POLITECNICO DI MILANO

School of industrial engineering
Master degree in management engineering

“*Optimal criteria to finance maintenance in renewable energy plants*”

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October, 2014

Academic year 2013 - 2014

Abstract

Italian

La tematica ambientale è ormai al centro di molte questioni, soprattutto per quanto riguarda i paesi già sviluppati. L'Unione Europea ha preso coscienza delle problematiche relative alla emissione di gas serra e di livello di inquinamento nel mondo. Una possibile soluzione per ovviare a questi problemi sembra essere la produzione di energia pulita attraverso fonti rinnovabili.

Concentrandosi sui paesi in rapida crescita ed in particolare sul mercato africano, studi recenti hanno dimostrato che entro il 2030 questo continente avrà bisogno di installare 250 GW per far fronte alla crescente domanda di energia. Senza dubbio l'Africa può contare su una vasta gamma di energie rinnovabili disponibili (eolico, solare, idroelettrico, ecc.), che non sono state ancora pienamente sfruttate.

In pubblicazioni precedenti, la convenienza nell'usare energie rinnovabili rispetto alle tradizionali fonti di energia, è già stata dimostrata. La possibilità di ottenere costi minori di produzione di energia attraverso le rinnovabili, rispetto ai combustibili fossili, è già stata sottolineata, in modo da aumentare il gap tra ricavi e costi.

L'obiettivo di questa tesi sarà quello di fare un ulteriore passo in direzione dello studio degli impianti a fonti rinnovabili. Siccome la convenienza economica nell'usare fonti rinnovabili è già stata dimostrata, lo scopo sarà quello di studiare i costi di gestione e manutenzione degli impianti (costi O&M).

Questo studio tenta di proporre nuovi meccanismi di finanziamento dedicati a finanziare questi costi, tenendo in considerazione la particolare situazione di investimenti americani in Africa. Il governo americano ha lanciato il progetto "Power Africa" nel 2013. Questa tesi è legata alla particolare situazione finanziaria di questo progetto, quindi molte considerazioni hanno senso solo se viste in quest'ottica o in situazioni simili.

ABSTRACT

I finanziamenti per costi O&M sono un argomento innovativo, che viene discusso quotidianamente. Lo scopo è quello di contribuire al miglioramento dei modelli tradizionali, per trovare il corretto modo di finanziare questi costi in relazione ai progetti in Africa.

ABSTRACT

English

The environmental issue is now the center of many discussions, in particular concerning developed countries. European Union has become aware of the problem related to greenhouse gas and of the increasing level of pollution all over the world. One possible solution seems to be the use of renewable resources in order to produce clean energy.

Focusing on the African market estimations have shown that this continent would need to install about 250 GW capacity by 2030 in order to satisfy the increasing demand. Without any doubt Africa can rely on a wide selection of clean sources (wind, sun, water, etc.) which have not yet been exploited.

In previous publications the economic convenience of using renewable energies in comparison to traditional sources have already been demonstrated. The possible lower cost of energy production through clean energies compared to fossil-fuels sources has been highlighted, thus increasing the gap between costs and income.

The scope of this thesis will be to make a further step in the direction of the renewable energy plants study. As the economic convenience of using renewable energies has already been proved, the aim will be to study operations and maintenance costs (O&M).

This study attempts to propose new financing models exclusively focused on these costs, and to find out which is the most convenient one, considering the particular situation of U.S. investments in Africa. The U.S. government launched a specific project called "Power Africa" in 2013. This thesis is related to the particular financing situation of this project, thus O&M financing proposals have sense considering this situation or similar ones.

O&M cost financing is an innovative topic that is being discussed at present. The aim is to contribute to the evolution of the traditional models to find out the correct way to finance these costs in relation to African projects.

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Executive summary

Nel corso di questa tesi si cercheranno di trovare interessanti soluzioni innovative per finanziare i costi di gestione e manutenzione (O&M) di impianti ad energia rinnovabile. Per fare questo è stato indispensabile partire da quella che è un'analisi del contesto delle tecnologie rinnovabili. Da questa analisi è poi stato possibile concentrarsi su quelle che sono le esigenze di manutenzione e gestione dei vari impianti e quindi contribuire con nuove idee e valutazioni. Il forte interesse per le tecnologie rinnovabili è partito in modo consistente in seguito al protocollo di Kyoto del 1997. Da qui, in seguito al crescente interesse per la riduzione di emissioni di CO_2 e gas serra, le fonti rinnovabili hanno iniziato a prendere piede. Nel corso del capitolo 2 viene fornita un'ampia descrizione delle risorse in termini della loro componentistica, del taglio delle dimensioni dei vari impianti e di quelli che sono i principali rischi non coperti, relativi alle tecnologie. In generale, ciò che può essere affermato è che rispetto alle tradizionali fonti di energia che fanno di solito riferimento ai combustibili fossili, le tecnologie rinnovabili non hanno ancora raggiunto quella maturità che garantisca la stessa competitività, ad eccezione dell'idroelettrico che invece presenta grande maturità e meccanismi di gestione simili a quelli di impianti tradizionali. Tuttavia, si può osservare un rapido e continuo sviluppo della tecnologia ed è già stato dimostrato come i costi di produzione di energia possano essere inferiori se ottenuti da risorse pulite in confronto a risorse tradizionali. Detto questo, ci si è concentrati su quella che è l'attuale situazione nel continente africano. In particolare si sono identificate due macro regioni: **Nord-Africa e Medio Oriente** e la regione dell'**Africa Sub-Sahariana.** La prima macro area è notevolmente più sviluppata rispetto alla seconda, in quanto i paesi qui collocati hanno facile sbocco sul mare che garantisce interazioni con l'Europa. Anche per quanto riguarda l'aspetto energetico, questi paesi sono notevolmente più avanzati e molti investitori europei hanno interessi legati allo sfruttamento di giacimenti di petrolio in questi paesi. I governi giocano tuttavia ancora un ruolo fondamentale, e la liberalizzazione dell'energia è fondamentale per un ulteriore sviluppo e connessione tra paesi (come avvenuto tra Spagna e Marocco). Per quanto riguarda invece l'Africa Sub-Sahariana, quest'area è nettamente meno sviluppata dal punto di vista energetico. Questo basso sviluppo dal punto di vista energetico si scontra con quello che è un elevato tasso di crescita in termini di popolazione, che richiederà nel corso degli anni sempre una crescente domanda di energia. Inoltre, anche il rischio politico, se pur ancora presente, calerà nei prossimi anni facilitando gli investimenti anche nelle aree più rurali. Proprio per questo enorme potenziale di crescita, le considerazioni fatte in questa tesi si focalizzano principalmente in quest'area. Si è scelto di riportare un esempio di un caso studio, per evidenziare la possibilità di sfruttare le esistenti centrali a fonte rinnovabile, e di collegarle tra loro per fornire energia a più paesi. Il caso preso in esame riguarda la Tanzania, l'Uganda e il Ruanda, dove sono già presenti, nell'area dei "Grandi Laghi", una centrale idroelettrica, un campo di pannelli solari e ci sarebbe l'opportunità di sfruttare le grandi risorse in Tanzania per costruire un terzo punto da collegare alla rete, che andrebbe a costituire una sorta di triangolo tra i tre paesi. Inoltre, nel corso del capitolo 2, si è voluta dare una descrizione delle "smart grid" perché considerate come un'importante opportunità da implementare in un ambiente vergine come quello africano. In particolare si sono evidenziate quelle che sono le principali tecnologie di immagazzinamento dell'energia e i principali attori coinvolti nella distribuzione di questa. Tenendo presente che, in paesi caratterizzati da una forte incertezza di domanda, applicazioni come il time-shift o l'arbitraggio sui prezzi potrebbero essere soluzioni molto interessanti.

A questo punto, nel capitolo tre, si è deciso di dedicarsi a quello che è il tema finanziario. Essendo questa tesi relativa a quelle che sono possibilità di finanziamento per costi di O&M, è stato utile ritrovare quelli che potevano essere rischi e barriere per i finanziamenti in questi paesi. Come è stato evidenziato dagli esperti del settore, i principali rischi fanno riferimento a tre fondamentali categorie: le **risorse di capitale**, le **considerazioni degli investitori** ed infine alla mancanza di **dati e standard** attendibili. La difficoltà di trovare capitale disponibile da investire in risorse rinnovabili è sicuramente un punto centrale. Inoltre gli investitori percepiscono ancora un elevato rischio e decidono di investire solitamente in grandi progetti, difficilmente rischiano su piccoli progetti dai ritorni incerti. Infine, tutti i vari strumenti assicurativi e di finanziamento, sono presi dal mercato tradizionale e riadattati a seconda del caso. Manca una vera e propria struttura finanziaria ad hoc per le rinnovabili. Oltre a questi rischi percepiti, bisogna considerare le barriere agli investimenti date dal rischio tecnologico, dalla disponibilità delle risorse (vento, sole e altre non è detto che siano disponibili tutti i giorni dell'anno a tutte le ore), dai lunghi lead-time di completamento dei progetti, il rischio di credito ed oltre a questi quelli che possono essere vari problemi e ritardi nella fase di costruzione, problemi relativi alla interruzione del business o della rottura di macchinari (basti pensare all'equipaggiamento per scavare necessario per l'energia geotermica). Infine, bisogna considerare che l'investimento iniziale è solitamente molto elevato e solo certe aziende possono permetterselo. Una volta evidenziati i rischi e le barriere agli investimenti, si sono definiti gli strumenti solitamente usati per finanziare questo tipo di progetti. E' divenuto fondamentale cambiare il ruolo che hanno avuto le azioni delle donazioni nel corso degli anni. Infatti, queste hanno avuto un effetto solo momentaneo sul mercato di questi paesi, senza garantire una struttura ed una metodologia per il lungo-periodo. Le donazioni possono essere ancora utili per dare credibilità e assistenza ai progetti, ma non devono avere un effetto spot. I meccanismi di finanziamento solitamente più utilizzati sono quelli classici come crediti, leasing, equity e mezzanine finance, obbligazioni. C'è una fondamentale differenza tra grandi e piccoli progetti in quanto quest'ultimi, hanno oggigiorno una grande difficoltà nel raggiungere la **massa critica** che gli consenta di rendere profittevoli gli investimenti. Per questo motivo molti progetti non vengono neanche presi in considerazione dagli investitori. La gestione del rischio diventa per le fonti rinnovabili una questione fondamentale. I principali rischi restano quelli legati al danneggiamento e rottura di tutto o parte dell'impianto, alla interruzione del business o a third-party liabilities, come avviene per le fonti tradizionali. C'è però una fondamentale differenza da far risaltare in questo mercato in rapida crescita rispetto ai mercati tradizionali: in un mercato come quello Sub-Sahariano, può non essere considerato il problema relativo agli incentivi. Mentre in paesi sviluppati gli impianti a fonte rinnovabile possono competere con quelli a fonti tradizionali solo esclusivamente grazie agli incentivi che ricevono, in questo caso c' è la possibilità di competizione esclusivamente sul costo di produzione dell'energia. Avendo fatto questa considerazione, nel corso del capitolo 3 sono stati elencati alcuni meccanismi di gestione del rischio che possono essere utilizzati per ottenere la credibilità necessaria dai progetti. Questi strumenti sono: derivati legati al tempo, derivati sui crediti e vari tipi di assicurazioni quali CLNs, CDOs, ART, società di riassicurazione (captive insurance), ILS, PRI, OBIs. Fondamentale è capire che il settore pubblico dovrebbe agire da catalizzatore tra le grandi aziende e le boutique private. Le grandi aziende cioè banche, brokers e assicuratori dovrebbero fornire il loro solido network distributivo, mentre le boutique private hanno la possibilità di creare nuove ed innovative soluzioni di protezione dal rischio. Il settore pubblico deve agire da facilitatore tra le due parti. Analizzando il background finanziario, la questione relativa ai costi di manutenzione e gestione di impianto è stata quindi introdotta. Si è visto che questi costi impattano solitamente per il 5% dei costi totali di impianto. La spesa maggiore è ovviamente quella che fa riferimento ai costi di costruzione che sono circa il 90% del totale. Attraverso ricerche e contatti diretti con un'azienda italiana che si occupa di rinnovabili, si è reso più chiaro quello che è il metodo tradizionale secondo il quale questi costi vengono finanziati. Solitamente infatti, è esclusivamente attraverso la vendita di energia che si è in grado di pagare annualmente i costi di O&M. Nel caso preso in esame nel corso di questa tesi invece, ci sono due principali aspetti che stravolgono la metodologia tradizionale. Prima di tutto i soldi vengono garantiti da autorità internazionali quali Banca Mondiale e Fondo Monetario Internazionale che fanno pensare alla possibilità di concentrare i costi di O&M nell'investimento iniziale. Inoltre, la vendita di energia non è cosa certa in questi paesi, infatti non si ha la sicurezza dei prezzi e della domanda in paesi a rapida crescita demografica. Queste incertezze hanno fatto si che si pensasse alla creazione di nuovi modelli.

Una volta introdotto il tema della manutenzione questo è stato approfonditamente studiato nel corso del capitolo 4. Si è visto come molti modelli relativi alla gestione della manutenzione abbiano origini molto datate e che difficilmente possono essere applicati efficacemente dalle aziende. In generale c'è una difficolta di comprensione dei modelli, molti di questi sono stati creati solo su carta per scopi matematici. Inoltre, esiste la possibilità che molte aziende che utilizzano modelli convincenti non siano interessate a divulgare questa loro competenza. Sicuramente bisogna considerare il fatto che la manutenzione coinvolge molti aspetti ed è difficile creare un modello che comprenda tutte le variabili, bisogna tenere in conto il fatto che l'ottimizzazione non è sempre necessaria e bisogna prestare attenzione nel concentrarsi sul giusto tipo di manutenzione. In questa tesi i dati di costo che sono stati riportati fanno riferimento in particolar modo a costi di manutenzione ordinaria, ma anche la manutenzione straordinaria non è stata tralasciata. Come si è potuto notare infatti, alcuni componenti necessitano particolare attenzione, è il caso degli inverter per il solare o del gearbox e del generatore per l'eolico. Questi componenti sono quelli che maggiormente si rompono e richiedono interventi di manutenzione straordinaria, tanto che stanno spingendo alcune aziende ad adottare una politica di integrazione-parziale: le aziende installatrici tendono a non lasciare più l'intera gestione al produttore secondo una logica full-service, ma sono esse stesse che tengono scorte di questi componenti ed intervengono direttamente. Per rendere più completa questa analisi, sono stati esaminati i costi di produzione dell'energia ed in particolare il LCOE, cioè il prezzo a cui l'energia dovrebbe essere generata per raggiungere il punto di break-even. Si può vedere come l'impatto dei costi di O&M sul valore di LCOE è minimo infatti risulta essere circa il 10% per quanto riguarda l'energia eolica on-shore e oscilla tra il 3 e l'8% per quanto riguarda il solare, a seconda delle fonti. L'impatto maggiore è sicuramente dato dai costi capitali e cioè dai componenti che costituiscono l'impianto come possono essere la torre e le pale per quanto riguarda una centrale eolica. Un'osservazione interessante può essere fatta comparando i costi delle energie rinnovabili con quelli delle energie tradizionali. Si è notato come alcune fonti rinnovabili siano già attualmente competitive con i costi delle energie tradizionali, mentre altre lo diventeranno nel giro dei prossimi anni. In particolare quello che pare essere più indietro e avere notevoli margini di crescita è l'energia solare, che comunque secondo le stime, raggiungerà la competitività economica entro il 2030. Per quelle fonti, come l'eolico on-shore, che sono già al presente competitive, la convenienza rispetto ai combustibili fossili diventerà chiara entro il 2020, senza considerare gli ulteriori benefici quali i benefici al clima, la qualità dell'aria, dell'acqua e all'intero sistema ecologico che si hanno utilizzando fonti pulite. Focalizzandosi sui costi di O&M sono stati riportati dati ricavati da vari documenti che sintetizzano i principali costi variabili e fissi di manutenzione. E' importante notare come alcune fonti presentano solo una tipologia di questi costi, mentre altre presentano entrambi. E' il caso per esempio dell'idroelettrico e delle biomasse in cui i costi sono presenti sia in relazione alla potenza installata (costi fissi) che al consumo (costi variabili). Per quanto riguarda gli impianti ad energia solare ed a energia eolica, questi presentano esclusivamente la componente fissa dei costi e si è visto come l'eolico abbia una necessità maggiore di manutenzione con un costo di 60 $/KW. Il solare ha costi lievemente inferiori e ciò che si può notare è che questi costi sono stimati in costante ribasso per il prossimi 40 anni, coerentemente col fatto che la tecnologia è ancora giovane e non ha raggiunto maturità neanche da questo punto di vista. Quando si considerano i costi di O&M non bisogna focalizzarsi esclusivamente su quelli relativi agli impianti in sé, ma sono stati analizzati anche quelli relativi alle strutture di trasmissione e distribuzione dell'energia. Infatti, si è considerata la parte di costi O&M come se fosse a carico dell'impianto che si aggancia alla rete, mentre ovviamente i costi di costruzione delle strutture di distribuzione non sono stati imputati ai proprietari degli impianti rinnovabili, ma ai responsabili di trasmissione dell'energia. Si è così ricavato l'impatto che hanno le azioni di manutenzione sulle strutture di distribuzione e che devono essere imputate ed aggiunte ai costi di O&M relativi agli impianti a fonti rinnovabili. Questi costi hanno un impatto minimo rispetto a quelli diretti sull'impianto, e sono esclusivamente costi variabili, dipendenti quindi dalla quantità di energia che viene domandata. A questo punto è stato possibile effettuare una vera e propria analisi, ottenendo grafici che evidenziano l'andamento dei costi di O&M nel corso degli anni. Il comportamento più particolare è stato riscontrato nei costi relativi all'energia delle onde e delle maree, in quanto tende a decrescere fino al 2040 e poi le previsioni stimano un incremento di costi fino al 2050.

Questo è dovuto all'iniziale diminuzione dei costi della tecnologia, essendo queste tecnologie ancora molto giovani, che porterebbero alla diminuzione anche dei costi di O&M e successivamente, dato il bisogno di sviluppare risorse a minore qualità, ci sarebbe un aumento di costi di O&M. In ogni modo, essendoci concentrati in questa tesi specialmente su eolico e solare, si è osservato come i costi di O&M per l'eolico siano stati stimati come costanti, mentre per quanto riguarda il solare si è stimato un continuo ribasso, come già affermato. Per quanto riguarda i costi di distribuzione, anche questi sono stati ulteriormente analizzati arrivando ad un valore di 1,2 $/MWh che è stato considerato costante nel corso della vita degli impianti.

Una volta ottenuti questi dati, si è passati nel capitolo 5, allo studio di nuovi metodi di finanziamento per questi costi. Per capire come inserire questi costi in un modo innovativo, si è studiato quello che è il meccanismo di finanziamento classico. Infatti, come detto in precedenza, solitamente è solo grazie alla vendita di energia che vengono finanziati i costi di gestione e manutenzione degli impianti, mentre nel caso preso in esame in questa tesi, si è cercato di includere i costi di O&M in maniera differente essendo costi ripagati da autorità internazionali. Avendo ben chiaro quello che è il meccanismo di finanziamento classico che avviene per i costi capitali (CAPEX), si è pensato a due nuovi modelli che includessero i costi di O&M. Nel **primo modello** proposto si rimane più legati a quello che è il meccanismo di finanziamento tradizionale dei CAPEX quindi, si è pensato di includere la sommatoria di tutti i costi di gestione e manutenzione stimati per l'intera vita dell'impianto (considerata di vent'anni), insieme ai costi CAPEX e quindi andando ad incrementare l'investimento iniziale che è richiesto alle aziende che investono in questi progetti. Ovviamente questo modello prevede che all'anno T_0 in cui avviene l'investimento, sia già stata effettuata una stima precisa di tutti quelli che saranno i costi di O&M per l'intera vita dell'impianto. L'azienda investitrice avrebbe il compito di effettuare questa stima e poi sarà ripagata nel corso dei vent'anni dai fondi che agiscono da intermediari tra le varie aziende investitrici e le autorità internazionali (FMI e WB). Nel **secondo modello** proposto invece, si è voluto fare uno step ulteriore, allontanandosi dal modello di finanziamento tradizionale. Si è pensato di dividere il processo in due parti: la prima è esattamente quella che si occupa di finanziare i CAPEX senza occuparsi di altri costi, la seconda parte del processo invece vede l'intervento di nuovi fondi d'investimento dedicati esclusivamente al finanziamento di costi O&M. Questo modello prevede anch'esso una stima di tutti i costi di gestione e manutenzione per tutto l'arco di vita dell'impianto, ma contrariamente al primo modello, le aziende investitrici (private parties) dovranno investire anno dopo anno solo la quota prevista per l'anno successivo di costi di O&M. Questo garantisce un esborso iniziale molto minore in quanto al periodo T_0 solamente i costi CAPEX e i costi di manutenzione per il primo anno saranno pagati dalle imprese investitrici, differentemente da quanto accadeva nel primo modello in cui tutti i costi di O&M venivano pagati per i 20 anni di vita dell'impianto. Questa opzione è stata proposta pensando anche al guadagno del fondo di investimento e non solo esclusivamente a quello delle aziende investitrici. Infatti, la stima del fabbisogno da richiedere alle autorità internazionali sarebbe effettuata direttamente dal fondo che poi passerebbe le previsioni alle aziende investitrici. Questo significa che se alla fine i costi effettivi sarebbero inferiori, il fondo guadagnerebbe la differenza tra la previsione e i costi effettivi. Allo stesso modo questo modello porterebbe vantaggi anche alle aziende investitrici, in quanto avrebbero un esborso iniziale inferiore garantendo la partecipazione a questi progetti anche ad aziende con inferiore capitale disponibile. Inoltre, ricevendo di anno in anno la quota spesa l'anno precedente più gli interessi, riuscirebbero a finanziare la spesa per l'anno successivo in una sorta di auto-finanziamento. Queste ed altre considerazioni riguardanti i tassi di interesse e il WACC sono state riportate nel corso del capitolo 5. Particolare attenzione è stata data al tema del **training** infatti, ciò che è stato riscontrata è la possibilità di insegnare ai locali ad eseguire un efficace ed efficiente programma di manutenzione così da istruirli per gli anni a venire. Ciò a cui si è pensato è un certo numero di anni in cui gli operatori specializzati delle aziende investitrici (americane) svolgano i lavori di manutenzione ordinaria, allo stesso tempo però dovrebbero svolgere un'azione di insegnamento e preparazione in-loco a quelli che dovranno farsi carico di queste mansioni. Ciò che si è visto è che esistono negli Stati Uniti numerosi corsi di preparazione per la manutenzione, ma molti sono esclusivamente scolastici. E' ancora difficile pensare ad insegnamenti diretti in-loco anche se alcune imprese come GE (General Electric) hanno iniziato a farlo offrendo anche piattaforme on-line di supporto. Questo garantirebbe uno sviluppo a 360° della gestione dell'energia in aree come quella africana, anche considerando il fatto della rapido sviluppo delle energie rinnovabili, ci sarà bisogno di personale con adeguati skill.

A questo punto si è effettuata una valutazione vera e propria di quello che è il valore dell'NPV per i due modelli presentati. Questa operazione è stata svolta prendendo in esame due casi studio. Si è considerato infatti sia un campo fotovoltaico in Ghana, sia due impianti eolici in Etiopia. Questi casi studi sono stati analizzati coerentemente con il loro apporto di energia alla rete dei rispettivi paesi e come detto in precedenza considerando anche i costi di distribuzione dell'energia. I risultati ottenuti in entrambi i casi evidenziano il fatto che il primo modello proposto sia quello più conveniente per le aziende investitrici poiché garantisce un valore NPV maggiore. Tuttavia, questo valore risulta essere più elevato specialmente per l'alto valore di interessi che le aziende riceverebbero dal fondo nei primi anni. Nel secondo modello, essendo pagati gli interessi esclusivamente sulla spesa dell'anno precedente, questi non raggiungo mai valori elevati. In ogni modo, prima di abbandonare l'idea di utilizzare questo modello, bisogna tenere in conto altre variabili come la possibilità di maggiore guadagno per il fondo e i minori costi iniziali di investimento. C'è la possibilità di migliorare e sviluppare ulteriormenti modelli di questo tipo che riguardano problematiche all'ordine del giorno. Questa tesi vorrebbe essere un trampolino di lancio per stimolare l'interesse verso questo argomento ed arrivare alla formulazione di nuovi modelli.

Per concludere, ciò che è stato fatto è stato comparare i ricavi derivati dalla vendita di energia in paesi con tassi di crescita crescenti, seguendo quindi un metodo di ripagamento dei costi di O&M più tradizionale, con i ricavi derivati da interessi e quota capitale garantiti dai fondi. Ciò che si è visto è che i ricavi arrivati dai fondi sono sicuramente maggiori e quindi, nonostante vadano a coprire l'investimento iniziale fatto, è sicuramente conveniente attuare questa nuova forma di finanziamento per O&M in quei paesi che presentano una situazione finanziaria di questo tipo, cioè in cui i finanziamenti sono già garantiti.

CHAPTER 1 - Introduction

This thesis attempts to study possible solutions to finance O&M costs in developing countries. This topic comes from the increasing energy demand in these areas. In particular the focus will be on the African market, following the principles offered by the "Power Africa" project, an American project that intends to install 8 GW of energy through Renewable energy sources in the first phase (see chapter 2). In order to have the possibility to study the maintenance costs and then to provide some possibilities to finance these costs, it is important to analyze the target market and to show what these projects in Africa have built in recent years. This topic is related to a context in which the demand of energy is constantly increasing, but especially in developed countries, some obligations (political and environmental) concerning the greenhouse gas emissions do exist. Therefore, the fundamental assumptions that RE will be basic for the future is the starting point of this paper work.

In this thesis the principal renewable technologies available on the market will be described, focusing on the economic and risk aspect more than on the technical one. Renewable technologies will be described even in their components and variants, but the aim is to understand the maturity level of the technology and the main risks involved. Once the main technologies have been shown, the opportunities and the current projects will be explained. In order to understand the market and the goals of the projects, the analysis of the current situation and of the present on going projects have been useful. In addition, a useful example relating the construction of a mini-grid energy system entirely based on RE plants has been reported to show the direction in which the projects are moving toward. The example of a useful interconnection between different RE systems has brought out the possibility to combine different sources in an intelligent way and furthermore, introduced the possibility of the construction of a smart grid in the Sub-Saharan part of Africa. Thus, a brief description of the smart-grid topic, and more specifically about the storage systems to manage the energy produced better, has been given.

The entire treatise has been written from an economic point of view rather than a still important, but already known environmental point of view.

In order to analyze the economic and financial issues better, the attention verged (in chapter 3) on the financial aspects for RE. Firstly, the main risks and barriers to an efficient financial closure in developing countries have been analyzed. These risks refer to the sources of capital, the investor considerations and on the quality and standards issue. Concerning the main barriers, they can be classified into cognitive, political, analytical, related to the market and finally technological barriers and their impact has been described in paragraph 3.1. Once the main risks and barriers have been understood, the actual financing tools for RE in developing countries have been shown, thanks to the documents provided by many American authorities that analyze this topic. It has come out that Credits, Leasing, Equity and mezzanine finance and Bonds are the most used instruments. In general it can be said that financial tools for RE come from the traditional energy market are case-by-case readapted to the particular situation, but specific tools for RE do not exist yet. In addition, some examples on how the specific situation has been faced in some different countries in Africa have been reported and also the most important difference between large and small-scale projects has been underlined. This is an important difference to understand and both types of projects should be considered to achieve the goal to deliver enough energy to this continent. Moreover, the outstanding role of charity has been analyzed, as it is important to understand that to achieve and develop the African market it is impossible to rely only on the money offered by donors, but charity can still play an important role. Furthermore, the risk management tools have been described. In particular an important distinction between developing and developed countries has been made, focusing on the role of incentives in developed countries. This role is fundamental to achieve the economic reliability in developed countries, but it is not an important point in developing countries and this is a key point that explains why RE can become really competitive in these markets.

The O&M topic has been then introduced. O&M costs study cannot rely on much bibliography or documents to be analyzed. This is an innovative topic in particular concerning the particular financing situation related to the “Power Africa” project that will become clearer in chapter 5. According to the “Operations and maintenance best practices” document published by the Federal Energy Management Program (FEMP) in 2010, the overall O&M program involves 5 different parts: Operations, Maintenance, Engineering support, Administration and training (see figure 1).

In this thesis, when analyzing costs, all these aspects have been included thanks to the availability of some data concerning RE operations and maintenance costs.

Figure 1: O&M integration structure, FEMP source

Thanks to the data available, a further study on distribution costs of energy has been carried out, in order to obtain sufficient data to evaluate the financial models.

Everything mentioned will be examined in depth during this thesis and in the results of the conclusions final considerations will be made.

CHAPTER 2 - Renewable energy issues

After this introduction, we enter the main part of this thesis. In this chapter we will analyze the general condition of our target market. In particular we will focus on the renewable resources available in the market, analyzing the pros and cons of each technology, and explaining how the technologies work. This is not a technical thesis so we will not enter into details of how each technology is built, but the technology assessments trying to highlight the principal issues and the conversion options to create energy will be described. Moreover, an overview of the current situation in Africa will be offered. Of course it is important to know what has been done and how the framework is, economically speaking, so as to have a good knowledge of the situation. Knowing what investors have done in the past years, and what they are actually doing in these days, is fundamental in order to trace the background in which we are operating. Since everything new must consider the past actions adopted, this contest description will be useful to have an important basis that must be considered when doing the consistent part of the thesis that will take place in the last chapters. Furthermore, the opportunities offered by smart grid technologies will be presented in this chapter. Renewable resources can be cheaper than traditional power sources, however the real problem is the initial investment, and the discontinuity of the power supplied. The intelligent use of the grid can provide a balance of the power established, and a constant availability of the energy in the grid. Therefore, a description of how these systems work and how they can be exploited to help the development of plants and connections in our market, is useful to understand the general conditions of the market and the opportunities we have.

2.1 - Overview on renewable energy technologies available in the market

Nowadays renewable technologies available on the market are well-identified, but they have not yet been developed, and more precisely, they are not yet affordable compared to traditional energy sources. In this chapter we will analyze the most common renewable technology, focusing on why they should be convenient in Africa, and which the most relevant barriers that are limiting their employment are. Firstly, a historical excursus should be made; on December the 11th 1997, the “Kyoto protocol” was underwritten. This international agreement obliged the participating countries to reduce the greenhouse gas emissions by 5,2%. Europe fixed its objectives to 8%. The mechanisms to be followed in order to pursue this goal have been identified in three categories:

Clean development mechanism: industrial countries can promote projects in developing countries so as to create benefits in terms of emission reductions and economic development. At the same time they could take advantage of emission credits.

Joint implementation: an industrial country can promote a project to reduce emissions of greenhouse gas in another country of the same group and doing so it will receive some emission credits together with the other country in which it has decided to invest.

Emission trading: this mechanism allows the trading of emission credits between industrial countries. A country, which has over-reached the objective of emission reduction, can sell its credits to another country, which on the other hand has not respected its obligations.

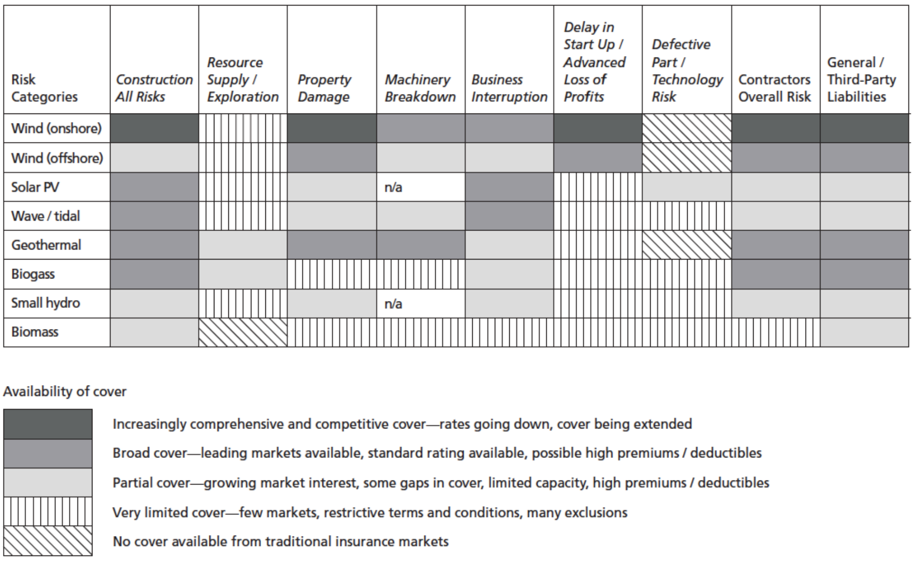
All these mechanisms have allowed the financing of new projects to reduce carbon emissions and thus to generate emission certificates called CER (certified emission reductions) that facilitate investing countries. Therefore, Africa seems the right territory to make this investment. The renewable solution seems ideal for these countries, considering a general view of continuous development. The role played by the investors will result fundamental, as they can find profitable investment, and at the same time pursue a diversification strategy. Furthermore, we should consider that industrial countries would probably keep on consuming oil and other fossil combustibles despite the shortage and the higher prices they are facing. As a consequence, investing in renewable energies would also mean increasing African raw material exportation, as they would not require them.

After this panoramic overview of the sector and of the main principles which are driving industrial countries to invest in Africa and in developing countries in general, we will present the technologies, actually available in the market, highlighting also the technical and economic barriers and risks related to them.

2.1.1 - Hydroelectric power

A general distinction must be made between small-scale and large-scale hydro projects. The Word Commission on Dams (WCD) declared the limits of 10 MW of capacity installed for mini- hydro projects, although bigger countries such as China or India are likely to reach higher boundaries: respectively 50 MW and 25 MW. While dealing with renewable resources, we will exclusively refer to small-hydro sources of power. The reason why we will exclude large-hydro projects is that, although they are effectively renewable, their plant management mechanisms are very similar to fossil materials plants. As the core part of the thesis will focus on plant management and maintenance, we have decided to avoid large-scale hydro project as their management issues are more similar to oil or natural gas alimented plants.

Mini-hydro projects could be divided into micro-hydro (with a power lower than 300 or 100 KW, depending on definition) and Pico-hydro (with a power lower than 20,10 or 5 KW). Hydroelectric energy transforms falling water into electric or mechanic energy. Small- hydro systems require a turbine, a generator, a water flow regulators and, of course, a structure to locate the plant. This is the more mature technology we can consider, costs of turbines, motors and power units are decreasing year by year as a consequence of the high standardization. It can be considered as a great alternative to diesel systems in order to supply electricity to rural part of the continent. The specific characteristics of these technologies are a low environmental impact and a long implementation period: from 20 to 30 years considering from the design plan to effective implementation. On the other hand, we should consider the long lifetime of the plant, which could also last 50 years. The work of civil engineers (weir, channels), lasts for many years with suitable maintenance. This is the reason why small-scale and smaller storage reservoir systems are the leading source of renewable energy, and they are being established in an increasing number in rural parts of the world. As you can see from the table below (figure 2), the most dangerous risks we can incur are those related to resource supply and exploration and the ones linked to delay in start up and technology risk. For the other panel of risk we can exploit at least a partial cover. It is important to underline that machinery breakdown is not a problem that could affect this system, differently from what will be stated about the next technology that will be presented, which in some cases is largely affected by this possibility.



Risk Categories	*Construction All Risks*	*Resource Supply / Exploration*	*Property Damage*	*Machinery Breakdown*	*Business Interruption*	*Delay in Start Up / Advanced Loss of Profits*	*Defective Part / Technology Risk*	Contractors Overall Risk	General / Third-Party Liabilities
Wind (onshore)	▓	▥	▓	▒	▒	▓	▧	▓	▓
Wind (offshore)	░	▥	▒	░	░	▒	▧	▒	▒
Solar PV	▒	▥	░	n/a	▒	▥	░	░	░
Wave / tidal	▒	▥	░	░	▒	▥	▥	░	░
Geothermal	▒	░	▒	▒	░	▥	▧	▒	▒
Biogass	▒	░	▥	▥	░	▥	▥	▒	▒
Small hydro	░	▥	░	n/a	░	▥	▥	░	░
Biomass	░	▧	▥	▥	▥	▥	▥	▥	░

Availability of cover

▓ Increasingly comprehensive and competitive cover—rates going down, cover being extended
▒ Broad cover—leading markets available, standard rating available, possible high premiums / deductibles
░ Partial cover—growing market interest, some gaps in cover, limited capacity, high premiums / deductibles
▥ Very limited cover—few markets, restrictive terms and conditions, many exclusions
▧ No cover available from traditional insurance markets

Figure 2: Generic RET risk transfer heat map, existing insurance products, UNEP source

2.1.2 - Biomass/Biogas

A significant effort has been made to develop production systems of small dimension, capable of exploiting biomass energy sources such as wood, agro-industrial remains, and agricultural waste. Through the direct combustion of these materials, electricity can be created, directly exploiting the gas derivate from the thermochemical gasification or through the biogas produced by a biological conversion. Biomass plants can vary from small entities of 4-5 KW to big plants of 50 MW and they have a huge potential in developing countries. This source is a perfect power source even for remote applications in rural villages. One of the most important barriers, especially when seeking finance for these projects, is the security of fuel supply and fuel price volatility. The fuel/waste supply exposure often prevents projects to reach a financial closure. When crops are involved, crop yield insurance may be a solution, but risks are not only related to it. Indeed, the most important risks are related to machinery breakdown and business interruption, two central aspects considering they are connected to the central core of my thesis (plant management and maintenance). Fortunately, an insurance covering these risks is widely available for biogas plants that use tried and tested machinery. Moreover, for biogas plants involving fermentation processes, technology and operational risks are a concern for underwriters as there are health risks associated with noxious gases. The need for a strict safety procedure to control the fermentation process is fundamental to obtain wide coverage. In addition to this, other important issues are the propriety damage, delay in start up and the technology risk. As can be seen in figure 2, other risks can be partially covered by existing insurance instruments.

