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**Model for evaluating the global
impact of Smart Grids in Sub
Saharan Africa**

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Abstract

The problems related to environmental issues are having an increasingly important role at international level and they come across a greater involvement by the most developed countries, especially with regard to energy issues. This interest stems from the awareness on the part of the countries of the so-called "first world" regarding the issues related to the relentless increase in pollution and the global problem of GHGs. The most effective solutions through which it is possible to deal with these problems turn out to be the exploitation of renewable energy sources and the use of new technologies that allow a more efficient distribution and use of energy.

In this context it is particularly interesting to focus on the developing countries, characterized by low rates of electrification but particularly high values of growth of energy demand. Among these, the focus was centered on the African continent, characterized by a high rate of future growth and a high proportion of renewable sources not yet properly valued but which, potentially, have the opportunity to fully respond to the increasing energy demand of the African countries in a sustainable manner.

The thesis therefore proposes to frame the African economic and energy context, focusing on the modalities of the energy distribution, in accordance with the common objective of reducing the rate of pollution at the global level. A greater availability of electricity has positive impacts on local economies, stimulating growth. In the African context, in particular in the Sub Saharan one, the low rate of electrification in rural areas does not allow an adequate development of human life and related business activities.

Due to the vastness of the territories and low levels of population density per km^2 , a possible extension of the traditional energy network seems to be a non-optimal solution, even from the economic point of view.

In this situation the off-grid solutions appear to be preferable; among them, there is a solution characterized by advanced technologies that allows a higher efficiency of energy consumption and an optimization of the supply of electricity, also for the one generated by non-continuous sources (such as the sun or the wind): the smart grid.

The aim of this thesis is therefore going to evaluate, through the use of a model created ad hoc, the impact on quality of life of the local populations of Sub Saharan Africa resulting from the implementation of smart grid in rural areas.

Abstract

Le problematiche riguardanti le tematiche ambientali stanno avendo una sempre maggiore importanza a livello internazionale e vedono un sempre maggiore coinvolgimento dal parte dei paesi più sviluppati, soprattutto per quanto riguarda le problematiche legate all'energia. Questo interesse nasce dalla presa di coscienza da parte dei paesi del cosiddetto primo mondo riguardo alle problematiche legate all'inarrestabile aumento dell'inquinamento mondiale ed al problema dei gas serra. Le soluzioni più efficaci attraverso cui sia possibile affrontare queste problematiche risultano essere lo sfruttamento delle fonti rinnovabili e la fruizione di nuove tecnologie che permettano una distribuzione ed un utilizzo più efficiente di energia.

In questo contesto risulta particolarmente interessante focalizzarsi sui paesi in via di sviluppo, caratterizzati da percentuali di elettrificazione ancora basse ma da valori di crescita della domanda di energia particolarmente elevati. Tra questi il focus è stato incentrato sul continente Africano, contraddistinto da un forte tasso di crescita futura e da una elevata presenza di risorse rinnovabili non ancora propriamente valorizzate ma che, in potenza, hanno la possibilità di rispondere totalmente alla crescente domanda energetica dei paesi africani in modo sostenibile.

Questa tesi si propone quindi di inquadrare il contesto economico ed energetico africano, focalizzandosi sulle modalità di distribuzione energetica, nel rispetto dell'obiettivo comune di riduzione del tasso di inquinamento a livello globale. Una maggior disponibilità di energia elettrica ha degli impatti positivi sulle economie locali stimolandone la crescita. Nel contesto africano, ed in particolare in quello Sub Sahariano, la scarsa percentuale di elettrificazione nelle aree rurali non permette un adeguato sviluppo della vita e delle relative attività di business. Data la vastità dei territori ed i bassi livelli di densità di popolazione per km^2 un'eventuale estensione della rete energetica tradizionale sembra essere una soluzione non ottimale, anche dal punto di vista economico.

In questa situazione risultano essere quindi preferibili delle soluzioni off-grid; tra queste, vi è una soluzione caratterizzata da tecnologie avanzate che permette un maggiore efficientamento del consumo energetico ed un'ottimizzazione della fornitura di energia elettrica, anche di quella generata da fonti non continue (quali ad esempio sole e vento): la smart srid.

Obiettivo di questa tesi è quindi andare a valutare, attraverso l'utilizzo di un modello creato ad hoc, l'impatto sulla qualità della vita delle popolazioni autoctone dell'Africa Sub Sahariana derivante dall'implementazione di smart grid all'interno di aree rurali.

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Executive summary

The purpose of this thesis is the evaluation of the impact on quality of life of rural population, following the implementation of a smart grid.

This evaluation is done into the African context and, particularly, into the Sub Saharan area of the continent, characterized by electrification rates still too limited, a great energetic potential thanks to an high availability of renewable resources and a growing energy demand from people whose necessity is to satisfy their primary needs.

Analysis of emerging countries

According to the definition by "International Business Times", countries classifiable as "emerging economies" are characterized by "social or business activities in phase of rapid growth and industrialization.

Among these is possible to find the Chinese and the Indian ones, globally known as the two greater emerging economies of the last years, and those of the African continent, an area characterized by a relevant growth outlook, on which several "first-world" countries has invested in last years (among these it is necessary to mention the "Power Africa" project, proposed by the Obama administration in 2013, whose aim is to improve the rate of electrification in rural areas of Sub Saharan Africa).

This definition is supported by the comparison between GDP's growth of China and India with the one of the countries belonging to the first world (for which it is used the U.S. economy as a proxy): while, between 2003 and 2012, Chinese and Indian economy were characterized by GDP's growth rate ranging from 8% to 14% (China) and from 3% to 11% (India), the value related to U.S. has ranged between a minimum of -3% and a maximum of 4%.

By analyzing at macro level the economic, political and energetic (with attention to the exploitation of renewable sources) contexts of the previously mentioned areas (China, India and the African continent), it has been possible to do a comparison of such frameworks; in order to make the analysis more proper, we preferred to divide the African continent in two macro areas: North Africa, composed by six

countries (Algeria, Morocco, Libya, Tunisia, Egypt and Djibouti), characterized by a more developed economy, longer life expectancy and higher electrification rates and Sub Saharan Africa, the poorest area of the continent, in which only a share equal to 26% of population is connected to the electric grid, the economy is still underdeveloped and life prospects are significantly lower than North African ones.

The economic comparison of the emerging areas taken under consideration has been done through an analysis of GDP's growth rates in last 10 years: all areas have been featured by positive values, however rates related to China and India are, on average, higher than African ones, both in North and in Sub Saharan areas. In order to evaluate the social development it has been analyzed the share of pupils attending the primary school: in this case is relevant the value relative to the Sub Saharan area (slightly less than 80%), which is significantly lower than the ones related to the other emerging economies, whose values are higher than 90%.

At least, the comparison of the electrical framework, has been done using the share of people able to access to electricity as benchmark; in this context is possible to observe that China and India present values close to 100%, North Africa a rapidly rising share close to 75% while Sub Saharan Africa have average values slightly above 30%. It is then revealed to be interesting the evaluation of the impact on the quality of life of rural populations in Africa gave by the implementation of a smart grid.

Economic and energetic contexts of Africa

In a context like the African one, characterized by an economy still underdeveloped and by electrification shares particularly low, it is interesting to present the results of some econometric studies that identify the existence of a positive correlation between a growth in electricity consumption, following an higher availability of power trough which people are able to satisfy their primary needs, and economic growth.

Such studies are confirmed by case studies, among which is possible to mention an investment for a grid extension project in Botswana, which has been followed

by significant positive impacts in several sectors (like industrial, commercial, domestic, institutional, wealth and education).

In order to have clear the context in which our model will be applied, it is useful to give a brief description of the economic and energetic contexts of the African continent.

The current economic situation is the consequence of a particular historical phase: the colonialism; during this period African countries have been forced to produce only for export markets: the production, which was controlled by European countries, was focused only on certain products and the economical development was considered as not important.

This policy has had an impact on the African continent after the decolonization: local economies, which till this period were oriented only to exports toward colonizing countries, were not ready to face the lack of internal production on open markets, thus leading African states to the current situation.

Regarding the energetic context it is possible to notice a deep gap between countries belonging to North Africa and those belonging to the Sub Saharan Area: the firsts are characterized by electrification shares close to 94%, even if they have quotas related to renewables still too limited (however, it is important to mention the existence of several projects related to clean energy, like the Desertec one); the latter, instead, feature a more backward framework, in which an average of 65% of people are not reached by electricity: in such situation it is not possible to begin an electrification process like the one which took place in the first world, but the solution results to be the implementation of "off-grid" systems. Even in this second case are present several projects for investments aimed to improve the energetic condition of nations, among which it is possible to mention the "Power Africa" project, characterized by a new way of financing trough which money is not given to local governments but it is provided directly to the companies involved in financed projects in order to avoid the money misuse that has characterized investments performed in past years.

In order to clarify the heterogeneous economical condition of the African continent, it was possible to briefly describe the situation of three African countries,

Mozambique, Morocco and South Africa, chosen according to the classification on income provided by the World Bank. Though this analysis results to be significant the comparison of the three countries about the the income level which characterize their population: shares of people living with an income lower than the living wage (the average monthly income needed to cover basic expenses like housing, food and public transport) are equal to 87.08% in South Africa, 94.73% in Morocco and 99.8% in Mozambique; a second level of income has been identified using, as proxy, the value of the installment due in order to purchase a car through a loan: the shares of people with an income in this bracket are equal to 6.04% in South Africa, to 4.08% in Morocco and close to 0% in Mozambique.

In such economic and energetic contexts results to be of particular relevance the foreign direct investments; according to certain econometric studies regarding their efficacy in development countries, it is important the existence of a simultaneous activity of the governments in terms of adequate reforms, both in social and in economic field, able to make the countries and their population capable to embrace and to take advantage of the funds.

Smart grids

After having outlined the energetic and economic contexts of the Africa continent, it is necessary to do a brief description of the technological solution on which our model is based, the smart grid, before proceeding to the description of the model for the evaluation of impacts.

Smart grids, according to Hamid Gharavi and Reza Ghafurian, can be defined as "an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient, and sustainable"; it brings several benefits to whom who benefit it terms of flexibility of electricity supply, self-healing capabilities, prediction of events related to the grid, interactivity with users and consumption's optimization.

Such benefits are enabled by the smart grid's technological components which can be grouped in 4 sets: smart power generation tools, communication and network

tools, smart metering and active demand tools and energy storage tools.

This type of network, for the benefits listed, thus appears to be optimal for the improvement of the energy context of the rural areas of Sub-Saharan Africa as it is able to manage independently and efficiently the high quantity of renewable resources present on the territory while avoiding wastes; it also allows to reduce the time for electrification as it does not require a pre-existing traditional network, but can also be implemented in an off-grid perspective, a choice that is the most convenient from the point of view of operation and economy, given the low population density of Sub-Saharan Africa.

The benefits listed are proved through the analysis of two case studies related both to an area of the first world (Austin, Texas), and to an area of a developing country (Guwahati, India).

Model

As previously stated, our model has the aim to determine the impact on quality of life of rural populations in sub-Saharan Africa consequent to the introduction of a smart grid.

At the base of this evaluation there is the hypothesis of an increase in energy consumption by the local population consequent to the implementation of the smart grid; these increases are due to: population growth, full satisfaction of energy demand through the elimination of outages and improvement of the local economy enabled, for example, by the ability to work during the night or to store perishable products in a refrigerator (such as food or medicines).

The model assumes two scenarios: a "base case", characterized by the presence of both renewable energy sources (wind and solar) and diesel generators that provide power when renewables can not guarantee the supply and are subject to outages due to overloading; a "case to-be" that expects the introduction of a smart grid (and the technological tools associated with it) capable to guarantee a higher availability of power for people who benefits of it.

The adopted methodology envisages the definition of a hierarchical tree structure whose apex is the index of *Quality of life* and whose branches are represented respectively by the *Economic* and the *Social aspects* impacted by the introduction

of the smart grid; in the definition of the model was also considered an additional branch, the *Environmental* one but, as a result of an impact assessment of smart grid on it, which proved to be irrelevant, it has been decided to not include it into the model.

The economic impact has been studied in terms of: *Impact on the local economy*, which includes the indirect impact, measured as an increase in the local GDP resulting from the rise of availability of power due to better reliability of the network, growth of population and new business activities (value that will be estimated through a sensitivity analysis as it is very complex to calculate), and the workforce necessary for the operation of the smart grid, which will not be considered as it has a little impact on average quality of life; *Impact on daily earnings* calculated as saving on energy costs for residents and quantified as the difference between the costs that characterize the base case, maintenance of renewable energy systems and purchase of diesel, and the costs in the case to-be, with the only costs associated to renewables.

The social impact has been studied in terms of: *Security and reliability of energy supply*, calculated as the increase in energy consumption resulting from the decrease in supply's outages made possible by the storage systems that are part of the smart grid; variation of the *HDI*, a synthetic indicator developed by UNDP in order to assess the quality of life from the social point of view in terms of life expectancy, education and living standards, calculated in relation to the increase of energy consumption through the study of its growth's function.

The final value of the index of *Quality of life* is then obtained by a weighted average of these branches: at the first level the values of weights are obtained by analyzing some surveys carried out in South Africa and are equal to 0.663 for the branch *Social Aspects* and 0.337 for the branch *Economy*; at the second level, instead, the weights used are all equal to 0.5 due to lack of data or surveys useful to define them (however their variation will be considered by the sensitivity analysis).

Executive summary

Lo scopo della tesi è la valutazione dell'impatto sulla qualità della vita delle popolazioni rurali conseguente all'implementazione di una smart grid.

Questa valutazione viene effettuata all'interno del contesto africano e più in particolare dell'area Sub Sahariana del continente, caratterizzata da percentuali di elettrificazione ancora eccessivamente limitati, un grande potenziale energetico (grazie all'elevata disponibilità di risorse rinnovabili) ed una crescente domanda energetica da parte delle popolazioni locali, la cui necessità è quella di soddisfare i propri bisogni primari.

Analisi dei paesi emergenti

Secondo la definizione dell'International Business Times i paesi classificabili come economie emergenti sono caratterizzati da attività sociali o di business in fase di rapida crescita ed industrializzazione. Tra queste economie è possibile ritrovare quella Cinese ed Indiana, riconosciute globalmente come le due maggiori economie emergenti degli ultimi anni, e quelle dei paesi appartenenti al continente Africano, area caratterizzata da significative prospettive di crescita, sulla quale, negli ultimi anni, molte nazioni appartenenti al primo mondo hanno concentrato ingenti investimenti (tra questi è necessario citare il progetto Power Africa proposto nel 2013 dall'amministrazione Obama, il cui obiettivo è quello di sviluppare la rete energetica in Africa Sub Sahariana).

A supportare la definizione di economie emergenti vi è il confronto tra la crescita di GDP di Cina ed India rispetto a quello dei paesi del primo mondo (di cui si è usata l'economia Americana come proxy): mentre tra il 2003 ed il 2012 l'economia Cinese ed Indiana erano caratterizzate rispettivamente da valori di crescita del GDP compresi fra l'8% ed il 14% (Cina) e fra il 3% ed il 11% (India), i dati relativi alla crescita del GDP Americano, invece, erano compresi fra il -3% e il 4%.

Analizzando quindi a livello macro il contesto economico, politico ed energetico (con un occhio di riguardo allo sfruttamento di risorse rinnovabili) delle aree emergenti sopra citate, Cina India ed il continente Africano, è stato possibile fare un

confronto di questi ambiti; per rendere i risultati del raffronto più corretti si è preferito analizzare il continente africano dividendolo in 2 macroaree: il Nord Africa, composto da 6 stati (Algeria, Marocco, Libia, Tunisia, Egitto e Djibouti), caratterizzato da un'economia più sviluppata, prospettiva di vita più lunga e da tassi di elettrificazione elevati e l'Africa Sub Sahariana, area più povera del continente, in cui solo il 26% della popolazione è connesso alla rete elettrica, caratterizzata da un'economia ancora poco sviluppata e prospettive di vita significativamente minori rispetto a quelle dei paesi nordafricani.

Il confronto economico delle aree emergenti prese in considerazione è stato fatto attraverso un'analisi dei tassi di crescita del GDP pro capite degli ultimi 10 anni: tutte le aree sono caratterizzate da valori positivi, tuttavia i tassi di crescita di Cina ed India sono in media più elevati rispetto a quelli dell'Africa, sia del Nord che Sub Sahariana.

Per effettuare invece una valutazione sullo sviluppo sociale è stata analizzata la percentuale di scolarizzazione primaria: in questo caso è significativa il valore relativo all'area Subsahariana (poco inferiore all'80%), rispetto alle altre economie emergenti analizzate, i cui valori si assestano a percentuali maggiori del 90%.

Il raffronto energetico, infine, è stato fatto utilizzando come metro di valutazione la percentuale di accesso all'elettricità; in questo caso si può notare che Cina ed India presentano valori prossimi al 100%, il Nord Africa una percentuale pari al 75% (in rapida crescita) mentre l'Africa Sub Sahariana si assesta a valori medi di poco superiori al 30%.

Si è quindi rivelato interessante valutare l'impatto dell'implementazione di una smart grid sulla qualità della vita delle popolazioni rurali nel continente africano.

Contesto economico ed energetico dell'Africa

In un contesto come quello Africano, caratterizzato da economia ancora poco sviluppata e da percentuali di elettrificazione particolarmente basse, è interessante introdurre i risultati di alcuni studi econometrici, i quali identificano la presenza di una correlazione positiva tra un aumento del consumo energetico, conseguente ad una maggiore disponibilità di energia attraverso cui le popolazioni locali siano in grado di soddisfare i propri bisogni primari e la crescita economica.

Questi studi sono confermati da esempi reali, tra cui è possibile citare un investimento relativo ad un progetto di estensione della rete in Botswana in seguito al quale sono stati riscontrati significativi impatti positivi in diversi settori (industriale, commerciale, domestico, istituzionale, sanità e settore dell'educazione).

Al fine di avere un quadro ben chiaro del contesto in cui verrà applicato in nostro modello è utile dare una breve descrizione del contesto economico ed energetico del continente africano.

La situazione attuale economica africana è conseguenza di una particolare fase storica, il colonialismo; durante questo periodo storico, i paesi africani erano forzati a produrre unicamente per il mercato di esportazione: la produzione, controllata dai paesi europei, era concentrata solo su determinati prodotti e lo sviluppo economico dei paesi africani non era considerato importante.

Questa politica ha avuto ripercussioni sul continente africano a seguito del processo di decolonizzazione: le economie locali, fino a quel momento orientate solo sull'esportazione verso i paesi colonizzatori, non erano pronte a confrontarsi con il mercato aperto al fine di compensare la mancanza interna di produzione, portando così gli stati Africani alla situazione attuale.

Per quanto riguarda il contesto energetico invece, è possibile notare una profonda differenza dei paesi appartenenti al Nord Africa con quelli appartenenti all'Africa Sub Sahariana: i paesi nordafricani, caratterizzati da percentuali di elettrificazione approssimabili al 94%, presentano delle percentuali di sfruttamento delle risorse di energia rinnovabile ancora limitate (ma va detto che vi sono diversi progetti volti ad implementare soluzioni di energia rinnovabile in quest'area, tra cui il progetto Desertec); l'Africa Sub Sahariana è invece caratterizzata da un contesto energetico molto più arretrato, in cui in media il 65% della popolazione non ha accesso alla rete: in questa situazione non è possibile avviare il processo di creazione della rete che è avvenuto nei paesi sviluppati del primo mondo, ma una soluzione preferibile risulta essere l'implementazione di sistemi off-grid. Anche in questo caso sono presenti diversi progetti di investimento finalizzati a migliorare la condizione energetica delle nazioni, tra cui è possibile citare "Power Africa", caratterizzato da un'innovativa modalità di finanziamento in cui il denaro non viene più consegnato

ai Governi locali ma viene fornito direttamente alle imprese coinvolte nei progetti finanziati per evitare gli sprechi che hanno seguito degli investimenti svolti in precedenza.

Per rendere inoltre più chiara l'eterogenea condizione economica del continente africano è stata descritta in breve la situazione di tre stati africani, Mozambico, Marocco e Sud Africa, scelti in base alla classificazione sul reddito fornita dalla World Bank. Da questa analisi risulta significativo il confronto dei tre stati circa il livello di income che ne caratterizza la popolazione: con un reddito minore della living wage (minimo mensile con cui coprire spese per cibo, trasporto e relative all'abitazione) vivono l'87,08% delle persone in Sud Africa, il 94,73% in Marocco ed il 99,8% in Mozambico; identificando una seconda soglia di income utilizzando come proxy il valore della rata per l'acquisto tramite finanziamento di una macchina, il valore in Sud Africa di popolazione all'interno della soglia è pari a 6,04%, in Marocco al 4,08% ed in Mozambico è approssimabile allo 0%.

In questo contesto economico ed energetico risultano essere di particolare importanza gli investimenti diretti esteri; secondo alcuni studi econometrici riguardanti l'efficacia di questi investimenti nei paesi in via di sviluppo, è necessaria una contemporanea attività del governo attraverso riforme sociali ed economiche adeguate che rendano la popolazione ed il paese stesso pronti ad accogliere i finanziamenti ed a sfruttarli al meglio.

Smart grid

Dopo aver delineato il contesto economico ed energetico africano, è necessario effettuare una breve descrizione della soluzione tecnologica su cui si basa la nostra analisi, la smart grid, prima di passare alla descrizione del modello di valutazione degli impatti.

