments, the economic efficiency of policy instruments is much less correlated with the individual project size but rather with the size of total investment that occurs on the national (in case of national policy instruments) or regional level (in case of sub-national instruments).
Therefore, policy instruments to improve the investment environment should primarily act on the national/regional level.

CONCLUSIONS

Renewable energy investment in developing countries is a very complex task. Providing energy to isolated communities can be accomplished by means of distributed power systems, as it represents the least-cost option where the national grid is too far to be extended. Off-grid renewable energy systems represent the best way to support rural electrification programs, hence developing the socio-economic conditions of the rural poor, and to protect the environment.
Hybrid renewable energy system is the most effective solution to overcome the traditional technical issue regarding clean energy, that is the dependence on weather conditions, and thus to increase the reliability of the system. The resulting configuration is a smart grid based on renewable energies.

A pre-selection of the technically-feasible alternatives should be carried out to at least ensure that investments are not made in projects that earn less than the cost of capital. Assuming the revenue and costs stream, this economic evaluation is also crucial to establish the profitability, as well as social and environmental, assessments for the sustainability of the investment.

In the decisional process, multiple alternatives are evaluated by multiple stakeholders, each one bringing a different point of view. In order to represent all the interests of the actors involved in the process, a significant set of criteria, spreading across all dimensions of sustainability, is to be proposed within the multi-criteria analysis. It is important for the success of the project to identify the key representatives of the investors and elicit their preferences in the criteria's selection and weighting.

Energy project financing faces severe hardships in low-income countries. Because of the massive amount of financing needed to deploy those projects, combined with low budgets of the host countries and public authorities, project developers call for the private participation in the investment. Anyway, renewable energy projects are still un-attractive because of the mismatch between the investors' expectations and the risk-return profile of the investment. In order to address this and other financial barriers, specific financial instruments are to be tailored to the context of application. Moreover, governments and national authorities should promote policy derisking tools to create a standard and robust business environment for the investors.

The proposed set of procedures is a valuable tool to guide developers through the assessment of renewable energy projects in developing countries. Our procedural method is meant to consider all the significant aspects that we found out during our analysis of the renewable energy investment and to be a user-friendly tool too. Specific considerations for the context of study have been performed, both in the technical and economic/financial evaluation, as the success of renewable energy projects in low-income countries is quite strictly related to the high level of customization of all the aspects of the project, comprising not only the deployment of the system, but also the tailoring of the economic and financial needs to meet the characteristics of the business environment.

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