2.1.3 - Solar power

Solar radiation can be directly converted into electric energy through photovoltaic solar modules: optoelectronic mechanisms composed of photovoltaic cells which allow the conversion of incident solar energy into electric energy through a photovoltaic effect. Three different typologies can be found:

- Mono-crystal module: the most efficient ones
- Poly-crystal module: cheaper but less efficient
- Thin-film module: used for consumer applications. They have an efficiency which is half of the best panels, but are a lot cheaper.

All these panels can last for almost 30 years. Each single panel can have a power of 80-200 W depending on dimensions and technology. Panels can be displayed all together to reach the deliverables required. Insolation can be defined as the quantity of solar energy received in a single point of the earth surface. Solar sources are universally available worldwide, but usually the closer they are to the Equator the higher the value of the energy received is. Indeed, it seems easy to understand that Africa, and developing countries in general, have a great potential possibility to host these systems to produce electricity. For instance in Tanzania insolation values are around 2500 KWh/m^2, although performances depend on the site, as a general rule we can consider that 1 KW installed will produce more than 4 KWh per day. As a matter of fact, solar power is highly influenced by seasonality, since during warm seasons insolation would be higher than in cold seasons and during precipitations seasons insolation would be lower. This last factor could be balanced with a mini-hydro plant that on the other hand, could exploit the higher water source available during rainy seasons. Of course we can take advantage of solar power just during the daylight and this aspect is well-connected to the last paragraph of this chapter where the possibility to store energy in batteries will be seen. This stored energy can then be used within a more complex system, a smart grid. Usually energy produced is in direct current, therefore it is often necessary to use supplementary components to adapt tension to specific requirements. Costs afforded for photovoltaic electricity are still higher than costs for electricity produced with other technologies, such as mini-wind farms or mini-hydro plants, however costs are decreasing consistently in advanced markets. Concerning developing countries costs could still be relevant, but the possibility to import the technologies from the investing countries should be evaluated. Developing countries still suffer from an inefficient distribution system, duty taxes, and the almost total absence of competitors, so these are the reasons why costs are still high. This technology is really reliable, safe for the environment and its convenience is increasing for families and local applications. Costs can vary depending on many factors, but for sure the hardware involves usually about 30/50% of the total capital expenditure. As has been stated usually solar power tends to be on a small-scale. For larger installations the need for regular maintenance is fundamental, as frequent breakdowns and wear and tear can cause attrition losses. As the size of installations will increase, also the commercial appetite for providing cover will improve. Nevertheless the remoteness of the applications and the availability of service industries to repair, replace and maintain these facilities will be of concern to insurers who underwrite machinery breakdown and business interruption insurance. Moreover, the exploration risk and the delay in star up risks are the ones for which just a partial insurance cover exists.

In the figure below (figure 3) the typical solar photovoltaic components have been reported to make it clear how the components are integrated.

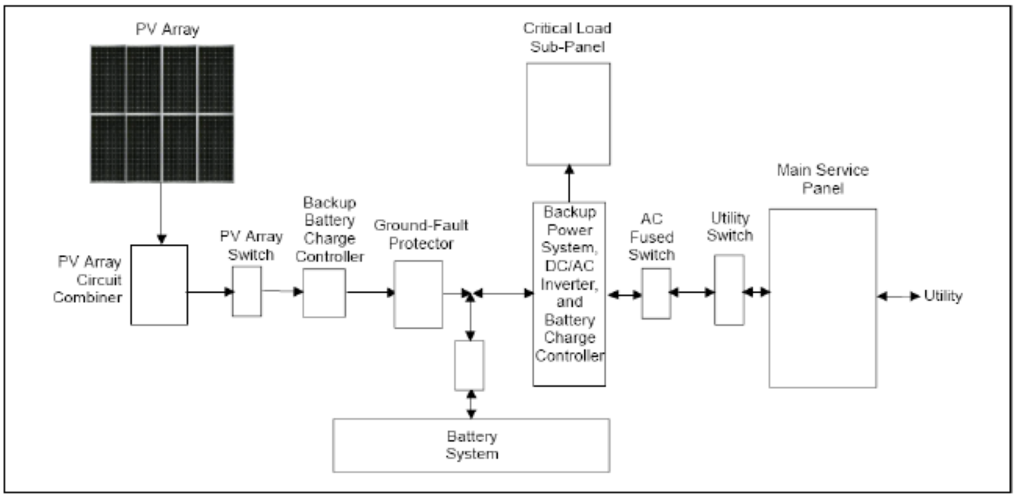


Figure 3: Components of a Solar PV system, CEC source

2.1.4 - Wind power

In this sector we can identify two different technologies:

- Windmill: produces mechanic energy to pump water into rural areas
- Wind turbines: generate electric energy for families and villages

We will focus on wind turbines, the most likely to be installed in our target market. Wind turbines convert kinetic energy of the wind into electric energy. Usually mini-grids use small wind turbines whose power can go from 1 KW to 20 KW. The regular small turbines are technically simple and have a long lifetime (50 years). The maintenance required is not relevant, and they can be used off-grid for many issues such as pump and treat potable water, irrigation, telecommunications, houses, schools, clinics, or to power a village. A wind farm, which provides up to 500 KWh, has a range of cost from 15.000 USD to 25.000 USD; however costs can also reach 150.000 USD for the biggest installations. For our purposes and target market, made up of rural entities, it is important to rely on mature and reliable technologies, which can exploit high quality standards to guarantee perfect performances during the project lifetime. Usually the most common models are horizontal-axis with 2 or 3 pales for a hybrid system. Wind source is extremely site specific; topography and obstacles significantly influence the speed of wind. That is the reason why wind farms are usually located on hills at least 10 meters high, to reduce the influence of high buildings and trees. This aspect is relevant for our target market as rural communities are often situated at the base of slopes or in the middle of valleys. The collection of information is fundamental before taking into consideration the launch of a new project. Normally the lowest speed of the wind to consider a project profitable is about 4-5 m/s. Election of specific turbines which could work with a low speed of wind level, might be a good idea, integrating the information collected. As stated previously for solar power, wind power is highly subjected to seasonality and depends on the daytime. Therefore the combination with other technologies becomes fundamental to produce electricity with a certain continuity. For instance batteries, as also stated in chapter 2.3, may be an intelligent storage system to guarantee stability of energy to the network system during the periods in which the wind does not blow. Considering the current produced, usually small turbines create direct current, at 12 or 24 V throughout permanent magnets. Depending on the architecture of the system a converter AC/DC might be necessary to charge the battery or the turbine may be directly connected or just with a converter AC/DC to regulate the components. Regarding the principal risks connected to this power source, they are principally related to the offshore projects. For on-shore operating wind energy projects a competitive insurance market exists, but regarding offshore projects it is significant that, although forming a very small proportion of underwriters overall portfolios, insured limits of up to EUR 300 million have been placed for offshore projects. This means that risk perception is still really high, and especially involve the construction stage of a wind farm: delays or damage during fabrication, transport, installation, testing and commissioning can affect the revenue profile of a project. In order to make the estimation of risk perceived clear, it is necessary to consider that for offshore wind energy construction project premium rates would be approximately 2 per cent of the estimated project cost, compared with premium rates for on-shore construction of 0.4-0.6 per cent. Moreover, another important issue is the breakdown risk. Project developers often have to rely on the warranties provided by turbine manufactures, indeed the creditworthiness of turbine manufacturers need to be considered and they often offer CSAs (contractual service agreements), which guarantee the technical availability of the system over the term of the financing agreement. They can also include maintenance, repair costs, or possible replacement. A further concern is the business interruption and the delay in start up, especially affecting offshore wind projects. Finally, resource supply and exploration risks are the most uncovered risks for both onshore and offshore projects (see figure 2).

In the figure below (figure 4) the typical wind plant components have been reported to make clear how the components are integrated.

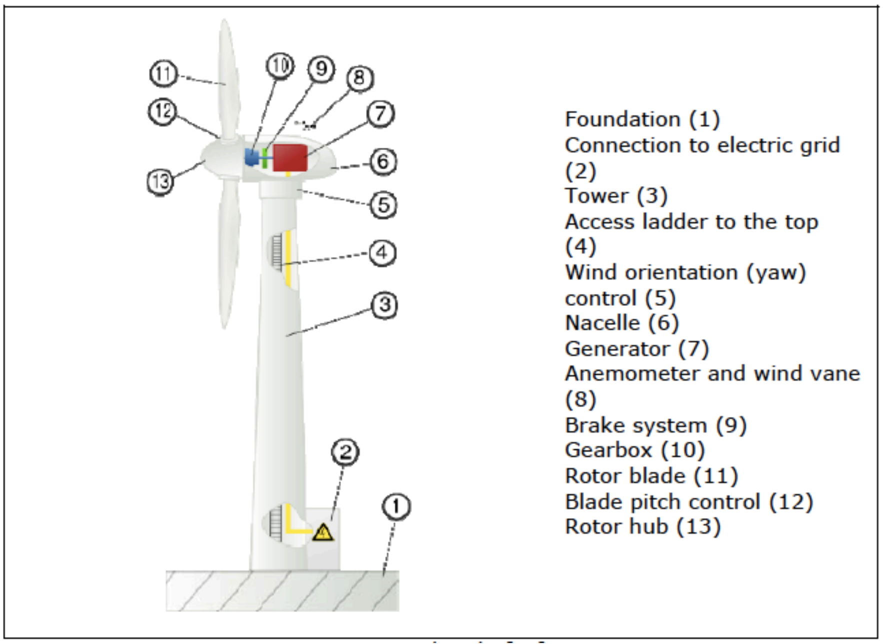


Figure 4: Components of a wind energy system, Wikipedia source

2.1.5 - Geothermal energy

Geothermal energy is thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. The geothermal energy of the Earth's crust originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%). The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. The Earth's internal heat is thermal energy generated from radioactive decay and continual heat loss from the Earth's formation. Temperatures at the core-mantle boundary may reach over 4000 °C (7,200 °F). The high temperature and pressure on the Earth's interior cause some rock to melt and solid mantle to behave plastically, resulting in portions of mantle convecting upward since it is lighter than the surrounding rock. Rock and water are heated in the crust, sometimes up to 370 °C (700 °F). Geothermal power is cost effective, reliable, sustainable, and environmentally friendly, but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have dramatically expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation. Geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are much lower per energy unit than those of fossil fuels. As a result, geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels. Geothermal projects require a high upfront capital investment for exploration, drilling wells, and the installation of plant and equipment, often employ some degree of public assistance. The most relevant risks are related to drilling activity. This activity is very expensive (from 1 to 5 million euros depending on the surface) and really risky as far as the possibility of delay is concerned. The main risks perceived, and consequently the direction in which the insurance market is moving towards, are related to: controlling a well or blow-out, costs of redrilling or restoring a well, and remedial costs associated with seepage and pollution. The key barrier is the possibility that the well does not achieve (economically acceptable) the minimum levels of thermal water production (minimum flow rates), so the exploration risk is consistent too. Finally, it would be important to develop a safe coverage system to cover the technology risk, as nowadays a valid instrument is not available.

2.1.6 - Wave/tidal/ocean current energy

Tidal power, also called tidal energy, is a form of hydropower that converts the energy of tides into useful forms of power - mainly electricity. Although not yet widely used, tidal power has potential for future electricity generation. Tides are more predictable than wind energy and solar power. Among sources of renewable energy, tidal power has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus limiting its total availability. However, many recent technological developments and improvements, both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, cross flow turbines), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be cut down to competitive levels.

Wave energy is the transport of energy by ocean surface waves, and the capture of that energy to do useful work – for example, electricity generation, water desalination, or the pumping of water (into reservoirs). Machinery able to exploit wave power is generally known as a wave energy converter (WEC). Wave power is distinct from the diurnal flux of tidal power and the steady gyre of ocean currents. Wave-power generation is not currently a widely employed commercial technology, although there have been attempts to use it since at least 1890. In 2008, the first experimental wave farm was opened in Portugal, at the Aguçadoura Wave Park. The major competitor of wave power is offshore wind power.

Marine current power is a form of marine energy obtained from the harnessing of the kinetic energy of marine currents, such as the Gulf stream. Although not widely used at present, marine current power has an important potential for future electricity generation. Marine currents are more predictable than wind and solar power. Marine currents are caused mainly by the rise and fall of the tides resulting from the gravitational interactions between earth, moon, and sun, causing the whole sea to flow. Other effects such as regional differences in temperature and salinity and the Coriolis effect due to the rotation of the earth are also major influences. The kinetic energy of marine currents can be converted in much the same way that a wind turbine extracts energy from the wind, using various types of open-flow rotors. The potential of electric power generation from marine tidal currents is enormous.

These technologies involve the same risks that are mostly related to the low development degree of the technology itself. Until insurance underwriters perceive a high risk also connected to small demonstration projects, requiring high minimum premium prices, it will be difficult to build large scale plants based on this system. Moreover, the concern of machinery breakdown is also relevant. The survival of the device is related to hostile marine environments and its location is related to collision risks. As it is a new technology also exploration risks and delay in start up should be taken into account.

2.1.7 - Fuel cell

Energy is created through an electrochemical process, which exploits the help of hydrogen and oxygen to produce direct current, heat, water and carbon dioxide. PAFC (phosphoric acid fuel cells), MCFC (molten carbonate fuel cells), SOFC (solid oxide fuel cells), PEMFC (proton exchange membrane fuel cells) are all different types of this energy source. The principal barrier to implementing these technologies can be the high costs which can go from 1000 USD to 1150 USD for each KW and operative costs estimated for 0,10USD/KWh. The IFC (international finance corporation) assigned 3 million dollars to IST Holding (Pty) and Plug Power Inc. with the intent to install 400 fuel cells in rural towns in South Africa. The entire project has a total value of 14 million of USD.

2.1.8 - Hybrid systems

Hybrid systems are those systems that use more than one power generating technology. A mixture of fossil and renewable sources is accepted and also a combination of different renewable sources such as wind and solar power and micro-hydro plants, which can be connected to storage systems as we have seen before, is expected. Hybrid system can supply a high quality AC (alternate current) to the network. For example a wind turbine of 5-100 KW can guarantee energy to a small local mini-grid system. Wind/diesel or hybrids like wind/solar/ diesel are perfect combinations to supply electric energy 24 hours a day, and furthermore they are the perfect applications for a mini-grid system. However, smart grid opportunities will be better analyzed in chapter 2.3.

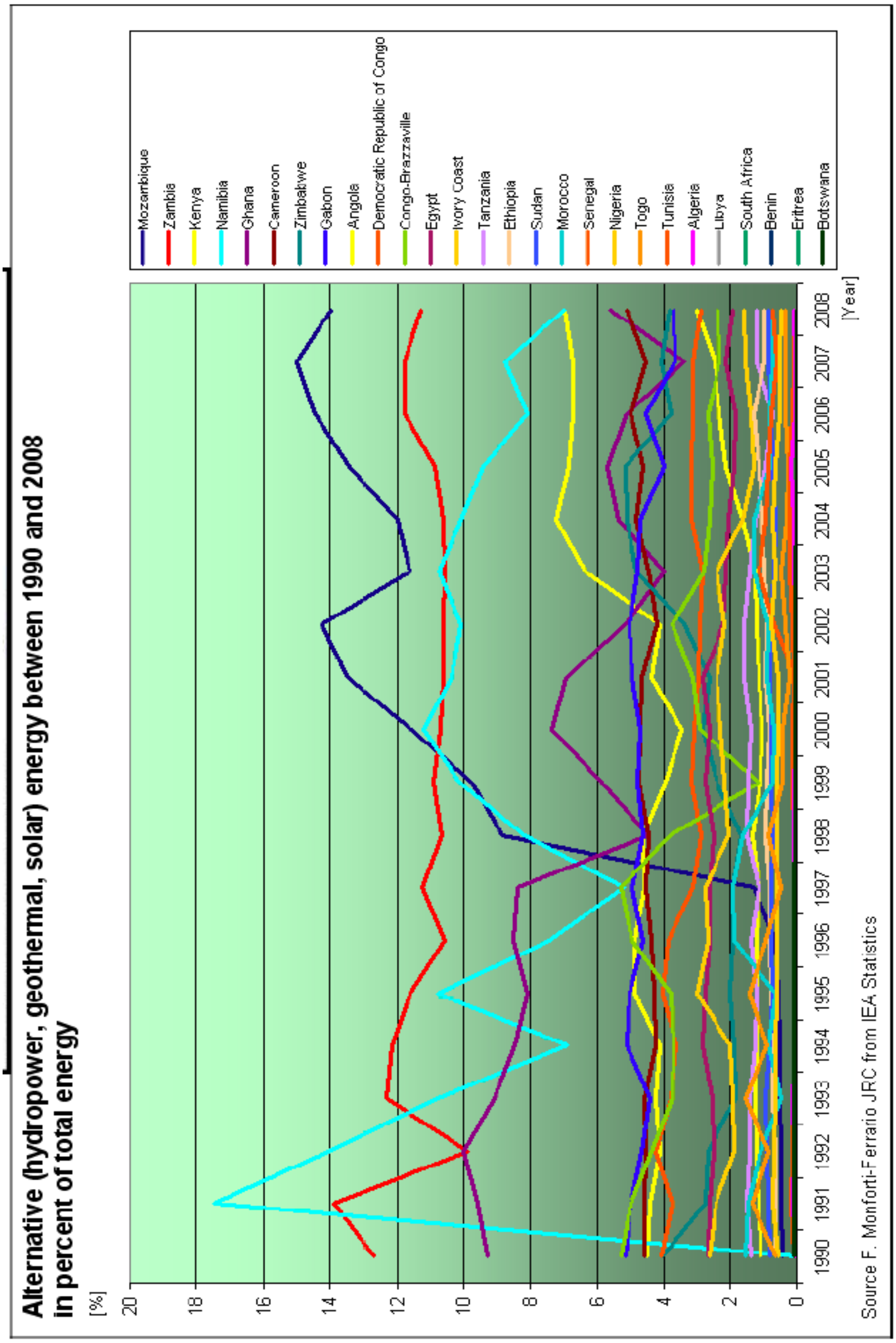
In paragraph number 2.1 a precise analysis on the different technologies available in the renewable energy market has been made. In the next paragraph the current situation in our target market, what has already been done by investors in Africa and what can be done further following the objectives of the “Power Africa” project will be dealt with.

2.2 - Analysis of the current situation and opportunities in Africa

To evaluate the situation in Africa we must consider that it is the second biggest continent in the world, after Asia, and for this reason there many differences depending on the area we are considering. In this paragraph the differences between these areas will be considered and the differences especially concerning the energy situation in these areas will be highlighted.

As a general assessment, one third of the houses do not have access to electricity and in the sub –Saharan Africa just 10% of rural areas have electricity access. Moreover, we must consider that there is a growth rate of 4% per year, just consider that 6 out of 10 of the most outgrowing economies of the world belong to the sub-Saharan territory. In the evaluation we must take into consideration this impressive growth rate to supply enough energy also for the future. There is a leading country, historically the richest one, which is of course South Africa, which can afford the highest investments. In South Africa 42% of energy production goal through renewable energy plants by 2020, has been fixed. As an intermediate objective they want to reach 3,5 GW in 2016 exploiting just solar and wind power. Countries that are located on the Mediterranean Sea cost and South-Africa, Botswana, Zimbabwe and Gabon are the countries that consume more energy. Other countries and communities consume less electricity, but actually because they do not have the access to energy, especially in rural areas as has been stated previously. These unsupported areas define 60% of the total population, concentrated in the central-southern area of the continent. More specifically, 589 million people do not have access to electricity. Form 2002 to 2010, the electrification rate has increased from 35,5% to 40%, with a urban electrification of 67%, but just of 19% regarding rural areas. The extended rural areas added to the low economic availability and to the low rate of electrification have always suggested rural areas to exploit local resources. Usually local energy sources refer to biomass, deriving from forestry and agricultural scraps, used for cooking or heating scopes. A relevant problem is that this waste is managed in an inappropriate way, with inefficiency and unproductiveness, causing problems of air quality inside the habitations.

This chart below (figure 5) shows how many different countries in Africa are oriented towards renewable resources.



Source F. Monforti-Ferrario JRC from IEA Statistics

Figure 5: RE sources favored by investments

The countries more oriented to renewable resources are usually the poorest, situated in the sub-Saharan region. Among the 6 best clean energy suppliers (Mozambique, Zambia, Namibia, Kenya, Ghana and Cameroon), 5 of them receive energy from hydroelectric plants, while Kenya exploits geothermal sources better. In the following pictures (figure 6) we can evaluate the degree of development of the electric network and the transportation network. Firstly, the difference of accessibility must be analyzed. 99% of the population, which do not have admission to the electricity network, is located in the sub-Saharan area, underlining a great disparity between this area and North Africa, where instead distribution infrastructure and energy production systems are well-operative.

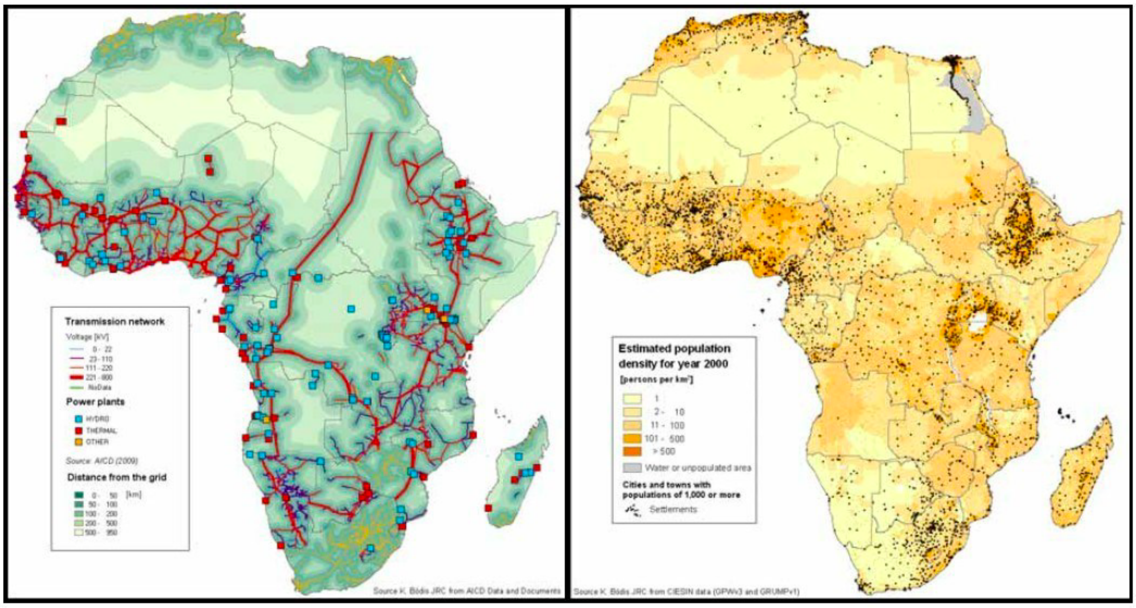


Figure 6: Transmission and distribution network and location of the plants (on the left), density of the population (on the right)

Comparing the first two pictures - the one on the left refers to electric network development and the one on the right refers to the degree of concentration of the population. It is easy to understand how many areas are still far away from an energy connection, despite the fact that they have a high density of population. In figure 7 we see how the fossil combustible supply is not always possible, because of the bad distribution conditions. This map gives us an idea of the considerable time which fossil sources need to reach each widespread rural area. Of course, the higher the delivery time, the higher the cost of the goods is.

Source: IRENA, adapted from United Nations Cartographic Section map 4045 Rev.7, Environmental Systems Research Institute, Africa Infrastructure Country Diagnostic GIS data (the World Bank)

Figure 7: The most important transmission lines in Africa

This consideration leads to the conclusion that, renewable sources, if well-managed, give a great opportunity to improve the access to rural communities. Furthermore, this topic has become relevant because of the CO_2 regulative policies and the aim to reduce the importation of fossil fuels. The concerns for renewable energy are far different from the concerns, which involve developed countries. The remarkable reduction of costs compared to traditional sources is the real added value of investing in RE in Africa.

Moreover, this clean energy increases the gap between costs and incomes, increasing the profit and also respect the environment. In our target market there are so many natural sources still unexploited that would reinforce the natural sustainability, playing an important role against greenhouse effect and carbon dioxide emissions, in still uncontaminated areas.

"*In an increasing number of cases, renewable energy is not just one of the easiest non-grid-connected options to establish, but also more cost-effective than the fossil fuel alternatives. This trend has led to speculation that developing economies may be able to 'leapfrog' developed countries in their use of renewable energy over the coming decade*" (UNEP and Bloomberg New Energy Finance, 2011).

In a previous master thesis, Africa has been divided into two macro-regions to describe the main differences between these two areas, due to the great differences representing these territories. For the purposes of this thesis, this division will be maintained and the most relevant aspects for each area will be pointed out.

North Africa and Middle East

As previously stated in this document, countries near the Mediterranean Sea are far more developed than the other areas. Renewable resources are already developed and well-exploited in this area. Thanks to the strong relationship with European countries, the electric network is already connected to the European one and in addition the huge availability of oil wells enable many important investments. The economy status is comparable to a few European countries.

Thanks to this existing framework, financial institutions are interested in investing consistent sums of money to initiate a clean energy project involving this area. The outstanding drivers include: existing market and clients, available renewable sources and potential market dimension. The increasing number of Islamic investors will play a fundamental role in supporting these projects. Nevertheless, a clear policy must be subscribed, to determine the entity of the investment and to enable the Islamic resources to be funneled into the renewable energy field. The projects must be oriented to a long-term energy development, guaranteeing credibility to the investors. Finally, the whole projects must be accompanied by an ad hoc incentive system. The opportunities, which can be exploited, are:

Growth in energy demand and purchasing safety: the high growth rate indicates an increasing number of people who will have new energy needs and so an increasing demand which can be satisfied with renewable plants.

Economic development: RE can substitute oil for local needs requirement and indeed exportation of the fossil combustible would increase.

Production and supply chain: these projects involve so many players and would create opportunities in many sectors.

Synergies in field: the RE sector also involves the agricultural and hydric fields.

Policies play an important role to attract new investors, as financing companies require clear and safe information about politics and normative contest whereas banks require a high rate of return to consider investing capital in this sector. Nowadays it is hard to consider a clear political line; however a few objectives have been established. For instance some countries have fixed a deadline to reach in the following years: 7% of RE in United Arab emirates; 5% in Bahrain and Kuwait; 10% in Saudi Arabia and Jordan, 20% in Egypt (12% from the wind power) and Morocco, all before 2020.

Despite these numbers, observing each country, if they are following their commitment can be verified:

- Turkey: is focusing on wind power

- Morocco: is implementing a self-made experience and knowledge on renewable issues.

- Egypt: is the country that benefits from the major number of resources. This makes it easier to achieve their target for 2020, but the big obstacle is represented by the private sector that cannot enter this market. Moreover, the recent coup d'état carries a lack of policies for the long-term development.

In order to enable the Feed-in Tariff, *"which are subsidies to cover the difference between generation cost (ideally including grid connection costs* (Swider et al., 2008)) *and wholesale electricity prices"* (M.A. Delucchi – M.Z. Jacobson, 2000), more sectors must be involved (water and energy). Indeed, RE needs to be evaluated as a specific contest as the specificity of the technologies involved. Just like for the European market, this financing mechanism would guarantee income stability for the long-term period.

Another important issue would be the electric market liberalization: this would produce a fast development of the financing policies and hopefully would attract new not energy-related investors, increasing the available and needed capital.

In the middle term a connection between the countries will be impossible: investors want to be informed about that. An example is the connection between Spain and Morocco, which in the future, will permit to export energy into the Iberian Peninsula.

To sum up, the national government still plays the most important role for the RE development. There is a relevant difference between African countries and Persian Gulf countries as the Gulf countries are reaching agreements for a shared energy development strategy and an interconnected network.

Concerning the economic considerations, these macro-area countries are thinking about moving subsidies, now useful for the oil extraction, to the RE market and to export oil. The main idea behind this action is to increase the exportation and exploit mostly RE than oil so as to increase margins throughout oil exportation. These increasing margins can be enough to repay the incentives system for the RE development. However, an incentive system guaranteed by the government is still preferred, because of the higher guaranties. Solar power is a competitive option compared to the fossil combustibles sources, if considered at its international vending price. In any case, solar power can supply energy to respond to demand peaks, which often occur in this area. However, the high initial investment related to a solar power farm must be remembered and in addition the importance of a subsidy system.

Sub-Saharan Africa

Entering the specific terms of the second macro-region, we must immediately underline that this is the area in which future investment will be mostly involved. The potential growth in economic terms is remarkable, considering demographical indexes and sources availability. Many studies have been carried out and they consider Africa as the continent that will represent 7% of the international GDP within 2040 and 12% by 2050 (considering the current value of about 4% in 2010). Historically many political and infrastructural boundaries have slowed the growth, but with the arrival of the new millennium, the growth has been extraordinary. It is difficult to define an economic growth module to be followed, as it can change depending on demography, political and economical issues and local resources. However, we can point out a few leader countries that can stimulate the growth: democratic republic of Congo, Ethiopia, Nigeria, Sudan and Tanzania.

The main drivers, which enabled the great growth of the last decades, are:

- Increasing price of commodities: which will be one of the most important drivers for the growth in the region.

- An increasing political stability.

- An economic policy, decided on by the governments.

- New investments in this area subscribed by new companies.

Certainly the most critical aspect refers to the political instability of this area. Due to wars, corruption and continuous change of political leaders, it is difficult to identify a political trend for the countries belonging to this area. In general, apart from Cameron, Gabon and Nigeria, where some aspects of democracy and autocracy are coming out, the lack of democracy is the biggest step to take. A stationary situation of democracy is usually the best form to launch projects of any kind, especially when, as in this case, the involvement of more countries is necessary. In recent years these political policies have weakened, but are still present, if we consider the coup d'état in Mali which occurred at the beginning of 2012. On the other hand, Eurasia Group, the world leader research and consulting company for political risks, foresees that 95% of these instability episodes will disappear in the next few years, due to the current general developing process. Concluding the political issues we should remember that countries that had a dictator can enjoy a better infrastructure system and a more stable contest. As a matter of fact they stand in the higher position of the GDP ranking for this area.

In order to proceed with our description of this area the implications of the crisis of the seventies should also be considered. After a great growth after the wars of independence, in the middle of the seventies there was a serious crisis especially involving the southern regions. The finance department turned to the World Bank and the IMF to solve the problems. In the Berg report it is underlined that the worst problem refers to the lack of economic policies: governments had to change their indications immediately. They focused on hedging the fiscal deficit and decided to liberalize the control of trading between foreign countries.

The leading countries nowadays can be considered Nigeria and South Africa (3.5% growth rate from 2000 to 2012 compared to the rate of 1.8% of the previous 10 years). Whereas Nigeria registered a growth rate of 6.5% for the period 2000 - 2012 when previously it was just 2%.

Service sector is also an important element to describe the general situation of the area. The increase in this sector and in the telephone market, prove an increase in the population and in the consumer markets which will lead to an increase in the GDP. Forecasts predicted a population of 2 billion people just for the Sub-Saharan area within the next 50 years. Furthermore, the fact that the average age is about 30 compared to 30 for Asia and 40 for Europe should be considered.

The first investment to be made is that of the infrastructure, because it would enable a long-term growth and because in its actual conditions it is still deficient. Moreover, the only successful investments are the Chinese ones. China is investing more than the Word Bank in its projects in Africa, and this is one of the main reasons why USA has decided to launch the project “Power Africa” as a kind of response to Chinese investments. However, also these oriental investments are not sufficient, as the infrastructure framework is still the worst, compared to other emerging countries, in terms of accessibility and capacity. Finally, the first step to be taken to ensure a stable energy offer with a short lead time, is the need to guarantee higher returns in the initial stages of the projects, as the risk associated to them is still too high to be afforded by many investors. However, risks linked to RE projects will better examined in chapter 3.3.

Continuing with the overview of the current situation in both these areas previously described, a **case study** will be presented to show how it can be possible to exploit the current facilities, already present in the territory, in order to produce and supply energy for many people in Africa. In particular the case study involves three countries in the sub-Saharan Africa, and intends to construct a mini-grid – the term will result clearer in the next paragraph – connecting existing plants. This case study has already been taken into consideration in a couple of previous thesis, but it will be summarized here, because it is considered an important starting point to show the possibilities and the direction that should be taken to improve the energy network. The case involves three countries in the rural area of the sub-Saharan Africa, where renewable plants are already present or can easily be built to concur to the grid. The three countries are: Uganda, Tanzania and Rwanda. Taking a look at the map below (figure 8) the area, which suits to host clean energy solutions better, seems the “great lakes” area. Using the example, we would like to point out how any mentioned countries could concur to the mini-grid.

Figure 8: Africa geography in the “Great Lakes” area, Google source

Uganda

Uganda is located in the Rift Valley, a geographical location that guarantees access to many energy sources. The Rift Valley generated from the detachment of two tectonic plates, therefore presents a high geothermal potential. If we consider that the geothermal potential can reach 450 MW, it is enough to consider an ad hoc geothermal plant: the subsoil temperature is stable between 150°C and 200°C. however the most important source is biomass, which supplies 97% of energy for the local population and 90% of the primary energy consumption. The presence of high trees (there are many forests of trees 5 meters in height) and many bushes, guarantee a constant supply. Solar power is also important as the solar radiation is on average 5,1 KWh/m^2/day with a variation rate of just 20% due to the proximity of the Equator. Concerning wind power, studies show that the average speed of the wind is insufficient to consider it as a source of energy production. Finally, the most useful source of energy for our grid is hydropower. Indeed, the estimation for hydric sources reaches 2000 MW for the area surrounding the White

Nile (which was born from the Victoria lake). Many micro and mini hydro plants are located in the oriental and occidental areas of the country, but what is of our interest is the dam on the Mpanga River. This plant (project of the African Energy Management Systems), located in the proximity of Mpanga River Waterfall (figure 9), can be exploited and connected to our micro-grid. Its power is about 18 MW and a new transmission line has already been built (33 KV). In past years it was unthinkable to use this plant to furnish energy to all the country, because of the isolation of each plant, but through the construction of the grid, it would be possible.

Figure 9: Hydroelectric plant on the Mpanga River

Tanzania

In Tanzania just 2-3% of the rural population have access to electricity. In order to spread the electrification rate in the rural areas, an important political effort has been made during the past years, but nevertheless, due to the vastness of the country, it is difficult to reach the whole rural areas. Wind power can be considered a valid resource only if integrated with other hybrid systems, because of the significant seasonality variations of the speed of wind. Solar power is an important resource to be considered as the insolation rate moves in a rage from 4,5 KWh/m^{2}day to 6,0 KWh/m^{2}day. The maximum insolation reaches the center of the country, but peaks are shown in other areas. The average rate is consistent to ensure the productivity of a hypothetical solar farm. For the construction of our grid, the ad hoc installation of solar panels has to be considered. In particular the north/west area, in proximity of the Victoria Lake, seems to be the most suitable place to begin the project. Indeed, wind, solar and hydroelectric sources are present in this area. Furthermore, it is a strategic spot on the map, because it is logistically well-connected through streets and the Bukoba airport. The idea is to install many solar panels, to exploit the River that flows in the area, and also the wind is sufficiently fast to contribute to the goal.

Rwanda

Since 2004, Ruanda has relied only on hydroelectric power, a sector with many inefficiencies and a lot of waste: for example 30% of the energy produced was wasted because of the shortage of maintenance investments during the last 30 years. From 2004 to 2006 a serious drought abated on the country drying out the water reserves. In order to solve this problem the government has decided to invest in diesel generators: a very expensive resource. Up dated to April 2012, 14% of the population has access to electricity and the government launched a rollout program to reach 60% within 2020. Solar power can benefit from a high radiation rate (4-6 KWh/m^{2}day), but there are obstacles to be overcome for the diffusion of this source, in particular the high initial costs. Many families who own cows (about 120.000 families) can count on biogas to heat their farms. The development possibilities are high. Geothermal energy is also relevant: there is an ambitious project to reach 150 MW from geothermal energy within 2017. Moreover, there is the possibility to exploit wind power in applications like wind farms or to pump water. For our scopes the best solution has been found in a **solar plant** located in the Agahozo Shalom Youth Village, in the Rwamagna district. This plant became operative a few months ago and it is the perfect solution to be connected to the other spots through a medium voltage connection.

In the map below we can see the “triangle” where this mini-grid is supposed to be built (figure 10). The use of middle-tension is preferable for reasons concerning isolation issues. Air has an electric rigidity of 30.000 V/cm, overpassed this level, an electric discharge is triggered off and can permanently damage conductors and insulating materials. Moreover, when cables and connections would be as long as in our case study, when the boundary is surpassed, other effects such as conductors-air discharges and corona discharges could occur, provoking the dissipation of energy and turning cables into luminescent connections.

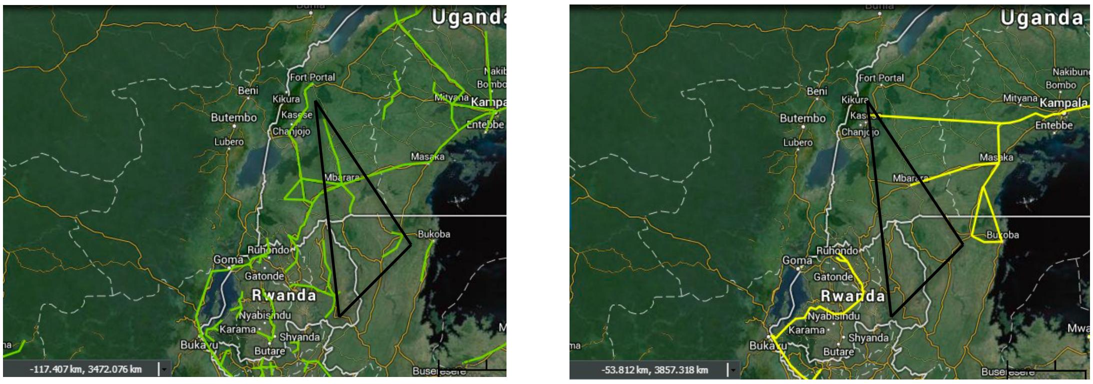


Figure 10: Overlapping of the mini-grid area and the existing medium voltage network

This is an example of how to use the current opportunities already present in the territory to supply energy in the long-term period. To conclude this paragraph we would like to define the main characteristics of the **"Power Africa" project**, which has been mentioned a few times in this paper work. On 30th June 2013, president Obama, during his visit in Senegal, South Africa and Tanzania, launched a project to increase the electricity productivity in the sub-Saharan Africa. The capital involved is around 7 billion of USD to be invested in 5 years for projects that involve: development of resources, production and distribution of energy. The main goal of the project is to add 10.000 MW of electricity production capacity in the first years, exploiting natural and clean resources (especially geothermal, hydroelectric, wind and solar power). The major US government agencies are in charge of managing the resources displayed for the project. USAD, OPIC, US Ex-Im Bank, MCC, USTDA, USADF are the main agencies managing the project in the partner countries: Ethiopia, Ghana, Kenya, Liberia, Nigeria, Tanzania, and Uganda. Moreover, private investors have guaranteed about 9 billion USD. To conclude, we would like to report a few examples of what has been possible, up to now, thanks to this project to understand the importance related to this thesis paper and for the future considerations that we will make. In Kenya and Tanzania wind power farms have been realized thanks to Aldwych International with a power of 400 MW. Still in Kenya there is another investment of 70 billion USD to build more wind plants sponsored by Harith General Partners. A third example can be considered the project to install 200 mini-plants in Tanzania, which would exploit biomass power (sponsored by Husk Power Systems). This project represents a great opportunity for all players of the RE field, including sponsors, investors, suppliers and lending institutions to participate at the electricity production growth of an entire area (the sub-Saharan area), guaranteeing a long term energy sustainability to an entire continent and of course, earning remarkable profits.