La smart grid, secondo Hamid Gharavi e Reza Ghafurian, può essere definita come un impianto elettrico che utilizza un sistema informativo bidirezionale e sicuro, accompagnato da una intelligenza artificiale integrata nei sistemi elettrici, al fine di ottenere un sistema che sia pulito, sicuro, affidabile, resiliente, efficiente e sostenibile; essa porta diversi benefici a chi ne usufruisce in termini di flessibilità della fornitura elettrica, capacità di rimuovere e correggere automaticamente eventuali

guasti, predittività degli eventi collegati alla rete elettrica, interattività con i consumatori e ottimizzazione dei consumi.

I benefici sono resi possibili dalle componenti tecnologiche della smart grid, raggruppabili in quattro gruppi: tools per la generazione smart di energia, tools per la comunicazione e lo scambio di informazioni, tools per il monitoraggio dello stato della rete e dei consumi e tools per lo stoccaggio di energia.

Questo tipo di rete, per i benefici elencati, risulta quindi essere ottimale per il miglioramento del contesto energetico delle aree rurali dell'Africa Sub Sahariana in quanto è in grado di gestire in modo autonomo ed efficiente l'elevato quantitativo di risorse rinnovabili presenti sul territorio evitando sprechi; esso inoltre permette di ridurre i tempi di elettrificazione in quanto non necessita di una rete tradizionale pre-esistente, ma può essere implementata anche in un ottica off-grid, scelta che risulta essere la più conveniente da un punto di vista operativo ed economico data la bassa densità di popolazione della zona Sub Sahariana del continente Africano. I benefici elencati saranno comprovati tramite l'analisi di due casi di studio relativi sia ad un'area del primo mondo (Austin, Texas), sia ad un area di un paese in via di sviluppo (Guwahati, India).

Modello

Come precedentemente affermato, il nostro modello si pone lo scopo di determinare l'impatto sulla qualità della vita delle popolazioni rurali dell'Africa Sub Sahariana conseguente all'introduzione di una smart grid.

Alla base di questa valutazione vi è l'ipotesi di un aumento dei consumi energetici da parte della popolazione locale conseguente l'implementazione della smart grid; questi aumenti sono dovuti alla crescita della popolazione, alla piena soddisfazione della domanda energetica attraverso l'eliminazione di eventuali interruzioni della fornitura elettrica e al miglioramento dell'economia locale portato, ad esempio, dalla possibilità di lavorare durante le ore notturne o di conservare i prodotti deperibili in frigoriferi (come cibo o medicinali).

Il modello prevede due scenari: un caso base che vede la presenza di sorgenti rinnovabili di energia (eolica e solare) e generatori diesel che forniscono corrente quando le fonti rinnovabili non riescono a garantire una risposta alla domanda e

sono soggette ad interruzioni della fornitura dovute a sovraccarichi e un caso to-be che vede l'introduzione di una smart grid (e dei tool tecnologici ad essa associata) in grado di garantire una maggior disponibilità per la popolazione che ne beneficia. La metodologia seguita prevede la definizione di una struttura gerarchica ad albero al cui apice vi è l'indice *Qualità della vita* nei cui due rami sono rappresentati rispettivamente gli *Aspetti economici* e gli *Aspetti sociali* impattati dall'introduzione della smart grid; nella definizione del modello è stata inoltre considerato un ulteriore ramo, quello relativo agli *Aspetti ambientali*: a seguito di una valutazione dell'impatto della smart grid su esso, dimostratasi irrilevante, si è deciso di non includerlo nel modello.

L'impatto economico è stato studiato in termini di: *Impatto sull'economia locale*, che comprende l'impatto indiretto, valutato come incremento del GDP locale a seguito dell'aumento di disponibilità di corrente dovuto ad una migliore reliability della rete, crescita della popolazione e nuove attività di business (il cui valore, molto complesso da calcolare, sarà stimato tramite un'analisi di sensitività), e la forza lavoro necessaria per il funzionamento della smart grid, il cui valore, di scarso impatto sulla qualità della vita media, non è stato considerato; *Impatto sui guadagni giornalieri*, calcolato come risparmio per gli abitanti sui costi energetici e quantificato come differenza tra i costi che caratterizzano il caso base, manutenzione dei sistemi di energia rinnovabile ed acquisto del diesel, ed i costi nel caso to-be, con i soli costi legati alle rinnovabili.

L'impatto sociale, invece, è stato studiato in termini di: *Security e reliability dell'approvvigionamento energetico*, calcolato come l'aumento dei consumi energetici conseguente alla diminuzione delle interruzioni della fornitura reso possibile dai sistemi di storage facenti parte della smart grid; variazione dell'indicatore *HDI*, indicatore sintetico sviluppato dal UNDP che valuta la qualità della vita dal punto vista sociale in termini di aspettativa di vita, educazione e living standard, calcolato in relazione all'aumento dei consumi energetici tramite lo studio della sua funzione di crescita.

Il valore finale dell'indice di *Qualità della vita* è quindi ottenuto tramite una media pesata dei suddetti rami: al primo livello i valori dei pesi sono ottenuti analizzando

dei sondaggi svolti in Sud Africa e sono pari a 0,663 per il ramo *Aspetti sociali* e 0,337 per il ramo *Aspetti economici*; al secondo livello, invece, i pesi utilizzati sono tutti uguali (e pari a 0,5) a causa della mancanza di dati o sondaggi utili per la loro definizione, ma una loro variazione sarà considerata tramite l'analisi di sensitività.

Chapter 1

Analysis of emerging countries

1.1 Introduction

The purpose of our thesis is to assess the impact that particular technological solutions like smart grids, which are a new paradigm that allow a more efficient use of energy and a better integration of renewable resources within the network, have on the quality of life of people living in rural areas.

The topic fits into the actual context, characterized by a steady increase in demand for energy in the developing world, distinguished by low rates of electrification, richness in renewable resources through which is possible to meet the demand for energy and by a growing interest in renewables both from the third world countries, which are becoming aware of their economic and energetic role in the near future, and the countries of the first world, which have political and environmental obligations in meeting the goal of reducing the greenhouse effects.

The discussion will be carried out by analyzing at macro level three emerging areas (China, India and the African continent) in order to outline their economic and energetic situation. After this first analysis the focus will shift on Africa, a developing continent rich in renewable energy resources on which there is a growing interest by the first world countries. A deeper analysis of three African countries (Mozambique, Morocco and South Africa), chosen according to the classification

of the World Bank concerning the level of income, will allow us to highlight the heterogeneity of the African continent in terms of social, political, economic and energetic situations that are very different from each other.

The focus of our thesis, the energetic context of the African continent, takes us to introduce the concept of Smart Grid, highlighting their features and the potential benefits that this kind of network could bring to the population.

Then will follow the description of the model through which it will be possible to assess the impact on quality of life of rural population resulting from the introduction of a smart grid and an example of application of the model in Sub Saharan Africa.

Everything mentioned until now will be detailed later in the development of the thesis.

1.2 Reasons of choices

The study focuses on the identification of main emerging countries at global level and on a subsequent analysis from the point of view of macro-economics, politics, geographical, social and energy-related components of those countries; the definition used to determine emerging economies is given by "International Business Times" [1] and it is "countries with social or business activities in phase of rapid growth and industrialization"; logically it must be underlined that high financial returns in such countries are strictly related to an high risk and volatility.

In order to identify emerging countries, starting from the previously given definition, were made evaluations on different variables: country potentials (in terms of economic growth), human capital (in terms of population, relevant element as it is a proxy of the internal demand of goods and availability of workforce), resources (with a special focus on energy resources, the main topic of the study) and the resulting politics and plans implemented by governments aimed to the growth of these countries.

The high performance achieved by the emerging countries compared to these variables that we identified, allowed them to be, in terms of growth, significantly

better than countries whose economies and growth rates are more stable (such as the U.S. or European countries).

The areas on which we decided to focus our attention were therefore two big players at the mono-national level, China and India (globally recognized as the two major emerging economies in recent years), and an agglomeration of countries, Africa, characterized by components, political and economic situations significantly different from China and India, but with substantial future growth prospects, on which the major economic player in the world have concentrated most of their investments (since many years the same China is investing infrastructures and resources in many African countries, including Sudan, Niger, Benin, Algeria and Morocco just to mention some [2], while the U.S., under the Obama administration, have recently announced the "Power Africa" project, which aims to invest \$ 7 billion over 5 years in Sub Saharan Africa in order to develop the electricity grid in an area where about two-thirds of the population still lives without electricity [3]).

This choice can be supported by data which demonstrates at the macro level the performances of countries identified as emerging (which then in following we will study in more depth), compared with those of the first world countries (in this case we opted for the single description of the situation in the U.S., as a proxy of the performance of all the developed countries); for example it is possible to note from Figure 1.1, which shows the annual growth rate of the Gross Domestic Product, how the values related to the index in China are significantly greater than those in the U.S., characterized by stable values from 2 to 3 percentage points (and a negative peak of -3 percentage points in 2009).

Moreover, if we analyze the data related to global energy consumption in 2012, it is possible to notice how the occurred net growth of +1,8% occurred is due, for the 90%, to China and India while, in the same period, consumptions related to OECD countries have declined by -1,2% (with a -2,8% of the U.S.) [4].



FIGURE 1.1: Growth rates of GDP in the U.S., China and India

1.3 Detailed analysis of China and India

After the brief preview of the thesis explained in the previous section, we proceed with the analysis of the current situation in China and India.

The elements that will be studied concern the country context (in terms of political situation, per-capita income and monetary environment), the trends and the potentials of the country, the policies implemented by governments in order to make the state more efficient in terms of energy and the current situation in relation to energy sources (both renewable and non-renewable)

1.3.1 China

1.3.1.1 Context

China, with its population of 1.351 billion people, is the most populous country in the world; however, still 651.364 million people [5] live in rural areas (as can be seen in Figure 1.2) where the rate of poverty is still high. The People's Repub-

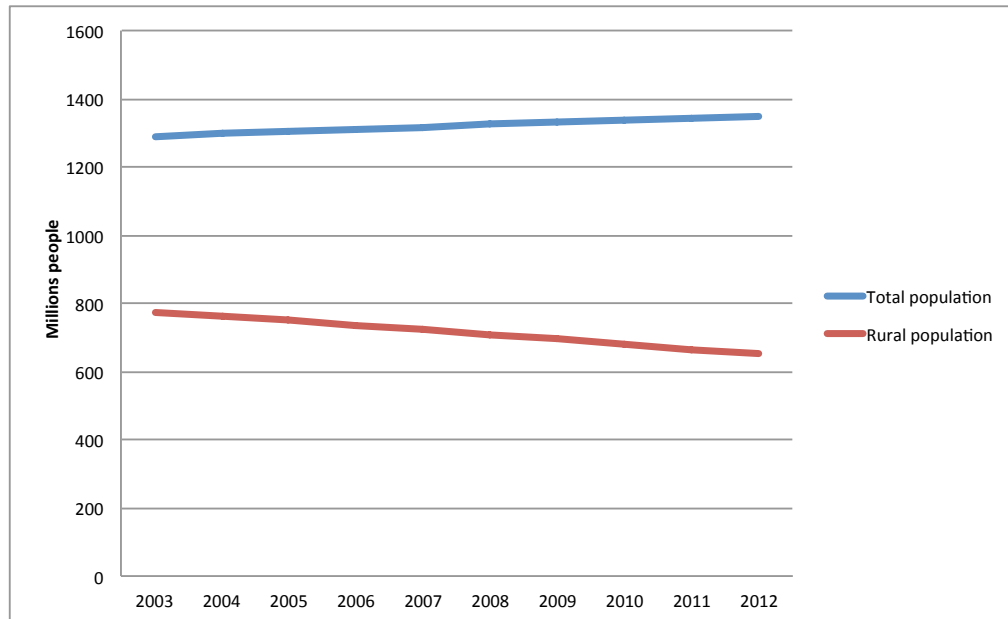


FIGURE 1.2: Rural and total population of China

lic of China is a sovereign state headed by a single party, the Communist Party, whose headquarter is located in the capital: Beijing. The state is divided in 22 provinces (23 considering Taiwan), 5 autonomous regions, 4 municipalities directly controlled by the Government and 2 special administrative regions (Hong Kong and Macau).

The currency in China is the Yuan (or Renminbi), it is linked to the U.S. dollar by a fixed exchange rate, revalued periodically only in case of real need (it should be underlined that, according to studies of the International Monetary Fund [6] based on the theory of purchasing power parity, the Chinese coinage is highly underrated).

These devaluations are used in order to facilitate exports, minimize currency risk and, most important, to try to reach the ambitious goal to turn the yuan into the new reserve currency to replace the U.S. dollar.

The urban population in China can be divided, according to its income, in six different social classes [7] as can be seen in Table 1.1; analyzing the number of families per class it is evident as in 2010 middle-upper classes had already a fair number of members, a value expected to rise within the next 10 years, according to the analysis of growth prospects.

TABLE 1.1: China's urban income

Class	Annual income available to households (kRMB)	Millions of households that have access to a given income (2010)	Millions of households that have access to a given income (2020)
High	200	1	12
Medium-High	100-200	13	53
Medium	60-100	34	69
Emerging Medium	40-60	61	66
Medium-Low	25-40	57	39
Low	25	36	23

Such analysis is also supported by historical data related to the growth of national GDP published by the World Bank, which show how this growth has been constant over the last decade (see Figure 1.3) in terms of total GDP and GDP per-capita. Many policies have been carried out in China in order to stimulate domestic consumption for the purpose of further stimulating the growth [7]: the rise of minimum wages, the extension of tax exemption, the introduction of subsidies for the purchase of vehicles and appliances, the acceleration of the urbanization process and the creation of a system of public welfare with adequate coverage.

However, we must take into account the fact that data relating to the GDP per-capita do not consider the big difference between urban and rural population, as it is only an average.

The growth of GDP (trend evident from the graph in Figure 1.1) has been clearly supported as well by growth of energy consumption in the country, which has increased by 113% between 2003 and 2010, although in 2010 the production was still based on coal and its derivatives in a percentage equal to 77% [5]. Energy production is the main source of pollution in the country, but it can not be reduced through a taxation on polluting factors due to a particularly low GDP per-capita in rural areas.

Poverty in rural areas is the reason why the government has not accepted bound targets to reduce emissions by a third party, such as the Kyoto Protocol (note,

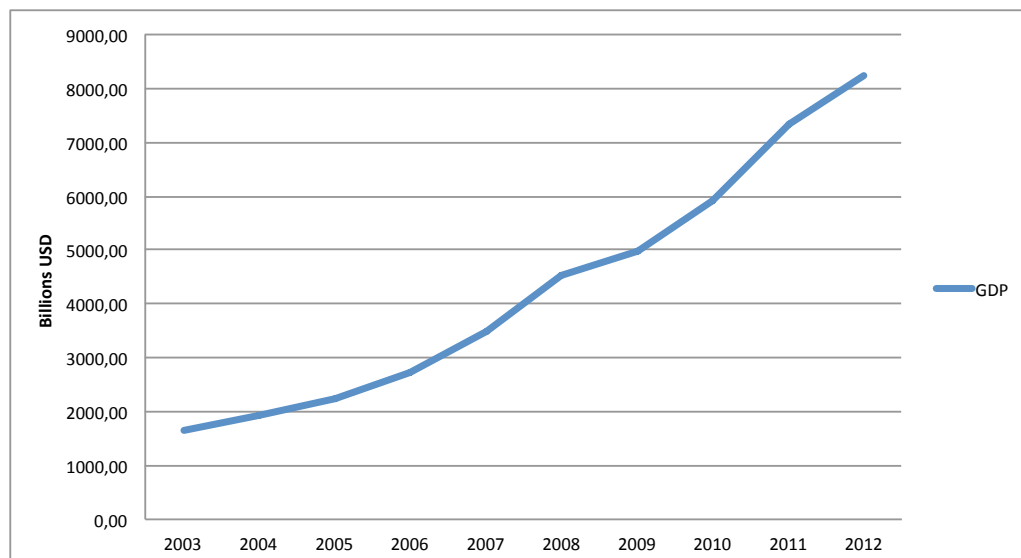


FIGURE 1.3: Evolution of Chinese GDP

however, as the Chinese state has also taken internal measures in that regard, which will be analyzed later in this thesis).

The high level of poverty in rural areas is also the cause for which the government had to embark on a policy that provides fixed rates for electricity, and the result was, in 2010, the sale of below-cost energy for 43% of the total energy production.

1.3.1.2 Government regulations

After having seen what are the characteristics of the country now we analyze how it is regulated by the Chinese government.

China's growth is regulated for years through five-year plans, which are used to define the objectives for the period of analysis and to outline the actions that will be performed; in 2013 is active the XXII five-year plan, which follows the period between 2011 and 2015.

The measures can be classified into two categories: on one side socio-political objectives and on the other economic objectives [8].

Regarding the first, the main political goal is to repair the serious damage left by twenty years of uncontrolled growth in the country, both in social and environmental areas; the planned solutions want to direct China toward a sustainable growth

model without slowing down the development. The most relevant social problems are related to the growth of social tensions between rural and urban population, those are caused by the gradual abandonment of the countryside toward towns (causing overpopulation in many cities) and the extension of urban areas that seriously reduced the cultivable acres in the suburbs.

The environmental problems are, on the other hand, related to unbalanced foreign investments: in fact during the '70s the only possible choice feasible, in order to revitalize the country's economy after the Maoist dictatorship, was to steer the investments to the coastal area (traditionally richer and more urbanized), neglecting the inland due to its pervasive poverty; looking at the results on the global level it has been the right choice on the short term, but it has dramatically increased the differences between the two areas and now it must be revised.

Regarding the economic objective, they cover four fields of action.

The first one is related to the enhancement of internal consumption: it is improved through the increase of minimum wages and consequentially through the stimulation of private expenditure; it is the main driver that can be used in order to reduce the dependence of China on exports.

The second regards the soft landing of real estate: it is made through the containment of real estate bubble generated due to common people which has sold their own houses and used the proceeds for leverage-buying (borrowing through a mortgage loan) of other apartments. In order to solve the problem the government has put pressure on banks for decrease the amount of mortgages and at the same time it has introduced new ways of investment, even in energy.

The third one takes into account the protection of the natural environment as it is seen as a key driver for fair and healthy growth of the country. The steps to do in this field have been defined as follow:

- Reduction of 17% of CO₂ emissions;
- Reduction of 16% of energy intensity;
- Increase in the use of non-carbon fuels (from 8.3% in 2010 to 11.4% in 2016);
- Strengthening of internal emission trading system;

- Reduction of the share of energy derived from carbon (from 72% in 2010 to 63% in 2016);
- Increase of the use of renewable energy (from 9.6% in 2010 to 11.4% in 2016);
- Construction of Hydro power plants in the south west;
- Further development of nuclear energy in order to reduce the risks related to it;
- Installation of 235 GWs of energy from non-fossil sources;
- Renewable energy's regulation: investments shared even with final users (supported by increases in the electricity bill), Feed-in-tariff and the introduction of a lower bound in the share of renewables for energy producers;
- Subsidies for \$ 585 million invested in research and development of renewable energy sources, construction of plants for renewable energy owned by the state (such as the Three Gorges Dam on the Yangtze River, the plant with the highest hydroelectric capacity in the world), subsidies for users of energy produced from rural-renewable and tax breaks for investment (especially in hydro and wind).

The fourth and final point concerns the promotion of the yuan as the currency used for international trade. Positive consequences of this action are:

- Proposes China as an alternative financial market;
- Offers to potential investors the opportunity to diversify risk by relying on a money relatively insensitive to market's fluctuations;
- Brings the growth of the financial structure of China;
- Slims Down of the supranational commercial traffics because it becomes easier to overcome the barriers imposed by bureaucracy.

1.3.1.3 Non-renewable sources

Coal China is the third country in the world with the largest proven reserves of coal (it is preceded by the U.S. and Russia), but since 2009 the production of the country was no longer able to guarantee the supply against the domestic demand (it is a very high demand as the Chinese energy production is based on coal for about 79% [9]), a factor which led the country to become a net importer, and soon became the largest in the world.

Clearly the high demand for coal does not come only from energy production: it is very relevant in terms of its consumption even the coke production that is used for the production of steel, sector in which China is the world leader.

The installed capacity for the production of energy from coal in 2008 was about 797 GW; as early as 2011 the capacity was increased to more than 1000 GW thanks to the renewal of many plants made possible by the intervention of foreign capital and know-how.

Oil The current oil production in China is about 200 million metric tons a year, with an import of about 230 million metric tons per year, a value that makes the country one of the largest importers in the world [10].

For this reason have been created over the years a growing number of collaborations with producers (and exporters) of oil in order to create pipelines which connect these players to China.

Natural gas According to estimates by British Petroleum and Energy Information Administration of the United States, the natural gas reserves of China are very high and are mainly located in the inland.

It is perhaps the least exploited resource because of the lack of infrastructure necessary for its transport within the country. The first pipeline that connects the east with the west of China was built only in 2004, by this time the importance of gas nationwide has increased steadily leading to the construction of a second pipeline already in 2011, with the provision of two additional pipelines by 2015

[11] (see Figure 1.4).