2.3 - Focus on smart grid opportunities and development

As has been previously stated, investing in developing countries could be a great opportunity to invest in new technologies. The opportunity offered by the smart grid technologies should be exploited. Especially concerning the developing countries and in particular Africa, the country the project "Power Africa" is focusing on, this innovative opportunity which has not yet been developed all over the world should be evaluated. Many storage systems, which will later be examined more carefully, are still in an embryonic stage of development for economic, technological and regulatory issues. In this chapter we will attempt to underline the most common and affordable technologies in order to build a storage system, giving a brief overview of the storage technologies that nowadays are present in the market. Moreover, the players involved in this smart grid chain will be examined and how they should behave and in which technology they should invest to gain profit and advantages from these systems. Finally, the possible scenarios that each actor of the grid could face will be examine and will be presented an economic analysis that will lead to a framework of which storage system is actually affordable and available for the developing markets and in particular considering the African market.

Much of the information here reported has been extrapolated form the "Smart Grid Report: Sistemi di storage ed auto elettrica", July 2013 sponsored by Politecnico di Milano.

Focusing on storage systems a first important distinction must be made as later it will be useful to describe the different scenarios into which each storage technology could lead. A storage system can provide two different performances:

- Power performance: in which a high exchange of power in a little time occurs. This performance provides really quick and prompt responses.

- Energy performance: in which the power exchange is almost constant and flat and usually has a few hours of autonomy.

Once these two kinds of behavior have been defined it is necessary to examine what a smart grid system and in particular a storage system are based on and what its fundamental composing unit does. Storage systems can be used for many applications, but one of the most significant for our scope is, without doubt, the time-shift. This means the possibility to postpone energy during time, from the moment in which energy is collected to the period in which there is a release of the energy previously collected. An example of the use that could be made of this time-shift application is the price arbitrage. We could store energy in the low-price hours and then deliver, sell or use it in the high-price hours. Focusing on developing markets this mechanism could be useful to improve the produced energy management. We could increase the plant auto produced energy storing the extra produced energy and using it during the hours in which the load is high. Another advantage deriving from this application would be contractual power reduction and the increase of the flexibility of the load curve. It would be possible to increase the low request of energy during the night hours and thus level the consumption through this storage systems (peak shaving). This application would be useful in developing markets in which we are actually not sure how the consumption curve will take shape after the investments of the companies in RE technologies. Throughout this mechanism we could store energy while analyzing the consumer behavior and release energy when it is needed. Another important application would be the leveling of investments to increase the network rate. Storage systems have to support the transmission network to maximize the exploitation, avoiding the unlucky possibility to urgently construct new connections that would be used only in cases of simultaneous peaks. Investment policies and insurances are a big deal concerning RE, as will be shown in next chapter. The blackout management throughout storage systems in developing countries and congestion resolution in programing phase of the plant would be really useful to these issues. As a matter of fact, the transmission network manager in order to restart the electric system after a blackout can use large storage systems. These technologies can start autonomously, without the electric network alimentation; moreover, they have a really short response time and the possibility to regulate tension and frequency.

Sometimes it happens that the cumulated updated programs of intake and overdraft used by the network owner, allow congestion during the programming phase of a plant. Storage systems could be a helpful tool for the network owner as they accept modifications, increasing or decreasing, compared to the cumulated updated programs. Now let’s introduce the most important technologies for our scopes. Storage technologies could be classified into three classes: Electrochemical, mechanic, Electric.

Electrochemical

This storage system allows the conversion of chemical energy into electric one. It is usually made up of two semi-cells divided by a porous septum. Each cell contains a metallic electrode, immerged in an electrolytic solution, which usually contains ions of the same metal. The principle, which governs these technologies, is the oxidation-reaction and the electrolysis reaction. Electrochemical technologies are the most common ones, and many typologies exist, all differing from the electrodes material and the electrolytic solution. For each category we are examining the most important technologies for our scopes, and then we will discuss why these technologies are likely to be the most useful. We will see how the transversal degree will result fundamental to understand which technologies would be easier to develop in Africa.

<u>Lead/ cadmium</u> storage system: the VLA (vented lead acid) allows gases to be emitted during reactions in the charging phase. Nevertheless they need ad hoc structures to sustain them being so bulky and more important, they need a frequent maintenance to reinsert the water in the electrolyte. The other category is VRLA (valve regulated lead acid) where a combination between hydrogen and oxygen is provided inside the cells and so there is a automatic regeneration of water, moreover they are less bulky and need less effort in maintenance. For theses reasons we are suggesting to prefer this second category which should be constructed following two different technologies: gel which allows a higher number of charge and discharge cycles and AGM (absorbed glass mat) which presents the same advantages as the gel ones, but can support higher tensions and charging currents.
This battery does not offer a great "energy performance" compared to other electrochemical technologies. Looking at present projects, the power established can be about 3,5 MW (2MWh), the price is lower than other technologies (1550 £/ KWh) due to the availability of raw materials.

<u>Nickel / Cadmium</u> storage systems: are particularly useful as they have a good transversal degree to be used for both power and energy performances. As for lead/acid technology, this presents a low discharge rate, but the high specific power - specific energy ratio gives the possibility to also use power performances. Nowadays just one big plant is installed worldwide supplying 27 MW (6,75 MWh). There are not new projects in construction, and

probably world attention concerning cadmium, has slowed the development of this technology.

Zebra (zero emission battery research activity): the main elements compounding this battery are sodium and nickel chloride. There's a slight difference between specific energy and specific power, so this battery can be considered "transversal", although it is preferable to use it as an energy performance. Concerning the energy storage, worldwide the only plant is in Italy, constituted by 10 modules of 23 KWh each. New projects are developing in USA.

Lithium/ion storage system: present many variants, but usually the anode is composed of graphite at the lithium state, the cathode is lithium oxide of a transition metal and finally the electrolyte is composed of lithium salt solved in a mixture of organic solvents. This explains why there are so many variants possible, the important point is to manage the trade-off between the level of security and the technology maturity. The principal feature of these batteries is the high specific power, consistently higher than for other electrochemical storage systems. For this reason these batteries are preferable for a power performance. Nevertheless, the consistent specific energy and the flexibility of the charge rate, give this technology a transversal characteristic, also permitting an energy performance. Nowadays the power established is about 120 MW, but new projects are coming up in USA.

Nickel / metal hydrate: the only difference compared to the nickel/cadmium battery is the negative electrode, which here is composed of inter-metallic composts. Raw materials necessary for this instrument are more expensive, however, it is preferable for the environmental impact to avoid cadmium. Like the nickel/cadmium battery, this technology suffers from the "memory effect" and therefore important research and development (R&D) centers are making a big effort to study these batteries. Like the others described previously, we can say this is a transversal technology, suitable for both power and energy performance. At present there are no effective plants that exploit this system, but this does not mean that this technology cannot be used in our future target market that is Africa.

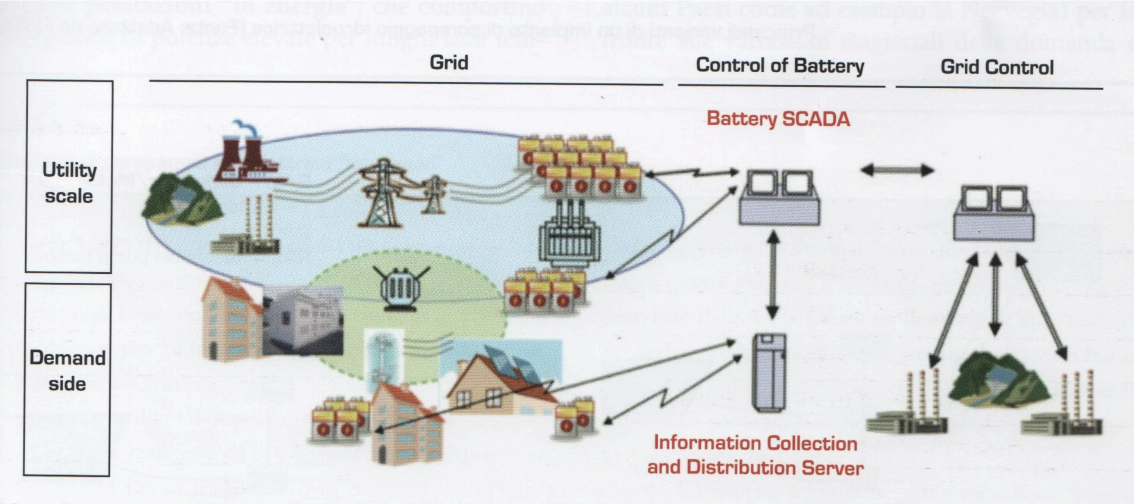


Figure 11: Project "Battery SCADA" scheme, Hitachi source

Mechanic

Mechanic storage system opportunities refer mostly to three different technologies: the storage as potential energy of a large mass of water (hydroelectric pumping), the storage of compressed air (CAES) and the storage of kinetic energy. As we did for the previous category, we are explaining the principal features that can make these systems suitable for our purposes, that is to say to supply new and green energy in Africa and in general to developing countries.

Hydroelectric pumping: the basic need to build a plant, which exploits this technology, is to have two masses of water at a different height. When it is necessary to produce and draw out energy from the network, water from the inferior pond is pumped to the superior pond, using an electric machine as a motor. Vice versa when it is necessary to give back the energy stored to the network, the fall of water from the superior to the inferior pond can be exploited. This mechanism activates a turbine, which allows, throughout an alternator, the production of electric energy. There are two different variants (figure 12) concerning this storage system: "traditional plants" and RTP (reversible pump turbine).

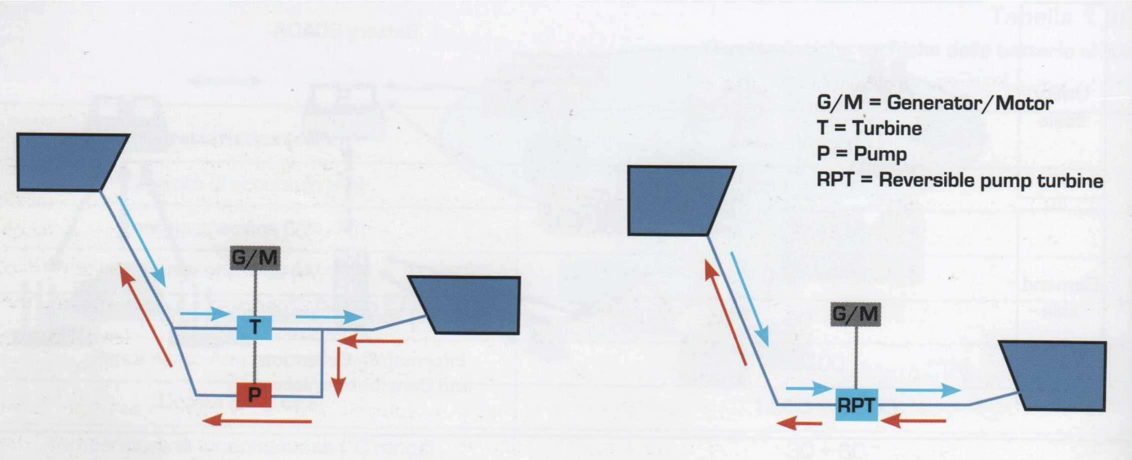


Figure 12: Principal variants of a hydroelectric pumping plant, EERA source

In the first configuration (figure 12) pumps and turbines are placed in a parallel configuration, while in the second possibility there is only one conduct used by the fluid in both senses. The main advantage of this kind of plant is the lifetime. Effectively, hydroelectric plants have a lifetime usually superior to 50 years, also involving a high efficiency of the cycle (up to 85%) and prompt lead-time. The discharging time is an important issue to evaluate when projecting the plant, dimensions of the ponds must be considered because large ponds could also take few days to discharge. The most important issue concerning these systems is, without doubt, the initial cost of the investment. Historical costs for these systems can be estimated from 350 to 1500 €/KW. These plants are suitable for energy performance and can especially exploit the possibility of "time-shift" explained at the beginning of the chapter, but the short lead-time permits also power applications. Hydroelectric pumping is the most ancient and spread storage facility. The first examples of this system appeared at the beginning of thirties, for these reasons the opportunity to deploy ancient and proved technologies together with new opportunities coming up in a developing country must be considered. The right mixture of both would be perfect to develop the energy economy in Africa. Something has already been done as a plant is under construction in South Africa with a power of about 1300 MW (21000 MWh). This plant is sponsored by Escom, a south African utility with an investment of 2,75 mld $. Of course we can compare South Africa with the rest of the countries in this continent, but somehow something is moving, which is for sure a first step.

CAES: the fundamental principle of this technology involves the opportunity to exploit the excess of energy produced to compress air and store it in a reservoir (natural or artificial). When energy is needed the compressed air is released into a gas turbine, which produces electric energy. As a matter of fact this is one of the best solutions to store high quantity of electric energy, but facing an important initial investment. As hydroelectric plants, CAES allows the release of energy for many hours, so they are preferable for an energy performance. The initial high cost is closely related to the morphologic and geologic characteristics at the site and of the size of the plant, however in our target area it should be a good deal. Differently to hydroelectric pumping, nowadays only two plants have been constructed, one is in USA (Alabama), and therefore there is a great opportunity to replicate it in Africa, as it is something they have already done in their country.

FES: it is an acronym for flywheel energy storage. It is a complicated system that enables the storage of electric energy in the form of kinetic, through the rotation of a rotor which during the charging phase is accelerated and then decelerated when energy is requested. This technology presents many advantages that could be exploited in our situation. Firstly, it offers a high efficiency during all the lifetime of the plant (up to 90%) and moreover we have to consider that the lifetime is really long as a plant can reach up to 1.000.000 cycles. Furthermore, it offers a high energy density and definitely fast recharging lead times (less than 15 minutes). The consistent disadvantage is the high cost of this structure, the technology is not mature yet and costs are related to the size of the plant. These systems are developed only in USA where three plants are already active and another five projects are being developed. It cannot be excluded that companies in charge of supplying energy in Africa will decide to adopt this technology.

Electric

Electric storage systems involve two principal technologies: EDLC (electric double layer capacitor) and SMES (superconducting magnetic energy storage).

EDLC: also known as ultracapacitor. They are more similar to a battery than to a regular capacitor, therefore they can be classified as halfway between a classic capacitor and a battery not just for what concerns the technical construction issues but also for what concerns the performances. The outstanding advantages are the high power density, the length of the lifetime and the almost unnecessary presence of maintenance (an aspect that will be better underlined in chapter 4). Despite these pros, there are not many examples of plants using this system to store energy apart from one project in USA.

SMES: are modern systems that can store energy in the form of magnetic field. This enables a great possibility to accumulate a high quantity of energy, instantly available and discharging. The principal features of this technology are a low level of specific energy, high rapidity to release energy and an impressive specific power, which can reach more than 100 MW/Kg. Moreover, they are characterized by a long lifetime, even more than 20 years. An important issue is the power quality, for this reason these applications should be more suitable for areas in which this aspect is not really relevant, that is to say the industrial countries. For this reason and considering that none of them have been developed yet as a storage system, it seems difficult to exploit this opportunity in our target market.

A brief description of all the main technologies that can be included in a storage system and therefore used to develop a smart grid has been made. Now it is important to focus on the economic aspects of the smart grid system and on the principal actors involved in the chain of energy distribution. At this point it should be clear which technology should be better used for energy or for power performances, in particular there are three technologies, which are better used only for power purposes. As has been previously anticipated, the transversal degree is fundamental to evaluate our options correctly, that is to say that it is important to distinguish which technologies are able to guarantee different and multiple functions and which are specific for a few applications. Moreover, other considerations that should be made involve the maturity degree of the technologies, in particular it could be useful to classify into mature, embryonic and developing technologies. Mature technologies refer to solutions available on the market, embryonic point out solutions which are living a research phase and developing technologies refer to solutions that are being studied on site, involving pilot small scale projects and are now being compared at a commercial level. The table below (figure 13) clarifies the portfolio of systems and degree of development of the technology.

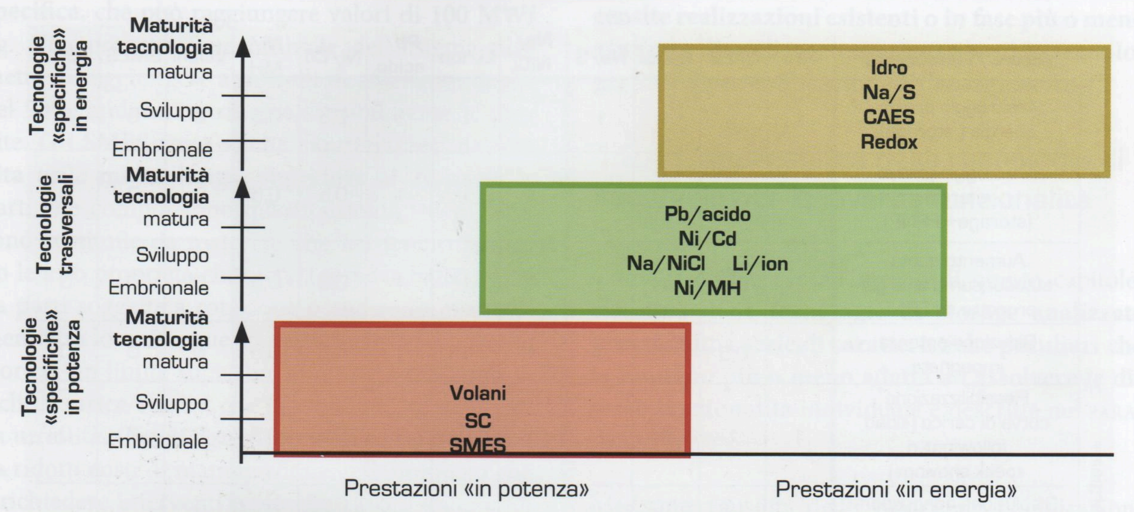
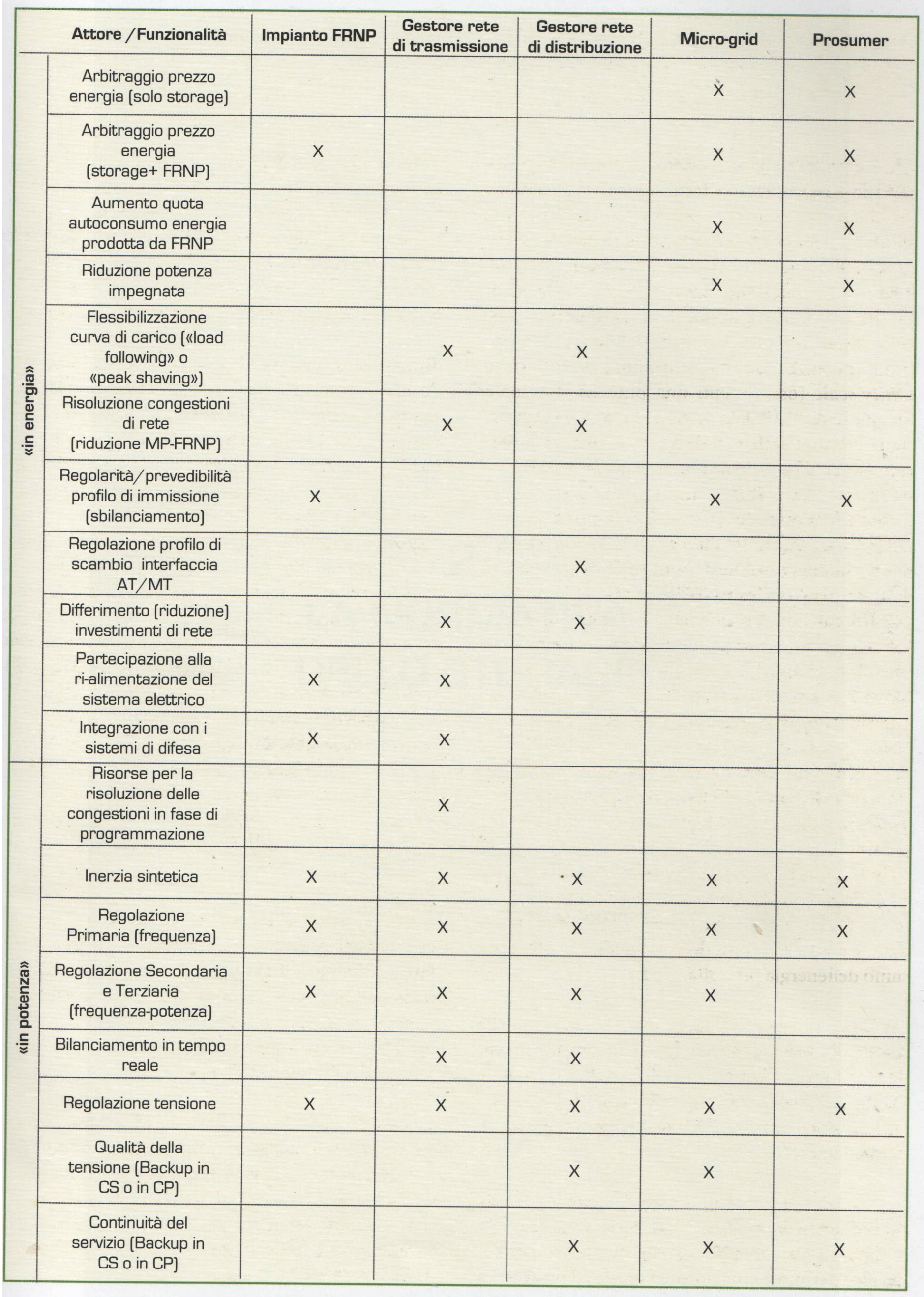


Figure 13: Storage technologies: a synoptic framework, ES - Politecnico di Milano source

In a few words, transversal and mature applications are principally the Pb/acid and the Nickel/cadmium batteries, which would gradually be substituted by new opportunities such as the ZEBRA battery. Let's focus now on the principal players which are involved in this process of energy distribution and in particular interested in a storage system. We can define five categories of players who can gain profit from a storage system: NPS (non programmable sources) plants, the transmission system operator (TSO), the distribution system operator (DSO), micro grid and professional consumers. A traditional production system, such as oil, carbon or natural gas plants, should also be included as it can also exploit the advantages of storage systems. In particular, traditional plants could partially decouple the plant from the network needs, reducing the device stress and, on the other hand, enabling a higher utilization index of the plants themselves. It is easy to understand that storage systems represent transversal technological solutions for all the players involved in the process. Concerning the NPS we are focusing on solar and wind farm of industrial size with a nominal power of more than 20 KW and utility scale with a nominal power of 1 MW. TSO and DSO refer to subjects who are responsible for the distribution service. Micro grids are connected to an important requirement of energy and refer to industrial realities, hospitals and commercial realities, alimented by NPS. Finally, with the term prosumer we will identify local producers or consumers of energy with a nominal power installed lower than 20 KW. A small number of technologies can be identified as transversal ones which is to say that a few technologies affect the whole players of the electric system. On the other hand, a large number of specific applications exist, which are attractive just for a small number of users. Reading the table below (figure 14), we can notice how some players have something in common, and therefore, we can create classes of players. In particular, micro grid and prosumers require almost the same kind of needs and functions for most issues, but not for those linked to the bigger size and the critical charges in the micro grid. A similar reasoning can be made about TSO and DSO, which differ only in the different role the operators cover in the electric system.



	Attore / Funzionalità	Impianto FRNP	Gestore rete di trasmissione	Gestore rete di distribuzione	Micro-grid	Prosumer
«in energia»	Arbitraggio prezzo energia (solo storage)				X	X
	Arbitraggio prezzo energia (storage+ FRNP)	X			X	X
	Aumento quota autoconsumo energia prodotta da FRNP				X	X
	Riduzione potenza impegnata				X	X
	Flessibilizzazione curva di carico («load following» o «peak shaving»)		X	X		
	Risoluzione congestioni di rete (riduzione MP-FRNP)		X	X		
	Regolarità/prevedibilità profilo di immissione (sbilanciamento)	X			X	X
	Regolazione profilo di scambio interfaccia AT/MT			X		
	Differimento (riduzione) investimenti di rete		X	X		
	Partecipazione alla ri-alimentazione del sistema elettrico	X	X			
	Integrazione con i sistemi di difesa	X	X			
«in potenza»	Risorse per la risoluzione delle congestioni in fase di programmazione		X			
	Inerzia sintetica	X	X	X	X	X
	Regolazione Primaria (frequenza)	X	X	X	X	X
	Regolazione Secondaria e Terziaria (frequenza-potenza)	X	X	X	X	
	Bilanciamento in tempo reale		X	X		
	Regolazione tensione	X	X	X	X	X
	Qualità della tensione (Backup in CS o in CP)			X	X	
	Continuità del servizio (Backup in CS o in CP)			X	X	X

Figure 14: Matching between players involved in the use of a storage system and functionalities, ES - Politecnico di Milano source

CHAPTER 3 - Financing: general principles

After having analyzed the main technologies and applications for RE and after having given an overview on the smart grid opportunities, in this following chapter the financial issues will be introduced.

Actually this is the most relevant issue to take into consideration, because all risks and barriers to improve the situation in Africa – and developing countries in general- principally affect the financing problem. The issue related to the creditworthiness of the projects. The technology issue, as mentioned before, includes developed and less developed solutions, but the real point to take into consideration is how to finance these huge projects, which is giving and investing money, which would be gained back, how risks and barriers could be hedged and through which kind of insurance systems. These are the important questions that will be answered in chapter number 3. In addition, another important issue will be introduced and it is being discussed in these hours. It is the influence of maintenance and management costs on the total costs of a plant. The idea to manage and to display a financing plan for the maintenance since the early stages of a project is a living matter, which is frequently being discussed these days. This will be the core part of my thesis that will be better dealt with in the next chapter, but here some preliminary results will be shown in order to give an idea of the impacts of maintenance and management on the total costs of a plant.

3.1 - The renewable energies financing problems and risks

In this paragraph the most common risks and barriers perceived from the experts of the sector, and which can obstruct the financing of a RE project will be dealt with.

On April 2012 there was an important roundtable in Stanford, California gathering 38 participants, leaders in renewable energy financing. The goal of the discussion was to generate insights on possible innovative financing options that could expand lower-cost financing for RE electricity generation in the United States and spark international conversation on RE financing projects. It came out that the main issues and problems can be classified into 3 categories: sources of capital, investor considerations and data and standards.

The information here reported has been extrapolated from the "Mobilizing Public Markets to Finance Renewable Energy Projects: Insights from Expert Stakeholders" sponsored by NREL, June 2012.

Sources of capital:

- ***For RE investments, there are limited opportunities to raise capital from a public financial market source***

Roundtable participants strongly agreed that renewable energy project sponsors generally rely on private and commercial sources of financing. This is true even for historically proven renewable energy technologies such as utility-scale wind or crystalline silicon solar photovoltaic systems. Consequently, the cost of this type of capital is comparatively high in relation to a public source of capital, because supply is constrained and concentrated among a selected number of financing providers.

- ***Retail investors have limited opportunities to invest in RE projects.***

Renewable energy investment opportunities for an individual investor are largely confined to investments in publicly traded companies. Opening alternative financial mechanisms such as master limited partnerships (MLPs) or real estate investment trusts (REITs) could enable investment through more liquid and transparent investment vehicles. However, MLP application would likely require legislative changes. REIT application may be possible through a clarification from the Internal Revenue Service.

- ***Tax equity investment for RE, while economically valuable, is limited in supply, creates uncertainty, and can be expensive to structure.***

Although the relative benefits and challenges of tax equity investment are well documented elsewhere, participants repeatedly discussed the difficulties of financing renewable energy when supported by tax-driven mechanisms. Limitations in the transferability of tax incentives were identified as a major barrier to investment in renewable energy from a broader, more diverse pool of investors.

- ***Participants suggested that foreign and domestic commercial banks, a primary source of financing for renewables in the United States, are highly capital constrained at present and may have limited appetites for long-term investments.***

Furthermore, stricter financial regulations (such as Dodd-Frank, Basel III, and Solvency II) could impede capital flowing to renewable projects that have investment periods of 20 or 25 years. Participants also suggested that the new regulations could limit long-term lending by European banks and provide an incentive for banks to move long-dated renewable energy assets off their books.

- ***Utility investment represents a relatively untapped source of capital and could be assessed further.***

Utilities are a significant source of low-cost capital and are creditworthy off-takers of power. To date, accounting regulations surrounding utilization of the investment tax credit (ITC) and accelerated depreciation have reduced the economic value of these incentives to utility-owned systems. However, the planned 2017 reduction of the ITC from 30% to 10% could prevent some of that competitive disadvantage. Participants suggested utility ownership and financing of renewable energy systems should be included in future assessments.

Investor considerations

- ***Financing strategies for distributed versus utility-scale developments are vastly different and will likely require distinct solutions.***

Because distributed systems are more common and easily bundled by installers, the roundtable participants considered them to be more easily pooled and securitized. Utility-scale systems would likely be more difficult to securitize, although standardized contracts, interconnection processes, and other relevant documentation could mitigate utility and financier due to diligence requirements.

- ***Although reportedly interested, most U.S. institutional investors have historically avoided significant renewable energy investment.***

The current mechanisms for investing in renewable energy development do not closely resemble traditional investments by large institutional investors (e.g., pension funds, select insurance companies, family offices, private wealth funds, and unions). Many participants reported that institutional investors are increasingly indicating their desire to invest in long-dated, climate-related investments but have been slow to invest in projects outside of their traditional risk and return comfort zone.

- ***Institutional Investors' minimum investment requirement eliminates all but the largest renewable energy projects from consideration***.

Project capital is highly fragmented between sponsor equity, tax equity, and debt, which may reduce the institutional investor's contribution. Alternatively, bundling several mid-sized renewable energy projects, or aggregating a large volume of small projects, may offer some institutional investment opportunities. In the absence of greater levels of standardization, however, such bundling would significantly increase the complexity and transaction costs of the arrangement.

- ***Investors may be wary of potential insolvencies among manufacturers of renewable energy generation technology due to intense international competition.***

Low market capitalization, poor debt-equity ratios, fierce competition, and uncertain policy outlooks put many manufacturers of renewable energy generation equipment under severe financial stress. Doubts as to manufacturers' continued existence affect investor faith in their technical support and the real value of their product warranties.

- ***The risk and return profile of a renewable energy project investment may not conform well to traditional energy investment classification.***

Renewable energy projects are capital intensive but have low operating costs and zero fuel costs. This investment profile was suggested to more closely resembled financial assets such as a fixed-income investment (e.g., a bond), an infrastructure investment (e.g., a toll road), or a real estate investment. Education about the risk and return profile of renewable energy projects may allow institutional investors to consider these opportunities more broadly.

Data and standards

- ***The lack of historical, publicly available data addressing renewable energy risks is one of the greatest challenges in engaging untapped capital.***

In particular, there is an immediate need for publicly available performance data for all renewable energy technologies both within and outside the equipment warranty periods. Additionally, historical data on default rates by the energy purchaser was noted as critical to assess creditor risks and develop solutions through financial innovation.

- ***There is little information available on the valuation of renewable energy generation assets after their eligibility for tax incentives ends.***

Most renewable energy plants are assumed to have a useful life of 20 years or more, often backed by manufacturer guarantees. This time span is significantly longer than a project's eligibility for tax benefits (e.g., tax credits and accelerated depreciation). The expiration of tax incentives increases the transferability of assets and could open the market to new types of investors, assuming the availability of reliable information and criteria for asset valuation.

- ***For renewables, there is no homogeneity among financial transactions, which greatly increases structuring costs and the due diligence requirements for each investment.***

Moreover, there is no standardization for contractual design and wording. In the absence of a standardization mandate - for example, by state public utility commissions (PUCs) - electric utilities tend to use their own power purchase agreements (PPAs), which differ widely in their terms.

• ***The credit rating agencies have a large role to play in the development of new financing opportunities for renewables.***

A "turn-key" process for acquiring an asset rating could help the development of institutional investors. It was suggested that institutional investors do not have the time for the extensive due diligence that the rating agencies can provide.

These insights have been extrapolated from the **NREL** (National Renewable Energy Laboratory) report published In June 2012. We have seen which the main concerns of the experts of the sector are, but beyond these concerns we should consider that there are also other barriers that affect the whole financing process. We can point out several kinds of barriers:

- **Cognitive barriers:** referring to the low level of awareness, understanding and attention afforded to RE financing.

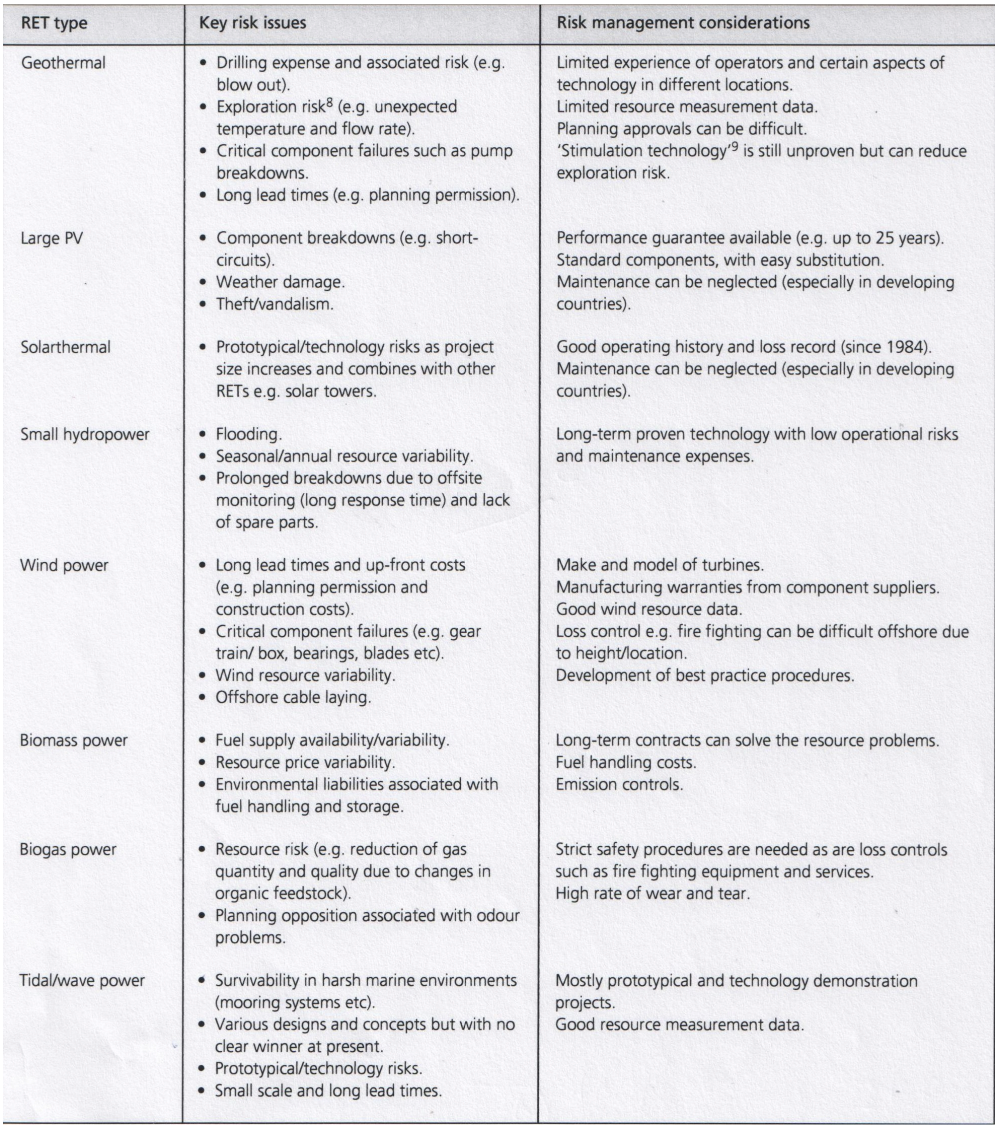
- **Political barriers**, which are related to the regulatory and policy issues and governmental leadership. For example in our target market the political barriers perceived are relevant.

- **Analytical barriers:** there is a shortage of quality and availability of information necessary for prudent underwriting. The necessity to develop quantitative and analytical methodologies for risk management is a priority to develop the whole underwriter markets and to create useful pricing models for environmental markets.

- **Market barriers:** there is a lack of financial, legal and institutional frameworks to support the uptake of RE projects in different jurisdictions.

As can be inferred, these barriers are likely to be more present in less developed countries, where financial, legal and institutional frameworks necessary for stable financial markets are not present.

To conclude this paragraph it is important to remember some of the most common risks that can affect, in a different way, the technologies established. This paragraph will focus on financial perceived risks, but when evaluating a project, underwriters also always consider the risks related to the technologies themselves. In chapter 2.1, when different technologies were listed, the main barriers that had to be faced adopting each technology were also defined. This is a brief summary (figure 15) of all the risks that we should consider, when investing in a RE technology, and which must be taken into consideration during the investing decision process.