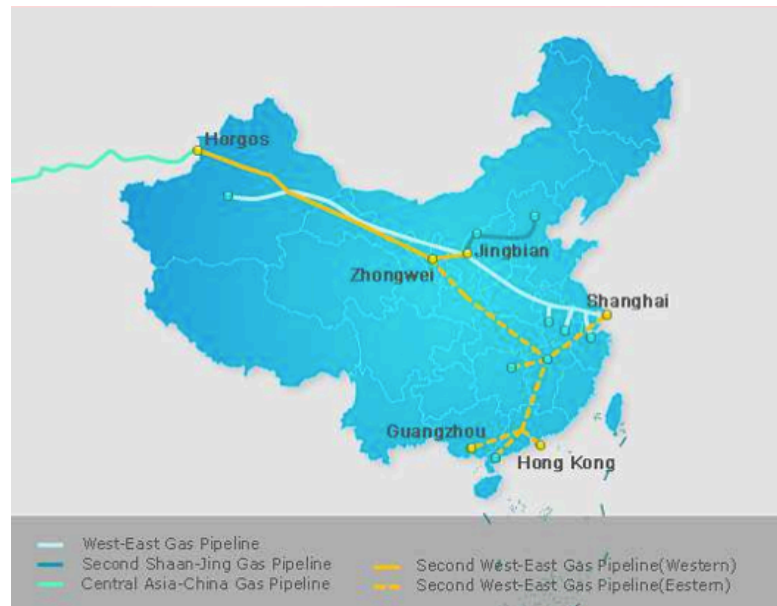


FIGURE 1.4: Existing and Planned Pipelines in China

Each activity related to the upstream phase of natural gas production is in the hands of state-controlled firms. In order to promote its diffusion, the Chinese government has always placed a ceiling price to make it more attractive for energy's production.

Recently seems to be relevant the shale gas which, according to certain estimations, should be present in very high amounts in the Chinese territory.

1.3.1.4 Renewable sources

Now we proceed with the analysis of the role of different sources of renewable energy in the country.

Hydroelectric China is the country with the highest installed hydropower capacity in the world (and its capacity is increased by 25% in the last years).

70% of the plants is in the central and southern parts of the country, but given the lack of links between the different regional power grids, it is impossible to fully exploit the energy generated in this way.

Another problem emerged with the presentation of the last five-year plan is the one related to the dams: they have a negative impact on the surrounding areas, so as to require the State to move entire villages because they were submerged by the basin created by the dam, inconvenience that has already led to the closure of some of these hydraulic barriers.

Considerable importance in the hydroelectric sector have held foreign investments, which have allowed some companies (among which we find Alstom, GE and Siemens-Voith) to get tax breaks from the government for the production of machinery related to this alternative energy source (with Chinese labor).

Solar PV The Peoples Republic of China is also, thanks to some government incentives promoted by 2008, the world's leading manufacturer of photovoltaic panels as well as producer of a third of the world supply. Initially, the 95% of the resources were exported but recently some interventions were made by the State [12] in order to improve the electricity transmission network and to be able then to connect this to any photovoltaic systems, thus also stimulating the domestic demand.

Thermal solar energy It is currently used mainly for small domestic installations but remains widespread.

Its technologies are widely marketed and the supply chain for the production well developed: Chinese production of this type of system occupies today the 64% of world supply.

Wind energy It is a widely used technology and distributed especially in the northern part of the country (see Figure 1.5); the systems are mostly onshore due to the high depth of the seabed that prevent the installation of offshore plants.

This technology has been used since the early 2000s though, until 2007, China had to rely on imports of the installations due to low internal production capacity.

To date, China is one of the leading manufacturers worldwide of plants based on wind energy, but to get this result foreign companies have been opposed by the

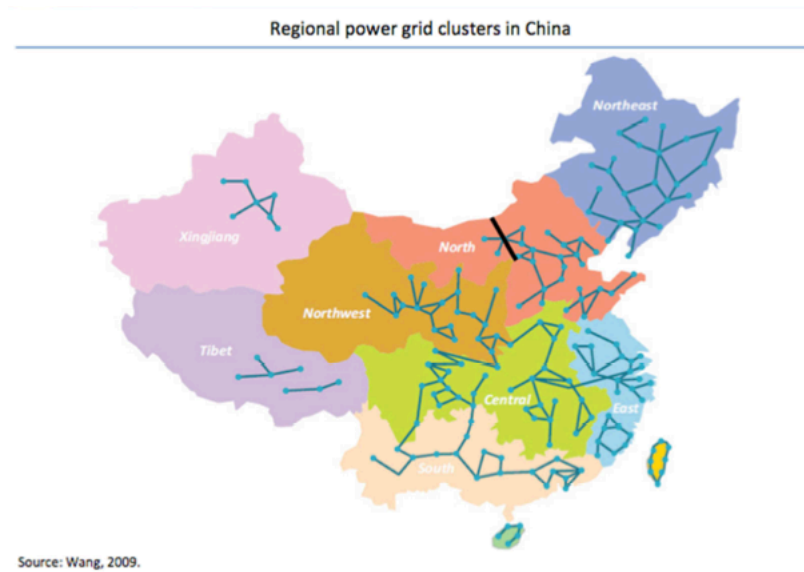


FIGURE 1.6: Clusters of local power grids in China

Problem which is accentuated even more in relation to seasonal renewables, making it impractical to carry any excess energy generated at certain times of the year and thus preventing you from getting maximum efficiency.

The project for connecting the various regional networks (see Figure 1.7) has already been started but is expected to be completed by 2020 with an investment of about \$ 40 billion.

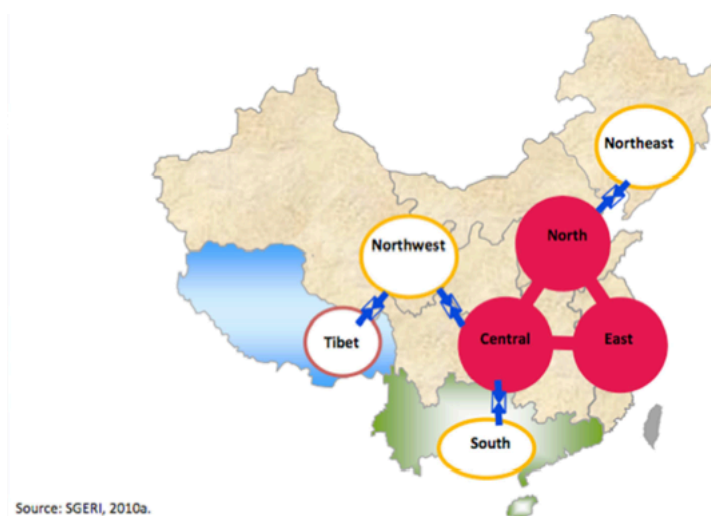


FIGURE 1.7: Links expected between the clusters of local power grids in China

1.3.1.6 Trends and potentials

After introducing the current situation in China, we proceed with the analysis of trends and growth expectations of the various sources of renewable energy, foreseen for the next decade by the Chinese government.

Between 2005 and 2010 we saw a huge increase in the use of renewable energy, equal to 68% (with an average of 13.6% per year), that suggests a deep-rooted desire to expand the use of non-carbon sources within the Chinese society.

The total capacity of energy produced by non-carbon sources installed in 1990 was equal to 37 GW, in 2000 to 83 GW and 278 GW in 2010, with expected target of 427 GW in 2015 and 696 GW in 2020.

We now analyze in detail how this capacity is shared between the various types of source [13]:

- Wind energy: the estimated potential is equal to 800 GW; the capacity installed in 2005 was equal to 1.26 GW in 2005 and 44.73 GW in 2010 (while the estimated target for 2020 was 30 GW); the estimated targets, retouched upward in 2010, are 100 GW in 2015 and 200 GW in 2020.
- Hydropower: the estimated potential is equal to 542 GW (the highest value in the world); the capacity installed in 2010 was equal to 216 GW; the estimated targets are 260 GW in 2015 and 340 GW in 2020.
- Solar energy: the capacity installed in 2005 was equal to 70 MW in 2005 and 700 MW in 2010; the targets estimated are equal to 15 GW in 2015 and 50 GW in 2020. It is important to underline that panels' production was able to supply enough pieces for generate about 8 GW already in 2010 but 90% of them was destined to exports.
- Biomass: the capacity installed in 2005 was equal to 2 GW in 2005 and 5.5 GW in 2010; the estimated targets are equal to 13 GW in 2015 and 30 GW in 2020.

It is important to also take into account that for the Chinese government even nuclear energy is a non-fossil energy source and then it also turns out to be one of the resources available to achieve the general target.

- Nuclear energy: the capacity installed in 2010 was equal to 10.82 GW (value higher than previously estimated); the estimated targets, revalued in 2010, are equal to 40 GW in 2015 (it is the previous target for 2020) and to 60-70 GW in 2020 (initially it has been revalued to 70-80 GW but it has been resized after Fukushima's incident)

1.3.1.7 Energy policies

Thanks to processes of industrialization and urbanization which happened in the last years, China has quickly become one of the countries that uses more energy in the world, with a share of 17% of total demand. For the reason just mentioned, because they are largely unexploited and have a great potential, renewables represent a good chance of growth for China. For this purpose Chinese government allocated more than \$ 300 billion for developing technology related to renewable energy sources in the XXII five-year plan.

1.3.2 India

1.3.2.1 Context

India, with its 1.236 billion people, is the second most populous country in the world; however 845.151 million of these live in rural areas [5] (as can be seen in Figure 1.8), where poverty rate is very high.

India is a federation of states with their own parliaments and governments divided according to spoken language by the "States Reorganization Act" of 1956; every state refer to a structure of central government with executive power is held by a Prime Minister. India is a pluralist democracy based on multi-party system.

The currency in India is the Rupee. It have been linked by fixed exchange rates

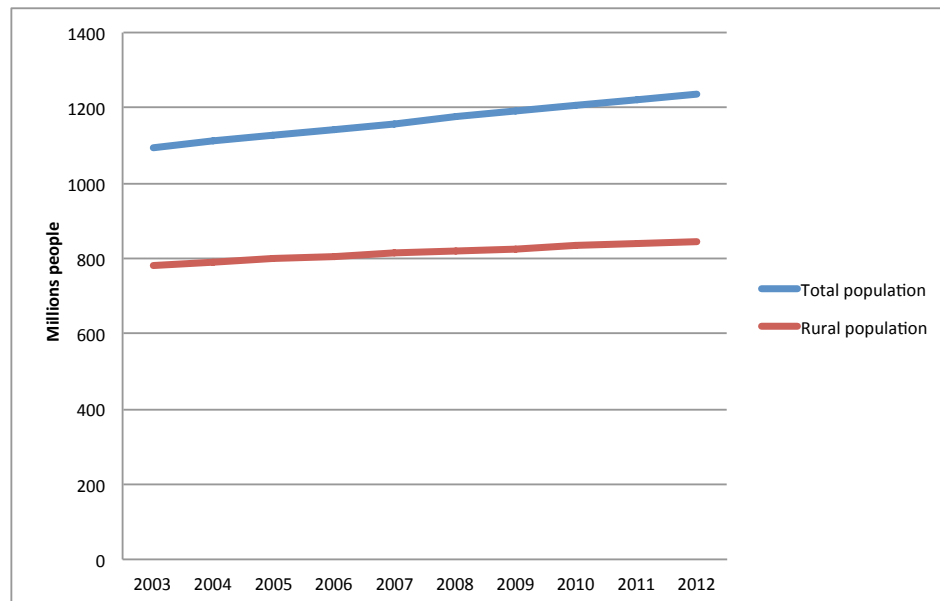


FIGURE 1.8: Rural and total population of India

to English Pound for years, from India's independence to the half of 19th century, and then with the U.S. Dollar (initially the exchange rate was set to 1, justified because India had no foreign loans at the time so it was fair to consider the Rupee equal to the Dollar [14]). Recently the exchange rate was made variable and the currency was devalued in order to promote the exports of the manufacturing sector.

Indian population, according to classification adopted by McKinsey Global Institute [15], can be split into 5 different income groups:

- Deprived - income of less of 90,000 rupees/year;
- Aspirers - income between 90,000 and 200,000 rupees/year;
- Seekers - income between 200,000 and 500,000 rupees/year;
- Strivers - income between 500,000 and 1,000,000 rupees/year;
- Global Indian - income of more of 1,000,000 rupees/year.

As can be seen from figure 1.9, in 2005, the class with the highest number of people was still that of the Deprived, which is the poorest one. This makes explicit the

high level of poverty in the country and can be correlated to the elevated share of Indian population (68%) that is still living in rural areas. However, it is important to analyze the projections for the future, which foresee a marked improvement with a relevant growth of population belonging to the wealthiest classes.

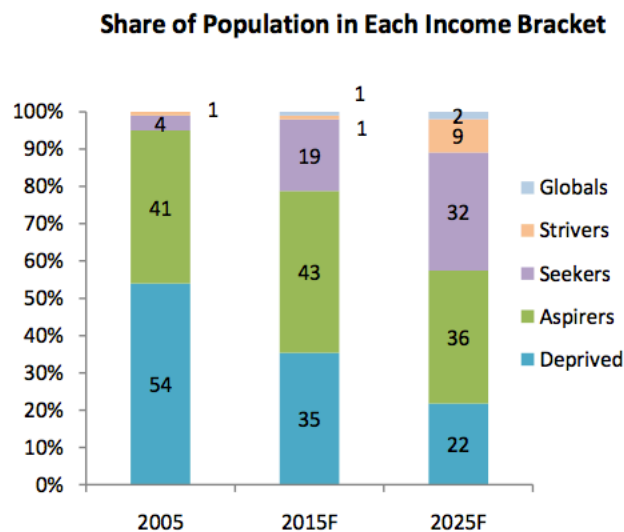


FIGURE 1.9: Distribution of the population of India in the income brackets

The high poverty level in rural areas can be attributed to the fact that, despite a share of 85% of villages are linked to the national electric grid, only 50% of dwellings have the availability of electricity. The huge gap between potential users of electricity and users with available electric power brings to an elevated growth expectation in electricity demand for next years; demand which is strictly related to GDP growth (as will be analyzed later in this treaty) which had a positive trend in last years as can be seen in graph in Figure 1.10.

The growth of GDP and energy demand are indicators of "good health" of the country and are representative of the large number of investments made for the development.

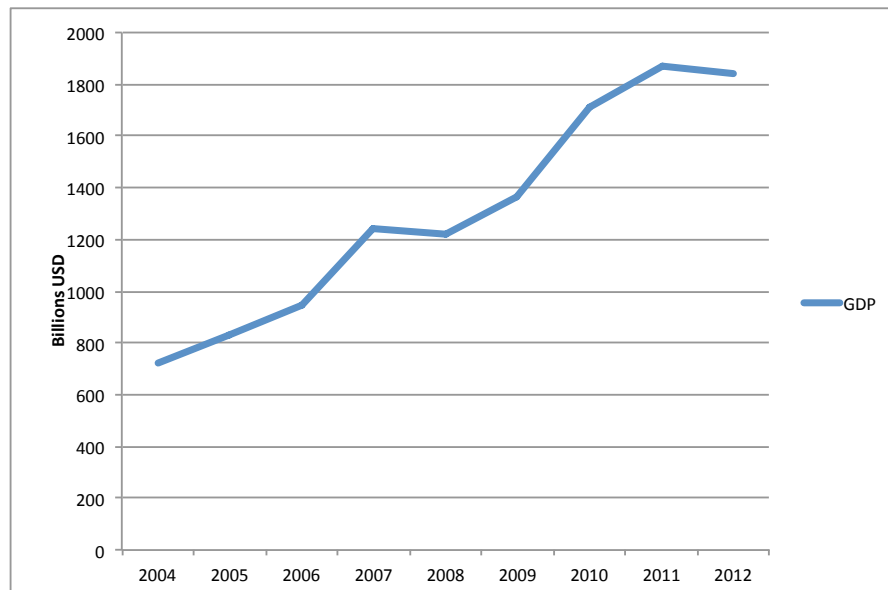


FIGURE 1.10: Evolution of India's GDP

1.3.2.2 Government regulations

Indian government has embarked on several initiatives aimed to stimulate investments in renewables in order to make them profitable for investors, both foreign and local.

The measures introduced by Indian Renewable Energy Development Agency (an institution created by the Indian government for project financing and project control related to energy) in recent years include [16]:

- income tax breaks;
- accelerated depreciation;
- custom duty/duty free import concessions;
- capital/interest subsidy;
- incentives for preparation of Detailed Project Reports (DPR) and feasibility reports.

In detail:

- 100% income tax exemption for any continuous block of power for 10 years in the first 15 years of operations;
- providers of finance to such projects are exempt from tax on any income by way of dividends, interest or long-term capital gains from investment made in such projects on or after June 1, 1998 by way of shares or long-term finance;
- accelerated 100% depreciation on specified renewable energy based devices or projects;
- accelerated depreciation of 80% in the first year of operations;
- interest rate subsidies to promote commercialization of new technology;
- lower customs and excise duties for specified equipment;
- exemption or reduced rates of central and state taxes;
- Elimination of ceiling on foreign equity participation;
- Streamlining the procedure for clearance of power projects;
- Formulating an action plan to setup the National Grid.

In addition to the reforms, to try to solve energy issues and to encourage the development of clean energy, has been recently created a "Ministry for non-conventional energy sources" in order to promote research and investment in green technologies. This ministry's goal is to bring the infrastructure for energy production to the rural population and to try to reduce the gap that has been created in the energy balance of the country, which is negative since the first half of the 80s and expected to grow if the government will not make the appropriate interventions, especially in the poorest areas of the country.

Other forms of subsidy have therefore been introduced by this ministry, more specific for projects related to renewable energy.

These concern:

- 2/3rd of the project cost subject to a maximum of Rs 20 million per 100 KW for procurement of modules, structures, power conditioning units and cabling to the implementing agency;
- Up to Rs 100,000 for the preparation of Detailed Project Report (DPR) for the grid interactive SPV power projects;
- 2.5% of its share of project cost, subject to a maximum of Rs 500,000 for performance evaluation, monitoring and report writing to the State Nodal Agency;
- Interest subsidy of up to 4% to Financial Institutions including IREDA and Nationalized Banks for captive power projects of maximum capacity 200 KW by industry;
- State reforms impacting the power sector: unbundling the State Electricity Boards (SEB) into separate generation, transmission and distribution companies, privatizing the existing generation, transmission and distribution companies and making tariff reforms by state governments.

1.3.2.3 Trends e Potentials

Due to the growth of the country, expected increases in consumption of electricity are of 4% per year between 2002 and 2025. Today, the main sources of energy are the not renewable (particularly coal) with the non-carbon sources (renewables and nuclear) that cover a share of 27% of the total installed capacity (in 2010) [17].

Regarding renewable sources the situation (to 2011) is as follows:

- Energy from biomass: the estimated potential is equal to 19,500 MW, while the installed one is equal to 554 MW.
- Solar energy: the estimated potential is equal to 20,000 MW (a very high value due to the favorable position of the country which has average temperatures ranging between 25 and 27 Celsius degrees), while the installed one

is equal to 15 MW. It is to be highlighted the presence of 9 solar cell manufacturers, 22 PV module manufactures and 50 PV systems manufacturers who can produce by themselves the national demand for PV systems.

- Wind energy: the estimated potential is equal to 47,000 MW, while the installed one is equal to 4,430 MW. It is relevant the fact that India is the second country in the world in terms of growth rate of installed wind power, for this reason the cost of wind energy is comparable with the cost of energy from non-renewable sources making it very profitable.
- Small Hydro: the estimated potential is equal to 15,000 MW, while the installed one is equal to 1,520 MW. The estimated potential is very high due to the high rainfall that occur during the rainy season in many areas of the country.

1.3.2.4 Non-Renewable sources

Coal India has about 7% of the world's coal reserves, they are distributed as shown in figure 1.11. They would allow the Asian country to fully satisfy domestic demand with mining activities but, due to the low level of technology and the consequent low quality of mined coal which make domestic production less profitable than imports, the Government of India was forced to import coal from Australia, Indonesia and South Africa.

For this reason the chairman of the Planning Commission of the Government, Montek Singh Ahluwalia, is promoting the "dismantling" of the monopoly of the public administration in order to liberalize and, then, allow the entry of foreign capital (and technologies) to increase the yield of domestic production [18, 19].

Oil India has about 9 billion barrels of proven oil reserves. They, as can be seen in Figure 1.12, are found mostly in open sea and, for this reason, the Indian government is trying to attract major oil companies in the country in order to exploit their technologies and resources for a better extraction from the deep ocean.

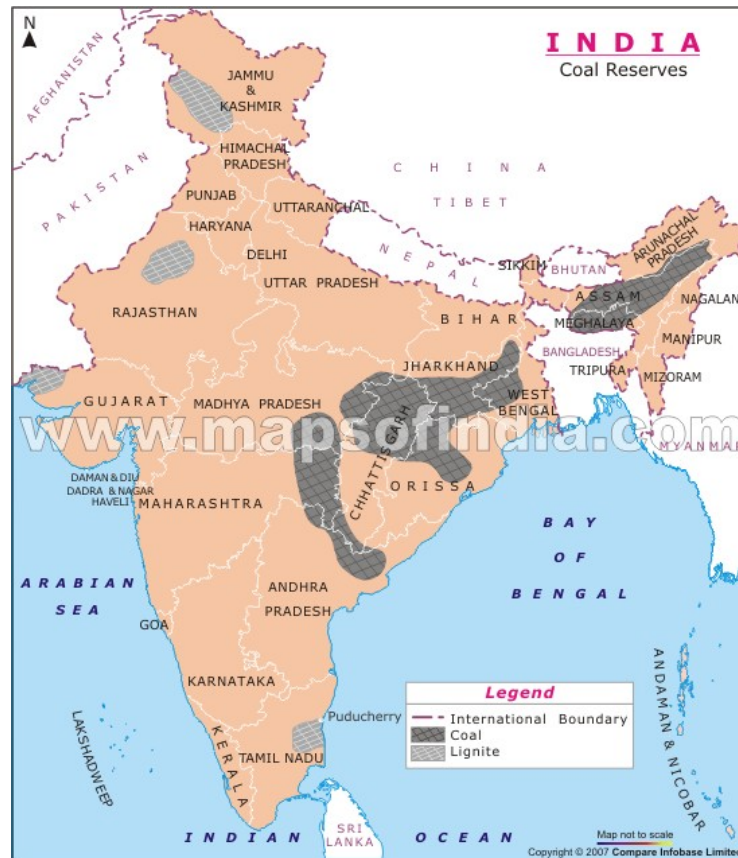


FIGURE 1.11: Distribution of coal reserves in India

The data relating to oil, to 2010, are of about 39 million tons of crude oil extracted, which, however, can not even provide the coverage of one-third of consumption (155 Mln tons). This fact makes the country very dependent on imports and this is why India has soon become the fifth-largest net importer of crude oil in the world, starting from the boom of its growth.