RET type	Key risk issues	Risk management considerations
Geothermal	• Drilling expense and associated risk (e.g. blow out). • Exploration risk[8] (e.g. unexpected temperature and flow rate). • Critical component failures such as pump breakdowns. • Long lead times (e.g. planning permission).	Limited experience of operators and certain aspects of technology in different locations. Limited resource measurement data. Planning approvals can be difficult. 'Stimulation technology'[9] is still unproven but can reduce exploration risk.
Large PV	• Component breakdowns (e.g. short-circuits). • Weather damage. • Theft/vandalism.	Performance guarantee available (e.g. up to 25 years). Standard components, with easy substitution. Maintenance can be neglected (especially in developing countries).
Solarthermal	• Prototypical/technology risks as project size increases and combines with other RETs e.g. solar towers.	Good operating history and loss record (since 1984). Maintenance can be neglected (especially in developing countries).
Small hydropower	• Flooding. • Seasonal/annual resource variability. • Prolonged breakdowns due to offsite monitoring (long response time) and lack of spare parts.	Long-term proven technology with low operational risks and maintenance expenses.
Wind power	• Long lead times and up-front costs (e.g. planning permission and construction costs). • Critical component failures (e.g. gear train/ box, bearings, blades etc). • Wind resource variability. • Offshore cable laying.	Make and model of turbines. Manufacturing warranties from component suppliers. Good wind resource data. Loss control e.g. fire fighting can be difficult offshore due to height/location. Development of best practice procedures.
Biomass power	• Fuel supply availability/variability. • Resource price variability. • Environmental liabilities associated with fuel handling and storage.	Long-term contracts can solve the resource problems. Fuel handling costs. Emission controls.
Biogas power	• Resource risk (e.g. reduction of gas quantity and quality due to changes in organic feedstock). • Planning opposition associated with odour problems.	Strict safety procedures are needed as are loss controls such as fire fighting equipment and services. High rate of wear and tear.
Tidal/wave power	• Survivability in harsh marine environments (mooring systems etc). • Various designs and concepts but with no clear winner at present. • Prototypical/technology risks. • Small scale and long lead times.	Mostly prototypical and technology demonstration projects. Good resource measurement data.

Figure 15: Key risks/barriers associated with Renewable Energy projects, UNEP source

- **Technology risk**: it's the risks related to the technology itself.

- **Resources availability risk**: it is the risk to explore and not to find the source expected or not to find it in the right quantity or quality. For instance, when sources involve a drilling process, there is a remarkable risk.

- **Long lead times:** the time to plan, execute and complete the whole project is consistent.

- **Credit risk**

- **Delay in construction and all risks involving construction**

- **Initial costs:** costs in the start-up phase could be relevant.

- **Business interruption & machinery breakdown:** these are risks that are usually covered requiring higher guarantees and certificates to the components manufacturers.

The aim of this paragraph is to overview the most significant risks and barriers, which the operators of the sector have to face when engaging in the decisional process. Risks related to long-term policies, large-scale investments, absence of insurance and coverage risks tools must be considered too. In the following paragraphs a few methodologies and insurance systems used to finance RE projects and then some risk management techniques will be shown. The starting point would be the present instruments available on the market for financing traditional energy resources, from this basis a specific insurance market for RE should be developed. Nowadays insurance for RE is arranged on a case-by-case basis, the need for specific instruments is one of the biggest concerns in order to promote investors to enter this sector.

3.2 - Financing process and tools for Renewable energies: large-scale and small-scale projects

Each individual RE project requires its own specific adequate mixture of funds and conditions to be financially viable. In general RE projects are capital intensive and have a long exposure period to risk. In this paragraph the general process to be followed in order to effectively finance a RE project will be principally displayed. Moreover, the most important instruments that usually have been used to finance RE projects will be briefly listed, highlighting the strong and the weak points of these instruments.

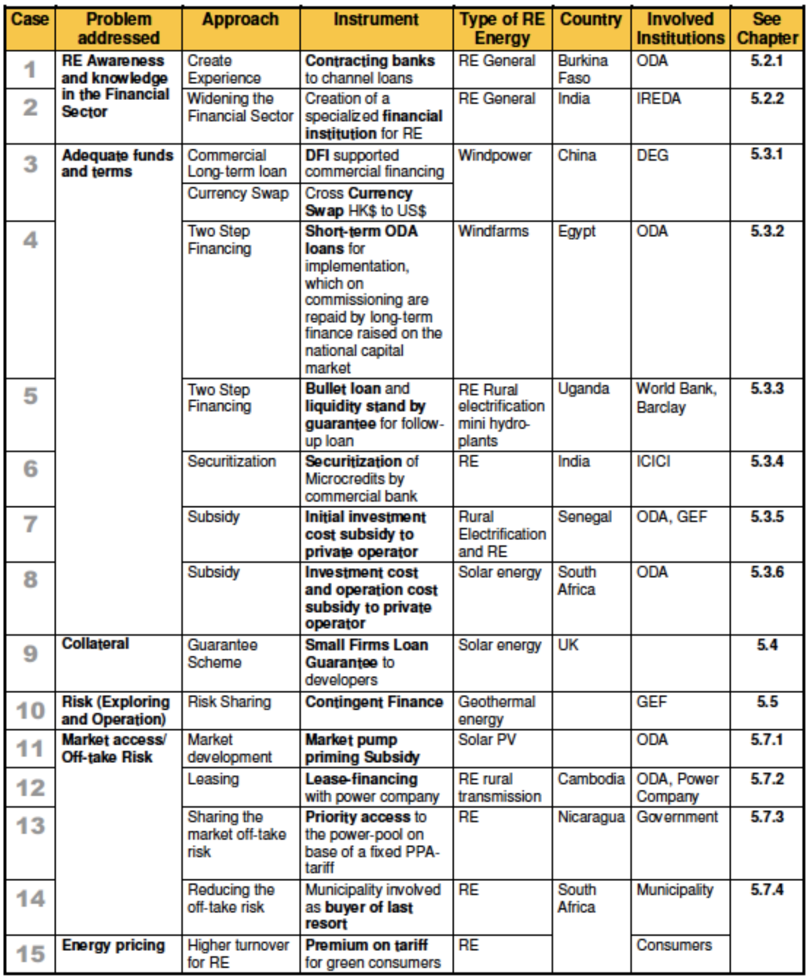
When financing these kinds of projects the first point to bear in mind is the high risk profile which is easy to incur: in paragraph 3.1 there is an expansive list of risks and barriers that investors should remember. This aspect leads to a still limited financial viability and to the need for special efforts in the financial structure. As already stated, the approach should be based on the general knowledge of the financing of traditional sources. From this point, it is important to determine cost reducing conditions together with income increasing measures, so as to create conditions for a financial viability. These 2 objectives should be applied to the whole project, but also to the framework and to the outside support. When a good mixture of financial instruments, which guaranties a good income, reducing cost has been found, it is time to allocate the risk. Risk allocation is a determinant step to achieve success in a project, and when concerning RE projects it is even more important. Risk must be shared among sponsors, contract partners, the (financial) market and the promoting institutions. This process requires a strong effort and usually a long time to be efficiently completed and especially to set clear responsibilities and rights on the project. Risk management methods will be better examined in paragraph 3.3. Once the risk has been allocated, it is time to use all the financial instruments that the financial market have available. Indeed, for viable projects, the financial world has a well-equipped toolbox ready, the point is how to use all these instruments coherently with these RE projects. The correct risk allocation policy enables the attraction of more funds and reduces the cost of financing in the market, thus a project can result creditworthy or, at least, more creditworthy. A relevant point is to pay attention to local markets, as they are often believed to be the solution for any financing problem, but they are limited on the different levels of financial deepening. However, for developing countries local capital markets could offer a good contribution for the financial closure. Promoting institutions have a fundamental role to play in this contest, as they should act as bridges for the financing gap of funds, terms and instruments. They could offer a higher risk-absorptive capacity and they can use their professional financing instruments to complete the market. However, they do not have an endless potential available, thus the approach should be selective and targeted. Finally, the role of donors is a key point for financing RE projects. Many donations have been made during the past years, but the objective of the project (Power Africa), is to establish available energy for the long-term period. Actually, the charity role has always had a spot effect on the energy availability. The goal is to create a new, independent and autonomous market, in which local inhabitants can trust and rely, which will last for the future and which will not have a spot effect. The need is to teach local people and local institutions how to produce and develop an energy system so that they can rely on that for their future.

The role of charity

As stated, the role of charity cannot be intended as the right solution for providing energy to an entire continent such as Africa. However, it can provide a supportive action, to enable a better competitiveness of several projects. Donors should offer their assistance in order to pick the low hanging fruits of projects which are close to market competitiveness. Exclusively in this order of ideas, charity can offer a smart subsidy to the development of the territory. Donors can be useful to create creditworthiness training for the financial institutions or for the sponsor and adopting new models of coverage and risk management. Furthermore, they could offer assistance in the sense of trying to reduce the risk of RE in order to be attractive for the market. This could be done by offering financial guarantees or a subordinated debt.

The main opportunities for donors are to support specialized financial institutions, which are specialized in RE financing or in microfinance. Of course they can also support private firms throughout seed capital or debt finance, that is to say providing the right equipment and financing tools to develop. Donors also have the possibility to create new applications for certain financing instruments, for example the use of revolving funds, credit lines and contingent business loans which can be adapted to the RE world. Finally, the great challenge, which can be addressed to the charity, but not only of course, is the opportunity to reduce the perceived risk of the investments. They can help in this issue through financial guarantees, which can be for instance pool guaranties, maturity guaranties and rolling guaranties. Smart subsidies are needed to act as a connection between the economic and financial viability of a RE project. Thanks to them it could be possible to achieve the least cost option reaching social goals, which should be the actual ultimate goal for a charity organization, and incentivizing the business to serve the target markets.

As pointed out since the beginning of the paragraph, there are endless financial instruments that can be applicable for RE. The point is to successfully define the right financing profile for each project. To give an idea of the possibility to address problems this table (figure 16) where different approaches and instruments are reported, has been included. As can be seen, many approaches have been used in developing countries.



Case	Problem addressed	Approach	Instrument	Type of RE Energy	Country	Involved Institutions	See Chapter
1	**RE Awareness and knowledge in the Financial Sector**	Create Experience	**Contracting banks** to channel loans	RE General	Burkina Faso	ODA	**5.2.1**
2		Widening the Financial Sector	Creation of a specialized **financial institution** for RE	RE General	India	IREDA	**5.2.2**
3	**Adequate funds and terms**	Commercial Long-term loan	**DFI** supported commercial financing	Windpower	China	DEG	**5.3.1**
		Currency Swap	Cross **Currency Swap** HK$ to US$				
4		Two Step Financing	**Short-term ODA loans** for implementation, which on commissioning are repaid by long-term finance raised on the national capital market	Windfarms	Egypt	ODA	**5.3.2**
5		Two Step Financing	**Bullet loan** and **liquidity stand by guarantee** for follow-up loan	RE Rural electrification mini hydro-plants	Uganda	World Bank, Barclay	**5.3.3**
6		Securitization	**Securitization** of Microcredits by commercial bank	RE	India	ICICI	**5.3.4**
7		Subsidy	**Initial investment cost subsidy to private operator**	Rural Electrification and RE	Senegal	ODA, GEF	**5.3.5**
8		Subsidy	**Investment cost and operation cost subsidy to private operator**	Solar energy	South Africa	ODA	**5.3.6**
9	**Collateral**	Guarantee Scheme	**Small Firms Loan Guarantee** to developers	Solar energy	UK		**5.4**
10	**Risk (Exploring and Operation)**	Risk Sharing	**Contingent Finance**	Geothermal energy		GEF	**5.5**
11	**Market access/ Off-take Risk**	Market development	**Market pump priming Subsidy**	Solar PV		ODA	**5.7.1**
12		Leasing	**Lease-financing** with power company	RE rural transmission	Cambodia	ODA, Power Company	**5.7.2**
13		Sharing the market off-take risk	**Priority access** to the power-pool on base of a fixed PPA-tariff	RE	Nicaragua	Government	**5.7.3**
14		Reducing the off-take risk	Municipality involved as **buyer of last resort**	RE	South Africa	Municipality	**5.7.4**
15	**Energy pricing**	Higher turnover for RE	**Premium on tariff** for green consumers	RE		Consumers	

Figure 16: Practice approaches to finance RE projects in LDCs, KFW source

To allow better understanding of the difficulty and the variety of the financial effort required, a few successful examples, which have been adopted in Africa, will be presented, so as to clarify some possible approaches to be pursued.

Wind farms in Egypt

This is a situation of wind farm installations near the Gulf of Suez. In this location the wind resources are among the best in the world. The build-up of wind farm capacity is impressive, but to fully exploit the economic potential of the farm the priority is to remove the capital market barriers and to overcome the energy-pricing problem. As a matter of fact, investors could rely only on bank loans to support their investment, usually with a long maturity (about 8 years) and at about 13% interest rate. Moreover, it should be considered that the equity market is poor and does no other form of financing such as bonds exist in Egypt. This results in a huge financial cost-benefit gap. Usually this project remains private in the sense of being owned by the project developers, but the possibility to make them public has been seen through a public offering of bonds. The bonds could be backed by the revenue stream of the wind farm and sold to the open market on a small-scale and to institutional investors. Furthermore, another financial innovation has been proposed: shares could be no longer publicity listed, but traded through the developer company that manages the wind farm. Individual investors could purchase non-listed shares in a specific wind farm. The figures below exemplify the 2 new proposals that can be applied (figure 17). These two-step finance new ideas can also be exported to other sectors beyond the wind farm world.

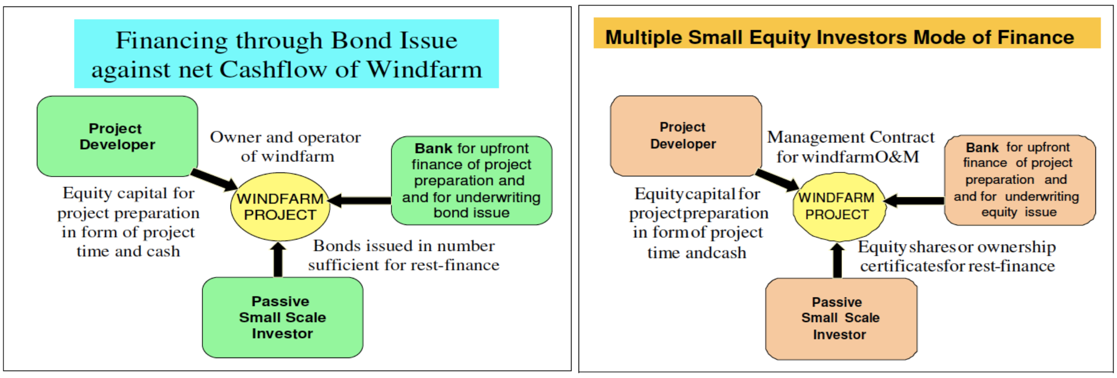


Figure 17: Revenue Bond financing option (on the left) and Multiple Small Equity Investors mode of finance (on the right), KFW source

Electrification in Senegal: the rural area

The idea of this project is to support the development of the electricity network and the access to electricity in the rural parts of Senegal. The sponsor of the projects (IDA and

GEF) offered an initial cost subsidy to private operators that have been chosen through a bidding process. The model is called fee-for-service. Senegal has been divided into many areas that require subsidies and these areas have been given in concession through a bidding process through tenders. Before the bidding process the target level of volume of subsidies financed by the IDA loan (International development association) is established and of course, the winner would be the one who offers to serve the highest number of individuals. Bidders can rely on both the IDA and the GEF grants (Global environment facility). They receive a double incentive as they are encouraged to increase the proportion of renewable in their proposal to get other subsidies from the 2 organizations mentioned. In addition, they would claim for the lowest GEF subsidy since their scope is to maximize the users who served to win using the amount of subsidy (IDA+GEF) allocated for each concession.

South Africa and the green electricity schemes

In South Africa policy makers have developed an interesting mixture of tools for financing wind energy projects. The adoption of green electricity schemes enables the reduction of the takeoff risk intervening on the project financial side as well as on the off-take side. South Africa is the country in the world which has the lowest cost for coal-fired power production, thus it can be easily understood which kind of challenge induces politics to invest in wind power, although the wind sources in this country are remarkable. Firstly, a private company tried to develop a wind farm on the cost, but the project was blocked due to the high production costs. The green electricity schemes came out as a valuable opportunity for the viability of the project. The fundamental innovation of this instrument is the role of municipality, which is now considered the buyer of the last resort, so as to take over the off-take risk. When distribution companies, the ones that resell electricity to "green consumers", cannot recover losses on non-sold electricity, the municipality takes over the market risk purchasing this unsold quantity to supply energy for its municipal institutions (see figure 18).

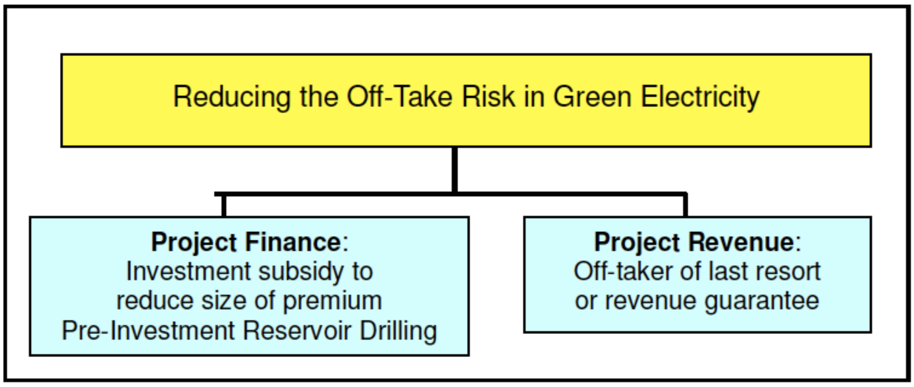


Figure 18: Reducing off-take risk in South Africa, KFW source

This technique has been useful in this context, but its potential replicability is too limited because there are not so many buyers of last resorts. However, it has enabled the feasibility of the project and made it clear that, besides the multitude of financial instruments, investing in RE requires willingness and a strong effort, as long as its price is not competitive.

We have seen a few examples that should clarify the variety and the difficulty in finding out the proper use of the financial instruments available on the market. The differences in financing RE depend more on the size of the project and on the debt solution adopted more than on the type of technology financed. When financing small on-grid projects a corporate finance is usually chosen, whereas for off-grid project consumer and microfinance is preferable. Instead, to finance large RE projects, we need a proper Project finance. Especially in developing countries, the financial supply side results in plenty of constraints to be overcome. Thus, some instruments have a limited impact on financial markets. We can observe a development sequence, according to the document "Financing Renewable energy" (KFW source, 2005), which occurs in many RE projects.

-**Credits**: they are used at the early stages of a project. They can be subjected to many limitations depending on the conditions of the local market, but they are an available instrument for RE.

-**Leasing**: is already being used in emerging financial markets, and can be further developed also for Low developed countries (LDCs).

-**Equity and mezzanine finance:** groups together a variety of structures positioned in the financing package somewhere between the high risk/high upside equity position and the lower risk/fixed returns debt position. This form of financing is becoming popular for advanced emerging countries. In poorer countries the market is not ready yet to offer these funds and tools.

-**Bonds:** the high transactions costs and the aversion of the market are limiting the development of this form of financing. However, as we have seen in the example above (Wind farms in Egypt), there are a few cases in which these tools can be perfectly applied.

To conclude paragraph 3.2, it is important to make a distinction between small and large-scale projects, because the needs of investments and the typology of investments are clearly different.
In this situation, both small and large-scale projects must be considered. Indeed in Africa, the territory is so varied that the possibility to aliment a small plant or the whole energy system must be considered during the plan of investments. In many rural areas there is the possibility to aliment a new local hospital with solar panels or for instance a small wind farm could supply energy for a storage system of a well in a desert. These examples refer to small-scale probable applications. These examples imply a different kind of investment framework and a different kind of implication compared to, for instance, a new plant that is going to be connected to the entire grid of the continent supplying energy and increasing the electricity availability for many people. According to the Clean Energy Group document (December 2011), there are four pursuable and complementary strategies to make **large-scale investments** possible.

- **Economic development policies:** link and coordinate the many stakeholders throughout the clean energy development chain. Moreover, they help to incentivize and build the case for the clean energy technology transition.

- **Financial mechanisms:** make it possible for a diverse range of private investors to get involved in clean energy investments, mainly through public interventions that reduce risks and new institutions and mechanisms that link public and private investments.

- **Innovation strategies:** drive cost reductions and performance improvements in new technologies and crucial enabling technologies.

- **Enabling Energy policies:** support favorable environments to make it possible for investors to rely on stable, long-term policy signals. Moreover, they mandate clean energy investments in infrastructure and new technologies.

High funding levels are needed for large-scale projects. The IPCC SRREN estimated a global entity of investments needed to be 1,360 to 5,1000 billion USD for the decade 2011 to 2020 and from 1,490 to 7,180 billion USD for the decade 2021 to 2030 (according to the Clean Energy Group). There is a general belief that a reduction of technology costs and the improvement of long-term investments in climate is needed. National clean energy infrastructure investment opportunities should be created, so as to enable the flow of capital. If the opportunities are present, private capital will flow to support a scale up in RE infrastructure. Otherwise, capital will obviously go to other investments.

Concerning **small-scale projects** the main problems are related to the critical mass issue. Critical mass refers to the need to reach a certain total quantity of money invested to make the investment profitable. This phenomenon is really common inside companies and it is related to many topics, for instance R&D (research and development) and also publicity commercials, but regarding RE small-scale projects it is the first concern. For that reason many projects are just not considered by commercial financiers. The attempts to group together different small-scale projects have been, to date, unsuccessful, although small installations of the same technology have been made. According to the UNEP (document: Financing Risk Management), typically a small RE project requires equity sponsorship of at least 25% and often 50% of the total value. For example, this issue is really common for solar power applications, which are usually small-scale applications and do not commonly attract the attention of commercial insures. If the size of the applications increases, consequently the commercial appetite for providing cover will improve. The risk perceived by insures is a fundamental issue, and for small applications the risk decreases with the increasing of the size. In the next paragraph we will point out a few risk management instruments to control, prevent and manage the risk for RE projects.

3.3 - Financial risk management instruments

Considering risk management, it is important to make a first fundamental classification between the meaning of managing risk for traditional source plants (such as oil, carbon, natural gas…) and the significant differences that come out when considering RE plants. The risk management issues and risks, which should be taken into consideration, are largely dependent on the area we are considering.

<u>Developed countries</u>

Developed countries can rely on an already well-developed distribution network, efficient and effective all around the territory. The main difference compared to RE risks refers in particular to the incentive policies. In general, the main risks regarding <u>traditional sources</u> of energy are:

- Plant damage risk, machinery and equipment breakdown risks
- Business interruption
- General/third-party liabilities

When considering <u>renewable resources</u> in developed countries, of course these risk categories are still relevant, even if they usually have a stronger impact. For instance it is easily understandable how an electricity production area alimented by solar panels can easily be damaged and subjected to breakdown or damage risks or to the possibility of having part of the functional material (such as the panels themselves) stolen by external agents, compared to a coal production plant, where all the transformation and production processes happen in a limited, safe and controlled area. Compared to RE, which should be exploited in-field, increasing the danger of bad functioning, breakdown and business interruption, traditional sources still present the same points of concern although less accentuated. These are the differences of the magnitude of risk which differs from traditional to renewable energies, but RE also have another important risk source that is important to deal with: incentive policies. This risk source does not show up in traditional energy markets. Incentives are fundamental in developed countries because they are the main point which enables the competition between renewable and traditional sources. Without incentives, RE would be no longer economically efficient and not comparable to the returns that traditional energy guarantee, thus the access to incentives becomes a fundamental risk area to manage properly in order to further develop the RE solutions in developed markets. The incentive delivery entity requires the plant owner to respect some laws and rules in order to actually receive the incentive contribution promised. For example, many incentive policies depend on the energy produced or on the respect of the scheduled time of the plant. If somehow, something goes wrong, this would affect the receiving of the contribution (decreasing and/or cancelling it) and suddenly the plant would be economically inconvenient. In the following pages the example of the Green certificates for the Italian market, considering it as a consistently developed energy network is reported.

Green certificates (GC)

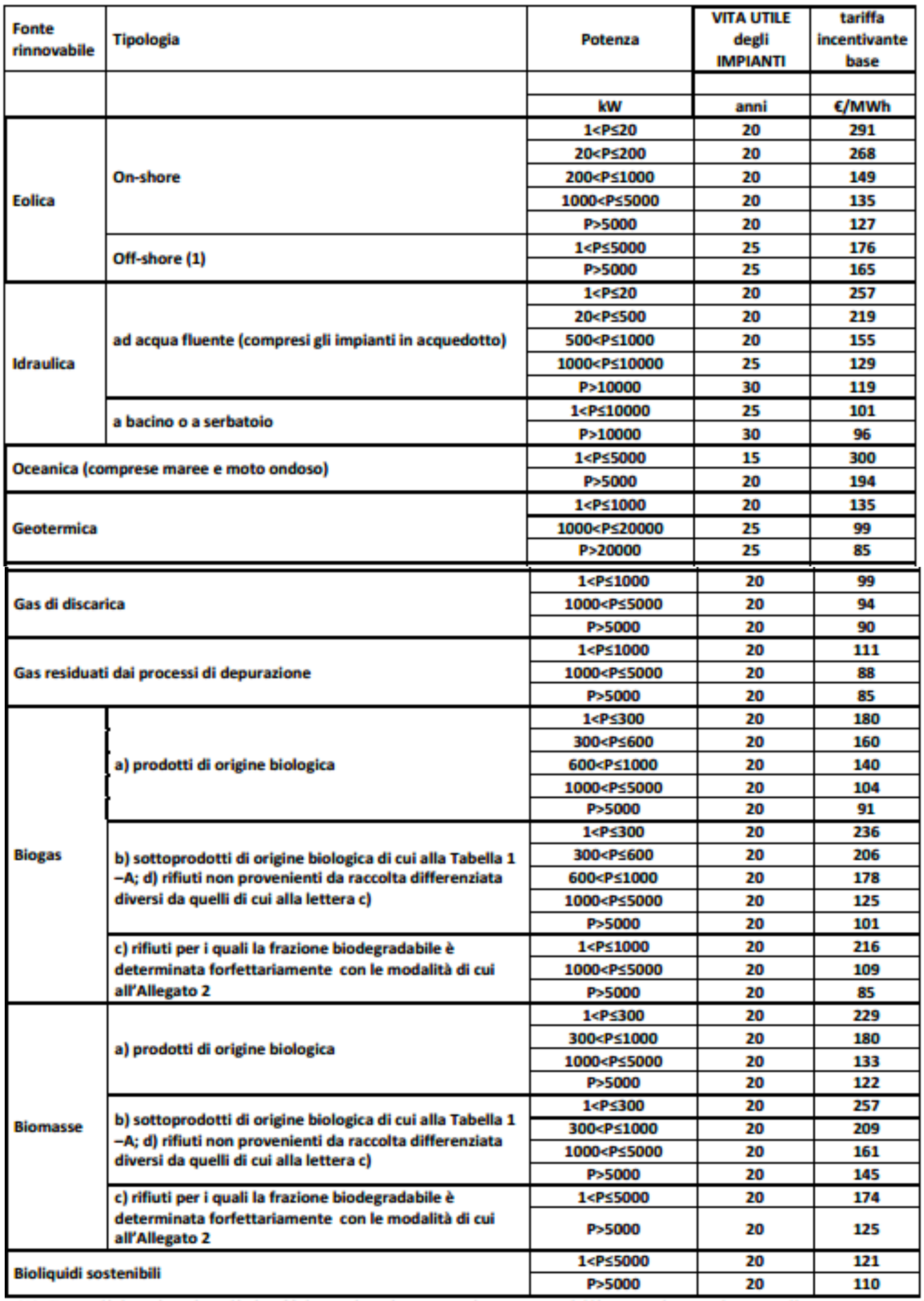
They are incentives, recognized for the production of electric energy from RC (with the exclusion of wind power) for plants with a power capacity above 1 MW.

- Standard value for a GE about 82,12 €/MWh (2012)
- Incentivize duration of 15 years
- The system would become sustainable throughout the creation of a GC market where energy producers must increase their production from renewable sources.

The number of GC recognized for each MWh of electric energy produced, has increased in the last years for some RE affected by high overall costs, for instance where the Raw material purchasing process or the initial investment is a difficult and expensive process.
Plants with a direct incentive scheme can exploit a total comprehensive tariff T_0 to valorize the net energy to network, defined as:
$T_0 = Tb + Pr$
Where:
Tb: basic fixed incentive tariff, specific for size and typology of sources used, decreased by 2% per year starting from 2014.
Pr: total amount of subsidies the plants might have access to.

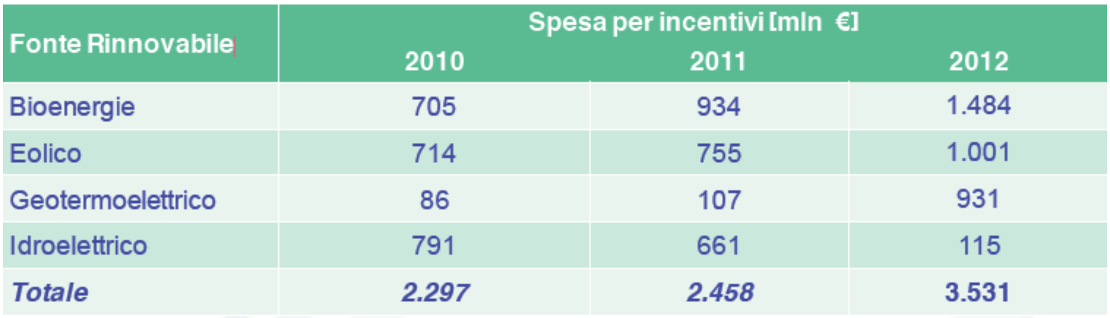
The total installed power following the direct incentive scheme, concur to determine the total amount of installed power subjected to incentives, thus affecting eventual revisions of the total power incentivabile through other schemes.
However, GC refers to certificates to promote the reduction of CO_2 emissions. The example

has been reported because it allows the competition and the right economic returns to develop RE. In the following tables (figure 19 and 20) some data concerning these particular kinds of subsidies have been reported, in order to give an idea of the impact of these instruments and to understand better why they can really make the difference between a profitable or non-profitable project. Wind power projects are not included because GC does not include wind energy support.



Fonte rinnovabile	Tipologia	Potenza	VITA UTILE degli IMPIANTI	tariffa incentivante base
		kW	anni	€/MWh
Eolica	On-shore	$1<P\leq 20$	20	291
		$20<P\leq 200$	20	268
		$200<P\leq 1000$	20	149
		$1000<P\leq 5000$	20	135
		$P>5000$	20	127
	Off-shore (1)	$1<P\leq 5000$	25	176
		$P>5000$	25	165
Idraulica	ad acqua fluente (compresi gli impianti in acquedotto)	$1<P\leq 20$	20	257
		$20<P\leq 500$	20	219
		$500<P\leq 1000$	20	155
		$1000<P\leq 10000$	25	129
		$P>10000$	30	119
	a bacino o a serbatoio	$1<P\leq 10000$	25	101
		$P>10000$	30	96
Oceanica (comprese maree e moto ondoso)		$1<P\leq 5000$	15	300
		$P>5000$	20	194
Geotermica		$1<P\leq 1000$	20	135
		$1000<P\leq 20000$	25	99
		$P>20000$	25	85
Gas di discarica		$1<P\leq 1000$	20	99
		$1000<P\leq 5000$	20	94
		$P>5000$	20	90
Gas residuati dai processi di depurazione		$1<P\leq 1000$	20	111
		$1000<P\leq 5000$	20	88
		$P>5000$	20	85
Biogas	a) prodotti di origine biologica	$1<P\leq 300$	20	180
		$300<P\leq 600$	20	160
		$600<P\leq 1000$	20	140
		$1000<P\leq 5000$	20	104
		$P>5000$	20	91
	b) sottoprodotti di origine biologica di cui alla Tabella 1 –A; d) rifiuti non provenienti da raccolta differenziata diversi da quelli di cui alla lettera c)	$1<P\leq 300$	20	236
		$300<P\leq 600$	20	206
		$600<P\leq 1000$	20	178
		$1000<P\leq 5000$	20	125
		$P>5000$	20	101
	c) rifiuti per i quali la frazione biodegradabile è determinata forfettariamente con le modalità di cui all'Allegato 2	$1<P\leq 1000$	20	216
		$1000<P\leq 5000$	20	109
		$P>5000$	20	85
Biomasse	a) prodotti di origine biologica	$1<P\leq 300$	20	229
		$300<P\leq 1000$	20	180
		$1000<P\leq 5000$	20	133
		$P>5000$	20	122
	b) sottoprodotti di origine biologica di cui alla Tabella 1 –A; d) rifiuti non provenienti da raccolta differenziata diversi da quelli di cui alla lettera c)	$1<P\leq 300$	20	257
		$300<P\leq 1000$	20	209
		$1000<P\leq 5000$	20	161
		$P>5000$	20	145
	c) rifiuti per i quali la frazione biodegradabile è determinata forfettariamente con le modalità di cui all'Allegato 2	$1<P\leq 5000$	20	174
		$P>5000$	20	125
Bioliquidi sostenibili		$1<P\leq 5000$	20	121
		$P>5000$	20	110

Figure 19: Incentive systems for RE in Italy (not photovoltaic), Politecnico di Milano source



Fonte Rinnovabile	Spesa per incentivi [mln €]		
	2010	2011	2012
Bioenergie	705	934	1.484
Eolico	714	755	1.001
Geotermoelettrico	86	107	931
Idroelettrico	791	661	115
Totale	***2.297***	***2.458***	**3.531**

Figure 20: Incentive expenditure in Italy, source Politecnico di Milano - GSE

The amount of incentives has increased during the last 4 years, more than 40%, reaching 3,5 billion € in 2012, for the Italian market.

Developing countries

It has been shown how the main source of risk, differential for RE compared to traditional sources, is the importance covered by the management of incentive policies, when dealing with a developed country. Differently, when considering developing countries, as it is the objective of the entire analysis in Africa, this difference is no longer important. The lack of institutions and of the regulated system of incentives, makes the difference between RE and traditional sources really limited. This is the main reason why the competition between traditional and RE resources is actually possible in a country like Africa, due to this issue of the incentive policies. The shortage of a well-articulated distribution network for electricity, enables the competition between RE and traditional energies. Of course many risk sources are still more relevant for RE compared to traditional ones, and exactly on these the following part of the paragraph is focused. Indeed, in this part many methodologies and hedging risk techniques will be examined for RE, not taking into consideration the incentive issue, as it is of little impact on the African market. The risks that will be considered also involve traditional energy sources, but it will be shown how to manage these risks in a specific way for renewable plants and so, how to make green power a valid and competitive alternative, also economically speaking, for the coming years. From now on only risks involving developing countries will be considered.

There is a panel of products offered to hedge the risk in RE investments in developing countries. A common characteristic of these tools is that they all come from the traditional sector and they are later being adapted for RE, usually on a case-by-case strategy. This point leads to obtain higher prices for the insurances and to get restrictive terms and conditions. In figure 1, the existing insurance products for the different kinds of RE are summarized. As already underlined in paragraph 1.1, there are some technologies, which still present a high risk of application and thus, still represent a struggle to find the right investors. As can be seen from the table in figure 2, some kinds of risks are still lacking as a reliable cover or are just partially covered. For example it is clear how a strong effort should be made to improve the insurances available in order to cover the technology risk, the delay in start up risk and the exploration risk. These mentioned risks do not match a satisfactory coverage product, which should hedge them. If we look at the rows in the table (technologies categories), we immediately notice that the most "uncovered" renewable energy is biomass, which has a very limited cover for about all the possible categories of risk, and do not have any possible cover available to protect the exploration risk. Furthermore, as we anticipated in paragraph 3.2, the size of the project has a relevant impact on the funds that can be collected. According to UNEP (document: Financial Risk Management), project of less than 15 million USD, have difficulty finding insurance cover, and as a result, financing (with the exception of small wind projects). In the following pages, we would like to make another overview on the main renewable technologies, as we did in paragraph 2.1, but only focusing on the most important traditional coverage adopted.

Wind power

Wind power is the most mature technology and presents the most developed insurance market. Usually for on shore applications the physical damages coverage is available, which involves a premium for the risk of about 0,3-0,4% of the total value of the project. On the other hand, for offshore applications, the risk premium rises to around 2%, as it is still an immature technology with a higher risk perceived. Connected to this application, there are also the remarkable risks of business interruption and delay in start up: for those risks insurance is only partially available. One of the main concerns is the construction risk which presents partial coverage possibilities. Other risks connected to the wind farms are related to the turbines. Indeed, new prototypes are not covered with a satisfactory insurance yet and the investors must rely on the manufacturer warranties. Therefore, evaluating also the solvency capacity of the manufacturers has become a primary concern. **CDS** (contractual service agreements) are solutions which enable the reduction of the risk. These agreements guarantee the technical availability of the turbine. Manufacturers offer these contractual services and they receive payment per KWh generated back. These agreements usually also include maintenance and repairing costs.

Geothermal power

Due to the fact that the geothermal environment is quite different from the petroleum one, costs of exploration and drilling are the main concern for this kind of source. Geothermal energy involves higher temperature, more corrosive fluids and generally harder rocks. Herewith is explained why the costs and the risks in drilling can be consistent. Costs for a drilling operation are usually between 1 and 5 million USD, depending on the nature of the surface. Also the exploration risks, mainly for the same reasons can represent a barrier to the flow of investments in this sector. Other critical points could be considered the initial start-up costs and the phase of installation, in particular for the effort required by public assistance. A few solutions have been found to cover especially the drilling and exploration risk. Usually for geothermal projects an **Operator extra expense** is being used. This particular kind of insurance, adapted from the oil industry, allows the protection of the lenders for geothermal projects from any kind of risk concerning the exploration and operating production of the wells. Indeed, this policy takes into account all the costs related to the costs of the well, blowout costs, redrilling and restoring costs and in addition, some measures associated with seepage and pollution. As mentioned in the UNEP document ("Financial risk management instruments for renewable energy), another insurance has been developed by **Rödl & Partner,** in collaboration with a private sector insurer. The aim is to cover the risk of not successfully achieving the minimum levels of thermal production, one of the key barriers for this source of energy.

Biomass/biogas

The most important risk to be covered when considering biomass and biogas resources is the high fuel price volatility and the security of fuel supply. In effect, during the production phases of the fuel, a lot of waste incurred and thus, prevent the project from reaching a financial closure. Usually, when the scale and a sufficient standardization of crops permit it, **crop yield insurance** is adopted to hedge these risks. However, other barriers affect this sector. In particular for biomass, the priority is to find a reliable coverage to protect from the risk of business interruption, so as to guarantee the fuel supply in the long-term. On the other hand, biogas can rely on insurances, which cover the damages and business interruption risks, as it is a more mature technology. For this source of energy risks are linked to the noxious gas emissions and to health care. The best way to hedge these risks should be by working to improve the technological and operative processes, especially the fermentation process, which uses biogas as a source of energy, so could be possible to obtain wide coverage.

Wave/tidal/ocean current

This specific sector is living a period of rapid development, showing a great commercial potential. On the one hand, it can be considered a positive aspect for this source, but on the other hand the insurance world is still developing. Coverage exists only for the technological risk in small-scale projects and usually relies on **third-party liability**, which requires really high premiums for the risk. Considering the machinery breakdown risk, and in particular the collision risk and the hostile marine environments, an insurance has been developed just for the Pelamis (the first wave energy converter), but this was possible only through the effort of many engineers who guaranteed the safety and the resistance of the device. Therefore, what can be said is that the insurance tools for this source are in continuous development and they are going to be adapted further, following the maturation process of the technologies.

Solar power

Solar power, as we anticipated in the previous paragraph 3.2, often tends to be a small-scale application. This aspect leads to a low attraction of commercial insurers, thus to a lack of coverage tools available. When considering large installations, the insurance industry is ready and well equipped to sustain investments, although a few points need further development. Usually maintenance is the main concern for underwriters. Solar panels require regular maintenance and frequent breakdowns can occur. In addition, wear and tear can cause attrition losses. Furthermore, we should consider that these installations are usually installed in remote places, like in rural areas in Africa. Thus the availability of service industries to repair, replace and maintain these facilities in the areas is one of the main concerns of the insurers who write these kinds of insurances.

Small hydro

As stated in paragraph 2.1 the large hydro plants have a management logic which is more similar to traditional energy plants. That is the reason why we do not take this source of energy into examination, although it is actually a renewable energy. However, large-scale hydro plants use mature technology and consequently the insurance offers match the need required. Small hydro plants also benefit from a good understanding of the technology itself and the lifetime of an installation is usually longer than 50 years involving a suitable maintenance effort. This makes the small-hydro power the leading source of RE, especially because it is suitable for applications even in remote areas, as shown with the example of the dam on the Mpanga River in Uganda (paragraph 2.3).

The most typical critical points have been shown in these previous pages and also the typical solutions that are usually used to face the risks involved with the use of a determined technology. However, as the state of technologies is under a continuous research to be perfected, also the market of insurance and cover tools is in continuous development. New possibilities are being explored and the direction to be pursued is the creation of a new market, specifically for RE. In the following pages, we would like to give an idea, without entering too much in specific terms, of the main risk management tools that are being developed to support the creditworthiness of RE projects and to protect the revenues of the projects themselves. These tools have been extrapolated from the UNEP document mentioned previously.

- **Weather derivatives**: are used to protect the revenues from uncertainty linked to temperature variability, precipitation, wind, etc. As a matter of fact, the primary source of financial uncertainty for the RE is the weather conditions that can vary from day to day. These derivatives can be traded in OTC (Over the counter) markets and can be useful to hedge the risk deriving from the unpredictability of the weather. As long as the data of forecasting results imprecise, these instruments will provide a valid hedging tool.

- **Credit derivatives**: are instruments that allow brokers to repackage small and non-liquid credits into tradable securities. Usually these derivatives, in developing and emerging countries, are connected to the sovereign debt. The idea is to put small and non-liquid credits together in order to then be able to attract the capital of institutions.

- **Credit linked notes (CLNs)**: the payments and interests are linked to the credit risk performance of the reference assets, which in our case can be one or even a pool of RE projects.

- **Collateralized debt obligation (CDOs)**: these instruments combine security and credit derivatives in order to classify into classes, called tranches (usually with ratings from triple-A to B), a pool of underlying swaps. Moreover, a senior tranche, represented by a default swap, and a final equity tranche, representing the "first loss", are established. The income of the notes is invested in government securities (usually with high rating). Principal and interests are paid to the highest rated notes first, whereas losses are borne by the more junior tranches. These instruments often become hybrid forms like ART, as they imply the convergence of capital and insurance markets, and security structures are often hybrids.

- **Alternative risk transfer (ART)**: includes the CDO structures. These instruments allow a "new capacity" structure for the RE. They offer the possibility to renew and extend the limits of coverage and they include risk finance mechanisms, but also risk transfer (Integrated Risk Management). These tools are usually organized as contracts, structures and solutions. A classic use which has been applied to RE, is to smoothen revenues, eliminating the unpredictable impacts on the operating income of a project.

- **Captives insurance**: also called reinsurance companies, are insurance companies that are created by the investing firm, to manage the retained risk of the project undertaken. The main advantage is the decrease of the cost of the insurance offered since the firm that created its own insurance company can supply the insurance product as if it were at a wholesale price. Large wind turbines manufacturers sometimes use this technique. It can also be useful for asset protection, as a captive company, by law, is capable of accruing reserves against contingency. Some additional frameworks can be exploited, for example a multi-parent captive can enable the risk diversification strategy across different companies and a group-captive can be created when the insured risks are common or anyway similar to many small firms, which alternatively would not have the resources to create their own captive. Protected cell companies and rent-a-captive: when a small RE investor looks for financing of retained risks, it can join other similar companies, thus creating a new group called protected cells.

The potential for captives or similar structures is really high, as they are sometimes the only way to achieve the sufficient cover to bait finance, especially when traditional methods are lacking in solutions and when the RE projects are exposed to high natural risks, such as windstorms.

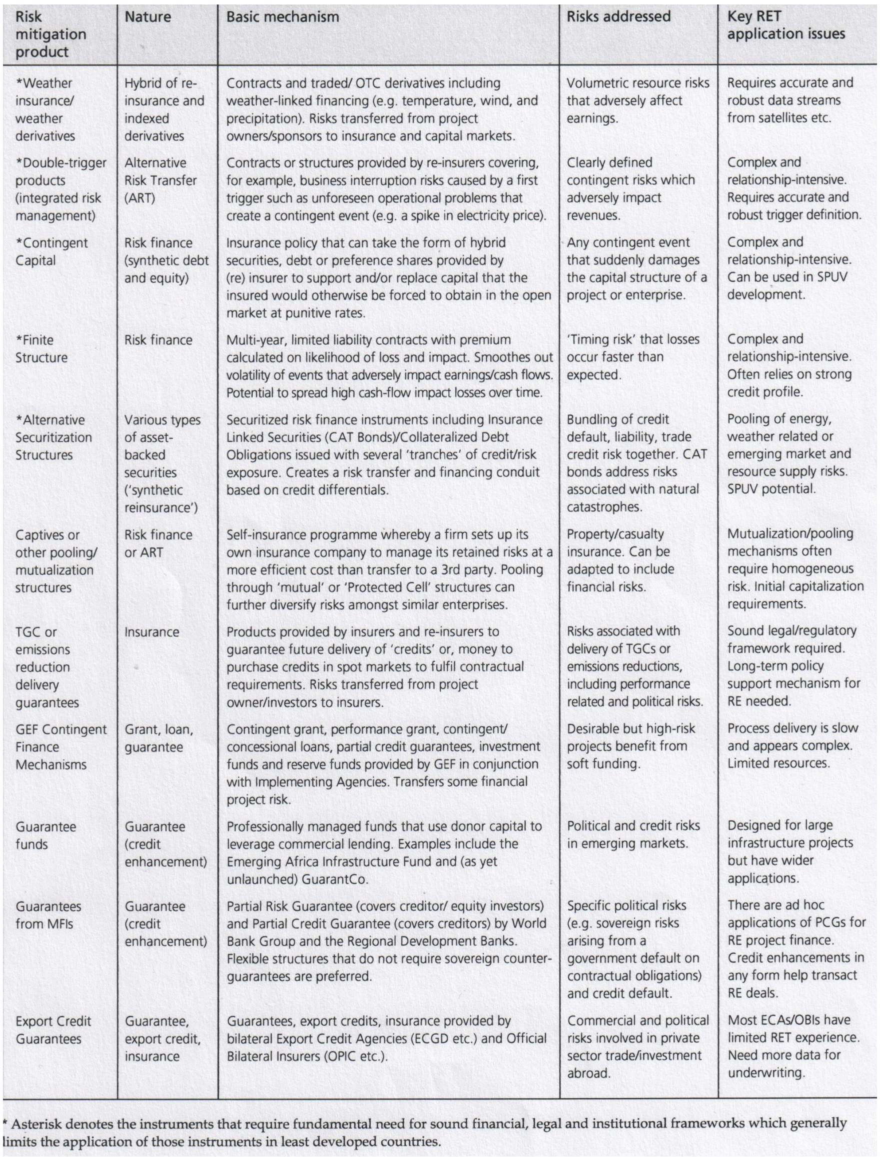
- **Insurance linked securities (ILS)**: the payoffs of these securities depend on the outcome of the reinsurance, which is offered by the special purpose vehicle issuing the notes. A typical example of ILS is the CAT Bond (catastrophe bond), where payments depend on a portfolio of premiums and losses caused by natural catastrophes, such as tornados, cyclones, earthquakes.

- **Political risk insurance (PRI)**: investors can use this tool to be protected against the possibility that the borrower is unable to convert the payments (interest and principals) from local currency into USD. Throughout this mechanism, the debt issuers can gain an investment rate rating, although the foreign currency rating is low. Forecasting for future years, foresees an increasing number of these tools, which are perfectly suitable for financing large RE projects.

- **Official bilateral insurers (OBIs)**: make up part of the public sector instruments. They usually provide insurance against three basic political risks: expropriation, war or civil war and currency risk. To date, OBIs have just a little experience with RE, but there are opportunities to further develop these instruments, in particular in developing countries where the opportunity for technology exports is higher. In Uganda for instance, an OBI credit enhancement, to help a telecommunication bond issue, was made many years ago and this path can be pursued also for other sectors. It is now clear that the private-public interactions are a fundamental point to be developed in order to boost the investments in RE.

- **GEF contingent financing**: the Global Environmental Facility offers many instruments of contingent financing, such as grants, loans and guaranties, to hedge the risk of incremental costs of a project. In RE projects are indeed a typical occurrence whose costs tend to increase and they are unpredictable and consistently different from the forecasting. GEF provides tools to face this common risk in RE investments and moreover the presence of GEF guarantees comfort to other lenders, leveraging additional commercial finance. The role of this organism could thus become important, attracting investors from the private sector in the long-term. Private sector indeed, could be in charge of commercializing the introducing programs of this institution. The GEF should help to create guidelines and template for RE that can be further explored and reused throughout the RE sector by private investors, with a better cost-efficiency performance.

In the next table (figure 21), taken from the document Financial Risk Management, Instruments for Renewable energy projects by UNEP (2004), there is a summary of the new mechanisms for RE that we have shown in the pages above. Of course, these tools have evolved consistently in the last ten years and even enhanced and improved their adaptability, but the table gives an idea on the complexity of the sector and on the multitude of issues that each instrument should take into account when applied.



Risk mitigation product	Nature	Basic mechanism	Risks addressed	Key RET application issues
*Weather insurance/ weather derivatives	Hybrid of re-insurance and indexed derivatives	Contracts and traded/ OTC derivatives including weather-linked financing (e.g. temperature, wind, and precipitation). Risks transferred from project owners/sponsors to insurance and capital markets.	Volumetric resource risks that adversely affect earnings.	Requires accurate and robust data streams from satellites etc.
*Double-trigger products (integrated risk management)	Alternative Risk Transfer (ART)	Contracts or structures provided by re-insurers covering, for example, business interruption risks caused by a first trigger such as unforeseen operational problems that create a contingent event (e.g. a spike in electricity price).	Clearly defined contingent risks which adversely impact revenues.	Complex and relationship-intensive. Requires accurate and robust trigger definition.
*Contingent Capital	Risk finance (synthetic debt and equity)	Insurance policy that can take the form of hybrid securities, debt or preference shares provided by (re) insurer to support and/or replace capital that the insured would otherwise be forced to obtain in the open market at punitive rates.	Any contingent event that suddenly damages the capital structure of a project or enterprise.	Complex and relationship-intensive. Can be used in SPUV development.
*Finite Structure	Risk finance	Multi-year, limited liability contracts with premium calculated on likelihood of loss and impact. Smoothes out volatility of events that adversely impact earnings/cash flows. Potential to spread high cash-flow impact losses over time.	'Timing risk' that losses occur faster than expected.	Complex and relationship-intensive. Often relies on strong credit profile.
*Alternative Securitization Structures	Various types of asset-backed securities ('synthetic reinsurance')	Securitized risk finance instruments including Insurance Linked Securities (CAT Bonds)/Collateralized Debt Obligations issued with several 'tranches' of credit/risk exposure. Creates a risk transfer and financing conduit based on credit differentials.	Bundling of credit default, liability, trade credit risk together. CAT bonds address risks associated with natural catastrophes.	Pooling of energy, weather related or emerging market and resource supply risks. SPUV potential.
Captives or other pooling/ mutualization structures	Risk finance or ART	Self-insurance programme whereby a firm sets up its own insurance company to manage its retained risks at a more efficient cost than transfer to a 3rd party. Pooling through 'mutual' or 'Protected Cell' structures can further diversify risks amongst similar enterprises.	Property/casualty insurance. Can be adapted to include financial risks.	Mutualization/pooling mechanisms often require homogeneous risk. Initial capitalization requirements.
TGC or emissions reduction delivery guarantees	Insurance	Products provided by insurers and re-insurers to guarantee future delivery of 'credits' or, money to purchase credits in spot markets to fulfil contractual requirements. Risks transferred from project owner/investors to insurers.	Risks associated with delivery of TGCs or emissions reductions, including performance related and political risks.	Sound legal/regulatory framework required. Long-term policy support mechanism for RE needed.
GEF Contingent Finance Mechanisms	Grant, loan, guarantee	Contingent grant, performance grant, contingent/ concessional loans, partial credit guarantees, investment funds and reserve funds provided by GEF in conjunction with Implementing Agencies. Transfers some financial project risk.	Desirable but high-risk projects benefit from soft funding.	Process delivery is slow and appears complex. Limited resources.
Guarantee funds	Guarantee (credit enhancement)	Professionally managed funds that use donor capital to leverage commercial lending. Examples include the Emerging Africa Infrastructure Fund and (as yet unlaunched) GuarantCo.	Political and credit risks in emerging markets.	Designed for large infrastructure projects but have wider applications.
Guarantees from MFIs	Guarantee (credit enhancement)	Partial Risk Guarantee (covers creditor/ equity investors) and Partial Credit Guarantee (covers creditors) by World Bank Group and the Regional Development Banks. Flexible structures that do not require sovereign counter-guarantees are preferred.	Specific political risks (e.g. sovereign risks arising from a government default on contractual obligations) and credit default.	There are ad hoc applications of PCGs for RE project finance. Credit enhancements in any form help transact RE deals.
Export Credit Guarantees	Guarantee, export credit, insurance	Guarantees, export credits, insurance provided by bilateral Export Credit Agencies (ECGD etc.) and Official Bilateral Insurers (OPIC etc.).	Commercial and political risks involved in private sector trade/investment abroad.	Most ECAs/OBIs have limited RET experience. Need more data for underwriting.

* Asterisk denotes the instruments that require fundamental need for sound financial, legal and institutional frameworks which generally limits the application of those instruments in least developed countries.

Figure 21: Emerging financial risk management instruments for Renewable Energy projects, UNEP source

In order to conclude paragraph 3.3, it is important to collect ideas on how to deal with risk when concerning RE projects. What has been done, and what is still happening is a learning-by-doing approach, which enables the testing and proposal of new ideas and techniques to deal with risks in this sector. Although it implies errors, this is the right direction to pursue in order to have specialized tools just for RE. Of course a strategic vision and low overheads are fundamental points for this approach to be successful, but this is the direction the market is moving towards. In order to reach the goal, any player involved has to play his role properly. <ins>Public sector</ins>, as we mentioned for the GEF, should act as a catalyst and third partner to mediate any team initiative and provide assistance on appropriately, it should play a role of "mezzanine facilitator" between private boutiques and large companies. Private boutiques can bring along their creative vision and should develop new products and service strategy. On the other hand, large companies, such as large banks, brokers and (re) insurers could provide their solid distribution network. The partnership among these three authorities is a priority to further develop the risk management approach for RE. The future for this sector could be accomplished through partnerships that combine the support, balance sheet and credit rating of public sector entities with creative vision of specialist private boutiques and distribution networks of large companies. These three parties joint ventures are the future and probably the only pursuable way to further develop the instruments for this sector. Many steps forward have been made during the last ten years, but to date we still have not reached a standard to cover each risk and the insurance sector is still dynamic and open to innovations.

3.4 - The impact of maintenance and management on the overall costs

During the pages of this chapter many financial issues have been touched on. To conclude the chapter some considerations about the O&M costs are herewith reported. As the core part of the thesis, beginning with the following chapter, will focus on the study of the maintenance (chapter 4) and later on with the description of new models to finance maintenance costs (chapter 5), it is important to introduce in this paragraph this core issue. In particular the aim of this paragraph is to show the impact of O&M costs on the total costs of a RE plant. It has been decided to anticipate here, in the financial area, this topic because these are the costs that will be studied better and analyzed later on. To find an efficient and effective way to finance these costs will be the ultimate objective of this thesis.

Following the guidelines offered by the NREL website, a general estimation of costs have been reported here. As mentioned by this Laboratory, each project can be generally categorized into 5 principle phases. Usually each phase generates a certain percentage of the total costs. These 5 phases of estimated costs give the possibility to the project manager or to the coordinators to make an initial estimation (Budget plan) of the future needs of capital to finance these costs. Some expenses, such as the project manager himself occur throughout more than one phase of the project, some others have a shorter time impact. In the table below (figure 22) the typical costs for each project phase are reported.

Project Phase	**Typical Expense Percentage**
Feasibility and Conception	**1–2%**
Project Design	**2–5%**
Pre-construction	**3–7%**
Construction	**70–90%**
Operations & Maintenance	**4–5%**

Figure 22: Typical Expenses for project phases, NREL source

As can be inferred from the table (figure 22), typical costs for maintenance are 4-5% of the total expenditure. Differently from other costs, these costs incur yearly. While the highest expenditures are attributed to the construction costs, as could be expected, with a range that goes from 70 to 90% of the total costs, depending on the projects. Of course, as stated in the NREL website, sources of capital used for development work, construction work, and operations and maintenance will depend on the financial structure of the project. However, the costs for maintenance do not usually vary a lot and can be confidently estimated around 5% of the overall costs. Thus, in the following pages, when referring to these costs, it is important to always keep in mind that we are referring only to a small percentage of the total capital need.

This estimation of about 5% has been inspected also comparing the data with an Italian company which largely operates in the RE business. Indeed, to have an opinion on the maintenance situation for RE, a leading Italian company has been contacted to receive useful information in this field. In particular during the meetings, solar and wind power have been analyzed better, because these are the two sources that will be deeply studied in the following chapters.

The first issue that came out is that it is usually the **manufacturer** of the components who takes care of the **maintenance** of the product delivered. The manufacturer not only provides substitutions, repair, routine and emergency maintenance, but also controls the availability and reliability of the components through a remote monitoring system. Nowadays, because of revenue reduction, a switch in direction of a Partial integration of the maintenance can be observed, but however the contribution of the supplier is still fundamental. Services for which the supplier is accountable for are reported with a "✔" in the tables below. Three kinds of maintenance have been considered:

- Full-service maintenance: the manufacturer is responsible for all the possible services;
- Partial Integration: some activities have been brought in-house;
- Integration: the investing company is in charge of the entire maintenance activities, exploiting a reduction of costs.

Furthermore, it has been explained how usually O&M costs are financed. What usually happens is to cover the capital costs (construction) with the initial investment (comprehensive of 20% of equity and 80% financed by banks) and then **O&M costs** will be financed thanks to the **sale of energy**. The percentages of 20% and 80% vary with the features of the projects and the market situation. This is the typical mechanism in the RE market, but as will be largely explained in chapter 5, this project (Power Africa) presents some peculiarities that enable a complete new financing plan. Usually the process is the one shown in the picture below, O&M is considered just when the project as been commissioned and performed (figure 23).

Figure 23: Priority of financing process, NREL source

Finally, the importance of technology has been considered, as the availability status of each component is strictly controlled by a **remote monitoring system**, usually owned by the manufacturer, who is capable of saying in every moment if there are any kind of problems occurring to the components of a plant. As underlined also on the NREL website: "Most manufacturers of renewable-energy systems offer a remote monitoring and management option with their systems. This feature allows manufacturers and in-house operators to track system performance and to identify potential system faults when, or even before, they actually occur. As a result, the monitoring systems can alert operators to maintenance requirements before they develop into larger, system-wide problems".

In the table below (figure 24 and 25) the main points emerged in the meetings have been summarized.

Solar Power

	Full-Service	Partial Integration	Integration
Remote monitoring	✔	✔	
Routine maintenance	✔	✔	
Emergency maintenance	✔	✔	
Warranty extension of principal components	✔		
Warranty extension of other components	✔	✔	
Warranty disposal	✔		
	35-25 K€/MW/year	30-15 K€/MW/year	20-10 K€/MW/year

Figure 24: Maintenance options for Solar Power

Costs reported have to be considered as initial costs, probable increases from the fifth year and beyond, have not been considered. The trend is to abandon the full service offered by providers of the equipment and to internalize the maintenance of principal components. For a solar photovoltaic plant of about 10 MW, saving can reach 15-10 K€/MW/year going from a full service to a complete integrated maintenance service. Actually, solar farm producer tends to use a partial integration, which means taking care of the principal components and still rely on the suppliers concerning routine and emergency maintenance. In particular, regarding solar power, the most critical component is usually considered the inverter. Many companies take care of the maintenance of this component themselves, but still entrust suppliers for others forms of maintenance (see figure 24).

Wind Power

	Full service	Partial integration	Integration
Remote monitoring	✔	✔	
Routine maintenance	✔	✔	
Emergency maintenance	✔	✔	
Warranty extension of principal components	✔		
Warranty extension of other components	✔	✔	
Warranty disposal	✔		
	60-45 K€/MW/year	45-30K€/MW/year	35-25 K€/MW/year

Figure 25: Maintenance options for Wind Power

Costs reported have to be considered as initial costs, probable increases from the fifth year and beyond, have not been considered. Similarly to what happens for solar power, the trend of the companies is to focus on the maintenance of principal and critical components. For wind power the critical components are usually considered the gearbox, generator and the transformer. Integrating the maintenance management of these components could halve the costs for maintenance. Of course the cheapest way for a maintenance program would be to internalize all the system, which could lead, for a wind farm of about 10 MW, to a great saving of up to about 30 K€/MW/year. Nevertheless, know how and the costs for the control system software should be included and considered, and that is the main reason why companies are moving in the direction of a partial integration of the maintenance system. The same consideration about the know-how competences and the software monitoring costs can be made for the solar power as well.

Together with this introduction of the O&M costs and this overview on how the costs are usually treated, chapter 3 is concluded. Now is time to enter more into the detail of the maintenance costs. From now on a study of the maintenance costs will start (chapter 4) and then, as previously anticipated, two finance models to relate with these costs will be introduced (chapter 5).

CHAPTER 4 - Cost study: focus on Operations and Maintenance costs (O&M)

In this chapter the O&M costs will be further examined. In particular a study of the maintenance will be the goal of this part of the thesis. Firstly, an introduction to describe why maintenance is important so as to explain why this has been selected as the main topic of the thesis. Thus, once the importance and the main concerns of a company related to this topic are understood, a cost study can be shown. In the cost study data which have been extrapolated from different sources have been considered and in the last paragraph a strong effort has been made to try and sort out these data so they become clearer and more useful. To classify and make these data understandable is one of the central parts of the thesis. Moreover, this effort has been made not just for the O&M costs of the plants, but also for the transmission and distribution costs of energy. The result of this chapter will be useful later on in chapter 5 when the data collected will be used to evaluate the economic convenience of the models proposed.

4.1 - Introduction to maintenance

As stated in the article “Renewable-Energy Systems: Important Maintenance Practices” by James Piper, 2011: “All building systems and components need some level of maintenance, and renewable-energy systems are no exception to this rule”. The specific maintenance requirements vary based on the type of system and components installed. Even if some manufacturers might say their systems do not require maintenance, if high-performance levels are what are expected from the systems, performing the required maintenance activities is a fundamental issue to guarantee the effectiveness of the system for many years. In particular concerning RE, it is proper maintenance practice to inspect the integrity of mechanical and electrical connections at least once each year.
Concentrating again on solar and wind power, what can be inferred from the mentioned article is that, especially solar panels need specific treatments.

Solar hot-water systems require periodic inspection of the panels for leaks, damage, and even build-up of dirt on panel surfaces. If the systems use a water-glycol mixture, technicians should test the system periodically for proper concentrations of glycol. They should inspect and test drain-down systems before the onset of cold weather to ensure the panels drain fully. Solar electric systems also require periodic inspection of the panels for physical damage, dirt build-up, and proper tightness of the electrical connections. Technicians should also make certain vegetation growing near the installation does not block sunlight to the panels. Shadows that fall on even part of one panel can cause a significant reduction in the system's total output. Solar electric systems also require that technicians periodically test the output from system inverters. Regarding the issue of the vegetation growing there is an interesting Italian example to report of a large solar field built in the countryside near Ravenna. In this area to control the growth of the grass, many sheep have been placed in the same territory of the solar panels so their eating the vegetation of the area, avoid the grass blocking sunlight to the panels. Nearby a cheese factory has been built in order to fully exploit also the presence of these ovine. This example could be successfully readopted in the rural part of Africa where solar panels can be installed.

Regarding wind farms, they also need a strong test action and inspection for electrical connections and inverters. Moreover, the moving parts, such as the blades and bearings, should be checked yearly following the manufacturer recommendations.

As we mentioned batteries, fundamental tools to go in the direction of a smart-grid system, are important to remember how systems that use large, standby batteries will have more maintenance needs. To date, most systems use lead-acid batteries. System operators must ensure the water level in these batteries remains at recommended levels to prevent battery damage. Depending on the capacity of the batteries and their cycling frequencies, technicians should inspect them at least once each month. They should also keep records of the amount of water they add to each battery, because increased water use can indicate a particular battery is approaching the end of its service life. It is equally important that technicians keep all electrical connections to the batteries clean and tight to prevent system losses and potential safety hazards.

Once the project is operational, it must be kept in mind that operative costs refer not just to maintenance itself, but as explained in James Piper's article (mentioned above), they are comprehensive of warranties, administrative fees, insurance, property taxes, land-lease payments and a contingency fund for unforeseen problems. In addition, some projects will have a period of revegetation and wildlife impact monitoring. Finally, after the useful lifetime of the machinery, some costs related to the reverse logistic may be taken into consideration.

A fundamental distinction should be made between:

- **Routine maintenance**: it is to say all planned activities that are scheduled immediately once the project has become operative. These activities are usually scheduled to meet the requirements of the warranty and usually it is a service offered by the vendor. Some industrial firms are specialized in these operations, especially for wind projects and can be a valuable alternative when the contract with the vendor expires. To hire a project crew from a nearby project can also be a possible alternative, if that project uses the same type of technology.

- **Preventative maintenance:** is particularly important for renewable energy projects because the off-warranty costs of major repairs involving mobilization equipment (e.g. cranes) and other equipment can consume many years of potential profit. As reported in the article of James Piper: "If the site is dusty or subject to seasonal insect infestations, the major components may need to be washed regularly. These issues should be included in the maintenance contract".

- **Emergency maintenance:** this kind of maintenance refers to all the unexpected breakdowns, incidents, problems that could happen to a piece of equipment and that could not be foreseen. Just an estimate of probability can be made and a prompt and effective intervention is required.

When thinking about the maintenance management, also other aspects should be considered. For instance the connection of the structure to the grid is a core element to take into consideration. That is why in the following pages there is a dedicated paragraph that consider this topic. The connection of the equipment to the grid must be created with the collaboration of a specialty company and define the issues in an interconnection agreement.

Moreover, the site management is to be considered. Especially for RE energy and in rural African areas, the danger of damages to the site due to external factors is a relevant topic. Site maintenance is important and may include noxious weed control, gate and cattle guard maintenance, signage installation, and road and erosion control. Competent local contractors can handle these tasks.

A lot of RE equipment, especially wind turbines and PV panels, is typically designed to have an operating life of **twenty years** (source FMP: Facility Maintenance Decisions). For this reason this is the value that will be considered later on in the development of the thesis. It must be taken into consideration that wind turbine blades, gearboxes, and brakes often require rebuilding or replacement. While preventative maintenance decreases the likelihood of a major expense, the replacement or rebuilding of a major component can be a significant financial commitment. Keeping a spare parts inventory, a reserve fund, and additional insurance can mitigate the financial burden of the replacement of parts. This suggestion has been provided also during the meetings with the company (see paragraph 3.4).

Once the main issues and concern regarding maintenance have been defined, before starting with the real cost study, it is now important to understand why it has been decided to concentrate this effort on this topic making a brief **historical review**. In order to do this the article “Applications of maintenance optimization models: a review and analysis” by Rommert Dekker, 1996 has been considered as a valuable source of information.

“Maintenance can be defined as the combination of all technical and associated administrative actions intended to retain an item or system in, or restore it to a state in which it can perform its required function”(Glossary of maintenance terms in Terotechnology, British Standards Institution, 1984).

As can be inferred from this definition the main goals of maintenance action are to guarantee the functioning of the system (availability, efficiency), ensuring the life of the system and ensuring the safety also for humans working with the equipment. An important consideration to be made in order to understand why maintenance is becoming such an important issue is that the automation degree has been quickly increased during recent years. This has certainly brought about a decrease in the workforce needed and thus led to a high dependency on the equipment. What can be observed is that maintenance now covers the largest part of the operational budget.

Since the very beginning of the 1960's some quantitative models have been announced to give a scientific approach to the maintenance management. Firstly, studies were about the reduction of downtime and failures. In the 1970's the focus verged on the prediction of failures thanks to the information of the actual state of equipment. A great step forward was made in the 1980's when computers were introduced to the management of the maintenance function. At the beginning they where used to facilitate the administrative process, but with the passing of time they gained more and more importance. In the 1990's also importance to qualitative approaches became important. An important approach is the RCM (Reliability Centered Maintenance): originally founded in the sixties to direct maintenance efforts to those parts and units where reliability is critical, in the nineties it has been fully adopted in many industries. As mentioned in the article by Dekker: "It is the more qualitative approach to where optimization models are the quantitative approach". Consequently other qualitative models have begun to develop, such as the Total Productive Maintenance in Japan.

As can be noted from the forementioned article, there are two main aspects why maintenance has to be considered a completely different management area compared to the others. First of all, it is strongly related to **stochastic events** and failure processes. As unplanned events and lack of time are constant issues to be faced, making it a really difficult area to relate to. Furthermore, the accuracy of the **budget** for the maintenance is a really delicate topic as this task includes so many different activities to be considered and it is really difficult to identify benefits. As a matter of fact maintenance is seen just as a cost function.

Many qualitative and quantitative models have been developed during the past years. The document that has been previously mentioned, classifies the possible models into 3 categories: case study, new models and application tools. **Case studies** usually refer to real data that have been used to provide advice to management on a real problem. **New models** usually come from existing applications through a variation or a reconsideration of the existing material and are usually proposed as a solution to an existing problem. In this order of ideas, models that will be shown in chapter 5 can be considered as new and innovative, even if they have to be considered more as new financial models for maintenance more than mere maintenance models. Finally, **application tools** are decision support systems or expert systems. A huge number of the 3 different cases can be found in the maintenance evolution history and the main problem refers to the same aspect, the data collection and analysis. This issue has been mentioned in accordance to the Dekker's article, and has also been verified during the draft phase of this thesis as the data collection and analysis phase has been the most effort-requiring and laborious phase. In particular the definition of maintenance benefits is a difficult point to clarify, as the impact on availability, reliability and efficiency should be taken into consideration. For the scopes of this thesis, in the O&M costs paragraphs, just direct evaluable costs have been considered.

As has been stated, many different kinds models have been implemented over the years, but it is still impossible to represent reality in a model. According to Dekker's article, there 6 aspects avoiding the possibility to successfully implement the myriad of models available.

- Difficulty of understanding → many models have a stochastic nature which made them not just difficult to implement by technicians and manger, but also difficult to interpret and understand the real meaning of the model.

- Just for evaluation purposes → some models have been implemented only on papers. They are just theoretical formulas developed as a consequence of logical passages, but are impossible to employ in a real case.

- Company not interested in publication → many companies may have found really interesting solutions to their maintenance problems and issues. However, they are not interested in sharing this value and thus, many useful management strategies may still be unknown to the public.

- Maintenance involves too many aspects → models developed cannot just cover all the possible implications involving a maintenance policy of a company. They can focus on some aspects, but inevitably some others would be overlooked.

- Optimization is not always necessary → in many models the final optimum has been researched. This is not always worthwhile as, in many cases, the potential savings are just too low to justify a sophisticated decision making process. In some other cases the savings are so intangible that it is also less convincing to higher management.

- Focused on the wrong type of maintenance → many of them, as a matter of fact, focus on routine maintenance whereas the other kind of maintenance should be better analyzed and developed. Manufacturers have made strong efforts during recent years to improve the performance of their products and to expand their services especially regarding the routine maintenance. Emergency and especially preventative maintenance for RE are those that should be further delved into. A consistent decision making process, funded on both quantitative and qualitative considerations, should be built to enable the reduction of uncertainty.

To conclude this paragraph it is important to remember that expenditures on maintenance will increase in future years as a trend shown by many companies. This is principally due to the strong technological push: the developing of software and computers and the lowering of the prices for technology devices which enable this process. Finally, the need of a solid maintenance decision-making system has emerged and many decision support systems incorporating maintenance optimization models have come out and are becoming standard tools that help modern maintenance managers.

4.2 - Energy production costs through Renewable energy

In this paragraph an analysis of the costs of energy production will be presented. It is important to introduce these costs because they consist of many different voices of costs and among these voices there are the O&M costs, the main objective of the thesis. O&M costs deeply influence the final costs of energy production and therefore the price of energy. That is why it is important to understand how they have an impact on the production cost of energy. Once their impact has been understood, from the next paragraph, the focus will be just on these costs.

Charts and reasoning presented will all refer to the LCOE (Levelised Cost of Energy).

“Levelised energy cost (LEC, also commonly abbreviated as LCOE) is the price at which electricity must be generated from a specific source to break even. It is 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, cost of capital, and is very useful in calculating the costs of generation from different sources” (source: http://www.appropedia.org/LCOE).

To understand how O&M remarkably contribute to the final costs, depending on the single technology adopted, the charts below (figure 26 - 27) can be really useful.

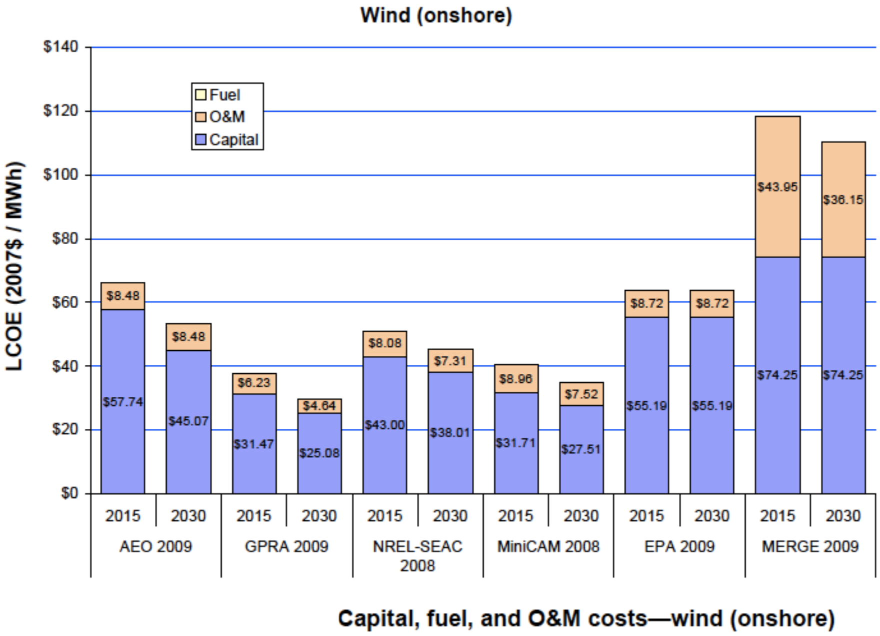


Figure 26: LCOE for Wind (on-shore) projects, NREL source

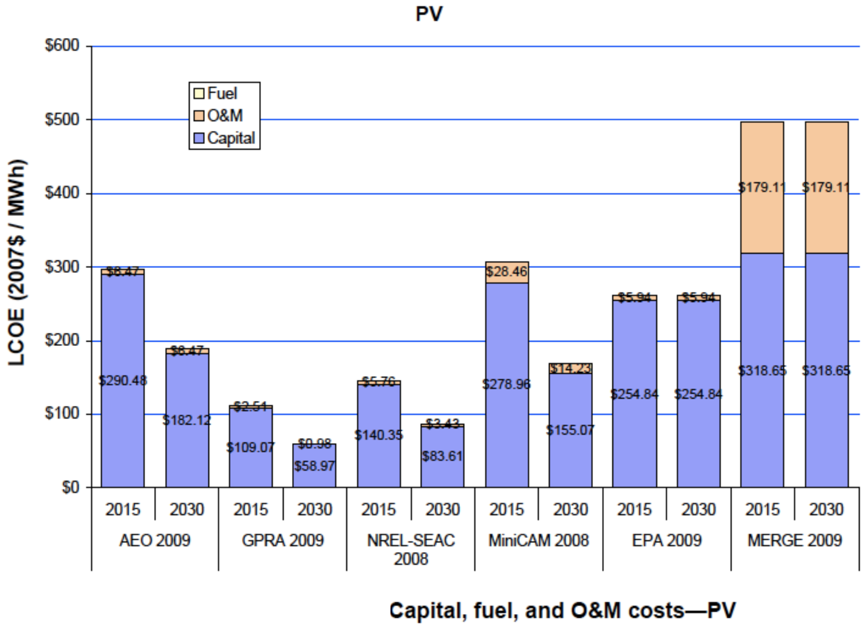


Figure 27: LCOE for Solar PV projects, NREL source

The charts above have been extrapolated from the “Cost and Performance Assumptions for Modeling Electricity Generation Technologies” document sponsored by NREL, 2010. As can be inferred from the charts, different data sets can provide different estimates of the costs. It is clear how, for RE, in addition to capital costs, it is especially the O&M costs that influence the LCOE. Another important consideration that can be made is the need of fuel. If the two charts above are compared with the chart of a traditional source of power it will be immediately clear how the cost of fuel is a really consistent cost to be taken into consideration when relating to traditional sources. In the table below (figure 28) the example of a coal plant has been considered.