The main challenge for India, in the short to medium term, concerns the stimulation of growth of domestic production of crude oil because, in recent years, this has remained constant despite the entry of private investors in the sector.

Natural gas The natural gas sector in India has better growth prospects than oil because, recently, have been discovered new offshore fields. They allowed the increase of the reserves of natural gas which have approximately doubled between 2000 and 2010 (and, consequently, increased domestic production). At this time the gas is only 10% of non-renewable resources used for the production of energy,

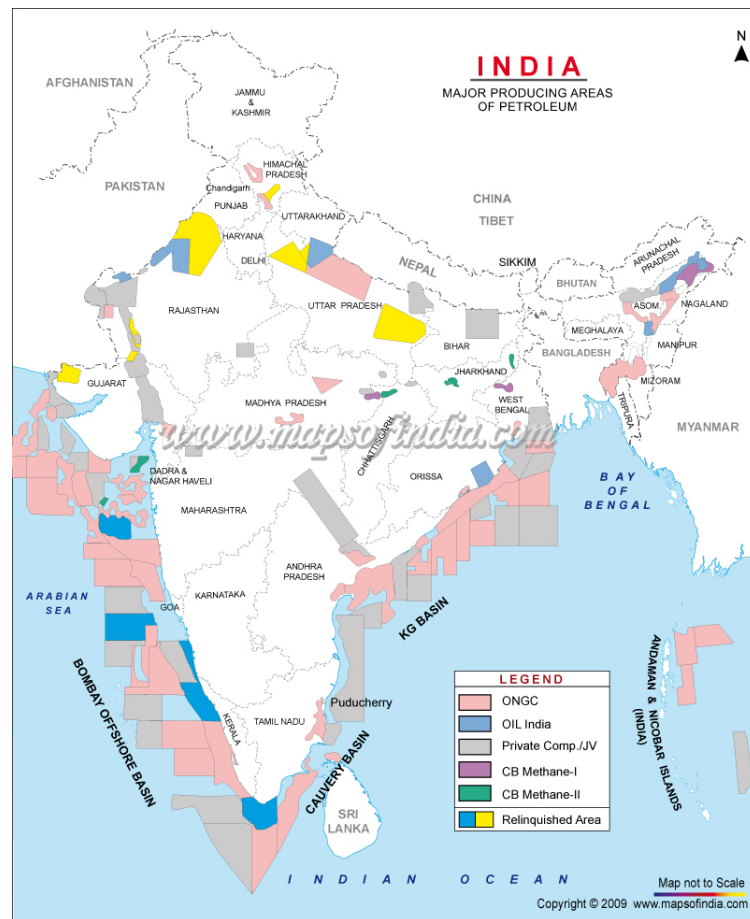


FIGURE 1.12: Oil fields in India

but this percentage is expected to increase to meet the need related to the diversification of energy sources.

Despite gas production has grown, it has not done so at the same rate of consumption, that has forced India to begin importing gas from 2004, making it, in few years, the sixth largest importer of liquefied natural gas in the world.

Nuclear energy Nuclear power, in 2010, represents 2.85% of the energy produced in India. Today there are several nuclear power plants in the area (as can be seen in Figure 1.13) and the number of these is likely to increase: the government has, in fact, provided a very high increase in the proportion of nuclear power in its energy mix that, according to some estimates, could cover up to 25% of the energy needs of the country by 2050.

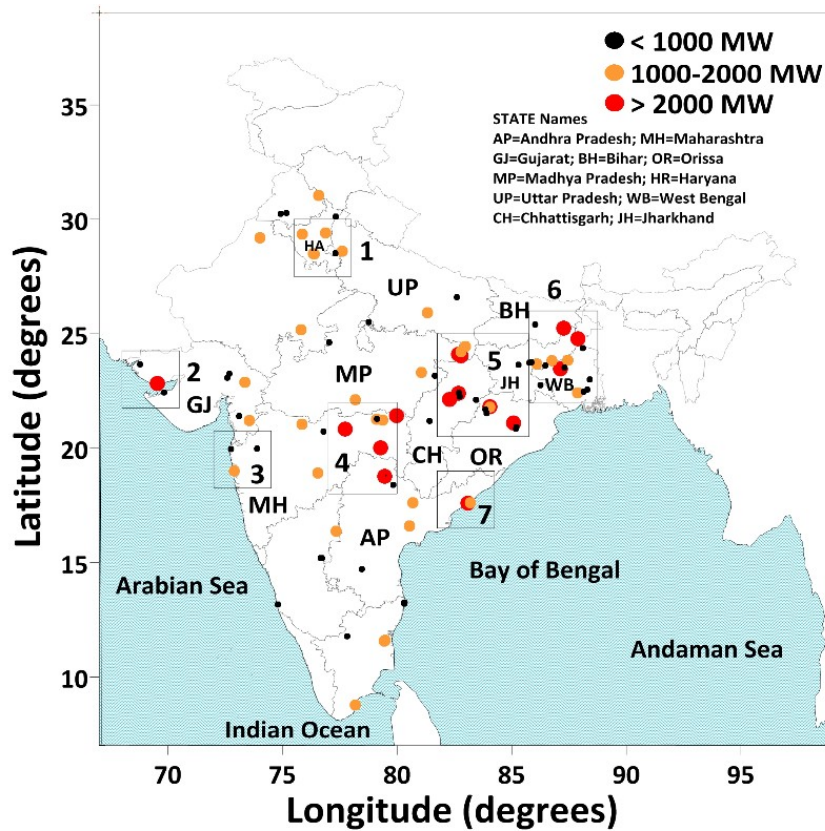


FIGURE 1.13: Distribution and capacity of nuclear power plants in India

1.3.2.5 Renewable sources

Wind The wind energy sector is highly developed in India due to the strong push that the government has given to the sector as soon as related technologies have begun to spread and to the high density of wind in the country (as can be seen in Figure 1.14).

The estimated capacity of the onshore facilities in this sector is very high (approximately 47,000 KW) and it can be improved thanks to the high possibility of development of the technologies related to the wind turbines (this estimation was done with data and technologies from 2007).

At the end of 2010 the wind installed capacity covered the 70% of the energy production from renewable sources.

The main critical issue related to wind energy is caused by the limited capacity of the installed turbines; this is due to the fact that the Electricity Act (2003) did not plan allocations and tax breaks compared to the installed capacity of energy

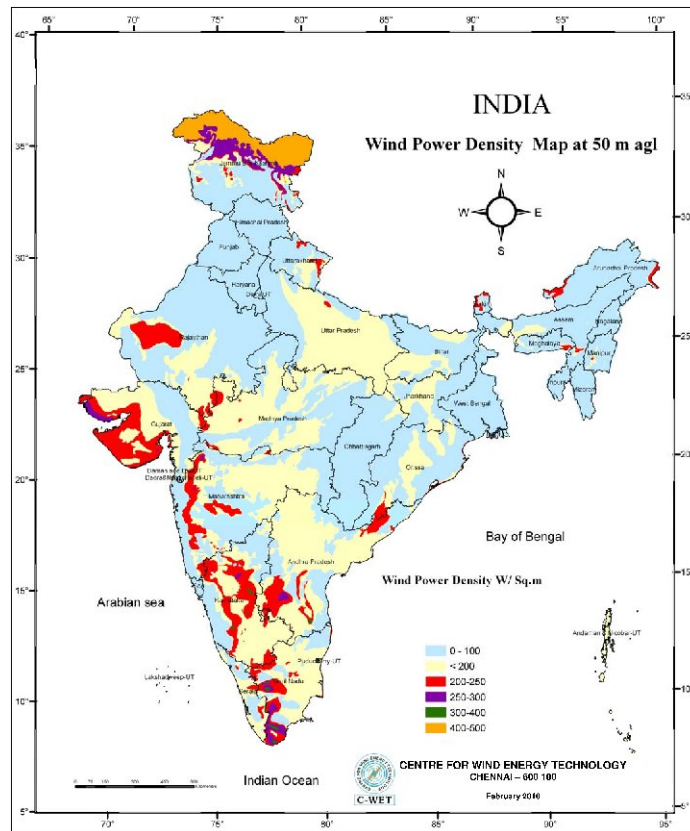


FIGURE 1.14: Density of the wind at 50 meters high in India

production but to the number of systems installed which led to the installation of several low-potential plants.

In 2008 the law has been amended, with the introduction of new incentives based on the installed capacity (5 MW at least) called GBI.

Recently, the growth of local producers, and consequently of competition, has led to a decrease in prices of turbines which enabled a further market expansion.

Solar PV Solar power, despite the high potential which is made explicit by Figure 1.15, is still largely untapped within the country [16].

Despite the many measures carried out by both the central government and by the state government, PV is not still attractive to potential investors.

Regarding the production of solar panels and photovoltaic cells, industry in which India is one of the major global players (further developed by government incentives on silicon production), it is estimated an high growth, from a market value

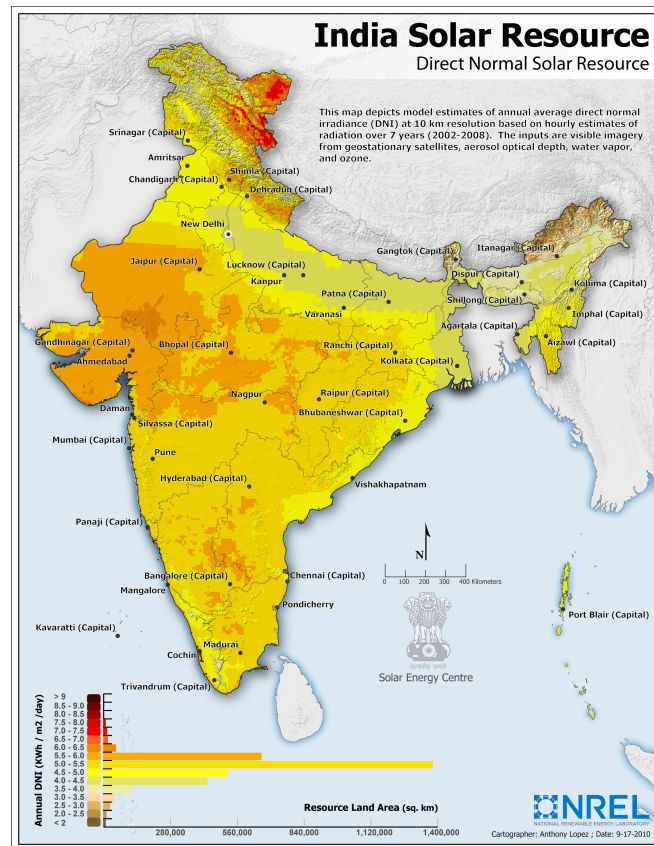


FIGURE 1.15: Solar intensity in India

of \$ 3.5 billion in 2013 to a potential market value of \$ 3,500 billion in 2022.

Concentrated Solar Concentrated solar virtually represent the future of solar energy in India, due to the ability of this technology to accumulate heat in order to avoid any fluctuations in the supply of energy.

Thermal Solar It is mainly used to make available hot water in dwellings and commercial and institutional buildings; in a small part it is used on an industrial level while unfortunately it has not caught on an hospital level.

Hydro power India has a large Hydro Power potential. This is due to the high level of rainfall present in the north-east region of the country [10] as can be seen in Figure 1.16.

Hydro power is the second source of energy on which the Indian economy depends

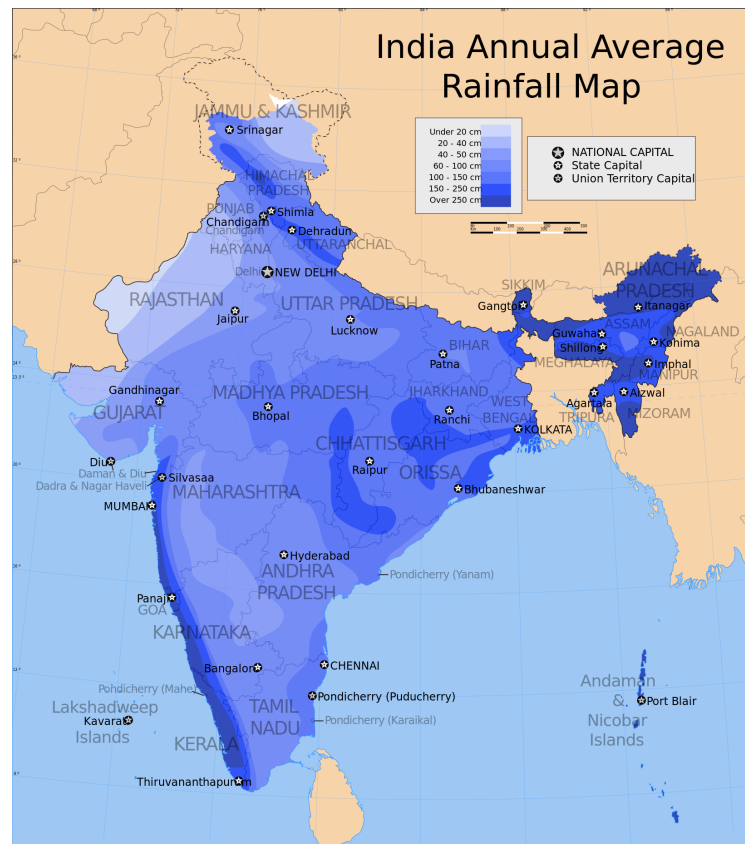


FIGURE 1.16: Rainfall intensity in India

(the first one is coal) to meet its energy needs and its use amount to 19.12% with 39,291 installed MWs [20].

It is important to highlight that dams, built for hydro energy production, are used even as an energy storage instrument, utilized to keep the energy produced by other renewable sources (like wind or solar) when the supply is higher than the demand [21].

Small Hydro These plants are highly widespread in rural areas thanks to the presence of numerous water courses scattered throughout the territory; it is very exploited due to the opportunity to install power plants even in areas not reached by the electricity grid.

Both the central government and state governments offer several incentives (in the form of capital funding) for the creation of new plants characterized by power ranging from 100 KW to 25 MW.

Despite these incentives, however, there have been still few investments made by foreign companies in this sector even if the potential of this technology offers great scope. The few investments have been done with the collaboration of Indian companies due to their greater knowledge of the territory and the means of obtaining licenses to install.

Biomass Biomass were, for many years, the main energy source in rural areas of India (bio gas is primarily used at the household level for cooking and lighting). There are many incentive forms created with the aim to develop this technology among which a financial support covering up to 50% of project's costs and incentives for energy recovery from municipal solid waste through the "Programme of Energy Recovery" or a refund of 40% of project's costs and a funding up to 400,000 \$/MW for waste water treatment plants.

Regarding foreign capital it is important to emphasize that many international companies set up joint ventures with public and private Indian companies such as EnviTec (Germany) with MPPL (India).

As regards the solid biomass, however, many cogeneration systems have been made in plants for the production of sugar, rice, distilleries, textile industries, fertilizer factories or mills. MNRE estimates that the use of cogeneration in industries may lead an additional electric power of 15GW but, at the end of June 2010, the total installed capacity connected to the electricity grid was only 2.322 MW even if solid biomasses incentive policies include tax breaks, feed-in-tariff and capital incentives.

Projects which use untapped resources to produce heat and electricity may receive 4,000 to 30,000 \$ for creating systems for gasification of 100 KW of power and up to 40,000 \$/MW for biomass cogeneration projects, subjected to the constraint that generated energy must be used in the same place where it has been produced. Liquid biofuels (especially bioethanol) are used to be mixed with traditional hydrocarbons in order to reduce fuel costs and emissions of the tools powered by the latter. There are several different incentives for these fuels such as the Ethanol Blended Petrol program, launched in 2003, which imposed a gasoline blending

with 5% of ethanol in 20 states and 8 territorial unions; for their production there are more than 20 Indian companies that almost produce 1 ton a year of ethanol.

1.3.2.6 Energy policies

Electricity sector Since 1991 there has been an attempt to liberalization to encourage the recovery from the crisis broke out in that year. However it has never really concretized because private individuals could only buy shares of public companies and can not acquire them in their entirety.

Central government is responsible for drawing up five-years plans and is responsible for the electrification of the most remote areas of the country while federal governments take care of distribution services.

Oil and natural gas In 2006, following the increase of private investors in this sector, the PNGRB Act was enacted: its aim is to regulate all the production phases of oil and gas in order to ensure continuity and security of supply all over the country and to promote free competition within the country.

Coal Policies to encourage the exploration, mining and coal distribution in the country have been made with the aim to reduce the country's dependence from imports.

Nuclear power A nuclear energy department has been created with the purpose of increase the share of energy produced by nuclear fission.

Any foreign participation in energy production's sector is rejected: the Indian government has only signed agreements with the U.S. Government for the transfer of know-how and the purchase of nuclear fuel.

Renewables In addition to the actions mentioned in the section "Government Regulations" we have to mention also bilateral agreements between India and the

European union created for the valorization of biomasses and their transformation into biofuels through biotechnological approaches.

1.4 African continent

After clarifying how emerging countries have been defined and examined and having presented a general framework of countries characterized by high level of growth as India and China are, we proceed with a comparison between these two countries and the African continent.

Before proceeding with the comparison we will perform an analysis of the continent in its entirety in order to justify our choice.

The African continent, the third-largest continent in the world with an area of 30,221,000 km^2 , is made up of 54 independent countries plus over three countries waiting to be approved at an international level; in 2012 1,020,201,229 people were living in Africa with a density of 33.76 inhabitants per km^2 .

The African continent is characterized by the highest percentage of poverty in the world: 47.5% of the entire population of the continent lives with less than \$ 1.25 per day (we have to say that this value is gradually improving) and has a high infant mortality rate which, however, has reduced of 12% in the last 20 years, indicating a slight improvement of life conditions of the African populations, even if it is not yet adequate.

Drawing inspiration from the division of African countries proposed by the World Bank it is possible to identify two macro areas in the continent:

- Sub Saharan Africa (to which belong the poorest countries of the continent, except for South Africa that is a special case in this cluster of states);
- North Africa (to which belong a lower number of countries - Algeria, Morocco, Libya, Tunisia, Egypt and Djibouti - characterized by an economy that is more solid and developed than the Sub Saharan one).

1.4.1 Sub Saharan Africa

This area of the African continent is formed by 48 countries, a population of 910.4 million people (63% of which live in rural areas) characterized, in the last years, by an annual growth rate of 2.7%.

The prospects of life of the populations living in those countries are much lower than those of the developed countries, the mean age for men is about 53 years while for women is a little bit higher and equal to 55 years; thus making a more detailed analysis of the population we can note that only 5% is over 65 years, the 54% has aged between 15 and 64 years and the remaining 41% of the population has aged between 0 and 14 years old.

Economic framework Analyzing the GDP of the countries belonging to this macro area, by considering the data made available by the World Bank [5] from whom it has been possible to extrapolate the graph below in Figure 1.17, it was noted that GDP continues to grow (despite a negative "peak" in growth in 2009), reaching in 2012 a value of \$ 1,414.6 billion (in 2003 the value of GDP was only \$ 620.3 billion).

Proceeding to analyze the income of the populations living in this macro area, by using the data from the database of World Bank, it is possible to highlight the percentage of poverty in these countries: much as 45.8% of people lives with less than \$ 1.25 per day, while the percentage increases to 69.9% if we consider the poverty line as \$ 2 per day.

Regarding the quality of life and, more specifically for the purpose of our research, the availability of electricity by the population, countries belonging to Sub Saharan Africa are characterized by the lowest rates of access to electricity of the world (26%); if we analyze this rate in the rural areas, his value is much lower, with an average value equal to 8% (it should be emphasized that only 37% of the population lives in urban areas). These values are of particular importance and they will be treated in a more detailed way in the following sections because they affect investments in energy implemented in these countries and even the type of energy upon which want to invest.

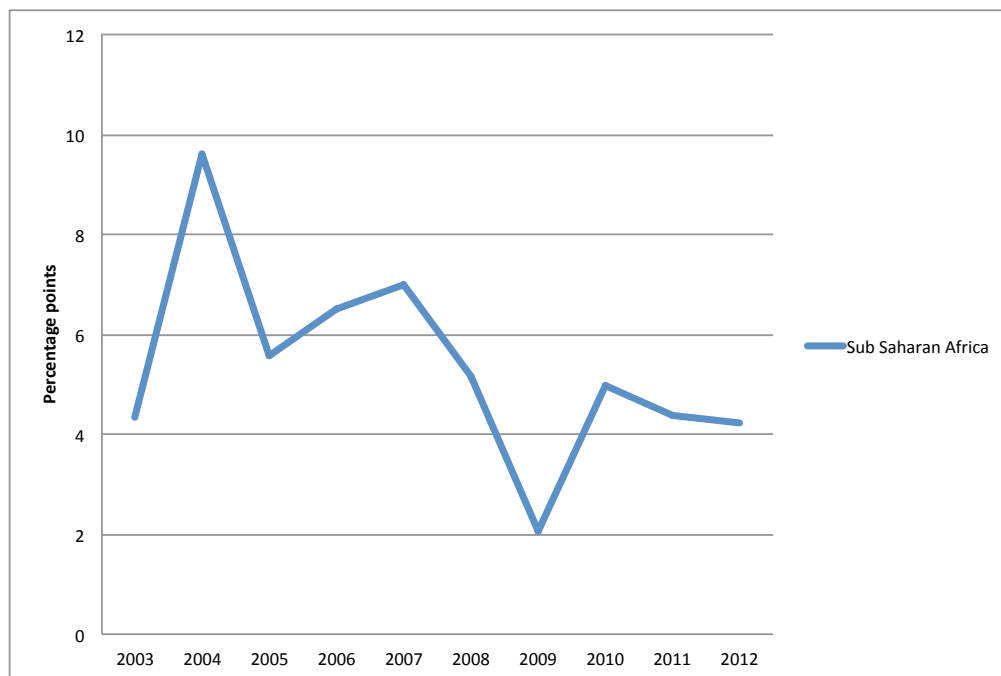


FIGURE 1.17: Growth rate of GDP in Sub Saharan Africa

As previously mentioned, theoretically South Africa is within Sub Saharan countries; however, analyzing the data related to this nation, you may notice that it is characterized by a stronger and more developed economy than the other one of other countries that belong to this macro area: only 38% of the population lives in rural areas (while in Sub Saharan countries the percentage is 63%), whereas 76% of population has access to electricity. This difference can be logically noted at the economical level: in 2012 the value of GDP per capita was \$ 11,190 (nine times higher than the average value of the other countries belonging to this macro area), characterized in the recent years by a constant growth of 3%.

Political framework Political framework in Sub Saharan Africa is very complicated: in fact in the same region coexist lots of different forms of regime which are more or less democratic. It is important to consider this different level of democracy and stability because, in developing countries, to its variation is linked a change in country risk (and hence of the rating) [22].

This complexity can be highlighted through the studies done by the "Integrated Network for Social Conflict Research" which analyses the countries both in terms

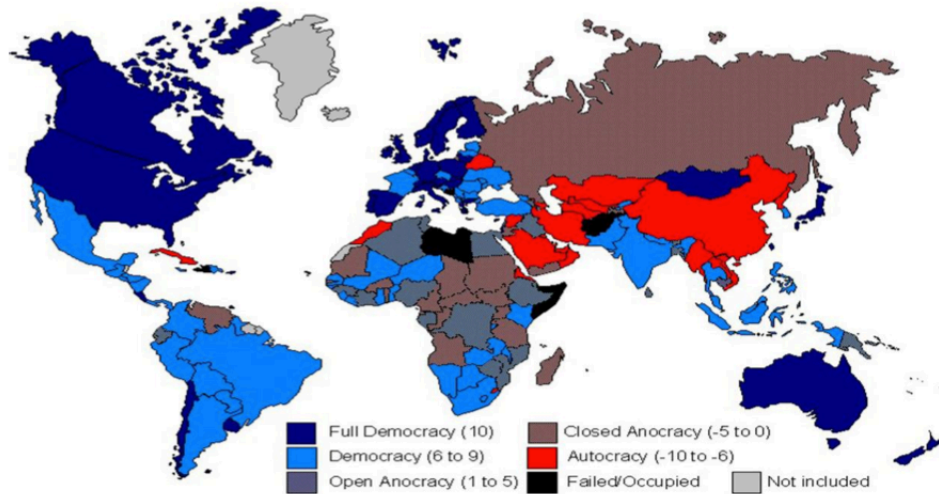


FIGURE 1.18: Distribution of systems of government (2011)

of stability and democracy [23] representing in a very effective way the fragmentation of the Sub Saharan region as expressed below:

- Analyzing data resumed in figure 1.18 relating to indicator Polity IV [24] it is clear that the most widespread regime is the anocracy, form of government where the central authority is weak or absent and the political control is disputed between different elitist group led by warlords, while democracy is relegated to a few countries of the southern part of the region.
- By examining data resumed in figure 1.19 it is evident that the stability of the countries of Sub Saharan region is very precarious: this positively influences the country risk and may be connected to the form of government (the most relevant levels of instability are present in countries characterized by a non-democratic regime).

1.4.2 North Africa

North Africa is composed of 6 nations (Algeria, Morocco, Libya, Tunisia, Egypt and Djibouti), with a population amounting to 109.8 million of people (of which

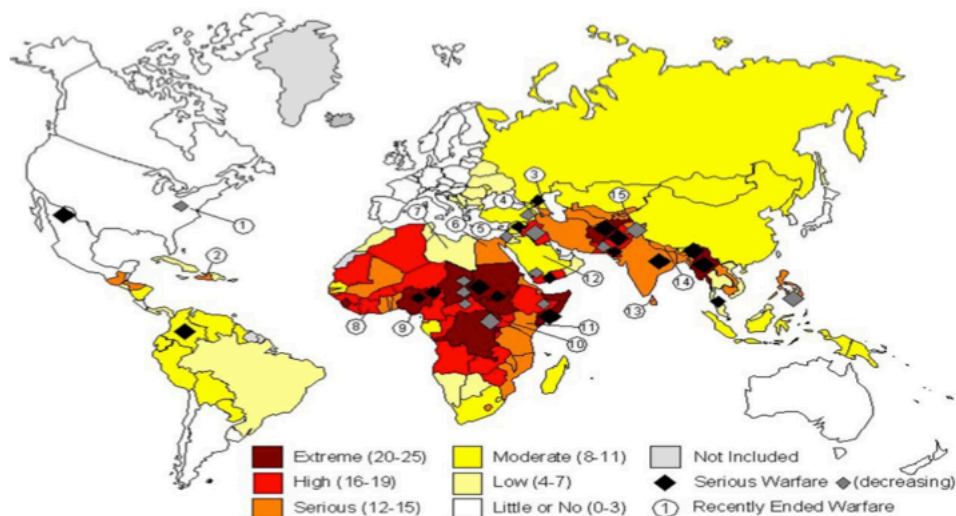


FIGURE 1.19: Distribution of the fragility of governments and conflicts (mid-2011)

36% lives in rural areas, but it is a decreasing value), characterized by a steady annual growth of 1.4% and a density of 45.6 inhabitants per km^2 .

The life prospects for the inhabitants of these countries are relatively better than those of the Sub Saharan area: the average life span is 72 years for men and 75 years for women; analyzing in a more depth the data concerning the division of north African population in age groups it can be noted how a greater percentage, compared to the data relating to Sub Saharan Africa, of population is over 65 years (6%), while values related to population aged between 15-64 and 0-14 are respectively equal to 66% and 28%.

Economic framework Analyzing the value of GDP per capita of the countries belonging to this area (see Figure 1.20) it can be noted how it has maintained a positive, but decreasing, growth rate (in 2003 the value of growth of GDP per capita was 7% while in 2012 it was 2.75%), settling at \$ 3938.5 billion in 2012 (while in 2003 the value was \$ 2429 billion), values significantly higher than Sub Saharan ones. As in the case of Sub Saharan Africa it is difficult to subdivide citizens into class of income, but it is possible to analyze the percentage of poverty in these countries: 2% of the population lives on less than \$ 1.25 per day, while

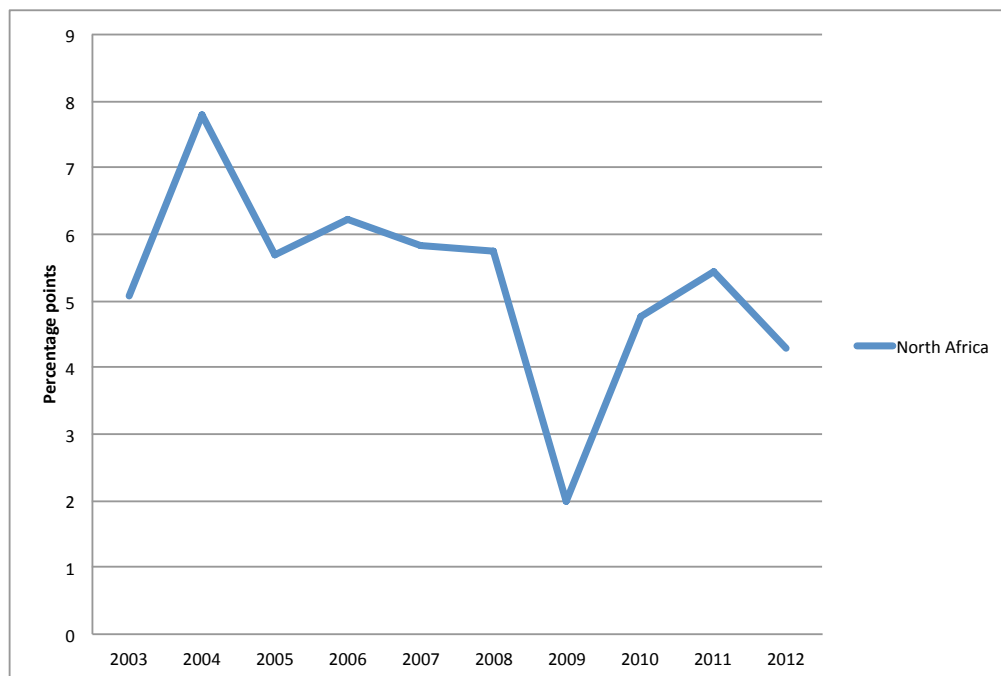


FIGURE 1.20: Growth rate of GDP in North Africa

the percentage rises up to 12% if you raise the threshold to \$ 2 a day.

These values are significant if you compare them with those of the countries belonging to Sub Saharan Africa (respectively 48.5% less than \$ 1.25 per day and 69.9% of population with less than \$ 2 a day): this justify our division of African continent in two macro areas and highlights the greater wealth of North African countries, characterized by a stronger and more developed economy.

This proposal may be supported by other data, including those of greatest interest to us, related to the access of population to electricity: from the database provided by World Bank it is possible to extrapolate data for the years 2009 and 2010 which state that 99.2% of population living in North African countries, in 2009, had access to electricity (value which rises up to 99.6% in 2010).

Even in this case it is considerable to compare these data with those concerning Sub Saharan countries, where, in 2012, only 26% of population was connected to the electricity grid.

Political framework The political situation of the countries belonging to North Africa, less fragmented than that which characterizes the countries of Sub Saharan

Africa, in 2011 was influenced by significant events related to the Arab Spring. The term "Arab Spring" refers to the set of protests (led by the younger generations) that broke out during 2011 (and still present in some countries) in the areas of Maghreb and Mashrek against dictatorial regimes ruling the countries of these areas [25].

The reasons which led to the riots are mainly the popular discontent derived from corruption, the lack of individual freedoms and the harsh living conditions that have characterized the last decades in some areas of the countries concerned [26]. As can be seen from figure 1.21 these protests have brought great changes in local government, even if, analyzing the values relative to the indicator of democracy Polity IV [24], not in all countries characterized by the riots had been possible to reach a state of full democracy (thereby maintaining a high level of country risk).

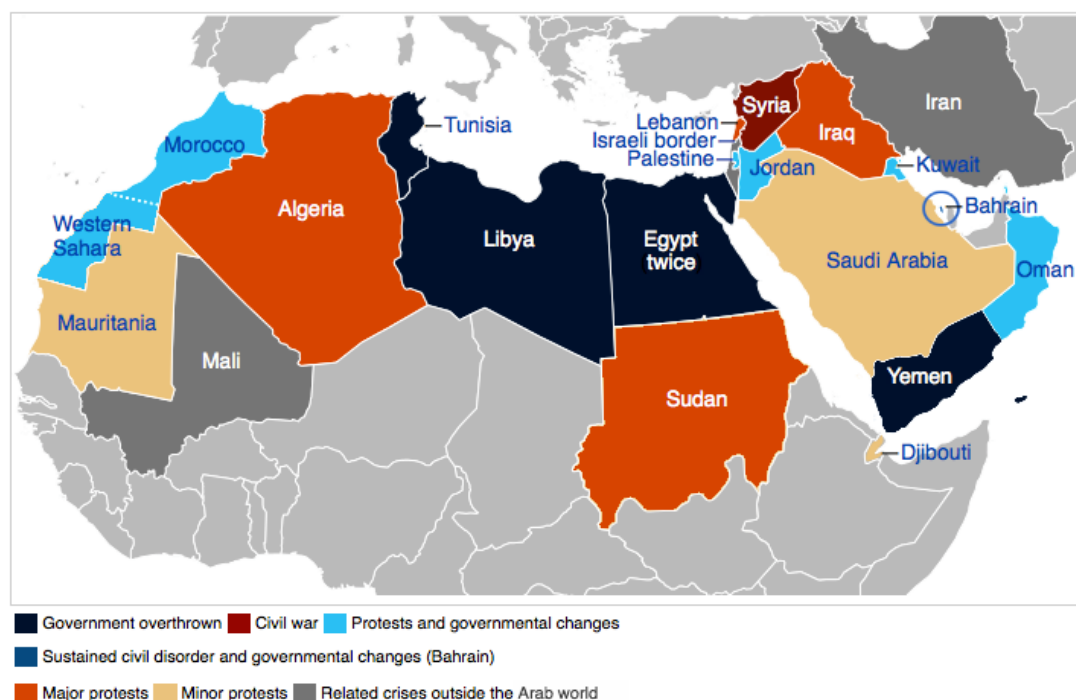


FIGURE 1.21: Consequences of the Arab Spring in the countries of the Maghreb and the Mashreq regions

1.5 Comparison

After outlining the economic and social context of China and India, with a special focus on the energy scenario, we moved to a comparison of the two states with the third emerging area previously identified, the African continent, trying to identify their differences and related causes.

First, it starts from the evident fact that China and India are important players at national level while the African continent is an agglomeration of countries characterized by political, social and economic contexts significantly different from each other, that did not favor neither development policies at the continental level, nor have enabled the growth of the individual states as major economic entities (this is the reason why, in Chapter 2, we will proceed with an analysis of the African context with a greater level of detail, in order to better understand the situations of the different countries in the continent).

In particular, the situation of domestic political instability (found in almost every of the states belonging to the African continent) is a major cause of the failure to the economic development of individual countries, due to the fact that a political environment characterized by high turbulence, usually, does not allow countries to attract capital or investors because of the high risk to which the potential investments are exposed (in this case it is possible to mention two categories of risk: Country and Political risk which include the risk of expropriation, breach of contract, war and civil disturbance).

1.5.1 Growth rate of GDP per capita

The first index that we analyze to compare the different areas is the gross domestic product per capita, a synthetic indicator able to explain in an effective way the growth of a country.

As can be seen in picture 1.22, it is evident how all the analyzed areas are characterized by values always positive, even if Chinese and Indian values are, on average, higher than the African ones.

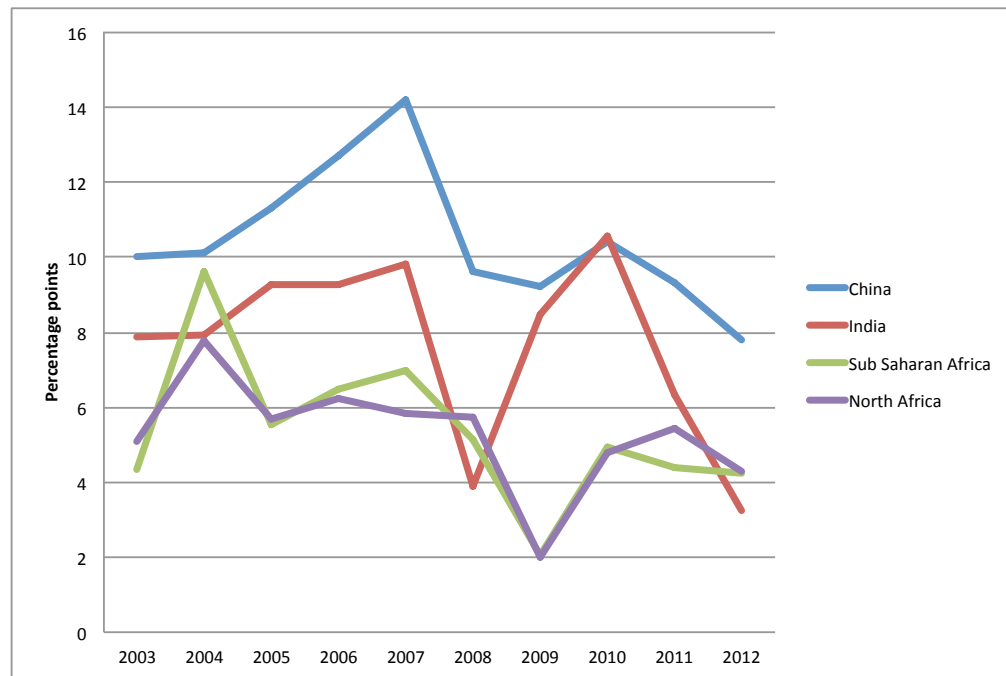


FIGURE 1.22: Growth rate of GDP per capita in North Africa, Sub Saharan Africa, India and China

This index therefore demonstrates that Asian region is at a more advanced stage of development, because of a precocious understanding of the market's synergies compared to African countries; these synergies allowed China and India to create a solid market in advance, both internal and external, able to support the growth. After having analyzed China and India and having underlined the major differences between these two countries and the African continent we can assert that the latter requires a more detailed study, as it is characterized by a set of political and economic circumstances, specific to each country belonging to it, and significant investment outlook mainly in the energy sector, where is meaningful the "Power Africa" project that has been proposed by the Obama administration in 2013; it will therefore be necessary a socio-political analysis, with the aim of having a clearer framework of the African situation, required for analyzing in a more specifically way the methods of financing in the energy sector of the continent.

1.5.2 Primary enrollment rate

The second index that will be analyzed is the primary school enrollment rate. Its importance in terms of country's growth will be explained in paragraph 2.5 but it's even an indicator that should be contemplated when doing a comparison between different countries.

As can be seen in Figure 1.23, the countries and regions which are the object of our research have had the same growing trend in last years in terms of primary school enrollment percentage.

Regarding China is important to highlight the absence of data related to years after 1997 but, considering the high enrollment percentage already present in that year and the introduction of strong policies about "compulsory education law", it can be assumed that the percentage of children attending the first two degrees of education is very close to 100% [27].

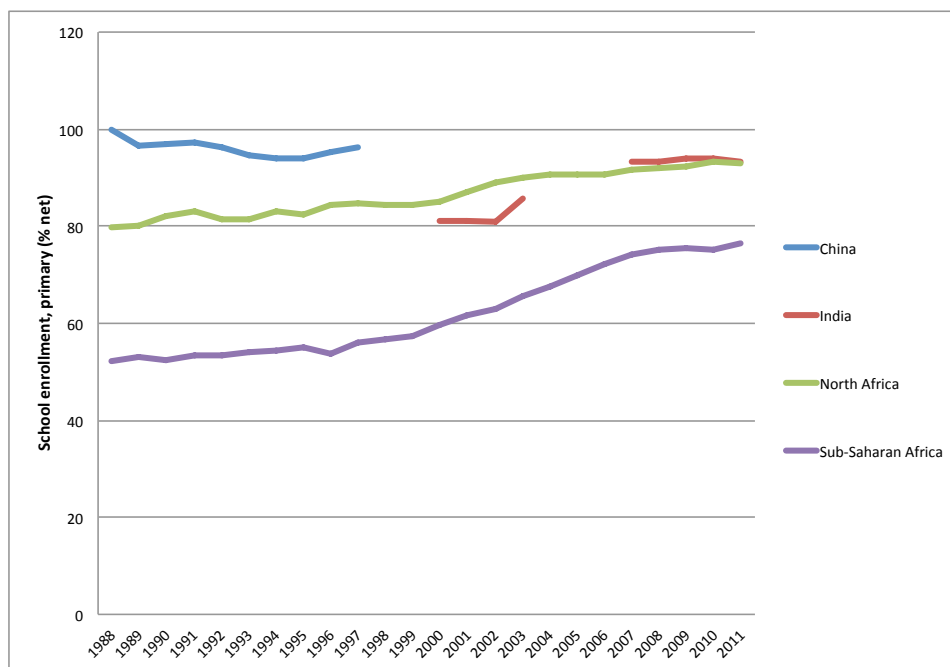


FIGURE 1.23: Primary school enrollment rate in North Africa, Sub Saharan Africa, India and China

About India and North Africa, using available data, is possible to say that both areas had the same behavior in terms of primary school enrollment. The main issues in reaching the full enrollment in such areas is the cultural barrier about

female's role inside the society: even if there have been changes in last years, great gender differences are still present about the primary school enrollment rates [28, 29].

Regarding Sub Saharan Africa the first thing immediately recognizable looking at the data is the low primary school enrollment rate. The problem is present in the whole area and, even if many organizations (like Unesco, World Bank and Unicef) are trying to solve the problem, a real solution to the issue is still difficult to achieve.

1.5.3 Access to electricity

The third and last index we are going to use in order to compare China and India with the African continent is the rate of access to electricity (even in this case it is preferable to analyze the African continent by splitting it in North Africa and Sub Saharan Africa).