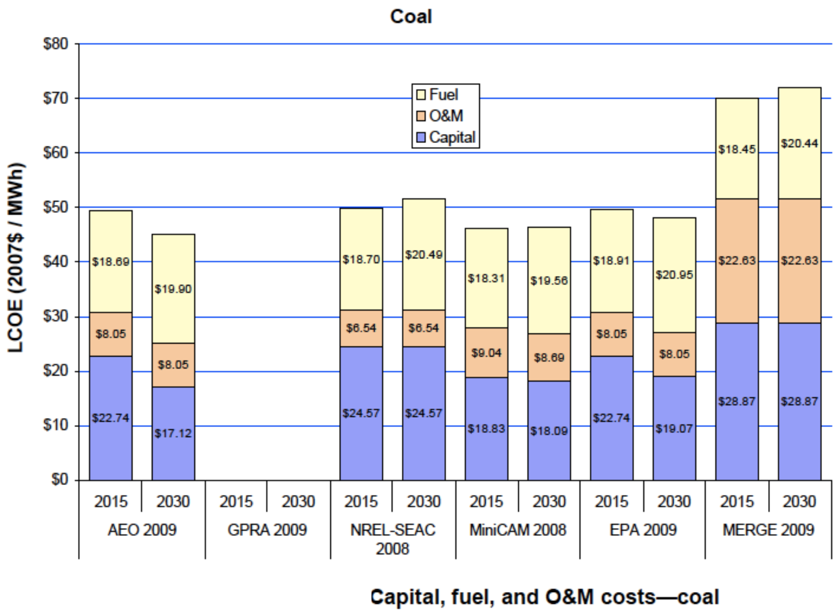


Figure 28: LCOE for Coal plants, NREL source

As can be seen, fuel costs impact the final LCOE almost in the same percentage as the Capital costs, and in some cases as for combined cycles it is largely the primary component of cost. This does not happen for RE where fuel is not needed, except for Biomass plants. Considering the different data set, the impact of O&M costs vary in a range from 3,4% to 8% of the total costs for Solar Power (PV), while for on shore wind the impact is higher and usually are over 10% of the LCOE. However, as is evident from the charts above, the main contribution to the LCOE is given by the capital costs. Capital costs are not the main objective of the thesis so they are not further examined, but it is herewith reported in charts (figure 29-30) that clearly explained where these costs come from in the case of Solar and Wind power.

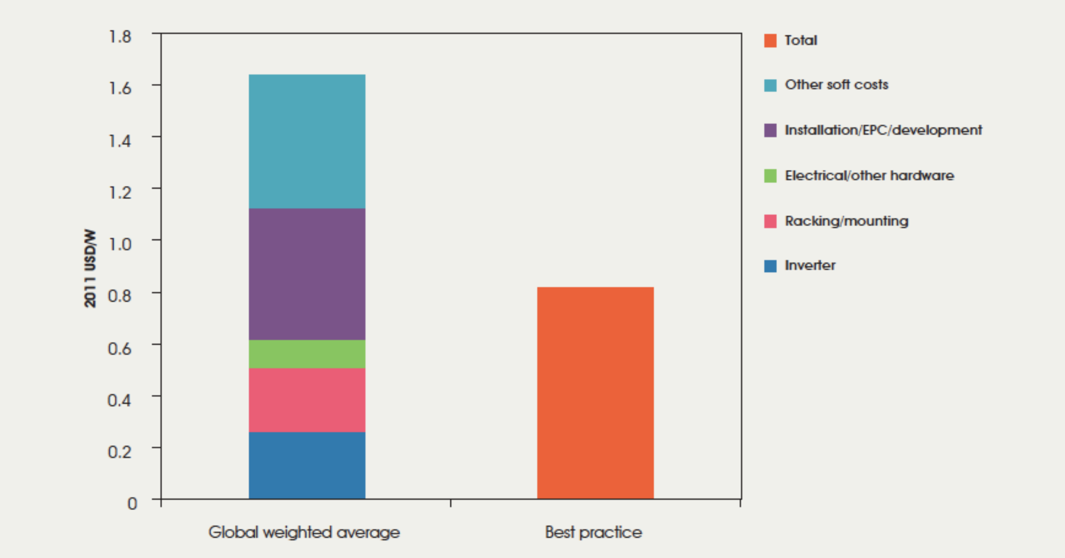


Figure 29: Typical Solar PV balance of system costs, Photon Consulting source

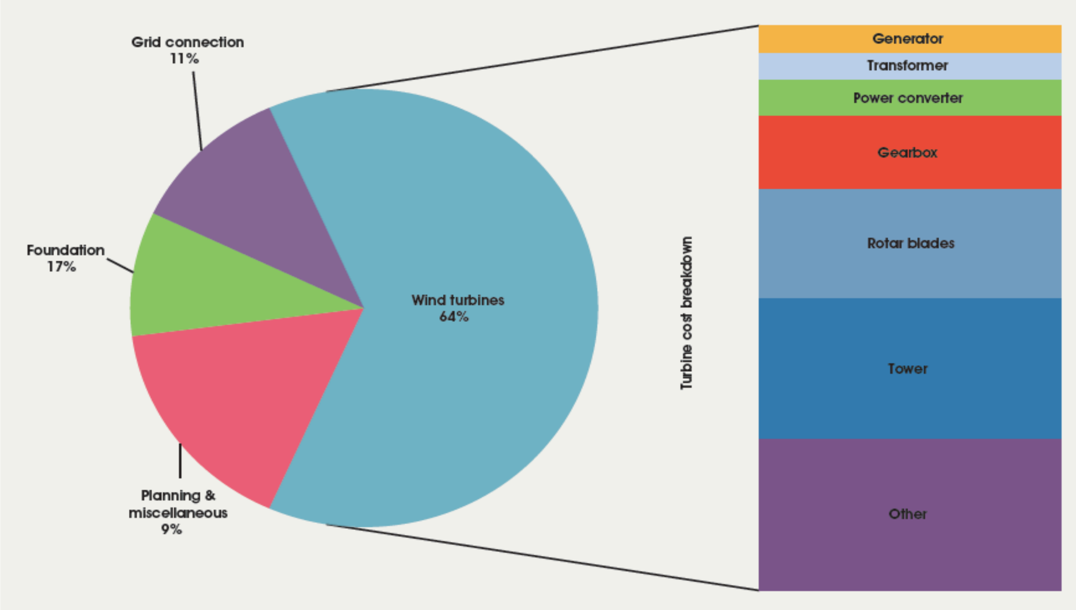
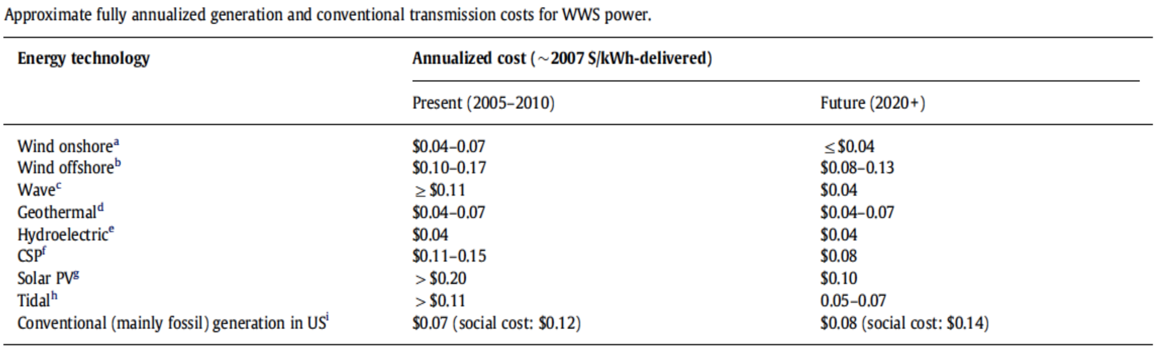


Figure 30: Typical onshore wind farm installed cost breakdown, Blanco source

These charts (figure 29-30) show how capital costs can be divided into their principal cost elements. Concerning Solar PV power, the main cost items refers to installation and other soft costs. Whereas for wind (on-shore) power, a great part (64%) of the costs derive from the wind turbines. In particular wind turbines are largely affected by the cost of the tower and the rotor blades, as can be expected. The most delicate and important elements to be managed when considering maintenance issues are not the most expensive in capital. Indeed, as explained in paragraph 3.4, the most subjected to risk elements, are the gearbox and the inverter for wind power and the inverter for solar power. These elements are really important for the functionality of the entire structure and really expensive to be maintained, but as shown in the figures 29 and 30 they have a partial impact on capital costs.

It is now time to analyze further the comparison with traditional sources of energy. As stated in the "Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies" document by Mark A. Delucchi and Mark Z. Jackobson (ELSEVIER, 2000), on-shore wind projects can be already considered competitive as fossil-fuel generation, and in some cases can even cost less. Solar power is the most expensive nowadays, but it can reach cost competitiveness by the beginning of 2020. In this mentioned document, it can be noted how by 2030, solar, wind and water project will all be economically compared to traditional sources of power. The table below (figure 31), extracted from the ELSEVIER document, shows the projection of energy production costs, comparing the year 2008 to future years (2020 and beyond). Transmission costs for energy are here included, but they will be analyzed better in paragraph 4.4.



Approximate fully annualized generation and conventional transmission costs for WWS power.

Energy technology	Annualized cost (~2007 $/kWh-delivered)	
	Present (2005–2010)	Future (2020+)
Wind onshore[a]	$0.04–0.07	≤$0.04
Wind offshore[b]	$0.10–0.17	$0.08–0.13
Wave[c]	≥$0.11	$0.04
Geothermal[d]	$0.04–0.07	$0.04–0.07
Hydroelectric[e]	$0.04	$0.04
CSP[f]	$0.11–0.15	$0.08
Solar PV[g]	>$0.20	$0.10
Tidal[h]	>$0.11	0.05–0.07
Conventional (mainly fossil) generation in US[i]	$0.07 (social cost: $0.12)	$0.08 (social cost: $0.14)

Figure 31: Approximate fully annualized generation and conventional transmission costs for WWS, ELSEVIER source

From the table above it is evident how the costs of energy delivered will consistently decrease, and will be economically convenient in a few years thanks to the maturation of technologies. Moreover, conventional fossil fuels suffer from the addition of social costs related to the pollution created, which affect their competitiveness.

As affirmed in the ELSEVIER document: "A large-scale wind, water and solar energy system can reliably supply all of the world's energy needs, with significant benefit to climate, air quality, water quality, ecological systems, and energy security, at reasonable cost. To accomplish this, we need about 4 million 5-MW wind turbines, 90,000 300-MW solar PV plus CSP power plants, 1.9 billion 3 kW solar PV rooftop systems, and lesser amounts of geothermal, tidal, wave, and hydroelectric plants and devices" (M.A. Delucchi-M. Z. Jackobson, 2000).

Another authority in the RE market also sustains the future competitiveness of green sources. Indeed, IRENA (International Renewable Energy Agency) published a report in 2012 called "Renewable Power Generation Costs in 2012" where these issues have been further examined. As can be noted considering the figure below (figure 32) some RE are economic nowadays. However, they will become even more convenient in future years. In the table shown (figure 32) the grey band refers to the typical cost range for fossil fuel power and as evident, some on-shore wind projects can already be considered convenient, while solar power (PV) is far distant from an economic convenience, but it will be competitive by 2020 and probably be totally convenient by 2030.

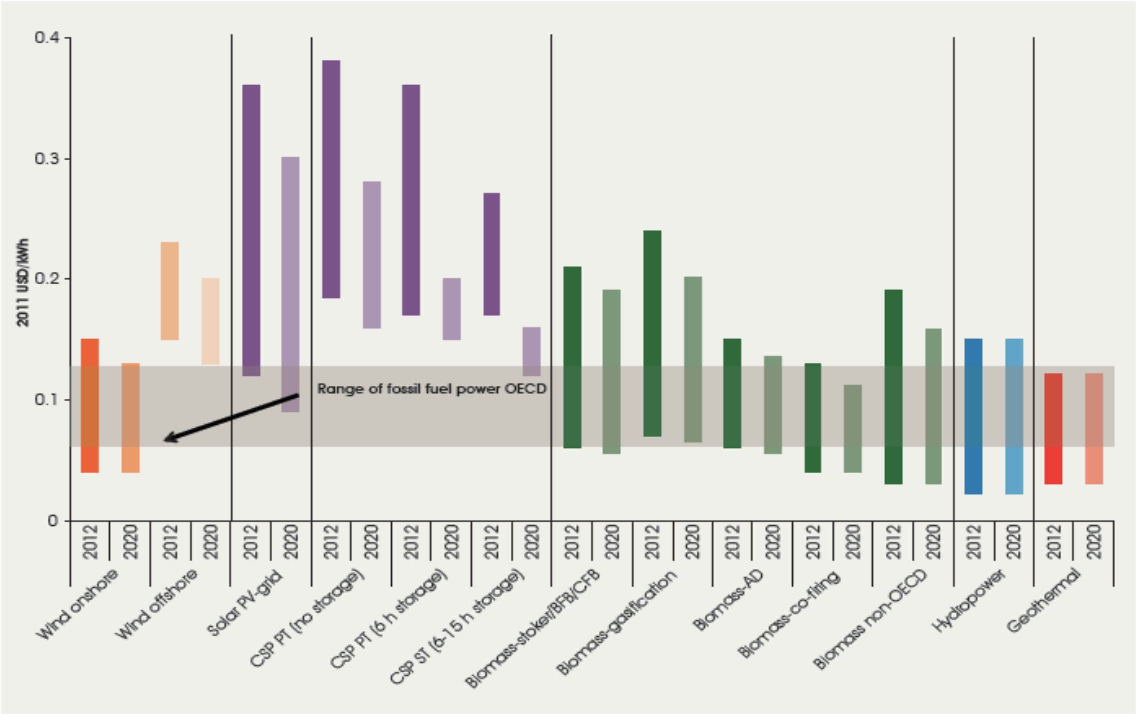


Figure 32: Typical LCOE cost ranges for renewable power generation technologies, 2012 and 2020, IRENA source

The impact of O&M costs on the LCOE and the future perspective for RE based on cost study has been shown. A focus on the African market is now useful to understand the development and economic possibility, from a cost perspective, not just in general, but in the target market considered in this master thesis. IRENA, in the mentioned report, provides a series of charts which are really useful to understand the costs of RE in Africa. Hereby two interesting figures related to this topic are reported (figure 33-34).

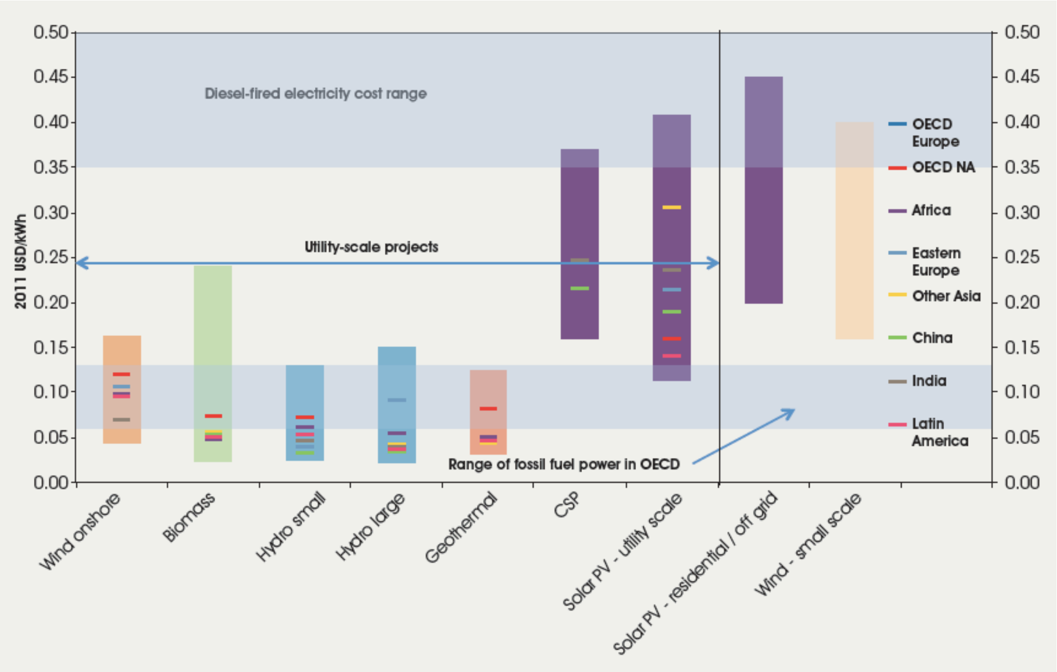


Figure 33: Typical LCOE ranges and weighted averages by region for renewable power generation technologies, 2012, IRENA source

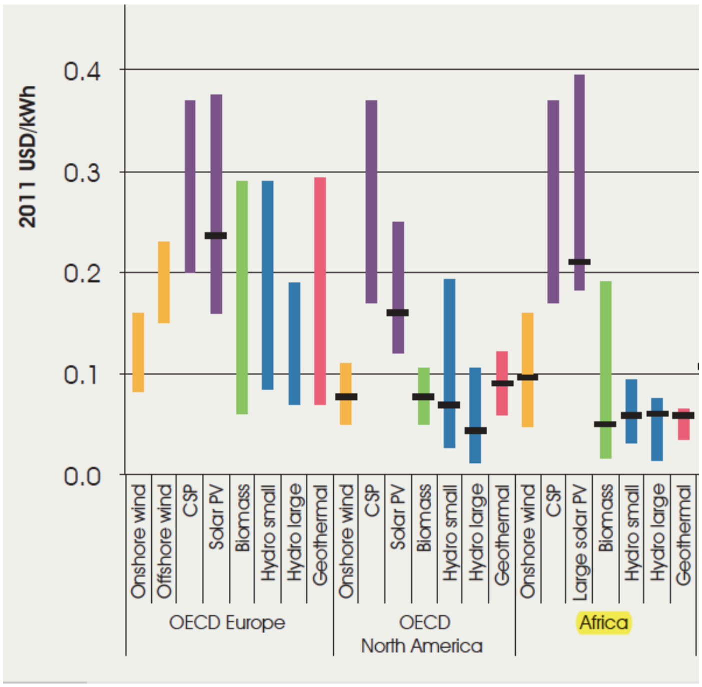


Figure 34: Typical LCOE ranges and weighted averages for renewable power generation technologies by region, 2012

Especially from the second, but also from the first figure, it is clear how RE can be really competitive especially in the African market. Compared to Europe and North America, costs in Africa can be even lower considering in particular hydropower and Biomass, for the great availability of the territory. Wind and solar power are aligned with the values of other territories. The usual consideration about solar power, which is far distant from the economic convenience compared to other technologies, is also clear from these charts. From the first chart it can also be inferred how, despite a low variance of values for RE in Africa, solar power exclusively in the African market suffers a strong variance of possible final cost. This high cost and variable costs depend on the fact that the technology is not mature. Nevertheless, solar PV costs are declining rapidly due to high learning rates for PV modules and the very rapid deployment currently being experienced. In addition to this, over-capacity in module manufacturing has led to cutthroat competition and driven prices down below the learning curve, at least temporarily.

To conclude this paragraph it is important to report data extrapolated from the ELSEVIER document to report the final estimation of LCOE for the year 2008 and then their possible evolution for the year 2030.

		2008			2030			
TECHNOLOGY		TOTAL COST			TOTAL COST		Increase/Reduction	
New coal scrubbed		0,065	$/KWh		0,056	$/KWh	-	0,138461538
IGCC coal		0,07	$/KWh		0,056	$/KWh	-	0,2
IGCC coal/CCS		0,097	$/KWh		0,073	$/KWh	-	0,24742268
NG advanced CC		0,096	$/KWh		0,079	$/KWh	-	0,17708333
NG adv. CC/CCS		0,146	$/KWh		0,11	$/KWh	-	0,246575342
Geothermal		0,047	$/KWh		0,081	$/KWh		0,723404255
Hydropower		0,052	$/KWh		0,053	$/KWh		0,019230769
Wind onshore		0,078	$/KWh		0,056	$/KWh	-	0,282051282
Wind offshore		0,157	$/KWh		0,123	$/KWh	-	0,216560509
Solar thermal		0,243	$/KWh		0,157	$/KWh	-	0,353909465
Solar PV		0,4	$/KWh		0,255	$/KWh	-	0,3625

Figure 35: Total costs and for each technology, 2008 and 2030

Considering data extrapolated from these documents, the estimated increase or reduction has been calculated through Excel. As the table above (figure 35) shows, almost all the technologies, traditional or RE, are expected to decrease their LCOE. In particular Solar PV can achieve a reduction of 35% of its present cost. On the other hand, Geothermal and Hydropower show a reverse trend with a sharp increase of 72% on the total costs for geothermal energy.

At the end of this paragraph it is important to remember, as mentioned in the ELSEVIER document, that: “By 2030, the social cost of generating electricity from any wind, water and solar power source, including solar photovoltaic, is likely to be less than the social cost of conventional fossil-fuel generation”. Furthermore, focusing on the African market the opportunity to successfully carry out the “Power Africa” project is underlined by this quotation: “Solar PV, biomass and wind are highly modular solutions to the challenge of extending electricity access to remote locations, and so helping to meet economic and social development goals” (IRENA Report, 2012).

4.3 - O&M costs for Renewable energy plants

This paragraph is the central part of the cost study (chapter 4), as here for the first time actual values of O&M costs are introduced. Similarly to the procedure used in paragraph 4.2, the scope of this one is to show and analyze tables of costs, but here just focusing on O&M costs. Each technology will be examined concerning costs related to maintenance, and some expansive considerations will be made. In this paragraph the goal will be to collect and formulate some ideas on the few data available regarding this topic. Once a complete overview of the costs per each technology will be clear, data will be further elaborated. In the last paragraph of chapter 4 some further reasoning will be made to figure out some trends related to them and later on (in chapter 5) to economically evaluate the new models that will be presented.

To begin this cost study there are herewith reported a chart indicating some recent O&M costs for RE technologies. This chart (figure 36) provides a compilation of available national-level cost data from a variety of sources. The costs in each specific location will vary. The red horizontal lines represent the first standard deviation of the mean. The source of this data is the NREL website and data have been made available from the U.S. Department of Energy (DOE) /Federal Energy Management Program (FEMP).

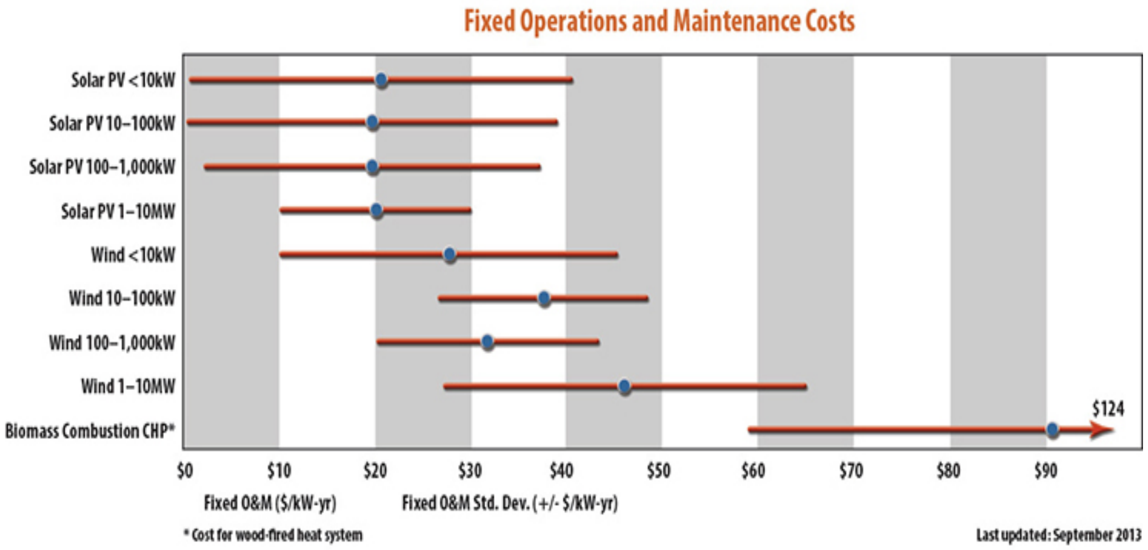


Figure 36: Fixed O&M costs for Wind, Solar and Biomass sources, NREL source

These are the most recent data available (September 2013). As the topic dealt with is really a living matter, it is not easy to find out many updated sources and that is why for the continuation of this task, some hypothesis and assumptions will be made (paragraph 4.5). The data refer especially to solar and wind power, the main interesting sources for the scope of this thesis. In the chart above just fixed O&M costs have been considered. As will be shown in the following pages some RE technologies also have to face the presence of variable O&M costs. The estimation of variable costs has been reported in the table below (figure 37)(source: NREL website).

	Variable O&M ($/kWh)	**Variable O&M Std. Dev. (+/- $/kWh)**
Biomass Combustion Combined Heat and Power*	$0.07	$0.02
*Unit cost is per unit kWh of the electrical generator, not the boiler heat capacity.		

Figure 37: Variable O&M costs for Biomass source, NREL source

Variable costs have been reported (figure 37) just for Biomass technology, but as will be clear shortly, it also affects Hydropower and Geothermal energies.

As anticipated in the introduction of this paragraph, some data have now been reported regarding O&M costs for RE. The data reported have been found in the “Cost and performance data for power generation technologies” report sponsored by Black and Veatch (2012). This report is quite recent considering this unexplored topic and the references and accuracy of data make it an appropriate document to be quoted when analyzing these costs. As declared also in this document, there are still little data available, and thus it is still difficult for policy makers to rely on this market. However, the data collected are increasing and in addition the technology market is developing and achieving a higher penetration, therefore the challenge is now on policy-makers as costs of electricity will probably decrease in future years, and would be lower than the data we report in the following tables. Renewable energy technologies need to work more closely together to unlock synergies and ensure that there is sufficient flexibility in the system in order to integrate high levels of variable renewables at least cost.

From now on each Renewable technology, for which reliable data have been reported, has been analyzed. Of course some considerations already anticipated in the previous paragraph, are still present here to further clarify the impact of these costs.

Wind power

Maintenance costs for wind turbines are typically less than those for conventional forms of electricity generation. As can be inferred from the Commission for Environment Cooperation (CEC) document, wind turbine maintenance is usually scheduled twice a year, resulting in about 12 to 18 hours of downtime for each turbine during the maintenance procedure. Generally, only a few turbines in a facility are down at one time for maintenance activities. The two items that most commonly require maintenance are usually gearboxes and generators. This is due to variable loads that are extremely difficult to predict. They are two of the parts most exposed to friction and wear, and sometimes a large crane will be needed to repair them. Blades usually do not require any kind of special maintenance: the only required, scheduled maintenance is for cleaning them or performing a visual inspection of their integrity, however after some years the blades or bearings may need to be replaced. In general, as reported in this mentioned document: “The main components of the wind turbine should be checked for corrosion; both bolts and electrical connections must be checked, and they must be tightened, as necessary” (CEC, 2010).

Fixed and variable operations and maintenance (O&M) costs are a significant part of the overall LCOE of wind power. For on-shore projects O&M costs typically account for 20% to 25% of the total LCOE of current wind power systems. However, costs have significantly declined since 1980 and now the estimation, comprehensive of fixed and variable costs, is around 0.01 $/kWh (in United States). Offshore projects still remain more expensive, with an estimated cost to be in the range of USD 0.027 to USD 0.054/kWh (2011). Reducing the O&M costs for offshore projects is a priority in order to develop the economics of offshore wind. In the table below (figure 38) there are data supplied by BLACK & VEATCH CORPORATION and refers to on-shore projects.

Year	Variable O&M cost ($/MWh)	Fixed O&M cost ($/KW-year)
2010	0	60
2015	0	60
2020	0	60
2025	0	60
2030	0	60
2035	0	60
2040	0	60
2045	0	60
2050	0	60

Figure 38: O&M costs for Wind power, Black and Veatch source

Hydropower

Once commissioned, hydropower plants usually require little maintenance, and operation costs will be low. When a series of plants are installed along a river, centralized control can reduce O&M costs to very low levels. Annual O&M costs are often quoted as a percentage of the investment cost per kW per year. Typical values range from 1% to 4%. The average can be considered 2,5%, even if for large hydropower plants they would be lower as the economies of scale effect is relevant in this field. The site- specificity of this technology can have an impact on the operational and maintenance costs, nevertheless estimation for future years can be made and we report it in the following table (figure 39).

Year	Variable O&M cost ($/MWh)	Fixed O&M cost ($/KW-year)
2010	6	15
2015	6	15
2020	6	15
2025	6	15
2030	6	15
2035	6	15
2040	6	15
2045	6	15
2050	6	15

Figure 39: O&M costs for Hydropower, Black and Veatch source

If we consider off-shore technologies, the fixed cost would increase, as we mentioned previously, and would be likely to be about 100 $/KW-year even for future years.

Solar power

Maintenance for solar power is generally straightforward. According to CEC authority, it includes ensuring battery terminals and connections are corrosion free for standalone systems; any building penetrations remain sealed; all electrical connections are tight and connection boxes are sealed; and PV panels are clean and in good working condition. A useful method to ensure that the panels are working properly is to check that the system voltage remains at or near the original design value.

A well-maintained solar system can perform, on average, 10% to 30% better than one that is not. The replacement of receivers and mirrors, due to glass breakage, are an important component of the O&M costs. The cost of mirror washing, including water costs, is also significant. Plant insurance can also be a large expense and its annual cost can be between 0.5% to 1% of the initial capital cost. On the other hand, automation reduced the costs of about 30%, so to date costs are likely to be approximately USD 0,025 KWh. Solar power benefit from important economies of scale when considering O&M costs. An example of

O&M costs can be the two proposed parabolic trough and solar tower projects in South Africa with estimated O&M costs (including insurance) of between USD 0.029 and USD 0.036/kWh. Data we report in the following table (figure 40) refer to concentrating solar power technology taking into consideration a typical 200 MW net power plant, with multiple towers configuration.

Year	Variable O&M cost ($/MWh)	Fixed O&M cost ($/KW-year)
2010	0	50
2015	0	48
2020	0	45
2025	0	43
2030	0	41
2035	0	39
2040	0	37
2045	0	35
2050	0	33

Figure 40: O&M costs for Solar PV power, Black and Veatch source

Biomass

Fixed O&M costs for biomass power plants typically range from 1% to 6% of the initial CAPEX per year. Fixed O&M costs consist of labor, scheduled maintenance, routine component/equipment replacement (for boilers, gasifies, feedstock handling equipment, etc.), insurance, etc. In the table below (figure 41) the estimated fixed and variable O&M costs for the most common biomass technologies are reported. Available data often combine fixed and variable O&M costs in one number, so a breakdown between fixed and variable O&M costs is often not possible.

	Fixed O&M (% of CAPEX/year)	Variable O&M (USD/MWh)
Stoker/BFB/CFB boilers	3.2 - 4.2	3.8 - 4.7
Gasifier	3 - 6	3.7
Anaerobic digester	2.1 - 3.2	4.2
	2.3 - 7	
Landfill gas	11 - 20	n.a.

Figure 41: Percentage of O&M costs for Biomass power, Black and Veatch source

Here in the following table (figure42) the estimation made in the "Cost report" document (February 2012) sponsored by BLACK & VEATCH CORPORATION is reported: fixed costs are here evaluated with their proper unit of measure and not just in percentage of the Capital expenditures (CAPEX).

Year	Variable O&M cost ($/MWh)	Fixed O&M cost ($/KW-year)
2010	15	95
2015	15	95
2020	15	95
2025	15	95
2030	15	95
2035	15	95
2040	15	95
2045	15	95
2050	15	95

Figure 42: O&M costs for Biomass power, Black and Veatch source

Data refer to a hypothetical biomass plant standalone, if considering a biomass cofiring technology, the variable O&M costs would be approximately 0 $/MWh and fixed costs around 20 $/KW-year.

Geothermal power

Concerning geothermal power, the quality of resources are site- and resource-specific, therefore costs of geothermal resources can vary significantly from region to region. A reduction of cost is possible thanks to the improvements of geothermal fluid pumps and development of multiple, contiguous EGS units to benefit from economy of scale for EGS field development. In the following table (figure 43) there are the predictions for the forthcoming years, following the ideas of the mentioned document by BLACK & VEATCH CORPORATION.

Year	Variable O&M cost ($/MWh)	Fixed O&M cost ($/KW-year)
2010	31	0
2015	31	0
2020	31	0
2025	31	0
2030	31	0
2035	31	0
2040	31	0
2045	31	0
2050	31	0

Figure 43: O&M costs for Geothermal power, Black and Veatch source

Ocean/tidal power

Wave capital cost in 2015 was estimated at 9,240 $/kW – 30% and +45%. This is an emerging technology with much uncertainty and many options available. A cost improvement of 63% was assumed by 2040 and then a cost increase through 2050 reflecting the need to develop lower quality resources. Tidal current technology is similarly immature with many technical options. Capital cost in 2015 was estimated at 5,880 $/kW - 10% and + 20%. More specifically for O&M costs we must include insurance, seabed rentals, and other recurring costs that were not included in the one-time capital cost estimate. In general Wave O&M costs are higher than tidal current costs due to more severe conditions. In the following table (figure 44) there are the expectancies for coming years.

Year	Fixed O&M cost ($/KW-year)
2015	474
2020	357
2025	292
2030	243
2035	203
2040	175
2045	208
2050	273

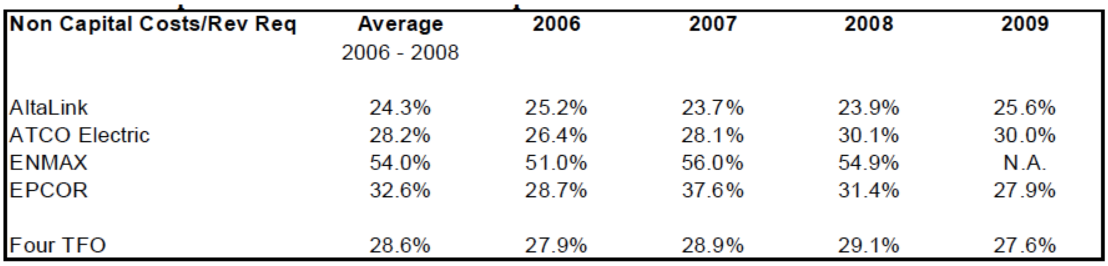
Figure 44: O&M costs for Ocean power, Black and Veatch source

Data are reported from the mentioned “Cost report” document (2012), exclusively referring to ocean wave technology. If considering ocean tidal current technology, estimated costs would be of the order of 120 $/KW-year.

4.4 - O&M costs for transmission and distribution facilities

In the previous paragraph we have studied O&M costs for RE plants. However, when considering a new plant, distribution costs to deliver energy all around this extended territory should not be forgotten. All the distribution system is in charge of the transmission facility owner (TFO) that is to say the energy supplier; so capital costs are not the responsibility of the private parties investing in the new plants. On the other hand, O&M costs and in particular routine and emergency interventions, should be down to private investors. When a problem occurs or some substitution concerning the distribution system is necessary, it is the investing private party, who is responsible and thus even the financing fund (as will be explained in chapter 5), which is responsible for the costs, concerning their part of energy. For this reason in this paragraph, a cost study on the transmission and distribution costs of energy will be shown. The attempt is to show the costs applicable to the private parties which invest in the construction of a RE plant are. These costs will be useful to evaluate, in chapter 5, the economic convenience of the financial models that will be shown. Emergency and routine maintenance costs related to the distribution of energy will be added to costs studied in the previous paragraph 4.3.

Following the guidelines offered by the "Electric Transmission Operating and Maintenance Costs study" report, a document sponsored by the Alberta Electric System Operator in 2009, O&M costs for distribution lines can have both a broad and a narrow definition. In the broad definition all non-capital costs are included in the O&M, comprehensive of other costs such as business taxes. In the narrow definition, the one that will be taken into consideration in this thesis, just costs directly linked to operation and maintenance activities will be considered, excluding overheads associated to these activities. Usually capital costs comprise 70% of the total transmission revenue requirement, whereas non-capital costs are about 30% as shown in the table below (figure 45).



Non Capital Costs/Rev Req	Average 2006 - 2008	2006	2007	2008	2009
AltaLink	24.3%	25.2%	23.7%	23.9%	25.6%
ATCO Electric	28.2%	26.4%	28.1%	30.1%	30.0%
ENMAX	54.0%	51.0%	56.0%	54.9%	N.A.
EPCOR	32.6%	28.7%	37.6%	31.4%	27.9%
Four TFO	28.6%	27.9%	28.9%	29.1%	27.6%

Figure 45: Non-capital costs in % of revenue requirement

Even if it has been stated that O&M costs are usually included in the non-capital costs, according to the mentioned document, capital and emergency maintenance should be considered as capital costs. However, the most consistent impact on O&M is represented by routine maintenance that is accounted for in non-capital costs. "Non-capital costs are predominantly labor costs associated with the operation, maintenance and administration of the electric transmission system and business" (Alberta Electric System Operator, 2009).

Operating and maintenance costs are usually functionalized into 3 different groups:

- **Bulk system**: is defined as the 240 KV and 500 KV transmission facilities, including substations that transform voltage to a lower transmission voltage, for instance 240/138 KV substations.

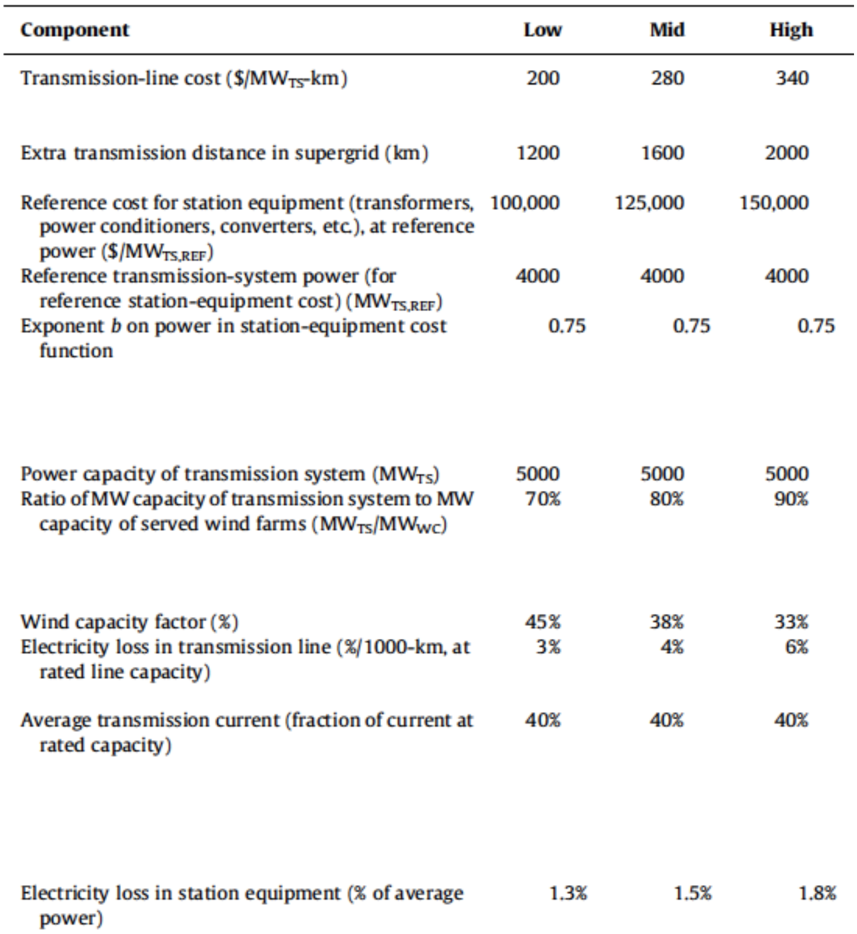
- **Local System**: it consists of the 138/144 KV and 69/72 KV transmission facilities

- **POD (Point of Delivery):** it includes radial transmission lines and point of delivery substations.

This is an interesting subdivision to understand the main parts of an electric delivery system. O&M costs could be allocated depending on the group they belong to; a complete and detailed study has been made in the mentioned report. Nevertheless, for the aim of this thesis, it is not useful to report this analysis, as the objective is to find out the costs of energy distribution that are applicable to the investing private party, these tables will not be reported.

Before focusing on this problem another issue of distribution system should be underlined. The **brushing issue** is certainly an important aspect of maintenance of the entire network structure. Brushing costs are a function of the area cleared and refers especially to the vegetation management. Vegetation management includes many different actions that create some not negligible costs. Examples of vegetation management could be, as mentioned in the Alberta Electric System Operator report: mowing, trimming, spraying, slashing and removal. All these activities involve expense and are priced in terms of area cleared.

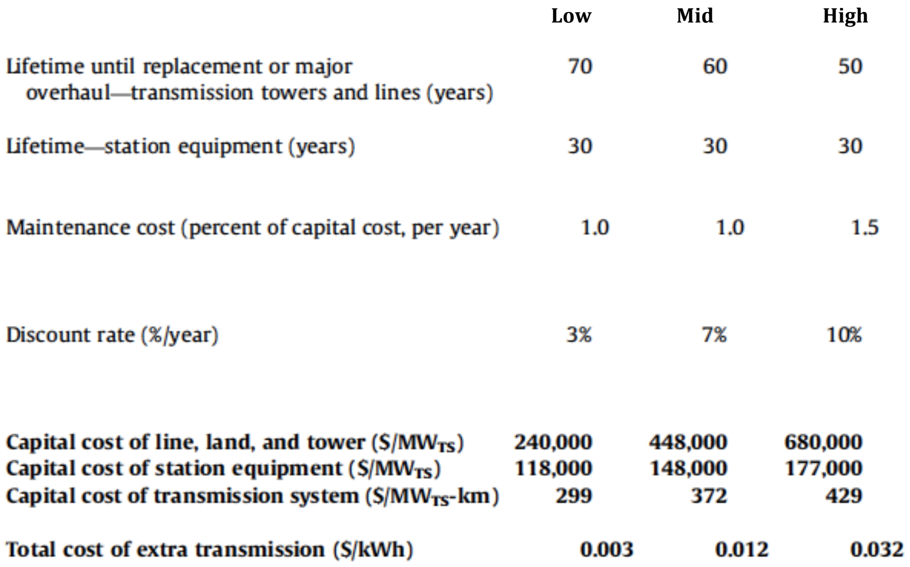
It is now time to focus on the O&M costs that will be used later to evaluate the proposed financial models. The objective has been to find data conforming to the unit of measure used in the previous paragraph so as to have homogeneous data to compare. As has been shown in the cost study for O&M costs of plants, the unit of measure should be $/KWh. In order to find out these data, the ELSEVIER document, already mentioned in the previous paragraph, has been really useful. According to this document, the cost of transmission depends on many factors. The cost of towers, lines, the distance of transmission, the capacity factor and the electricity losses in lines are all elements that strongly affect the total cost of the structure. Moreover, equipment is another relevant item of cost: in particular it refers to converters, transformers, filters and switchgear. Among all these issues, maintenance is not really an influencing item of cost, but certainly concur to increase the total cost of the structure. To estimate the impact of maintenance, and in particular the focus is on routine and emergency one, it is necessary to find out what the total cost of transmission is. To provide these numbers, tables published in the ELSEVIER report have been used. The numbers refers to a long-distance, high voltage (about 500+ KV) Direct current transmission, for a system 100% realized with water, solar and wind sources. As anticipated previously, the main costs concurring to the final cost of the facility are towers, transmission lines, equipment and obviously the cost of the land. According to this document, where many other studies have already been confronted, costs for a 500 KV, 3000 MW HVDC transmission-line can vary from 0,3 million $/km to about 2 million $ /km. Whereas a station equipment cost can vary from $ 200 million to about $500 million. The table below sums up all the influent costs of an energy distribution system. Costs in the table (figure 46) have been estimated in 2007, and present 3 different values as they follow 3 possible scenarios: low, mid or high costs.



Component	Low	Mid	High
Transmission-line cost (\$/MW_{TS}-km)	200	280	340
Extra transmission distance in supergrid (km)	1200	1600	2000
Reference cost for station equipment (transformers, power conditioners, converters, etc.), at reference power (\$/$MW_{TS,REF}$)	100,000	125,000	150,000
Reference transmission-system power (for reference station-equipment cost) ($MW_{TS,REF}$)	4000	4000	4000
Exponent *b* on power in station-equipment cost function	0.75	0.75	0.75
Power capacity of transmission system (MW_{TS})	5000	5000	5000
Ratio of MW capacity of transmission system to MW capacity of served wind farms (MW_{TS}/MW_{WC})	70%	80%	90%
Wind capacity factor (%)	45%	38%	33%
Electricity loss in transmission line (%/1000-km, at rated line capacity)	3%	4%	6%
Average transmission current (fraction of current at rated capacity)	40%	40%	40%
Electricity loss in station equipment (% of average power)	1.3%	1.5%	1.8%

Figure 46: Typical costs of a transmission system, ELSEVIER source

Figure 46 gives an idea of the principal items of costs for the transmission costs of a wind farm. In this example a wind farm has been considered, but the percentage of maintenance costs will be considered plausible also for other RE sources. On the next table (figure 47), still obtained from the ELSEVIER document, the other important characteristics and costs of the structure considered have been estimated.



	Low	Mid	High
Lifetime until replacement or major overhaul—transmission towers and lines (years)	70	60	50
Lifetime—station equipment (years)	30	30	30
Maintenance cost (percent of capital cost, per year)	1.0	1.0	1.5
Discount rate (%/year)	3%	7%	10%
Capital cost of line, land, and tower (\$/MW$_{TS}$)	**240,000**	**448,000**	**680,000**
Capital cost of station equipment (\$/MW$_{TS}$)	**118,000**	**148,000**	**177,000**
Capital cost of transmission system (\$/MW$_{TS}$-km)	**299**	**372**	**429**
Total cost of extra transmission (\$/kWh)	**0.003**	**0.012**	**0.032**

Figure 47: O&M costs and other parameters for a transmission system, ELSEVIER source

In the table above (figure 47) the estimates for maintenance costs have been made. Considering plausible data reported on this table, maintenance costs would be between 1% and 1,5% of the capital cost every year. Chan (2010) states that usually costs are more typically 1%, even if a value of 2% would be ideal. Another aspect that should also be considered is that these estimates have been made for the American market. When concentrating on a developing market, like the African one, values are likely to be higher because of the inexperienced and unskilled workforce that take a longer time for maintenance intervention. For a developing market O&M costs could be considered 2-3% higher than in a developed country concerning energy transmission (NREL source), so in this thesis an **O&M cost** of **4% of capital costs** would be considered.

Some considerations can also be made on the costs, to understand better the whole process of distribution. For instance, the dependence between cost and line capacity has been proved. “Cost decreases with increasing line capacity, which is expected, because higher voltage lines generally have a lower cost per unit of capacity” (M.A. Delucchi – M.Z. Jcobson, 2000).

GE Energy (2010) study has estimated a total transmission-system cost of $ 1600/MW-mile, calculated on 35% of wind and solar power in the western interconnection region of the US. This data is consistent with figure 47 shown above. From this data it has been possible to obtain the value in terms of $/KWh unit of measure. An average of 0,009 $/KWh has been estimated for US projects considered. However, the range varies from 0,001 $/KWh to 0,03 $/KWh and for this reason a value of **0,03 $/KWh** will be considered for this thesis, also consistent with the high scenario shown in figure 47 above. Thus, costs of maintenance that will be used in the following part of the thesis will be the 4% of 0,03$/KWh, it is to say 0,03 *4/100 = 0,0012 $/KWh = **1,2 $/MWh.** It has been decided to convert this value into $/MWh to make it comparable to the values of plants variable costs in paragraph 4.3. This value has to be added to the plant O&M costs and has to be the responsibility of the private parties (and therefore the investing funds) that finance the construction of new plants. This value will be useful in chapter 5 when an evaluation of new models proposed will be made.

4.5 - Data homologation and standardization: analysis

In this paragraph some evaluations on the data collected will be made, to make them useful for the purposes of this thesis. The purpose, as has already been stated, will be to evaluate some financial models to finance O&M costs related to the specific project "Power Africa" and thus, to propose a new way to include these costs in the initial evaluation of a project. In order to do that it is important to give an evaluation of the RE sources costs for a 20-year period, as the lifetime of the new plants will be considered of this length. In paragraph 4.3 and 4.4 the forecast for the coming years has been made by some authorities for the future years.

Firstly, the focus has been on plants O&M costs and then some integrating reasoning on distribution costs have been made.

Plants Costs

To make this data useful the use of the Excel software has been convenient.
Firstly, data collected in paragraph 4.3 have been reported on an Excel sheet. Then RE sources have been grouped for similarity of costs. Four groups have been found.

1- Solar and wind

These sources comprehend just fixed O&M costs. The values collected in paragraph 3.4 have been displaced on a chart to make the trend clear (figure 48).

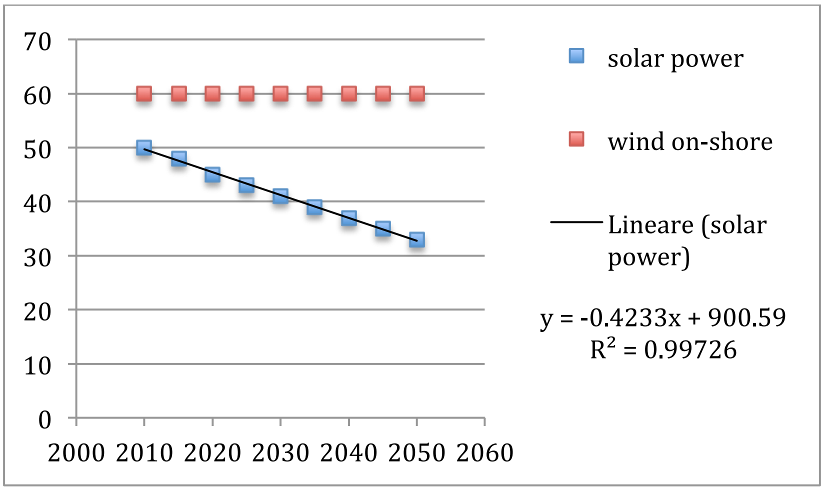
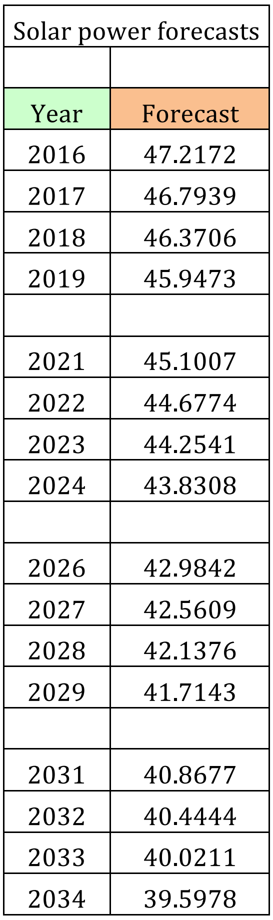


Figure 48: Solar PV and Wind on shore trends

In this example just on-shore wind has been considered, but even considering off-shore wind the constant trend would have been similar, just with higher values (according to the Cost Report by BLACK & VEATCH CORPORATION). Solar power shows an interesting trend that has been further analyzed. As can be seen in the chart above, it shows a decreasing trend that reflects what has been stated previously. Indeed, solar power is not yet mature and competitive and thus costs would decrease in the following years. The estimation is that costs would decrease by nearly 40% in the next 40 years. A linear trend has been hypothesized in this thesis. A liner correlation line has been created and the R^2 coefficient has also been calculated in the chart. As can be seen the coefficient is really high that means that almost all the variance can be explicated by this linear trend and therefore, the hypothesis of a linear correlation is consistent. It may be noticed that to use a regression model the data available should have been a lot more. Here in this thesis it has been decided to use this model because the data collected are comprehensive of all the variations of the next 40 years. This means that data have been supposed to be more than they actually are, because the forecasts implicitly consider the yearly variations of the next 40 years. Moreover, the hypothesis of a linear decreasing trend has also been found in many documents and thus it has been considered consistent. Once the linear correlation has been found, the data year by year have been calculated. This data will be useful in chapter 5 to evaluate the models and are reported in the table below. To calculate the data the formula $y = -0{,}4233\,x + 900{,}59$ has been found thanks to the Excel software, which has been used (see figure 49).



Solar power forecasts	
Year	Forecast
2016	47.2172
2017	46.7939
2018	46.3706
2019	45.9473
2021	45.1007
2022	44.6774
2023	44.2541
2024	43.8308
2026	42.9842
2027	42.5609
2028	42.1376
2029	41.7143
2031	40.8677
2032	40.4444
2033	40.0211
2034	39.5978

Figure 49: Solar PV forecast for missing years

The data for years 2020, 2025, 2030 and 2035 have not been estimated because the forecast made by BLACK & VEATCH CORPORATION reported in paragraph 4.3 will be considered. The forecasts in paragraph 4.3 go until the year 2050, but the estimation in the table above has been made until the year 2035 as the lifetime to be considered is just of 20 years (from 2015 to 2035).

On the other hand wind power does not need a further elaboration of data as a constant value of 60 $/KW-year will be considered.

2 - Geothermal

Geothermal energy presents just variable costs that will be stable for the next 40 years at a level of 31 $/MWh (see paragraph 4.3).

3 - Hydro and Biomass

Hydroelectric and Biomass have been grouped together because they comprehend both variable and fixed O&M costs. As shown in the chart below (figure 50) the impact is really different for the two sources.

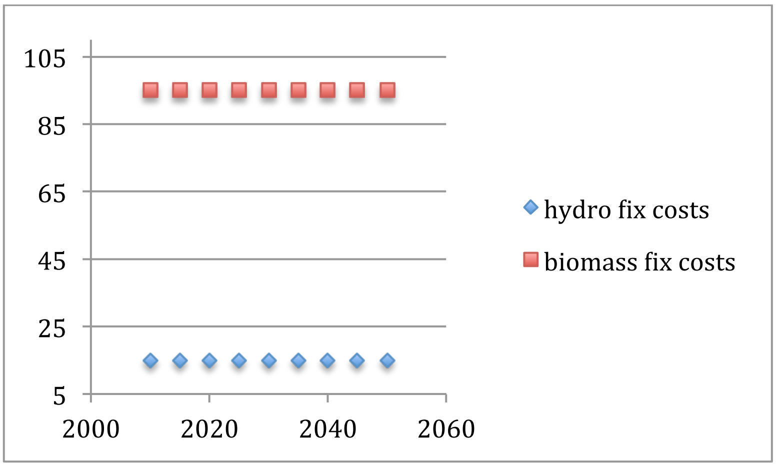


Figure 50: Hydro and Biomass trends

In the chart (figure 50) only fixed costs have been reported. As can be seen from the chart Biomass source presents the higher fixed costs, even if compared to Solar and On-shore wind in figure 48. Whereas, Hydro power has the lowest fixed costs, consistent to the fact that, as stated previously, it does not need a lot of maintenance and it is the most mature technology.

4 - Ocean, tidal power

Ocean and tidal power have been grouped as a stand-alone category because, although they are affected by only fixed O&M costs, the trend shown is peculiar. As shown in the chart below (figure 51) cost estimations will follow a parabola trend.

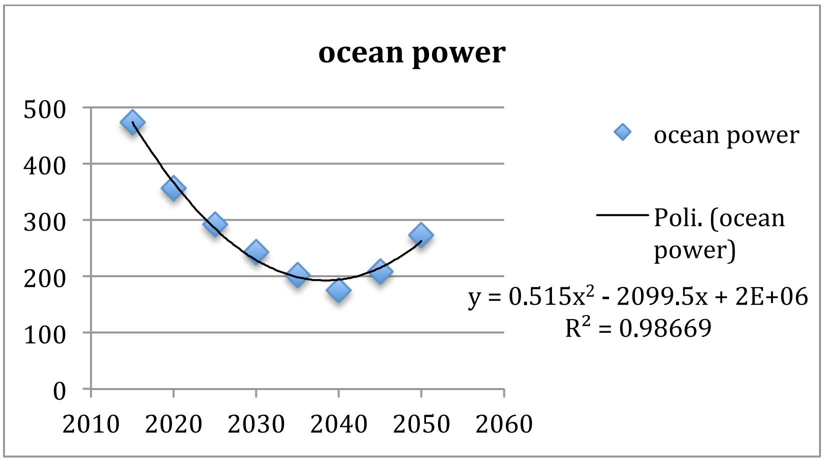


Figure 51: Ocean power trend

The chart above (figure 51) refers only to ocean power, but similar considerations can be made for tidal power too. Estimates made by BLACK & VEATCH CORPORATION and reported in paragraph 4.3 suppose a continuative decrease of costs until the year 2040 and then a re-increase of costs until the year 2050. The reasons for this particular trend have been explained in paragraph 4.3. Similar to solar power, a forecast for each year for the next 20 years could have been made, making the same assumptions concerning the use of a correlation line made for solar power. The R^2 indicator is really high and, therefore, it reflects the parabola trend. Here the estimates have not been performed because the evaluation of the financing models that will be shown in chapter 5 will be made just for solar and wind power, and therefore it is not necessary to obtain data for every year of the next 20 years.

Plant O&M costs have been further analyzed in this paragraph, in particular the most useful data for the continuation of the thesis will be the one referring to wind and solar power as anticipated. These data will be used, together with data referring to the distribution of energy, to evaluate the new financing models.

Distribution costs

A deepened analysis of distribution costs has already been made in paragraph 4.4. Consistently with what has been stated, maintenance costs accountable to the private parties investing in the new plants will be 1,2 $/MWh. This means it has little impact on the whole O&M costs structure. The estimate of this number has been made consistently with the information obtained from the NREL study on many wind farms in USA. For the continuation of the thesis, and thus for the evaluation of the models in chapter 5, this will be considered an annual and constant cost for the 20 years considered. The value of **1,2 $/MWh** will not vary during the 20 years for two main reasons. The first reason is that distribution facilities are a mature technology so their costs are unlikely to vary over the years. The second reason is that a reliable forecast is not available on the market and therefore this value has been considered constant. Even if a small percentage of error is present, this will not affect the future evaluation of the financial models, because the impact of the costs is limited. As a matter of fact, comparing this value to variable costs of hydro, geothermal or biomass sources, it is by far the smallest number. This is consistent with the fact that private investors should be in charge of the construction of the new plants and they should contribute to the cost of distributing energy only in a minimum part.

CHAPTER 5 - Financing maintenance during the plant lifetime

This is the final chapter of the thesis. In this chapter the attention will focus on the financing strategy for O&M costs. Thus, it can be considered the chapter that fulfills the objective of the paper. Once analyzed in chapter 4 the costs structure and values for both RE plants and energy delivery systems (transmissions and distribution costs), here in chapter 5 a proposition of new models to finance these costs will be shown. These models are innovative ways that, consistent with the present financial scheme, try to develop innovative solutions to take into consideration, since the early stages of the project, O&M costs. This is an innovative solution, as usually O&M costs are paid back through the sale of energy (see paragraph 3.4). Once the new models have been described, they will be analyzed with their pros and cons to take also qualitative aspects into consideration. A paragraph is also dedicated to the training issue as will come out in the following pages. It is an important issue to be managed when considering these new models. And finally a quantitative evaluation, using the data of chapter 4 has been made to try and describe with models which would be more suitable for the “Power Africa” project or in general for similar projects in the future.

5.1 - New financial options for maintenance

In this chapter the goal will be to find out new possible financing techniques to provide sufficient capital to support, not only the capital expenditures related to the construction of the new plants and transmission facilities, but also to predict a method to finance O&M costs during all the plant’s lifetime.

These two categories of costs are completely different, as capital costs for the construction have an impact on the balance sheet of the local utilities investing, whereas the O&M costs have a direct impact on the income statement and therefore on the income of the companies. Finding a new financing strategy for these costs is fundamental for the project we are taking into consideration, as it includes many peculiarities. In developed countries, usually the investors plan to repay the O&M costs through the sale of energy. This means that every year part of the income is designated to finance the ordinary and extraordinary maintenance procedures. In our context, two factors allow us to look for new models to finance this costs:

1 - Uncertainty about the energy sale

In Africa, as in other developing continents, there is not the full certainty that all the energy produced will be sold. International public financing is used to guarantee the construction of all the infrastructures to produce and distribute energy throughout all the African territory. However, the point is, we cannot be sure that the energy produced will be actually sold and exploited by the African population. This point introduces a strong risk issue to be considered and hedged. We cannot afford, in the planning phase of the project, to rely on the income derived from the sale of energy. This is why since the first phase of planning, it is interesting to include all the O&M costs that will affect plants and transmission utilities during their entire lifetime. Taking into consideration these costs from the very beginning and developing a new model, the risk of not having enough money to provide maintenance would be avoided. Unfortunately, in developing countries, this risk largely affects the investment schedules and models.

2 – Money guaranteed by international public funding

Two of the major sponsors of these energy projects in developing countries are the World Bank and the IMF (International Monetary Fund). These authorities guarantee to fund back all the investments that private parties make to build up the entire expected energy network in Africa. These authorities will cover all the costs and therefore, give us the opportunity to include and estimate from the planning phase, all the O&M costs that the entire network will need. The certainty that local utilities can rely on this money arouses the interest in another direction. The problem is no longer, where to find money, but how to use this money and following which kind of financing scheme or tool.

As a result of these two points, the opportunity to develop new models to finance these costs arises. The scope of this chapter, and probably the most innovative part of my thesis, consists in proposing new ideas on how to include these costs at the very beginning of the planning and through which financial model these costs could be financed and returned to the private parties that invest money for the construction and maintenance of the entire system.

O&M costs, deeply studied in chapter 4, must be distributed along the whole lifetime of the plants. For this purpose, **20 years of lifetime** could be considered a realistic forecast especially focusing on the maintenance needs. This means that for 20 years there is a plan of maintenance already scheduled and defined since the very beginning of the project.

To provide new solutions to the financing scheme for the O&M costs of the plants and network, it is important to understand how nowadays the process of capital financing of the process has been structured (see figure 52). That is to say, how capital expenditures (CAPEX) have been financed. Once it is understood how these expenditures are financed, some considerations and hypothesis can be made to reach a new model that also includes O&M costs.

CAPEX financing

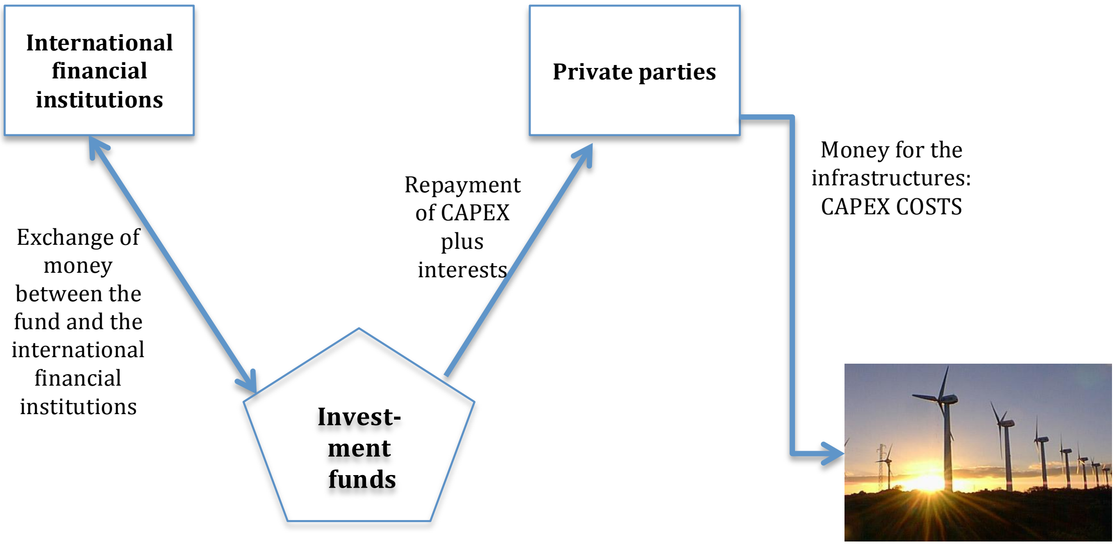


Figure 52: CAPEX financing scheme for new projects in Africa

In this model we can see 3 players involved. This is the classic scheme used to finance the capital costs for the new infrastructures.

Private parties: they are the subjects that invest for the construction of the new facilities. They can rely on the money guaranteed by the international financial institutions. They invest money that will be repaid by the international authorities, as assumed before, in 20 years. They relate to an investment fund appointed for this project.

Investment funds: they act as a mediator between the international authorities and the local utilities that have to be financed. It collects the payments comprehensive of the interests from the international authorities and addresses them to private investors, year after year.

International financial institutions: they finance the whole capital investments with the support of an investment fund. They guarantee the money that has been allocated for the "Power Africa" project. They are also in charge of the interests of a 20 year loan.

The repayment scheme for the private utilities would be the following one:

$$-CAPEX + \frac{\frac{CAPEX}{20} + INTERESTS}{(1+WACC)^1} + \frac{\frac{CAPEX}{20} + INTERESTS}{(1+WACC)^2} + \cdots + \frac{\frac{CAPEX}{20} + INTERESTS}{(1+WACC)^{20}}$$

Where CAPEX are the initial investment of the private utilities, INTERESTS will be gained together with capital tranche every year from the international authorities, as considered for the "Power Africa" project. WACC is the weighted cost of capital to actualize the value to the present value. Every year a constant part of capital repayments is paid back to the private investors, which is the reason way every year a CAPEX/20 payment is planned. Interests will decrease over the years because the outstanding debt decreases year by year.

Once the streamlined mechanism through which the capital costs are financed is understood, it is time to introduce the O&M financing issues. The two following schemes are two options that could be taken into consideration to finance the O&M costs in an innovative way.

1st Option: including the O&M together with capital costs

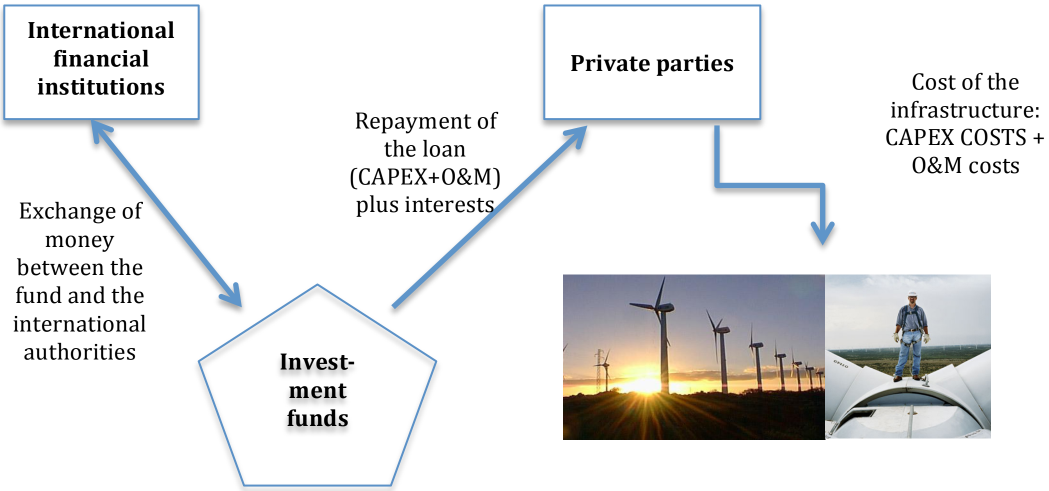


Figure 53: O&M costs financing scheme: first option

In this model (figure 53), there are three players. The difference would consist in including the forecast of the O&M costs in the total amount that will be paid back by international authorities. In this particular case, private investors would make the forecast and plan of the O&M costs. These actors have to estimate all the needs that the structures will require during all the lifetime of the facility. Once these costs are predicted, the loan would comprehend both capital and O&M costs. The financial repayment scheme would be unvaried compared to the one above, with the addition of these costs.

$$
\begin{aligned}
-CAPEX - Tot.O\&M\ costs &+ \frac{\frac{CAPEX}{20} + \frac{O\&Mcosts}{20} + InterestsCapex + Interests\ O\&M}{(1+WACC)^1} \\
&+ \frac{\frac{CAPEX}{20} + \frac{O\&Mcosts}{20} + InterestsCapex + Interests\ O\&M}{(1+WACC)^2} + \cdots \\
&+ \frac{\frac{CAPEX}{20} + \frac{O\&Mcosts}{20} + InterestsCapex + Interests\ O\&M}{(1+WACC)^{20}}
\end{aligned}
$$

As in the CAPEX financing scheme, all the money is given in the very first period that will be later called T_0. In this case, the addition of O&M costs must be considered. Regarding the repayment scheme, the considerations made above are still valid.

The most important consideration about this model is the initial disbursement that private parties would have to provide. Considering the evaluation of O&M costs made in chapter 4, this would consist in a consistent increase of initial investment, also increasing risks and financial exposure. Thanks to the importance of the sponsors and international authorities taking part in this project, this amount will surely be repaid within 20 years, and this is the reason why this model is actually a possible option to take into consideration.

-2nd Model: a new fund intervention

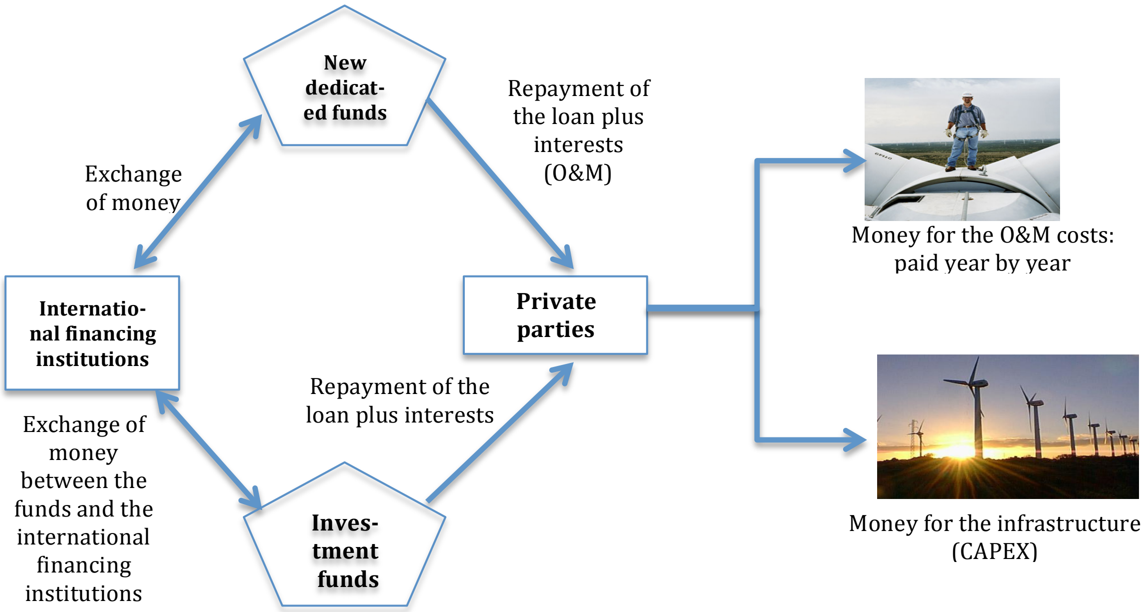


Figure 54: O&M costs financing scheme: second option

This model (figure 54) proposes to announce the most innovative model because it is detached from the classic framework, still present in model 1.

In this new model a new actor appears, a new fund that should deal with only O&M costs. In this new perspective, the new-dedicated fund would repay money year after year just for the quantity necessary to meet the maintenance and management cost needs. The availability of money is a guarantee as always, by the international authorities taking part at the "Power Africa" project. This new model would lead to pros and cons.

Pros → the management of the operative costs would be detached from the capital costs and therefore, can be managed in a more appropriate way. Moreover, the forecast of all the O&M needs for the entire lifetime of the structures would be in charge of the new fund. Once the forecast is made, the fund would try to save money in the maintenance and management operations, so as to save money and receive a higher return from the utilities than the quantity foreseen. Indeed, the repayment scheme for the utilities would be based on the forecast made by the fund, if the costs were actually lower, this fact would imply an income for the fund. Finally, through this method, the initial investment would be lower, because money would be invested year after year and there would not be an initial disbursement that covers all the future costs. This in turn gives the possibility to readapt the need of money year after year in case of bad forecasts.

Cons → This model considers a new actor in this financing scheme. It introduces all the problems of coordination that arise when adding a new figure to be part of an already complex framework. There would be a higher complexity in managing the different players connections. Moreover, this would be a completely new model, which carries together with it the uncertainty of effectiveness and the problem of benchmark when you propose something that has never been done before. Great flexibility is required to figure out and solve problems that undoubtedly would come out when using a new model.

Differently from the other repayment schemes, here we would have two different cash flows, which would finally merge into the international sponsors, but until then the 2 flows would be completely separated. The first flow would be exactly the same as in the case we are just financing CAPEX, and would be managed by the investment fund also considered in the other options.

$$-CAPEX+\frac{\frac{CAPEX}{20}+INTERESTS}{(1+WACC)^1}+\frac{\frac{CAPEX}{20}+INTERESTS}{(1+WACC)^2}+\cdots+\frac{\frac{CAPEX}{20}+INTERESTS}{(1+WACC)^{20}}$$

The second one refers only to O&M costs and the new dedicated fund would be in charge of it.

$$-Forecast_{O\&M}\ year\ 1+\frac{Forecast\ year\ 1+INTERESTS}{(1+WACC)^{1}}-\frac{Forecast\ year2}{(1+WACC)^{1}}$$
$$+\frac{Forecast\ year2+INTERESTS}{(1+WACC)^{2}}-\frac{Forecast\ year3}{(1+WACC)^{2}}+\cdots$$
$$+\frac{Forecast\ year\ 20+INTERESTS}{(1+WACC)^{20}}$$

As has been previously stated, this new model would avoid a great initial expenditure for the private utilities regarding the O&M costs, and moreover the fund would be the owner of the forecast, differently to what happens in model 1, with the possibility to achieve the difference from the actual costs and those forecasted if the costs are lower.

In the following part of the chapter my objective would be to evaluate which model would be more convenient for the private investors of the project, analyzing for both solar and wind power which is the most convenient option. The cost study in chapter 4 will be used to find out the most profitable option.

5.2 - New models issues

Before starting the evaluation of which of the models proposed is the most convenient for the companies involved and investing in this project, it is interesting to consider some of the issues related to the 2 different proposals made. These two models bring with them some general considerations that are important to clarify before proceeding with an economic and total evaluation of these opportunities. The evaluation of the convenience should be made not only considering the economic evaluation but other soft aspects, such as ease of implementation, hidden costs, and management difficulties. All these factors should be considered when taking the decision of which of the two innovative models should be implemented. After the two different models are examined in order to highlight their key points to be considered. The classification of the various issues is made as a comparison between the 2 options given.

<u>Maintenance plan</u>

First option: private parties should schedule the maintenance and all O&M costs for the entire lifetime of the structures, considered as being 20 years. Before investing in the construction costs (CAPEX), they should also provide their forecast concerning all these costs.