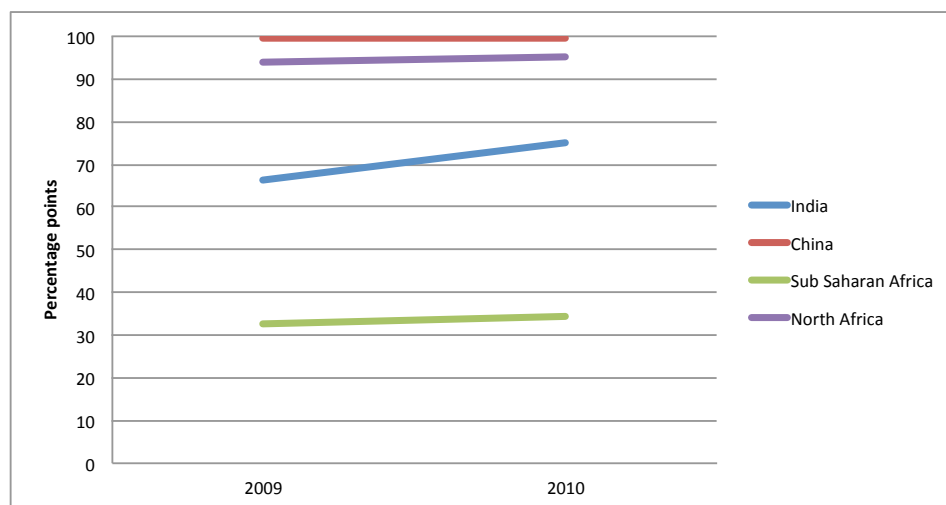


FIGURE 1.24: Access to electricity in North Africa, Sub Saharan Africa, India and China

Analyzing the Figure 1.24 is clear the great difference in the values which characterize China and North Africa (whose datas are close to 100%) than those related to Sub Saharan area (32% in 2009 and 35% in 2010), while India is characterized by intermediate values (66% in 2009 and 75% in the year after) because of the

high percentage of population living in rural areas of the country which are not as developed as China's ones.

It is therefore evident the need to invest in infrastructure which will enable the development of the energy network in Sub Saharan Africa, in order to create a widespread connection to ensure that people which are living in the rural areas of the continent will be able to take advantage of the electric current.

Chapter 2

Economic and energetic contexts of Africa

After reviewing the African continent at level of macro areas in social, political and economic terms, we proceed now with a depth analysis of the events that led Africa to the actual economic situation and its energetic context.

This analysis is concluded, as mentioned in section 1.1, with insights on three African countries, Mozambique Morocco and South Africa (chosen according to the classification of World Bank about the income of population), which has been carried out in order to highlight the heterogeneity in political, economical and energetic terms of the entire continent.

2.1 Connection between increase in the energy consumption and the economic growth

The theory behind the following analysis is the existence of a link between the economic growth and the increase in the consumption of electricity in a developing country. This theme will be crucial to justify a few considerations that follow.

The purpose of this section is to analyze the possible existence of a link between the increase in the consumption of electricity and the economic growth in a developing

country.

This topic arises in our study concerning the evaluation of the consequences in the quality of life of local people regarding the implementation of an electrical network in rural areas; this theme will be crucial in order to justify a few considerations that follow.

The analysis is supported by the researches carried out both from econometric studies of the casual relationship between the two factors and surveys among African companies: they both affirm that economic growth is positively related to a rise in energy consumption in rural areas, related itself to an increase of electricity availability which allows native population to satisfy its basic needs, such as cooking or lighting.

The results of the analysis can be synthesized as follows:

- Estimation by OLS (Ordinary Least Squares): it demonstrates the existence of a mono directional relationship, both in short run¹ view than in the long run² perspective, between economic growth and increase in energy consumption in different poor countries such as India and Malawi [30];
- Test ARDL (AutoRegressive Distributed Lag): it demonstrates that energy consumption is cointegrated with economic growth in different countries of the African continent, also highlighting an impact in a long run perspective between the two factors (countries among which we can find Ghana, Sudan and Senegal) [31];
- Granger causality test: it demonstrates the existence of a bidirectional relationship between economic growth and increase in energy consumption in Gambia, Ghana and Senegal and a mono directional relationship (the economic growth causes an increase in energy consumption) in Sudan and Zimbabwe [31].

As mentioned above, in support of the data, there are as well some surveys carried out by the World Bank [32, 33] with companies from Sub Saharan Africa. The

¹analysis with both fixed and variable inputs

²analysis without fixed factors of production

obtained results show that there is awareness of the relationship between economic growth and energy consumption also among entrepreneurs, as can be seen from the answer to the question: "Do you identify electricity as the main obstacle to the success of the business activities and growth?" which, on average, is positive for more than 50% of respondents (with peaks reaching over 70% in countries such as Chad or the Republic of Congo).

As well as the econometric tests mentioned above, which have highlighted the link between economic growth and energy consumption, it is possible to analyze some case studies in which are described the consequences of electrification of rural areas in Africa (in a qualitative way).

It has been decided to consider, as example of positive effects of the connection to the grid for final users, public administration and firms, a case study written by Peter P. Zhou (in collaboration with "Intelligent Energy Europe") concerning a grid extension in the municipality of Manyana (Botswana), a medium type village (by Botswana's standards), characterized by a population of about 3200 people [34].

The interesting thing in such case study is related to the financing policy used in order to be able to reach almost all facilities of the village: "The Rural electrification Collective Scheme is a financing policy that assists rural customers in the form of a loan to reduce the burden of up-front costs of connecting to the electricity grid.

Potential consumers form groups of 4 or more customers when applying for connection to benefit from economies of scale i.e. share the cost of extending the grid closer to their premises. This loan scheme requires potential grid electricity consumers to pay a deposit and make repayments over a period. The Scheme began in 1988 and has undergone several phases and modification with regard to deposits, repayment periods and loan interest rates".

The different sectors of the village taken into account by the study, and the relative infrastructures, have been linked to the grid in about five years (since 2002); the latter are: Health (1 clinic - electrified), education (1 secondary school - electrified and 1 primary school - partly electrified), government (tribal authority -

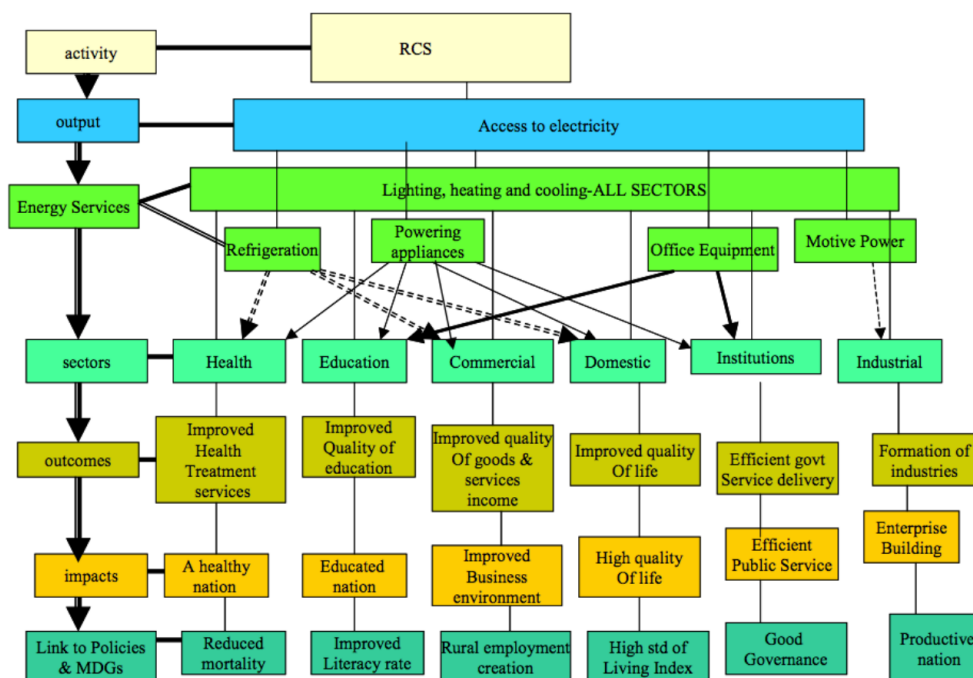


FIGURE 2.1: Elaborated causal chain of the RCS and related sectors

electrified), communication (1 postal agency - not electrified), Small and Medium Industries (welding and sewing - both electrified), commercial (13 general dealers, butcheries, restaurants, bottle stores - 6 electrified) and the domestic sectors (about 640 households with about 82% electrified).

For the purpose of our study it is therefore important to highlight that in rural areas, characterized by low percentages of electricity access and by the presence of energy demand from the local population whose aim is to satisfy their basic necessities, an investment related to the implementation of grid has important consequences on the daily life. This is outlined in Figure 2.1 which thus emphasizes, for each of the areas mentioned above, the consequences of increased availability of electricity, thereby confirming the thesis of econometric tests discussed earlier which stressed the presence of a connection between rise of consumption of energy, made possible by an higher availability of electricity, and economic growth.

After having thus described the link between economic growth and energy consumption, we are going to delve into the relative contexts in the African continent; particularly, as regards the previously analyzed economic context, a purely historical analysis will be carried out starting from colonialism, of which the main

consequences at the macro level will be evaluated.

2.2 Economic context

In order to better describe the economic situation of the African countries it is important to make an historical analysis, through which it is possible to identify the most significant causes and the consequent transformations that led the economy of the African continent to its current state.

2.2.1 Colonialism

The development of colonialism in Africa and its consequent partition done by some European countries arrested the natural growth of the continent. The main aim of colonialism was to exploit human, physical and economic resources of the controlled areas, trying to provide the maximum economic benefit to the colonizing powers at the lowest price.

This phenomenon forced the African nations just to produce for the export market, keeping prices low for the European consumers: to the colonizing nations the individual needs of their colonial subjects were not important (economic development and the education of the African countries were considered unimportant and were left to the private sector). The production, controlled from start to finish by European countries (they wanted to "vertically integrate" the production processes of their colonies), was concentrated on certain goods thus leading to significant impact on the local economy. In Tanganyika, for example, "the colonial authorities shifted labor from food production and attempted to create a surplus of a labor intensive, nonfood cash crop, cotton" [35] (this led to inadequacy of the food reserves and subsequently chronic malnutrition and famine).

Doing so, the colonizing countries undermined the existing economic power structure and made Africa totally reliant upon Europe for their economic destiny; they focused only on the export component of the economy and improved infrastructure

as well (this resulted in most of the roads and rail systems in colonial Africa to be oriented towards the coast). Their interests were not to improve or enrich the colonies but solely to improve transport of raw materials to market.

Also the technological and industrial development in Africa was interrupted by the colonialism: before the partition of Africa, local production provided Africans with a wide variety of consumer goods but the policies of colonialism forced the demise of African industry and created reliance on imported goods from Europe. This caused the focus of the Colonial African economies on the production of one or two agricultural products for consumption in the world markets.

2.2.2 Post-Colonialism

The end of World War II and the consequent ratification of the Atlantic Charter by Imperial Powers which had control on Africa brought to the decolonization of the continent.

This process left the former colonies in a situation of economical and political inefficiency and of commercial isolation as results of years of domination geared only to wealth of colonizers [35].

Economy Regarding economy is necessary to underline the main cause of the inefficiency: colonies were structured in order to provide maximum economic benefit to the colonizer at the lowest possible cost without taking care about colonies needs. This fact brought the economy of controlled countries to be oriented only to the exports to their former owners, exports which were characterized by low prices unable to support the public expenditures of new, autonomous, governments. Another interesting thing is the relation between the economies of the colonies and the goods produced, chosen by the colony's owners (the fluctuations in the demands of such products were disruptive for producer): "the economic well-being of Africa became sensitive to the rise and fall of the demand for these primary products and the movement of industrial prices, over neither of which she had any control." [36].

Politics The exit of European Powers from the African continent led the new institutions to face with the gap left in legislation by colonizers. The former controllers in fact, as said before, had never do anything related neither to the growth of economy, nor to the improvements of life condition like policies for the control over children's and women's work and instruction.

Trade Obviously trading routes were improved during colonialism but every intervention which had been taken was oriented only to transport goods from colonies to their settlers. After decolonization the countries had to deal with open markets but they were not prepared for it as they were not able to trade to each other and to countries of other continents in order to compensate for the lack of internal productions [35].

2.2.3 Impact on present day

The explained consequences of colonialism have led to long period problems in terms of public debt.

In fact the lack of control over these elements brought the continent to a huge public debt which is still present (and growing) nowadays even if it has been renegotiated by several institutions (like International Monetary Fund or World Bank) during last decades [37].

Such debt is function of many economic determinants like:

- reduction of internal consumption and price collapse;
- consequent deflation which reduced the revenues from exports even if they were rising [38];
- uncontrolled growth of interest rates owed to contractors of public debt.

Clearly African governments, with few exceptions, would never have been able to manage the widespread debt which was affecting their economies, so, in this

scenario, two initiatives of the IMF and WB have played a very important role: the "Heavily Indebted Poor Countries Initiative" and the "Multilateral Debt Relief Initiative" [37, 39].

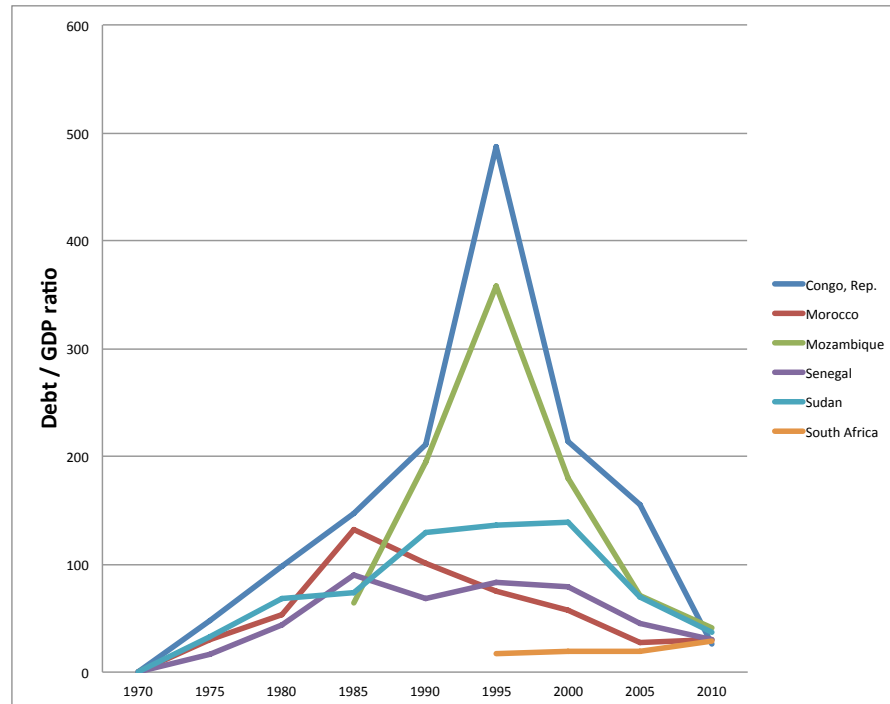


FIGURE 2.2: Convergence of the debt/GNI ratio

These initiatives have acted to substantially reduce external debt positions of African countries through the use of debt relief actions provided under various conditions related not only to economic performances but even to the ones linked to people's welfare [40].

Furthermore, in recent years, many regional economic communities have sprang up in order to try to bring the economies of the African countries to an economic convergence through the bounding of various economic performances like inflation rate, "tax revenues/GDP" ratio, "overall budget deficit/GDP" ratio, etc [39] and their actions' effects (joint to debt reliefs) could be exemplified by Figure 2.2 that shows the convergence of the "debt/GNI" ratio [5].

2.3 Energetic context

Africa can be subdivided in two areas, North Africa and Sub Saharan Africa, not just in social and political terms (as we saw in Chapter 1) but also in terms of energy issues.

As we will describe in more depth in the following sections, while North Africa has levels of electrification very similar to the first world countries' one, the Sub Saharan area of the continent is still characterized by low values, especially in rural areas where, as mentioned previously in Section 1.4.1, lives 63% of the population. It should however be pointed out that the two areas have in common the worth related to the percentage of electricity produced from renewable sources: it settles on values near to 1%, too low especially for areas rich in sources of clean energy.

2.3.1 North Africa

North African energy context is almost comparable to that of more developed countries.

In this region the average share of population reached by electric current is approximately 94%, although the contribution to the energy consumption from renewable energy is less than 1% [5], despite there being a high potential in the region [41]. The latter is highlighted by different studies, such as the one drawn up by the German Areospace Center [42] which affirms that the amount of energy producible through PV technologies is high enough to be able to meet alone the global demand of electric current for decades to come (as can be seen in Figure 2.3).

Then analyzing the causes that led the North African area to have such a low share of electricity produced from renewable sources, the high level of subsidies stimulating the use of energy from not clean sources results to be determinative.

As is pointed out by the International Monetary Fund [43], these types of energy subsidies are widespread throughout North Africa; doing a worldwide analysis in fact, nearly 50% of global energy subsidies are distributed among the nations of North Africa and the Middle East, of which about half is intended to petroleum

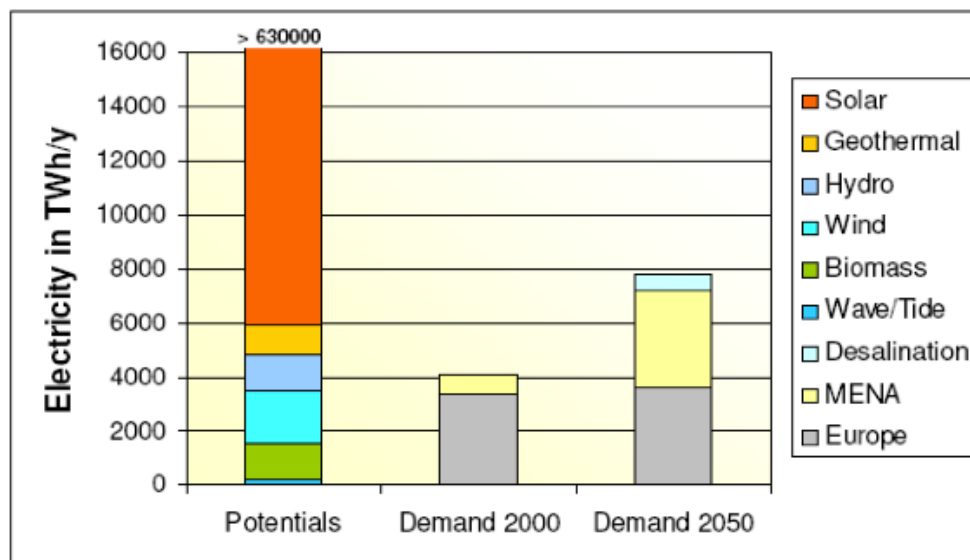


FIGURE 2.3: Potential of renewable energy sources in North Africa and the Middle East compared with the demand for electricity

products, while the rest is aimed to stimulate the consumption of electricity and natural gas.

The negative environmental externalities from energy subsidies are therefore considerable. They cause overconsumption of petroleum products, coal and natural gas while they are reducing incentives aimed to stimulate investment in energy efficiency, public transport and renewable energy.

As stated by Michael Mason and Dennis Kumetat in their study relating the future energy context in North Africa "In their plans to move beyond heavy dependence on fossil fuel imports (Morocco and Tunisia) or to maximize export revenues from domestic oil and gas reserves (Libya, Algeria and Egypt), the North African states stand at a crossroads in terms of energy policy: interest in adopting renewable energy and/or nuclear energy presents opportunities for a strategic realignment of national development paths." [44].

Relatively only a small part of the new global investment in clean energy has made in North Africa. None of the three Maghreb countries had new investment for more than \$100 million in 2009 while Egypt invested \$500 million in clean energy, most of which was engaged in a 200 MW wind project in the Gulf of El Zayt (it must be said that Morocco announced the will of investing \$ 9 billion in

2 GW of solar energy capacity over the next ten years).

Talking about the energy context and the investments focused in the exploitation of Renewable sources in North Africa, we can not fail to mention the Desertec Project [45]. This project was managed by the Desertec Foundation, whose aim is to support the use of renewables in deserts and arid regions. In fact, according to European advocates of renewable energy, the development of a Mediterranean Electricity Ring can facilitate the exportation of electricity produced in North Africa to the European Union, thus increasing the economic viability for investments in concentrated solar power plants in the Maghreb region.

The map of possible infrastructure for a sustainable energy supply for Europe, North Africa and the Middle East, according to the Desertec project, is shown in Figure 2.4.

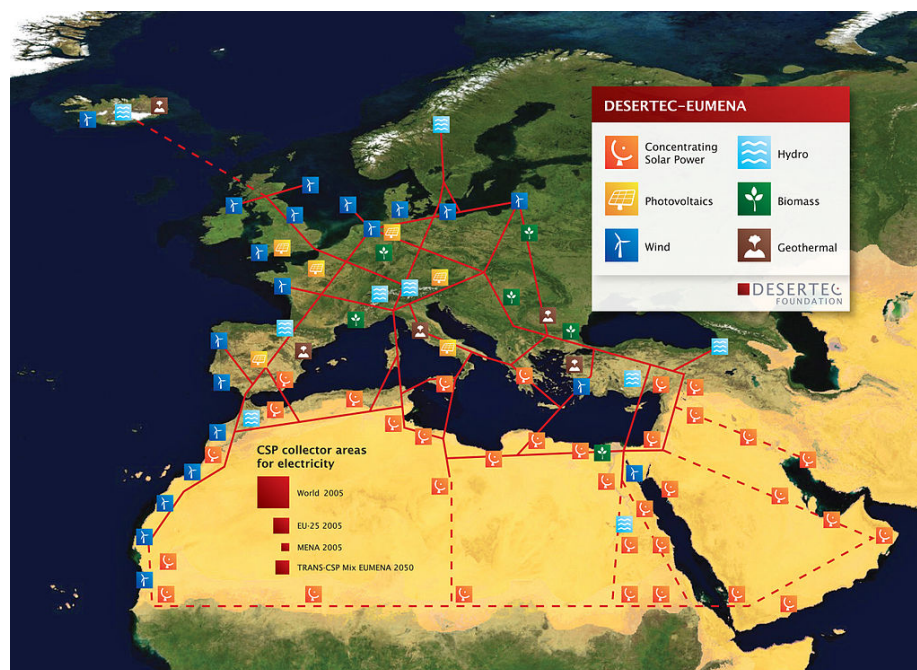


FIGURE 2.4: Desertec Project map

2.3.2 Sub Saharan Africa

In Sub Saharan Africa the situation is much more complex because the high level of poverty in the region has not allowed the development of an energy context similar to that of first world countries.