Second option: considering this option, the maintenance plan would be in charge of the new fund. The new fund would have the possibility to estimate the needs for the O&M costs that WB and IMF will finance in the next 20 years. This would be an opportunity to take the whole process of estimation under control and not incur exaggerated estimation by the private parties. In the previous model the private party would have the possibility to inflate the forecast to receive more interests every year. With this option the fund is the owner of the process and interests will be paid back year after year based on the capital quote estimated by the fund itself. Moreover, the fund has an additional opportunity from this mechanism. If the actual expenditure of the fund is lower than the predictions, it would lose something paying more interest to the private parties, but on the other hand it would gain the difference from the actual costs and those forecast as a profit for the fund. The loss on the interests is likely to be lower that the profit on the lower O&M costs.

Routine and emergency maintenance

First option: this is a critical issue for both models. The idea is to leave the private parties in charge of the routine maintenance at least for the first years. After a while, for example 5 years, the routine maintenance could be delivered to the African utilities that manage the plants. Emergency maintenance is strongly related to the urgency of the intervention needed. For some specific and fundamental components, such as the gearbox for wind farms, to stock the component in loco could be a plausible solution. The locals would provide the maintenance operations needed, but on the other hand, their competence in managing and installing such delicate components should be tested. More realistically, the supplier is likely to be more reliable in managing his own product. Nevertheless, for both routine and emergency maintenance, a strong **training** section for local African parties seems to be necessary.

Second option: the same line of reasoning for the first option is still valid for this one. Moreover, it should be considered that in this option the forecast is made by the fund and not by the private party that will also manage the maintenance having a direct connection with the supplier of the components. In this second model the fund would probably need a third part to predict the costs and then to manage the connections between the supplier of the components (which usually makes the maintenance operations) and the private parties that built the structures. Private parties would not gladly accept that a third party makes the forecast and then is not directly involved in the process of maintenance. In addition, the fund would incur higher costs due to delegating the estimate of O&M needs and the project management process to a third party. These extra costs could be considered as 0,5% of the total maintenance costs (NREL source).

In both options, the importance of a solid **training program,** for local African parties, is very important. This particular aspect will be evaluated better in the next paragraph.

Initial investment

First option: this model requires a high initial disbursement as private parties would provide all the necessary capital to finance construction costs (CAPEX) immediately and furthermore O&M costs, all at T_0 year. This increase of costs probably makes this model suitable for big companies, which can afford to invest a lot of money on the project immediately. Small and medium size companies, as the additional costs for O&M is relevant (see costs study in chapter 4), are not likely to have enough resources to invest immediately on CAPEX and O&M. This possibility must be further examined through a cost analysis. There is the possibility that this model would be discriminating for the dimension of the companies taking part in the project, big companies would have the possibility to get richer and bigger.

Second option: in this model, the initial expenditure would be lower considering that just a little part of the O&M costs would be included in the CAPEX investment at the T_0 year. This innovation would give an opportunity of just a slight increase of initial effort, as therefore also medium and small sized companies would be able to take part in the project, having the possibility to develop and increase. Of course big sized companies would still lead the majority of the work to be commissioned, but considering the dimensions of the infrastructures that the project aims to build (medium size and well distributed to cover large part of the territory), even medium- small companies would consider participating.

Repayment scheme

First option: following this model, the investment fund would pay back the interests through a constant capital quote (QC in the chart below) every year, equal to 1/20 of the total expenditure. The installment (Rata in the chart below) would decrease year after year as interests received from the private parties, which would probably prefer a fix installment repayment so as to receive the same amount of money each year. Moreover, with a fixed installment scheme they would be repaid initially only with the interest and the capital quote would be repaid in the last periods. The sequent chart (figure 55) shows the repayment scheme that would follow this model.

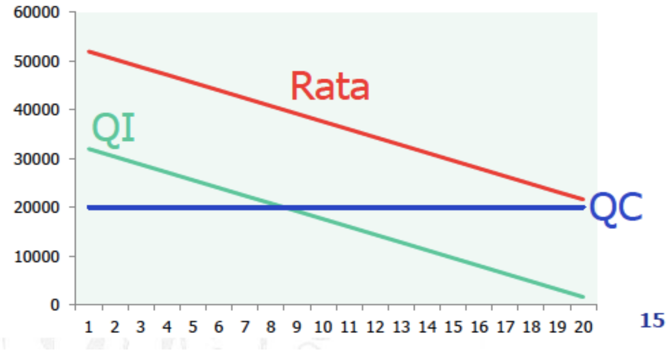


Figure 55: Interests, Capital and Installment payments for a constant capital disbursement financial scheme, Politecnico di Milano source

Second option: in this second model, the repayment scheme is for sure really innovative. Indeed, private parties could use the money that they get from the fund every year together with interests, to finance the O&M costs of the following year. This mechanism would guarantee at least a partial recovery of the yearly expenditures for the O&M costs by the private parties. What would realistically happen would be that only the difference between the forecast and the yearly amount from the fund would be paid. It would be a kind of self-financing if the 2 flows would be equal and the disbursement would be tolerable for privates. If the forecast decreases over the years, private parties would eventually even earn extra money (in addition to the interests) from this process. Although this is not realistic as maintenance interventions would probably increase with the passing of time.

<u>Interests</u>

First option: the point is how to select the interest rate that should be applied to the financial scheme. In this first option the interest rate for CAPEX and O&M will be likely to be the same, as the entire amount is considered as a whole, managed by the same fund and repaid by the WB and IFM. A fixed rate seems more appropriate for long term guarantees to be covered from the fluctuations of indexes compared to a floating rate.

Second option: considering this option, the interests flow for O&M costs would be completely separated from that of CAPEX, as they are managed from a different fund. For this reason different rates for CAPEX and O&M may be considered, depending on the characteristics of the funds involved. Moreover, while for the interests paid on the CAPEX is still appropriate to consider a fixed rate (long-term strategy), for the O&M flows interest is paid on the capital quote of the previous year and that is why a floating rate may be considered. Nevertheless, for the scope of this thesis, the analysis would be carried out considering a fixed rate for this second option as well.

As declared in the "Financing Renewable Energy project" document, 2000 (DTI: Department of Trade and Industry) usually a floating rate is provided by lenders and varies with, for example, changes in Base Rates or in LIBOR (the London Inter-Bank Offered Rate). However, when it is important for the economics of the project that interest rates are fixed, this can often be achieved by purchasing financial instruments such as swaps from banks. That is the reason why, for the scope of this thesis, a fixed rate like a swap tool will be used. Coherently with the GSMA document – Green Power for mobile by Areef Kassam: a real annual interest rate (nominal interest rate minus inflation) of 10% has been considered, which is a common value in many developing countries.

WACC

First option: concerning the weighted average cost of capital, it depends on the characteristic of the single company investing in a project. In particular on the quantity of equity and of debt capital each single company is structured on. Therefore, an average value of the sector will be considered to conclude the study.

Second option: the same considerations used for the first option could be made regarding this issue.

WACC depends on the level of Equity and of debt capital of a company, but it is also influenced by the risk of the business and other factors. For example, as reported by the Greenrhinoenergy group: "The WACC is influenced by the level of maturity of technology, the predictability of the energy yield, the fuel supply risk and also the policy risk. The risk of solar PV is particularly low because the forecast of energy yields of solar modules is more accurate than for other sources".
In this study a value of 6% will be considered for the Solar Power and 7% for the wind power (figure 56) (source: Greenrhinoenergy).

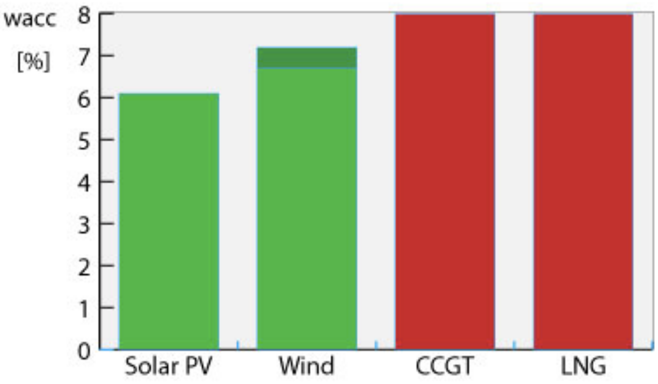


Figure 56: Typical WACC for RE source, Greenrhinoenergy source

5.3 - Focus on the training

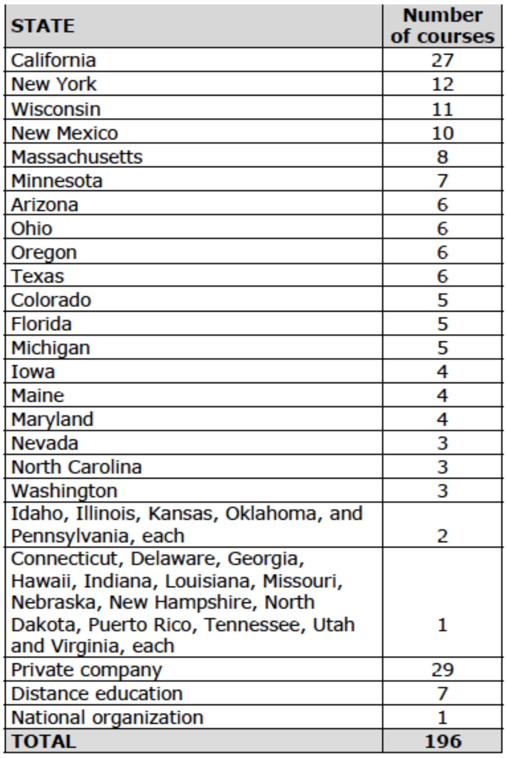
As anticipated previously in the text, one of the main concerns related to the new models proposed, is the training of the local workforce. This is a fundamental aspect, in particular related to the routine maintenance, because it would guarantee the creation of skilled local maintenance that could take care of the reliability of the structure for its entire lifetime. This point would mean that private American investors (private parties), would not just construct the infrastructure and then manage it as if they were in the USA, but there is a program to help develop the local utilities to give them the possibility to deal with such issues. They will have the possibility to provide the necessary safety and intervention when needed for the entire lifetime of the plant. Of course that would need a few years of hard training programs to give them the right competence to deal with all the maintenance issues. The idea is to organize during the firsts years some courses in loco to make sure local utilities really understand how the job should be done. Moreover, as the routine maintenance program would be scheduled (by the privates parties in the first option, by the fund in the second), for the first years when the skilled personnel would come to operate in the structure, the local African party that would be in charge in the following years of the maintenance process, will be assisted by the skilled technicians and learn from them in a sort of learning-by-doing process. The maintenance experts must be understanding and available to teach the futures owner of the process.
According to the CEC (Commission for Environment Cooperation) there are 2 issues why it is difficult to expand the maintenance support through the existing training programs to another region:

- The market is not yet sufficiently established to give a clear signal to academic institutions and potential students that this is a viable field for employment. For many institutions, this means that investing the resources to establish themselves, as providers of training in the field of renewable energy, may be too risky.

- There is growing concern that the lack of availability of skilled labor may create a bottleneck in the expansion of the industry, if rapid growth continues without a focused recruitment strategy in place.

The last point highlights the need to create a valuable recruitment strategy on-site, to give creditworthiness to the entire project for the future years.

The USA already offers many courses to provide and develop the knowledge on this topic, following the study of 2010 by CEC there were 196 available courses so distributed:



STATE	Number of courses
California	27
New York	12
Wisconsin	11
New Mexico	10
Massachusetts	8
Minnesota	7
Arizona	6
Ohio	6
Oregon	6
Texas	6
Colorado	5
Florida	5
Michigan	5
Iowa	4
Maine	4
Maryland	4
Nevada	3
North Carolina	3
Washington	3
Idaho, Illinois, Kansas, Oklahoma, and Pennsylvania, each	2
Connecticut, Delaware, Georgia, Hawaii, Indiana, Louisiana, Missouri, Nebraska, New Hampshire, North Dakota, Puerto Rico, Tennessee, Utah and Virginia, each	1
Private company	29
Distance education	7
National organization	1
TOTAL	**196**

Figure 57: Number of O&M training courses for each American State, CEC source

From this table (figure 57) it is easily understandable how the preparation of the private parties can be really performing. The challenge would be to transfer the same preparation and skills to the local African parties that will be in charge of the maintenance program for the entire lifetime of the plants. These courses should also be organized on site, where local utilities have an easy access and should be paid by the private American parties, as they would do for their employees. The costs would be repaid and included in the total amount of the O&M costs that the WB and the IMF will pay back to the investors.

Going deeper into the job training, it should be stated that this program is already developed especially for wind and solar power. According to a study developed by The Delphi Group, most firms provide training either internally or on the job in order to develop the required skills.

Concerning solar power, in some cases the companies ask for some trade schools (electrical or mechanical) to prepare the personal for them or in some cases companies could also train some skilled engineers themselves for more specific skills for the solar power.

In the wind power industry, the major players, such as GE (General Electric), already offer their own internal and very structured training. Still following the Delphi Group study: “some firms focused on design and installation activities send staff on solar certification courses, while some manufacturers send staff for other forms of training, such as software and design.”

It is now time to try and evaluate the costs of training. To make the importance of such activity clear it is herewith reported a sentence from John G. Schuster, president and CEO of American Trainco Inc., which appeared in an article of 2011 for EHS Today: “Total business losses in industry due to downtime alone are estimated to be nearly $50 billion per year worldwide, and studies show that 60-70 percent of that downtime is caused by human error. In other words, these losses primarily are caused by improperly trained maintenance personnel.”

This is to give an idea of the importance that correct training would have on the total costs of maintenance, in particular if it affects the poorly skilled maintenance personal of a developing country.

As reported in the same article, the effort made on a good training program, so as to reach a proactive maintenance way of thinking inside the company could bring many benefits, for instance 20% reduction of the overall maintenance costs, and 15% increase of the productivity. This proactive maintenance thinking could be reached through an effective training system. The best way to change the way of thinking of the personnel into a proactive way of thinking is the training, as gaining this knowledge requires education and the most efficient and time-saving form of education is training received from others who have already experienced the job. To evaluate the benefits of a good training better the **cost of failure** (CoF) should be considered: that is to say the downtime cost that a company experience every year and at what cost. Moreover, the **benefits of success** (BoS) should be calculated: that is to say the cost saving that is possible through an effective maintenance program, in a dollar-based benefit and lastly the **cost of training** (CoT) should be calculated. To reach the total dollars saved just take the CoF add the BoS and subtract the CoT (as explained in the article by EHS Today, 2000, http://ehstoday.com/training/news/training-and-value-reducing-maint-cost-0701).

$$\textbf{\textit{Dollar saving}} = \textbf{\textit{Cof}} + \textbf{\textit{BoS}} - \textbf{\textit{CoT}}$$

Focusing on the cost of training it should be comprehensive of instructor/facilitator fees or salaries, course materials/videos/workbooks, equipment rental/use, facility rental/use, the cost of employee "time off" for training, travel that in our case would be an important entry considering the distance to be covered, administration costs and training design or curriculum development if required.

These are the main points that should be considered when evaluating the cost of training, however it should result as a small percentage of the total cost of downtime.

According to the CEC document, Renewable Energy Training Resources - Survey and Assessment, there are several factors that affect the expansion of the current maintenance and installations programs. The study of the document mentioned refers to the training programs in North America, but some aspects are certainly valid and even more suitable for the projects in Africa: in particular the need for local specific programs for RE markets. Moreover, considering that the market has not established itself sufficiently, a specific and detailed training is required and not just some general elements and an overview on the technologies to be used. A local recruiting strategy, as has been suggested, becomes a key point: the rapid growth of the RE market especially in developing areas, may cause the unavailability of skilled labor and thus the training for African parties must be developed. This means intensifying the courses and developing more appropriate and specific ones, for instance as suggested by the document mentioned, there are just a few PV-related courses. The actual needs of the market should be considered, a specific training program related to the "Power Africa" project should be planned better, the benefits of a functional program have been discussed and the gap between the offer and the actual needs is consistent. Another important point would be the presence of adequate and professional trainers. As suggested previously, in accordance with this project, the training could be held by the private parties maintenance operators who, when scheduled, would go on-site and would teach this task (for the firsts years) to the locals. The teaching competences of these operators are to be guaranteed if the effectiveness of the program must be protected. This new program would be an innovation and therefore the procedures would be standardized and collected for other possible future programs. The shortage of standardization and reference is evident in this field. Of course, as suggested in the mentioned document, to ensure that these workforce development efforts are successful, the **policy system** should be powered for the investors who support the creation of this capacity. Some more grants or incentives should be placed on this market. All the new programs developed should follow the existing **best practices** and further the possibility to implement **new courses** or to perfect the existing ones should be evaluated. However, every course should be **certified** and conform to the existing **best- practices institutions** such as the Institute for Sustainable Power Quality (ISPQ). In order to be successful a training program should receive the **input from the industry** stakeholders, to be sure of a development and to be aligned on the goals of the industry. Finally, an **online platform** may be built to help and support the online training capacities. As mentioned in the document related to the Mexican market, it would be useful for the African market as well, to help from a distance the African operators and to develop the RE training market.

5.4 - Evaluation of the two options from an economic point of view

It is now time to make an evaluation of the models presented in this chapter. The evaluation will be carried out considering just two renewable sources that is to say solar and wind power, as previously stated in the text. The data considered will include all the considerations made in chapter 4 about O&M costs for solar and wind power. Moreover, some other data and consideration need to be made in order to evaluate successfully the relevance of the models. The two case studies will be analyzed, the first concerning a solar PV field in Ghana whereas the second includes data related to two wind farms in Ethiopia.

Solar Power in Ghana

In Ghana a solar photovoltaic field called Navrongo (Ecowas source) has been installed with the power capacity of 1,92 MW. This is the only Photovoltaic field connected to the distribution grid in Ghana. During this reasoning, the stand-alone plants will not be considered. Thanks to the EIA (U.S. Energy Information Administration) data related to the Total Electricity Capacity Installed and to the Total Electricity Net Consumption for each country in Africa have been collected. In Ghana the Total Capacity Installed is (in 2011) 2,18 Million KW that is to say **2180 MW**. Comparing this value with the **1,92 MW (1920 KW)** of the solar PV field, the impact of solar on the entire network in Africa becomes clear. 1,92/2180=8,8074*10^-4 → This means that just a 0,088% of the energy in Ghana can be accounted for on the solar source. Following this reasoning the energy demand that should be fulfilled through the solar field would be just 0,088% of the total Ghana demand which is **8,238 Billion KWh** = 8.238.000 MWh (EIA source).
The demand of energy accountable on the solar power is just 8,238*8,8074*10^-4 = 0,007255486 Billion KWh = **7.255,486 MWh**

Once these data have been obtained, the evaluation of the models is possible.

1° Option

The formula is the one shown in paragraph 5.1 when presenting the first option for financing O&M costs. Here only the first year has been reported, but all the calculations have been made thanks to the Excel software for the entire lifetime of the plant (20 years). Capex costs will not be considered since the economic evaluation related to Capital costs has already been made and demonstrated in many other documents. For this reason the focus will be to obtain exclusively a positive NPV value for O&M costs. A positive CAPEX evaluation has been hypothesized in order to make this estimate and furthermore, it would not change the result of the calculation since the CAPEX repayment scheme is the same for both option 1 and 2. Thus, just O&M costs have been included.

$$-Tot.O\&M\ costs+\frac{\frac{O\&Mcosts}{20}+Interests\ O\&M}{(1+WACC)^1}+\frac{\frac{O\&Mcosts}{20}+Interests\ O\&M}{(1+WACC)^2}+\cdots+\frac{\frac{O\&Mcosts}{20}+Interests\ O\&M}{(1+WACC)^{20}}$$

The total amount of O&M costs has been calculated thanks to the table in chapter 4 (see figure 40 and 49). Year 2015 has been considered the year of the initial investment therefore, the sum of all the costs has been made from year 2016 to year 2035 (20 years). The total O&M costs result in **862,52 $/KW**. This means that the annual installment would be 862,52/20= **43,126 $/KW**. Interest for O&M costs result in 43,126*0,1 = **4,3126 $/KW** (10% fixed rate as stated in paragraph 5.2). The distribution costs, examined in paragraph 4.4, should also be included. The total O&M cost for distribution of energy is 1,2$/MWh *20 = **24 $/MWh**. The annual installment is **1,2 $/MWh** and thus, interests are 1,2 * 0,1 = **0,12 $/MWh**. The WACC is 6% as assumed in paragraph 5.2.

$$-862{,}52\frac{\$}{KW}*1920\ KW-24\frac{\$}{MWh}*7255{,}486\ MWh+\frac{43{,}126*1920+1{,}2*7255{,}486+862{,}52*0{,}1*1920+24*0{,}1*7255{,}486}{(1+0{,}06)^1}+\cdots$$

The final value of this option result in 520.383,16 $ (calculation made with the Excel software).

<u>2° Option</u>

In the second option the CAPEX costs will not be considered as well, but the repayment scheme changes consistently (see paragraph 5.1 – Option 2: a new fund intervention). The repayment scheme has already been here reported with data. The data related to the distribution costs are still valid for option2, this means that every year an installment of **1,2 $/MWh** is considered. The yearly forecast used is the one shown in figure 49.

$$
\begin{gathered}
-1.2\,\frac{\$}{MWh} * 7255{,}486\ MWh - 47{,}2172\,\frac{\$}{KW} * 1920\ KW \\
+\frac{1.2\,\frac{\$}{MWh} * 7255{,}486\ MWh + 47.2172\,\frac{\$}{KW} * 1920\ KW + 0{,}12\,\frac{\$}{MWh} * 7255{,}486 + 47{,}2172\,\frac{\$}{KW} * 0{,}1 * 1920KW}{(1+0{,}06)^{1}} \\
-\frac{46{,}7939\,\frac{\$}{KW} * 1920KW - 1.2\,\frac{\$}{MWh} * 7255{,}486\ MWh}{(1+0{,}06)^{1}} + \cdots
\end{gathered}
$$

The final value of this option is 42.690,845$. All further comments have been left for the part of the conclusions (chapter 6), but it is immediately clear how this model provides a lower NPV value compared to option 1.

Wind power in Ethiopia

In Ethiopia two wind farms connected to the grid exist. The Adama farm has a 51 MW power capacity installed, whereas the Ashegoba wind power can provide a power of 120 MW (SNC Lavalin source). As in the case study of solar power in Ghana, only plants connected to the grid have been considered. Thanks again to the EIA (U.S. Energy Information Administration) useful data regarding the total amount of energy installed in Ethiopia and on the total demand of energy, have been collected. Ethiopia has a total capacity installed of 2,12745 Million KW = **2.127,45 MW** and a total electricity net consumption of 4,5913 Billion KWh = **4.591.300 MWh** (data 2011). The total power provided by the wind farms is **171 MW** (51MW+120MW) = **171.000 KW**. This means that the impact of the wind power on the total energy installed is 171/2127,45 = 0,08038 that is to say a little more than 8%. Following this reasoning the energy demand that should be fulfilled through the wind farms would be 8% of the total Ethiopian demand. 4591300*0,08038= **369.039,1314 MWh** is the demand accountable on wind power.

Once these data have been obtained, the evaluation of the models is possible.

1° Option

The calculations follow the same methodology and the same repayment scheme explained in paragraph 5.1 and reported also in the case study of the solar farms. Regarding distribution costs, the same values used for the evaluation of the case study in Ghana, have been used consistently to what has been stated in paragraph 4.4 and 4.5. The data related to the O&M costs and used for this evaluation are reported in figure 38. The yearly O&M cost is 60 $/KW thus, the total initial investment in O&M for the private parties would be 60*20=1200 $/KW. The WACC is 7% for wind power (see paragraph 5.2 figure 56) and the interests are still 10%.

$$- 1200\frac{\$}{KW} * 171000\,KW - 24\frac{\$}{MWh} * 369039{,}1314\,MWh$$

$$+ \frac{60\frac{\$}{KW} * 171000\,KW + 1{,}2\frac{\$}{MWh} * 369039{,}1314\,MWh + 1200\frac{\$}{KW} * 0{,}1 * 171000\,KW + 24\frac{\$}{MWh} * 0{,}1 * 369039{,}1314\,MWh}{(1 + 0{,}07)^{1}}$$

$$+ \cdots$$

The result of this NPV evaluation is 60.858.518 $ (calculated through the Excel software).

2° Option

As in the case study in Ghana, here the repayment scheme changes as well. Nevertheless, it will be easier to calculate the final NPV result as the yearly installment is constant during the 20-year time while concerning solar power a decrease of O&M costs during the years has been observed.

$$-1.2\frac{\$}{MWh} * 369039{,}1314\ MWh - 60\frac{\$}{KW} * 171000\ KW$$

$$+\frac{1.2\frac{\$}{MWh} * 369039{,}1314\ MWh + 60\frac{\$}{KW} * 171000\ KW + 0{,}12\frac{\$}{MWh} * 369039{,}1314\ MWh + 60\frac{\$}{KW} * 0{,}1 * 171000 KW}{(1+0{,}07)^1}$$

$$-\frac{60\frac{\$}{KW} * 171000 KW - 1.2\frac{\$}{MWh} * 369039{,}1314\ \ MWh}{(1+0{,}07)^1} + \cdots$$

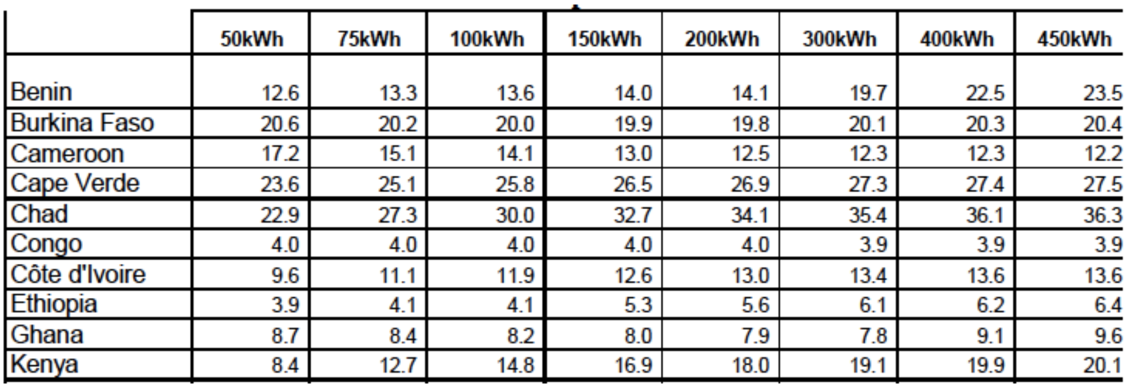
This formula leads to the final value of 3.401.583,4 $ (calculated through the Excel software). As is immediately clear comparing this value to the value of option 1, this is lower and thus, the convenience of the option 1 financing method can be affirmed.

CHAPTER 6 - Conclusions

In order to conclude this thesis, the most important results will be highlighted. From the last paragraph in chapter 5 (paragraph 5.4), some important considerations can be made. Firstly, the convenience of the first proposed model (Option 1: Capex and O&M costs all together) seems clear. This fact is due to the strong impact of interests during the time. As stated previously, interests decrease during the 20 year lifetime supposed for the plants. Nevertheless, they have a strong impact on the first periods, as the outstanding debt is still high and interests are paid on that. This is the reason why the first option shown seems to be the more convenient for the private parties indeed, they can exploit the highest interests gained in the first periods in order to achieve higher NPV values. However, the second and more innovative option is still profitable for the private parties and as explained in paragraph 5.2 it can be profitable for the new dedicated fund as well. A situation of **global win** can be obtained rather than in the first option in which the funds are only giving money to private parties without earning a lot apart from some fees. In this second option, as explained before, the possibility for the fund to earn extra money from the misalignment between actual costs and forecasts is an important issue. This model should be analyzed and improved further, in order to be as convenient as the more traditional one. Some reasoning about the interest structure should be made since it is the most important aspect influencing the lower returns. As interests have been supposed to be paid only on the debt of the previous year and considering that every year private parties pay only for the estimate of the year after, the quote of the interests is really low and constant over the years. The evaluation made in paragraph 5.4 has been just an economic evaluation, however some other considerations have been made in paragraph 5.2 and they highlight many pros that this new model could have, such as the possibility to achieve a sort of self-financing situation. This happens for example in the case of solar power in Ghana (presented in paragraph 5.2) where, thanks to the decrease in O&M costs over the years, the installment received from the funds is higher than the annual expenditure that the private party makes for O&M costs of the following period.

Moreover, a final evaluation in order to demonstrate the difference of use between these methods, which implicate a total coverage of costs from the international authorities (through the funds) and a more traditional model in which the sale of energy compensates O&M costs, is herewith reported.

Thanks to the document published by the World Bank in 2009 “Monitoring Performance of Electric Utilities”, data regarding the effective residential tariffs have been collected. It has come out that the range of cost for monthly consumption levels spans from 0,02 US/KWh to 0,036 USD/KWh. Higher prices would not be affordable for the African population whereas lower prices would be far from reaching an economic convenience. Focusing on the Ethiopian market, since a case study has been reported in the previous chapter, an average price of energy has been calculated and resulted in 3,588 cent $/KWh, depending on the consumption belonging to each block. Indeed, there are some blocks of energy consumption assigned depending on the monthly consumption and usually the price of energy rises with the block assigned. However, as usual the level of household monthly consumption is 100 KWh, the value of 0,041 US/KWh has been chosen for the continuation of this analysis (see figure 58).



	50kWh	75kWh	100kWh	150kWh	200kWh	300kWh	400kWh	450kWh
Benin	12.6	13.3	13.6	14.0	14.1	19.7	22.5	23.5
Burkina Faso	20.6	20.2	20.0	19.9	19.8	20.1	20.3	20.4
Cameroon	17.2	15.1	14.1	13.0	12.5	12.3	12.3	12.2
Cape Verde	23.6	25.1	25.8	26.5	26.9	27.3	27.4	27.5
Chad	22.9	27.3	30.0	32.7	34.1	35.4	36.1	36.3
Congo	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.9
Côte d'Ivoire	9.6	11.1	11.9	12.6	13.0	13.4	13.6	13.6
Ethiopia	3.9	4.1	4.1	5.3	5.6	6.1	6.2	6.4
Ghana	8.7	8.4	8.2	8.0	7.9	7.8	9.1	9.6
Kenya	8.4	12.7	14.8	16.9	18.0	19.1	19.9	20.1

Figure 58: Effective residential tariffs by level of household monthly consumption, World Bank source

Considering the total consumption of energy of 369.039,1314 MWh only regarding wind power, as explained in paragraph 5.4, the total income would be 369 Million KWh * 0,041 $/KWh = **15 Million USD**. If considering the O&M costs for the first year related to the wind farms, these costs amount to 60 $/KW * 171.000 KW + 1,2 $/MWh * 369.000 MWh = **11 Million USD**.

Where 60 $/KW is the cost for O&M of the plants, 171000 KW is the capacity installed of the wind farms and 1,2 $/MWh is the O&M cost for the distribution facilities.

This means that the income from the sale of energy would be able to cover the O&M expenses in the first year and the net income would be approximately **4 Million USD**. However, the uncertainty of the energy demand and the hypothesis made of a household monthly consumption of 1000 KWh must be taken into account.

Moreover, considering the Option 1 shown previously in this document, after one year the private party receives back **32 Million USD** thanks also to the interest payments. If this value is compared to the **4 Million USD** income that is earned in a traditional system, it is clear how the new way to finance O&M costs in Africa is more convenient. Of course, this money received would repay the initial investment, but anyway after 20 years the income would be greater than in a traditional system. Furthermore, the sale of energy will not contribute to the coverage of any cost and thus, the income for private parties will be higher. Finally, it is not always true that the sale of energy entirely repays the O&M costs as can be inferred from the table below (figure 59). In Ghana for instance, the energy revenues cannot repay the Operational Expenses.

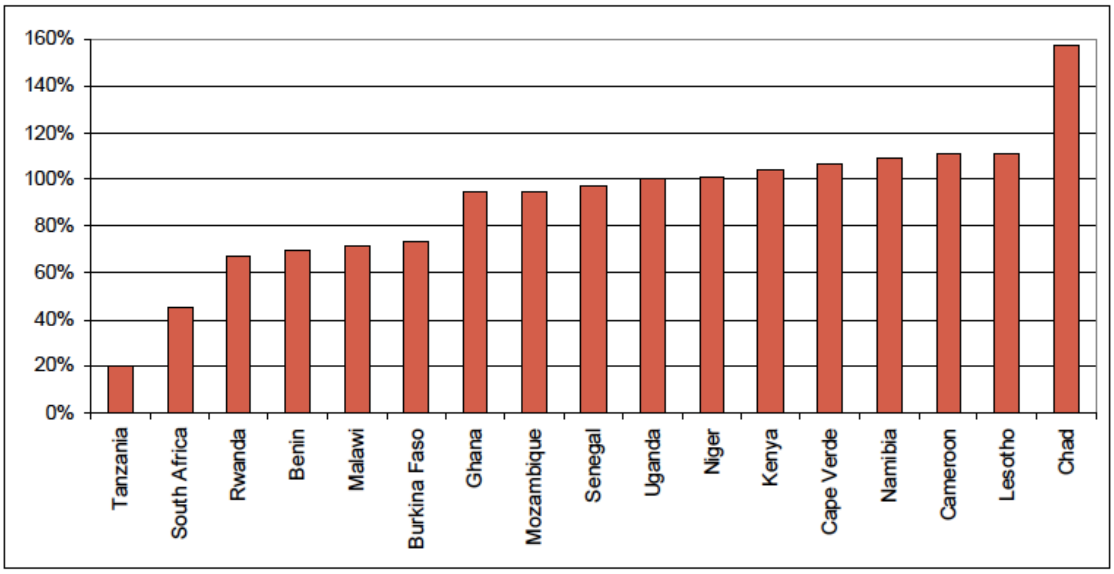


Figure 59: Operating expenses covered by revenues, %, latest year available 2004-06, World Bank source

In conclusion, there are possibilities to develop further some new models for the African market, in particular the focus in these days is principally on Operations and Maintenance costs. As a matter of fact, these costs represent an important area of study for the future since the particular financial situation in this continent and of the “Power Africa” project require a specific and innovative financing solution. Some profitable models have been analyzed here in this thesis, highlighting the convenience of including O&M costs in the initial investment as if they were Capital Expenditures. However, another profitable and more innovative model has been shown and it could be further developed. This thesis aims at being a starting point in order to develop and enrich the interest in this topic, it attempts to stimulate the possibility of other future models and in-depth analysis of this topic. This is a really relevant and current topic to be discussed. The possibility to figure out and develop innovative financing models is an interesting issue in order to increase the income for funds, private investors and as an ultimate goal, to give a durable and consolidated energy supply to Africa.

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Acknowledgements

With the conclusion of this thesis I also conclude a really long and intense period of study, but at the same time a period which gave me plenty of satisfaction and fulfilled my objectives. Thus, it is correct to pause for a minute in order to thank all the people who made this goal possible.

Firstly, a great "THANK YOU" goes to my family that has always supported me during these years. I will always be beholden to my parents that supported me financially, in order to give me the possibility to study in Milan, and mentally in those difficult moments that inevitably must be faced in such a long and difficult path. A "thank you" also goes to my sister who has always been my first friend and confidant for my life, not just regarding university issues. A "thank you" to all my grandparents, uncles and relatives that have always inspired and spurred me on thanks to their example. A particular "thank you" to my grandpa Evaristo, who will surely be proud of me on this day.

Moreover, I would like to thank all the teaching staff of the Politecnico di Milano. In particular my supervisor Professor Alessandro Gandelli who guided me in this one-year long path. He has not just enriched my knowledge, but thanks to a special student-professor relationship, he has taught me many useful things for my future career.

I cannot forget my university colleagues; they have been the "salt" of my daily routine that I lived every day in Milan, inside and outside the university. Thanks to Vittorio, Andrea, Paolo, Luca, Francesca, Antonia, Elisa, Matteo, Simone, Jacopo and to all the others that I have not mentioned here, but who made all these years really special. We created a fantastic group that can be defined, as we often say, "a family in Milan".

Finally, thanks to my "old" friends, from Ravenna. Although we have known each other since we were children, they have always found a way to make me laugh and enjoy the days I spent at home. Real friendship never ends and it is clear every time we are together.

In Italian:

Con la conclusione di questa tesi termina per me un periodo di studio molto lungo e intenso, ma allo stesso tempo pieno di soddisfazioni e obiettivi raggiunti. È giusto soffermarsi un attimo per rendere omaggio alle persone che hanno reso possibile il raggiungimento di questo traguardo.

Come prima cosa un GRAZIE va sicuramente alla mia famiglia che mi ha sempre sostenuto in questi anni. Sarò sempre grato ai miei genitori che mi hanno sostenuto finanziariamente, dandomi la possibilità di studiare a Milano, ed anche mentalmente nei momenti di difficoltà che inevitabilmente bisogna fronteggiare in un percorso tanto lungo e complicato. Un grazie va anche a mia sorella che è sempre stata la mia prima amica e confidente nella vita, prima che per questioni universitarie. Un grazie a tutti i nonni, zii e parenti che mi hanno sempre dato il buon esempio e mi hanno spronato a raggiungere un obiettivo così importante. Un grazie particolare a nonno Evaristo che sicuramente sarebbe orgoglioso di me in questo momento.

Vorrei inoltre ringraziare tutto il corpo docente del Politecnico di Milano. In particolare il mio relatore Professor Alessandro Gandelli che mi ha seguito in questo percorso durato un anno ed oltre, arricchendo il mio bagaglio culturale e rendendo speciale il rapporto studente-professore, dandomi insegnamenti utili per il proseguo della mia carriera.

Non posso certo dimenticare tutti i miei compagni di corso che sono stati il sale della quotidianità vissuta ogni giorno a Milano, in università e fuori. Grazie a Vittorio, Andrea, Paolo, Luca, Francesca, Antonia, Elisa, Matteo, Simone, Jacopo e a tutti gli altri che non ricordo qui, ma che hanno reso questi anni veramente speciali. Si è creato veramente un gruppo fantastico che come diciamo spesso può definirsi una “famiglia a Milano”.

Grazie infine agli amici di sempre, quelli di Ravenna, che pur conoscendoci da quando siamo bambini hanno sempre trovato il modo di farmi distrarre e divertire ogniqualvolta sono tornato a casa. La vera amicizia non finisce mai e si vede ogni volta che siamo insieme.