Indeed, by analyzing the energetic context of the region, two critical issues stand out: they are mainly related to the lack of development of energy infrastructure both in the upstream, the stage that deals with the supply of resources to power plants which have the task of generating electricity (such as gas pipelines or oil pipelines), and in the downstream, the stage that deals with the production, transmission and distribution of energy all over the territory.

The first problem encountered (related to the widespread infrastructure of the downstream stage) regards the absence of a connection to the electricity grid of a relevant portion of population living in the sub Saharan area: on average 65% of people are not reached by electric current (share already relevant which reaches higher values, 91%, in the poorest countries such as Malawi and Uganda [5]).

The second problem, related to the quality of infrastructures, concerns the continuity of the electricity supply to those who are connected to distribution networks: it is not uncommon, indeed, that power supply is suspended during the peak hours, forcing companies to close temporarily and hospitals or schools to work in the dark [46, 47].

This criticality plagues most of the African countries, with a particular relevance in those that, according to the World Bank classification based on levels of income [5], fall into the low-income section as can be seen in Figure 2.5 [48] which gives a representation of the intensity of the phenomenon.

Tackle these obstacles is therefore a priority in the countries covered by our analysis in order to promote economic growth.

These critical issues in fact, as mentioned above, can be seen as one of the main barriers to the development of the African continent since access to electricity has become, in the last decades, one of the key requirements to enable companies to create value [48].

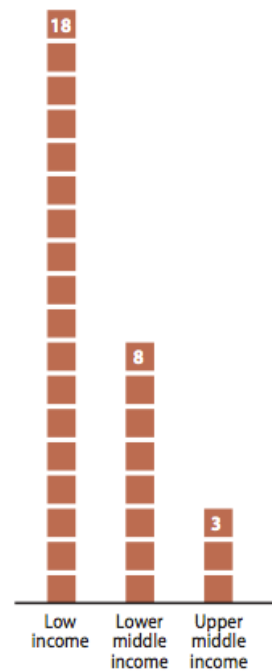


FIGURE 2.5: Average number of interruptions in the supply of electric current for a company in a month

To solve these problems we have two alternatives:

- The replication of processes which led to the development of infrastructures in the first-world countries through the traditional energy sources (gas, oil or coal);
- The introduction of a new mode of development exploiting renewable energy sources.

The replication of the evolutionary processes occurred in the first world countries seems to be the easiest way to follow as it would provide a large amount of data concerning the procedures to be adopted for the development of infrastructure; however it is also the less convenient way for the following reasons³:

³To clarify why it is less convenient to regress the event that took place in a first world country it has been decided to use as a reference the pattern of development of the United States, in order to exemplify precisely the critical points that should be tackled in the case we should decide to use this solution. The reasons, however, can be considered as valid even in the case it would be made a comparison with China or India.

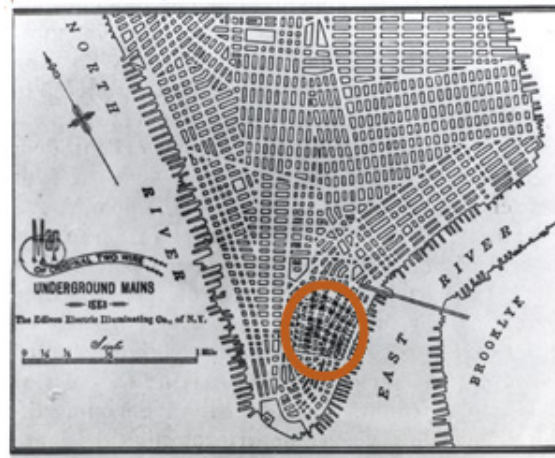


FIGURE 2.6: Area reached by the Pearl Street Station in Manhattan in 1882

- The evolutionary process that led to the formation of a distribution network of electric current in United States has been deferred on a very long period of time, equal to about 150 years, starting from the first power plant built by Edison in 1882 [49] (which, as can be seen in Figure 2.6, could only provide electricity to a very limited area of Manhattan), until today, with a network able to guarantee the supply of electricity to the whole country's population [5] (as can be seen in Figure 2.7). These timing result to be inconsistent with the objective of the United Nations to achieve universal access to electricity by 2030 [3, 50].
- In case we want to develop a unique network (or more sub-networks connected by points of exchange) one should deal with very high costs [51].
According to Piers Evans, Production Editor of "Renewable Energy World Magazine": "Extending grids to tackle these issues often looks wildly unfeasible. Construction costs can surge, in sparsely populated regions such as Mali, up to US\$ 19,070/km, according to World Bank figures. Difficult terrain often presents a further obstacle to reaching remote populations which, in any case, may lack the demand to justify the investment" [52].
The theory mentioned above is therefore supported by various researches, from which we may cite the relation done by Szabó, Bódis, Huld and Moner-Girona: by comparing in the African context the costs of electrification

arising from a grid extension with those of an off grid solution characterized by the presence of solar panels, they affirm the preferability of an off grid electrification with respect to the other solution; in fact it is stated that the latter, under the present conditions of Sub Saharan Africa characterized by a particularly large surface and insignificant values of population density per km^2 , appears to be an overly expensive solution [53].

- The extreme poverty characterizing most of the countries belonging to the continent (highlighted by the distribution of African countries in the income brackets in the classification of the World Bank, where almost all of them belong to the low-income bracket [5]) does not conducive to the presence of private investors to support local governments with investments in energy (as opposed to what happened in the U.S. where the first facilities for electric current have been built by private investors, like Thomas Edison or George Westinghouse [49]).

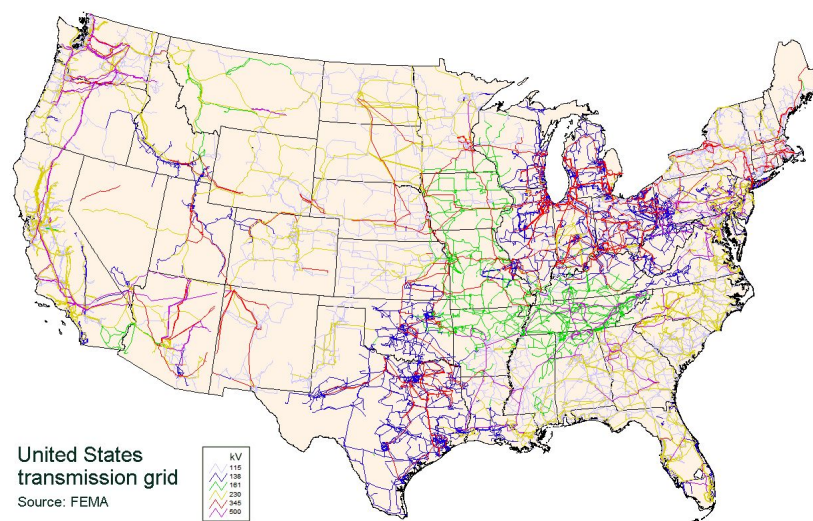


FIGURE 2.7: Representation of the power grid of the United States in 2013

Actually many projects for the implementation of clean energy plants are under development in the Sub Saharan area, under the patronage of first world's countries like United States and nations from the European Union.

The most important one is the previously mentioned "Power Africa" project which

sees the collaboration of the US Government, the African Governments, the private sector and institutional entities like World Bank and African Development Bank; it aims to the electrification of several Sub Saharan countries like Ethiopia, Ghana, Kenya, Liberia, Nigeria and Tanzania (as can be seen in Figure 2.8) making electricity access available for about 20 million people by adding 10,000 MW of power by using wind, solar, hydropower, natural gas, and geothermal resources [54] with a total investment of \$ 7 billion by US Government, \$ 14.7 billion by private sector founding partners, \$ 1.1 billion by private sector partners and \$ 8 billion by financial partners.



FIGURE 2.8: Power Africa countries

The "power Africa" project was presented by the President of the United States, Barack Obama, in 2013. During his trip in Africa, in two speeches following the presentation of the project, the President highlighted the need for the U.S. Government to take more significant actions aimed to mitigate impacts of global climate change. Lastly, during a speech at Georgetown University in June 2013, he called for the need to "help developing nations leap-frog dirty energy technologies and reduce dangerous emissions".

Some Power Africa funding will be addressed specifically for projects related to renewable energy; for example, the Overseas Private Investment Corporation (OPIC) and U.S. Trade and Development Agency (USTDA) will provide up to \$20

million in grants aimed to project preparation, feasibility and technical assistance to develop renewable energy projects.

These efforts will be coordinated through the "U.S. - Africa Clean Energy Finance Initiative" (US-ACEF) and supported by the recently launched "U.S. - Africa Clean Energy Development and Finance Center" (CEDFC) in Johannesburg, South Africa.

While explaining the Power Africa project it is important to underline also how its innovative financial scheme works.

It is designed starting from the assumption that Sub Saharan countries are characterized by the presence of the risk that governments are not able to self-manage funds received from supranational institutions like World Bank or International Monetary Fund (as demonstrated by previous experiences like what happened in Uganda, where a fund suspended five grants totaling over US \$200 million because there were suspicious about inappropriate expenditure and improper accounting by members of government [55]); so, in order to avoid this misuse of money in activities not related to project's core, the entire project is financed by a pool of private entities and the deployment is provided by trusted multinational firms which are able to grant the scheduling, the quality of the plants and may be able to exploit new opportunities while work is in progress.

The project's operation and financing are discussed and developed side by side, in order to make investors able to assess the returns which the investment will bring to them; particularly such remuneration to private entities will be provided to them as a bond repayment, in a term which is sustainable for their financial operations (about 20/30 years), by supranational structures which, till now, had lent money directly to African governments with poor results due to money misuse and corruption; according to what is stated by Adam Lerrick in his "Aid to Africa at Risk: Covering Up Corruption" [56], the amount of stolen money which is stashed away in private accounts in off-shore banks could not be accurately tallied but is estimated to be more than US\$ 500 billion.

In conclusion, advantages brought by financial scheme of Power Africa project are:

- Money provided by supranational institutions are not misused but canalized on a specific project;
- the remuneration is granted through bonds and occurs over a sufficient number of years which will not affect the operation of supranational institutions;
- payments to contractors and sub-contractors are granted because are made by entities able to grant adequate funds to manage the entire operation from the beginning;
- Sub Saharan countries are relieved from spend their liquidity (obtained by exports of raw materials) in projects related to energy and, so, are able to invest in other projects (ad example, related to instruction or health);
- people living in such countries have the opportunity to rise their consumption of electricity and, consequently, their business activities.

2.4 Insights of the political, economic and energetic contexts: case studies

In order to bring an overview of economic and energetic situation of Africa, being excessively laborious doing an analysis of every country belonging to the continent, we decided to scan in more depth three states, selected according to a classification proposed by the World Bank about the income levels of the population.

The nations examined are: Mozambique (belonging to the low income bracket), Morocco (Lower Middle Income bracket) and South Africa (Upper Middle Income bracket).

In order to better clarify differences between these countries we also carried out an analysis based on income levels of local population; because of the scarcity of data in the literature we decided to define two levels of income:

TABLE 2.1: Income comparison

Value	South Africa	Morocco	Mozambique
LW (LCU)	4,840 ZAR	3,826.01 MAD ⁴	15,816 MZN
Car cost (LCU)	79,350 ZAR	187,965 MAD	950,000 MZN
i	9% (2012)	12% (2005)	17% (2012)
Installment ⁵ (LCU)	3,240	3,674.75	21,134
E (LCU/\$ - 2012 Avg.)	8.21	8.63	28.37
LW (\$PPP2005)	471.62	375.71	401.07
E (\$/\$PPP2005)	1.25	1.18	1.39
LW + Install. (\$PPP2005)	787.37	736.57	937.00
1 Level	87.08%	94.73%	99.80%
2 Level	93.12%	98.81%	100.00%

- 1st level: we have chosen the living wage [57], the average monthly income needed to cover basic expenses and to live in a dignified manner (housing, food and public transport);
- 2nd level: in order to define this bracket, it was decided to use as a proxy for the quality of wealthy life the ownership of a car (calculating the value as the amount of the installment to be paid [58] to cover the costs of buying a car, a Volkswagen Golf 1.4 90KWH Trendline [59], by using the average interest rate of the country in 2012 [5]);
- 3rd level: the last level represent the richer share of population with an income that is higher than the one relative to people belonging to level 2.

In order to render the data proposed comparable all monetary values have been converted in \$PPP2005, as one can see from table 2.1, while the percentages corresponding to different levels of income (for every country) have been obtained by means of a tool for calculating the thresholds of poverty provided by World Bank [60].

The obtained results are observable from the chart in Figure 2.9 and are confirmed by the World Bank's classification by income; however it is important to emphasize that differences between the three countries are observable over a narrow range of

⁴Estimated from the Living Wage of South Africa through the Price Level Index

⁵Calculated over 72 Months

percentage: South Africa, for example, belonging to the richest bracket of income, is characterized by 87.08% of population living below the living wage.

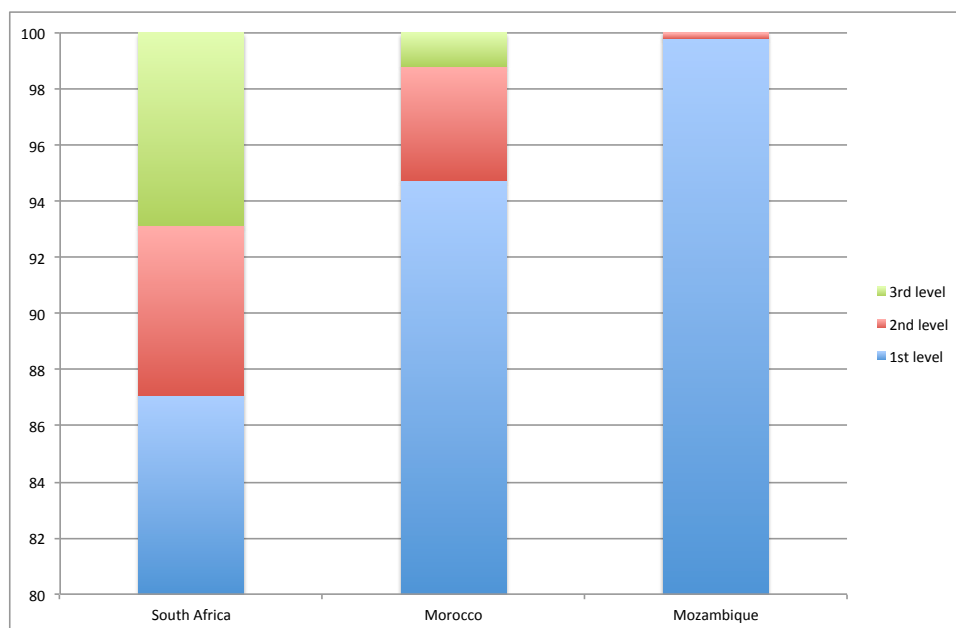


FIGURE 2.9: Comparison between income groups in South Africa, Morocco and Mozambique

2.4.1 Mozambique

Plagued during the 80's by a bloody civil war, ended in 1992 with peace treaties in Rome, Mozambique has enjoyed up to now a good stability in politics.

The actual situation of equilibrium is, however, undermined by deteriorating social and economic conditions for the local population, mainly due to the increases in the price of food, fuel and utilities (in respect of which in 2012 there have been some urban riots).

Social and economic condition of the country, in spite of the high grow rates in recent years, it is still worrying because of a development model excessively dependent on official development assistance (ODA) and on foreign direct investments (FDI) but partially interconnected with the rest of the economy.

Analyzing Sub Saharan countries characterized by the absence of oilfields, it can be noted that Mozambique has been distinguished, between 1993 and 2009, by the

highest level of economic growth (with an average annual rate of 7.5%); the values of GDP growth are destined to settle at levels close to 8%, thanks to new activities of the extraction industry and to the increase of public investments, mainly due to:

- substantial FDI mainly related to mining, electricity, tourism, telecommunications and construction sectors;
- significant Official Development Assistance (ODA);
- strong growth of the agricultural sector.

Despite the steady progress that has characterized the last years of the life of the African nation, the economic structure remained almost unchanged: services represent 45% of GDP, followed by agriculture (30%) and industry (24%).

Macroeconomic policies pursued by the government of the African country, aligned with the policies of the supportive tool of IMF, were focused on supporting economic growth, price and exchange rate stability and the implementation of a program for structural reforms. In attempt to mitigate the discontent of population, the Parliament also approved an amendment to the budget to account for additionally expenses necessary to implement measures aimed to alleviate the cost of living.

However, in 2011 the International Monetary Fund highlighted in a report the necessity of further additional efforts to [61]:

- Achieve and sustain a more inclusive growth;
- Increase the efficiency in revenue mobilization;
- Improve the existing social protection schemes;
- Refine macroeconomic management of natural resources.

According to the World Bank the rise of the extraction industry will lead Mozambique by 2025 to reach the status of a middle-income country, thanks to significant

investments in the sector (ongoing and planned) involving the participation of both the public administration and private lenders [62].

As for the energy context, Mozambique is characterized by a high potential in terms of coal reserves, gas and hydro power, but the local utilities are not yet able to better exploit this potential and provide the population the energy continuously during the day; in 2011 only 17% of population had access to electricity, of which about 2 million of people through the use of photovoltaic systems.

90% of the country's energy generation (totally equal to 2392 GW) comes from a hydroelectric plant in Cahora Bassa; 35% of total electric production of the country is mainly exported to South Africa and Zimbabwe; there are also planned numerous projects which, by exploiting renewable energy, should be made available to the local population 4,000 MW of electricity.

When analyzing other sources of renewable energy, it is clear the significant, and untapped, potential derived from solar: it is approximately 1.49 million GWh (value often greater than the country's current energy consumption).

It is therefore important to emphasize that solar energy represents a potential key resource for areas of the country where is absent an adequate energy network (for this reason, thanks to investments by FUNAE, Fundo Nacional de Energia, and the Indian government, a domestic production of solar panels has been initiated) [63].

2.4.2 Morocco

Morocco enjoys good political stability thanks to the process of democratization started after the seizure of power by King Mohamed V with reforms on governance and revisions of the constitutional texts.

Nevertheless, during 2011, the North-African country was the scene of internal conflicts linked to the series of protests and unrests that characterized many Arab countries (as already mentioned in chapter 1) from 2010, defined as "Arab Spring"; regarding Morocco the protest, lasted from 2011 to 2012, was caused by the increasing intolerance of population towards the monarchy of King Mohamed VI.

North African country's economy, traditionally dependent from agricultural sector, began to diversify its structure thus reaching significant results: between 2004 and 2011 Morocco has been characterized by an average growth equal to 4.9% of GDP (doubling the value of growth that has characterized the 90's), despite an unfavorable context, characterized by a drought in 2007 and the global economic slowdown since 2008. These results are a consequence of a gradual structural transformation towards an outsourcing of the production sector.

Since 2009, in order to safeguard the economic growth from the instability of the financial markets and the economic downturn of its main European partners, Morocco adopted different steps [64]:

- the implementation of major construction projects and the protection of the purchasing power of population helped to support non-agricultural activities and to achieve the growth targets;
- the establishment of the "Strategic Monitoring Committee" (CVS) in February 2009 to assist the government to cope with the consequences of the crisis;
- a stimulating fiscal policy has been done and had an important role as an engine for growth of domestic demand;
- tax breaks on income and the priority given to structural projects that have stimulated consumption and investments (increased, respectively, by 18.3% and 16.5% over the last three years, since 2011).

From the energetic point of view, Morocco imports nearly all the energy it consumes: domestic energy production mainly derives from the thermal power plants (which has an impact on electricity costs, influenced by the cost of oil), while the installed capacity of hydroelectric plants is smaller and their operation is strongly influenced by climatic factors (mainly rainfall).

In the North African country, in order to improve energy security and mitigate the effects of energy production on climate change, several projects based on the exploitation of renewable energy sources have been undertaken.

For example, during 2012, the "African Development Bank" approved two major projects:

- Ouarzazate solar power plant of UA 150 million;
- An integrated project of hydropower-wind and rural electrification PERG of UA 320 million.

The Clean Technology Fund (CTF) partly contributed to these two projects, as they are prone to renewable energy; it has made available for their financing UA 140 million (of which 62 million for projects related to renewable energy and the remaining 78 for the second project) [65].

2.4.3 South Africa

South Africa, as one can see from the data related to the indicator Polity IV [24], enjoys a good political stability and, from a governmental point of view, is marked by a constitutional democracy headed by the President of the Republic (who also covers the role of Prime Minister) from 1994, year in which were held the firsts elections by universal suffrage after the conclusion of apartheid.

South African economy, as is possible to see from the data relating to the country's GDP provided by the World Bank [5], is characterized by an increasing trend over the last years, during which, except in 2009, it has seen an increase in the value of its GDP of about 3 percentage points per year. This growth has to be considered positive even if in 2012 it was below the expectations of about 2 percentage points due to the recession that has plagued the countries of the European Union (Europe is the major economic partner of South Africa) [66].

Analyzing the data in the report drawn up by the "Statistical center of South Africa" it is observable that in recent years the towing sectors of the country have been the financial, manufacturing and government services which respectively bring a market share of approximately 24%, 17% and 15% of the total GDP in South Africa. This factor is an indication of the shift from the primary sector

to the tertiary sector; it is highlighted, for example, by the decline of the mining sector's contribution to the GDP, which passed from 8.12% (1993) to 5.49% (2012), while in the same period the financial sector's one passed from 20.51% to 23.87% [67].

Despite a fair political stability and good performances in economic terms, the country presents serious problems on a social level: characterized by a value of the Gini coefficient equal to 0.7 (in 2011) [5], South Africa has, in the world, one of the most high inequality in terms of income distribution. This inequality is a consequence of the apartheid: it caused a distinct separation of both ethnicity and race within the population for which, since 1994, were enacted several laws to facilitate the integration and the access to fundamental services (especially regarding health care and education) for all the country's inhabitants [68].

Despite of the good performances in broad terms, it is important to observe the values related to renewable energy sources: only 1% of the energy produced in South Africa, in 2011, has been generated from renewable sources [5].

In this regard, the South African Department of Energy has undertaken several initiatives to improve this situation, among which seems to be very interesting the will to introduce a Feed-in-Tariff system, with the aim of bringing the share of energy produced from renewable sources to 6% by the end of 2013, to 9% by the end of 2018 and 27% before the end of 2030 [69]. Naturally, the investments needed to get these targets are not the prerogative only for the utilities, but the Government of Pretoria takes part in it too with huge investments, such as the recent allocation of \$3.3 Bln for completing 17 projects related to renewable energy required to install a total capacity of 1456 MW [70].

2.5 Development policies needed for FDI

After highlighting that the preferable solution to expand and render efficient the electricity grid in the African continent, thus increasing the energy availability to the indigenous population, is the use of FDI aimed at financing renewable energy's projects, it is important to emphasize how necessary it is the development of social

and economic policies by the country that is the potential target of the investment, in order to increase its attractiveness to investors.

Analyzing literature it has been noticed that several researches and analysis focused on developing countries, whose objective was the study of the factors enabling and directly influencing any foreign investment within countries, have been carried out, in some cases specifically for Sub Saharan countries.

Borensztein, De Gregorio and Lee [71], in order to analyze how FDI affect economic growth in the recipient country, developed a model through which they identified a strong correlation between the level of education (used as a proxy for the level of human capital available in the host country) and FDI.

This concept has been emphasized by other studies, such as that performed by Steven Globerman [72] about the role of the governance structure in the context of global FDI flows: through the use of regression models, he demonstrates the importance of the link between FDI and human capital emphasizing how, within the framework of possible foreign investments, the lack of educated and healthy workers may represent a significant, and sometimes crucial, deterrent.

Starting from the results and the resulting thesis proposed in the two studies mentioned previously, it is possible to assert that, in our case (related to developing country whose will is to attract foreign capitals able to invest in energy structures, with the final aim of enabling greater availability for local populations) it is required the persecution of a policy of economic and social reforms by the local government.

According to the correlation identified between FDI and human capital, Borensztein [71] occurs that the FDI's effect on economic growth of the country to whom they are addressed is closely linked to the level of human capital, whereby foreign investments start to be advantageous only if the concerned country has at the disposal a minimum level of human capital (using the percentage of educated people as a proxy of human capital, the regression model identifies a minimum level required of 52%).

In this regard we can quantify the commitment of increasing the level of education

by the states belonging to the African continent, and more specifically Sub Saharan Africa (characterized by extremely low percentage of schooling), examining the "Millennium development goals report" [73] by United Nations. From the latter is possible to know how the Sub Saharan area is the birthplace of more than half of the world's children not attending school; but by analyzing the time horizon between 2000 and 2011 it is possible to observe that the net enrollment rate has increased from 60% to 77%: it is therefore important to emphasize the presence of a increasing demand for education from a growing population (in 2011, there are 32 million more children in primary school age compared to 2000), which does not yet allows Africa to get to adequate levels of schooling, not even comparable to other areas of the globe, such as the Asian one.

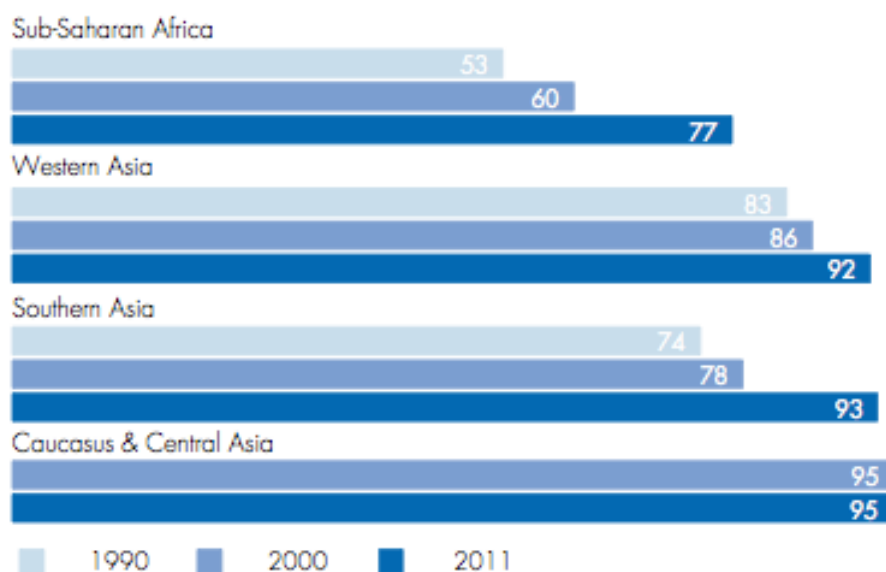


FIGURE 2.10: Net enrollment rates in 1990, 2000 and 2011 (in percentages)

Moreover, in order to better attract foreign investments and to improve their flow, to a need of a higher level of instruction is flanked the need for developing countries to liberalize their trading regimes, aiming to increase the competitiveness on the market, thus giving the opportunity to reduce prices.

As Elizabeth Asiedu highlighted in her study focused on the determinants of FDI in Africa [74], the full benefits of liberalization will be achieved just if the investors will perceive the reforms as credible and not subjects to any reversals (consequently is equally important the development by African governments of

mechanisms aimed to strengthen the credibility of the reform process and ensure a greater political stability).

The case subject of the thesis is also concerned by the themes mentioned above and it is therefore important to point out the necessity of policies aimed to improve the preparation and the quality of local human capital and market liberalization by the governments that receive the foreign capital, so that it is possible to have an attraction from foreign investors to particular African countries and an optimization of the investment performance.

Chapter 3

Smart Grids

The study of our thesis is focused on the economic and energy context of the Sub Saharan Africa.

As written previously, in the area taken into consideration that is characterized by an energy context still underdeveloped and very high percentages of people not reached by electricity, the introduction of a new mode of exploit and supply energy seems to be the best solution.

For this reason we decided to focus our study on the implementation of the Smart Grid in rural areas, creating a model that allows to assess the impact of these networks on the local population.

Before introducing the model and describing its various components it is necessary to provide a description of the Smart Grid, its characteristics, the technological components that compose it and, finally, the benefits derived from an implementation of such networks.

3.1 Definition

Introducing smart grids is necessary to begin giving a definition.

According to Cedric Clastres [75] the definition is not unique but can be declined in two different ways.

The first definition, mostly used in Europe, cares about the relationships between the smart grid itself and its users and can be enunciated as: "Smart grids are electricity networks that can intelligently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies."

This statement, even if correct, does not explain how the grid works and which are its peculiarities, so it has been decided to study in deep a second, and more complex, definition which cares about the aims and the elements needed to qualify a grid as "smart": "A smart grid is an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient, and sustainable." [76].

Clearly, to fully understand the potentials of the smart grids, is necessary a deeper explanation of the characteristics involved in this second definition, that can be summarized as follow [76–78].

Flexible A smart grid is able to connect each user to different sources of energy according to their availability and to vary them in real time in order to minimize the losses.

Self Healing Due to his flexibility, a smart grid is able to remove faulty equipment from service when it fails, reconfiguring the system through the creation of new routes and "power-islands" able to link customers to different electrical sources.

An example is given by Figures 3.1 in which is possible to observe the system in a normal situation (picture A) and the automatic reconfiguration occurred after an outage of the electrical line (marked in red) through the creation of two different power-islands (picture B).

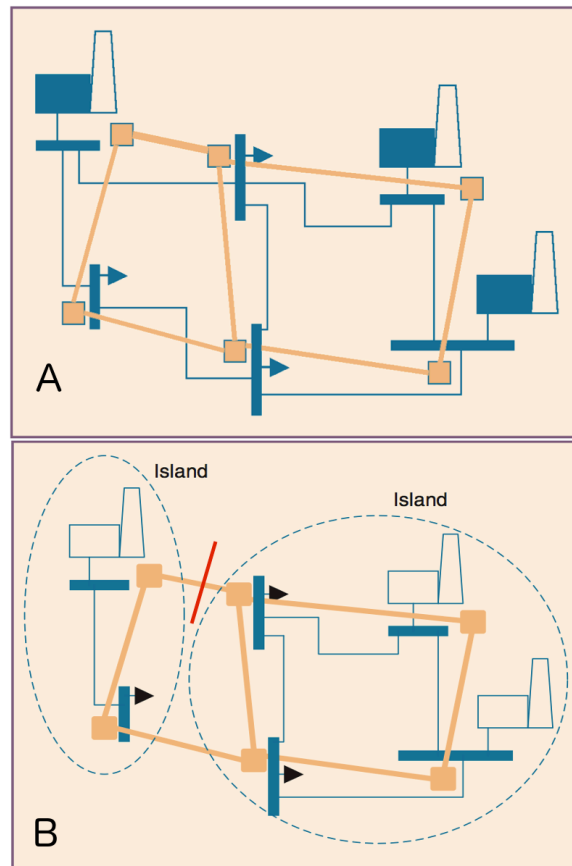


FIGURE 3.1: Power islands - Self healing

Predictive Thanks to information systems, the smart grid is able to predict events (like energy shortages due, as example, to weather changes) in order to take the most advantageous choices both for producers and final users.

Interactive The two-way information system allows customers to adapt their activities to the energy's availability letting them to play an active role in energy management and to take economic advantage by minimizing their costs.

Optimized The previously mentioned characteristics make a smart grid able to optimize the costs for electrical power routing energy paths through the best one in real (or near real) time.

3.1.1 Technological framework

In order to define a grid as "smart" is required the presence of different tools and instruments that are the enablers of the intelligent network. Such elements, according to "Energy and Strategy Group of Politecnico di Milano" [79], can be divided in four classes of smart tools: "smart generation", "smart network", "smart metering and active demand" and the last one that is represented by "storage systems" which connects the other three kinds of elements, as represented in Figure 3.2.

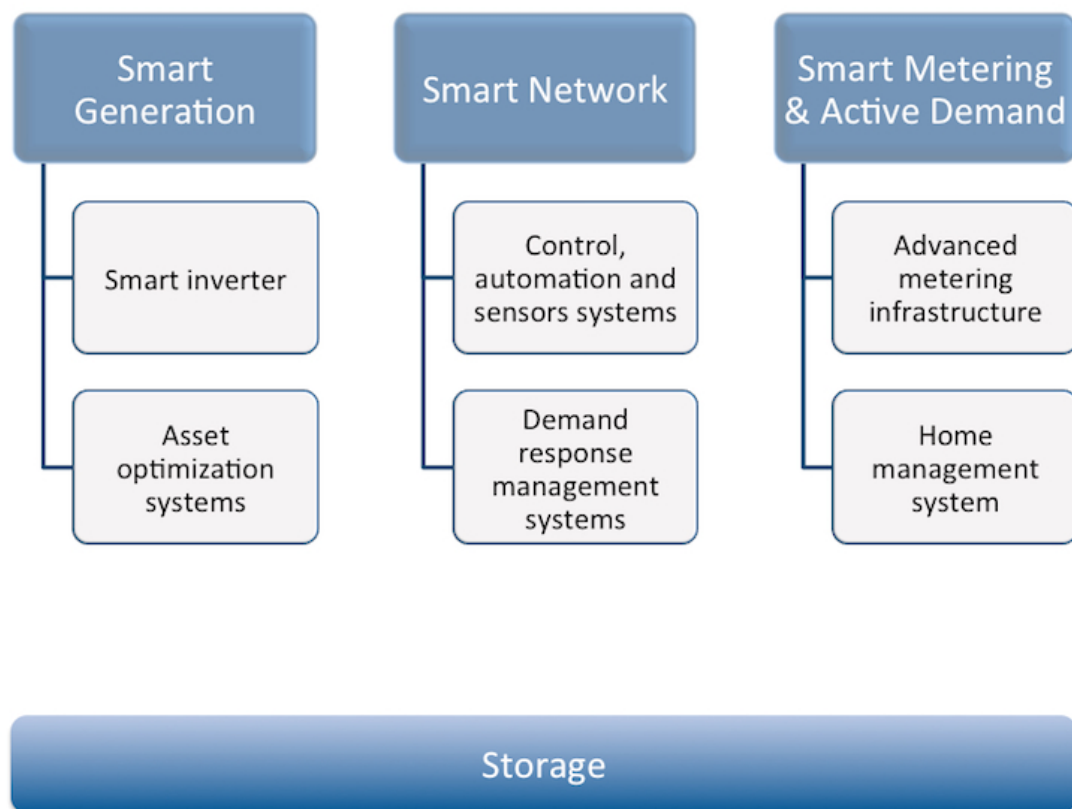


FIGURE 3.2: Elements of smart grids

The first class, smart generation, is composed by **smart inverters**¹, namely traditional inverters connected to a processor able to gather information about production's and facilities' status in order to consequently implement innovative ways

¹through smart inverters is possible to manage outages, bound the provided power, increase the selectivity of protections and keep insensitivity to rapid voltage drops

of management and **asset optimization systems**², systems of hardware (like sensors and actuators) used for monitoring power plants, governed by a software platform.

The second class, smart network, contains **control, automation and sensor systems**³, systems of hardware used for monitoring the grid status, governed by a centrally managed software platform and **demand response management systems**⁴, which is an information system able to process in real time the data collected by other smart tools.

The third class, smart metering & active demand, includes **advanced metering infrastructure**⁵, that is an infrastructure composed by smart meters, data compressors and a platform for Meter Data Management and **home management system**⁶, namely a set of smart appliances and related software for manage end user's tariffs for communicate consumption data.

The last class of items is represented by **storage systems**, components that can be applied transversely on the different levels of the power system, with the aim of ensuring: energy time-shift, renewables integration (by saving energy when there is a production surplus and, then, releasing it when the demand is higher than the supply) and management of grid's congestion.

3.1.2 Benefits of smart grids

The mentioned characteristics bring to a wide number of benefits for all grid's peers. According to report by "Grid Wise Alliance" [80] such benefits, which are represented in picture 3.3, can be declined as follow.

²through asset optimization system is possible to define the optimal production plan integrating renewable sources and to automate the maintenance processes

³through control, automation and sensor systems is possible to manage the load distribution on the transmission network, monitor grids and substations, optimize activities of energy distribution and infrastructure control and to collect and transmit information to verify the status of the network in terms of safety and reliability

⁴through demand response management systems is possible to forecast RE plants' production, demand, load of the transmission network and grid's status

⁵through advanced metering infrastructure is possible to enable two-way communication between users and power systems, collect data from smart meter's clusters, provide forecasts about demand of energy and automate the collection of data

⁶through home management system is possible to estimate energy consumption and manage multi-hourly tariffs

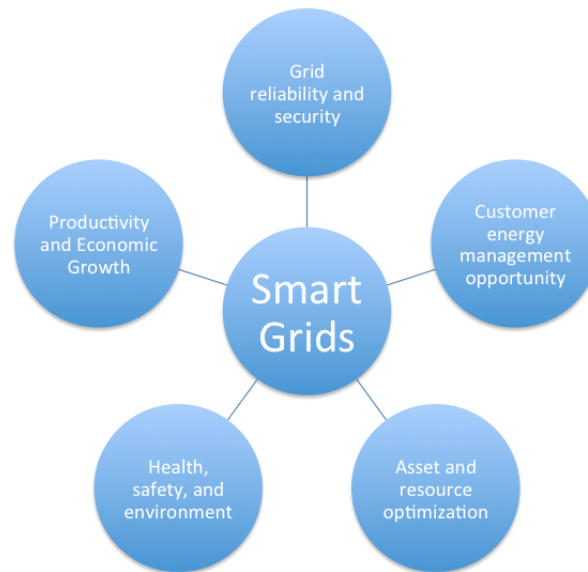


FIGURE 3.3: Benefits of smart grids

Grid reliability and security Smart structures allows users to be "always on" thanks to the ability of changing the energy sources in case of outages and to the presence of various storage options able to keep the energy's surplus produced from renewable sources.

Customer energy management opportunity Elements like smart meters let consumer to empower their "energy's attitude" by having a full vision on power consumption and, therefore, on expenditures related to it. This empowerment will bring benefits in terms of reduced peak demands, increased system reliability, enhanced customer service, and integration of demand side resources with wholesale markets (customers will be able to sell energy's surplus produced by their renewable systems).

Asset and resource optimization The use of smart grids will allow the optimization of grid's operations and planning which, combined with energy efficiency measures obtained through the use of demand side customer applications, will bring to a net reduction of energy consumption.

Health, safety, and environment In smart grids the large use of renewables and the better handling of their intermittent nature will have a positive impacts on health and environment (by reducing GHG emissions) and on safety (by lowering the number of incidents through real time monitoring and forecasting of events).

Productivity and Economic Growth The modernization of grids will improve the productivity of utilities thanks to gains in terms of operation's management and automatization, furthermore the high commitment of governments and private sector's agents in smart grid's technologies will create new job opportunities both in R&D and in construction sectors.

At the end of our analysis was therefore possible to create the figure 3.4, representing more specifically the technological determinants (represented by the seven technological components described above) of the benefits just listed.

	Smart inverter	Asset optimization system	Control, automation and sensors system	Demand response management systems	Advanced metering infrastructure	Home management system	Storage
Productivity and Economic growth		X		X			X
Health, safety and environment		X		X			X
Grid reliability and security	X		X				X
Customer energy management opportunity				X	X	X	X
Asset and resource optimization		X	X				X

FIGURE 3.4: Relationships between tools and benefits related to smart grids

3.2 Why smart grids in Sub Saharan Africa

The implementation of Smart Grid may enable Sub Saharan countries to move ahead from traditional power systems in order to reach more effective solutions. This solution may help the African countries accelerating national and regional electrification timeframes, while improving service and minimizing costs and environmental impact.

The main target is to optimize grid systems and their operations, improve the reliability and efficiency of electricity supply, also integrating high levels of renewable energy (of which Africa has abundant resources).

From a technological point of view it is important to say that, in the short term, some "Smart" components available today are a good basis for avoiding legacy grids' models; while, on the long term, other elements will be an essential precondition, required in order to enable the transition, in future, to smarter energy networks without technology lock-in [81].

If we consider the short term, what is expected is the leapfrogging for the components based on information and communication technologies (ICT), a significant part of many Smart Grid systems.

Concerning the possibility of the development of ICT regarding Smart Grids, it is important to say that the African continent has already had optimal experiences in leapfrogging to more efficient solutions: even if it is not a perfect analogy, "the information revolution" which affected Sub Saharan Africa in the mid-1990s regarding the fast growth of mobile phones offers some useful lessons (it gave people access to communication without diverting via extensive conventional telephone networks); this fast development was characterized by huge numbers: Africa becomes the world's fastest increasing market, with growth rates in the order of 300% per annum in countries like Kenya and Cameroon [82].

The main reason which led the mobile sector to a great success was the inability, both in terms of quality and number of connections, of the conventional telecommunication systems to meet consumer demand; thereby it is possible to make a parallel between the failure of telecommunication systems with the inability of

current electricity networks in Sub Saharan Africa to meet the needs of the local populations.

Furthermore the high presence of mobile phones in Sub Saharan Africa is an important factor for the development of Smart Grids: modern telecommunication allows particular payment schemes, such as pre-paid subscriptions, and facilitates the foundation of a converged system able to transmit information about electricity consumption to a mobile device capable to inform the user and let him reacting quickly to reduce possible losses.

3.2.1 Grid options

Analyzing the theme of Smart Grid in Sub Saharan Africa is important to mention that there are two main possibilities to implement the network: grid's extension or the creation of local mini-grids.

Depending on the circumstances, grid extension may prove to be the least-cost option; however, in other circumstances, a mini-grid system could be economically the best solution to be applied.

In our case, aimed to the improvement of electrical availability for people living in rural areas of Sub Saharan Africa, where the grid is still in a germinal phase and so the most percentage of population is not connected, off-grid solutions may prove to be a better choice than grid's extension.

The underdevelopment of the grid networks also shows that mini-grids, based on local renewable energy, may prove to be more affordable than grid extension in specific regions, because of the high cost of grid building in the case of a low, expected, electricity load [53].

Making the choice between the grid extension and the off grid solution it is important to say that in the Sub Saharan context some of the renewable energy technologies are much more productive than in regions where RE are already present in the national energy mix with a high percentage (e.g. the same photovoltaic panel may produce two times as much electricity in Africa than in Central Europe, on average).

As can be seen in Figure 3.5, representing the economic comparison of diesel versus photovoltaic in the case of an off-grid option's choice, the Sub Saharan countries are characterized by a prevalence of PV, while in North Africa the most economic option is diesel, mainly due to large fuel subsidies provided by local governments.

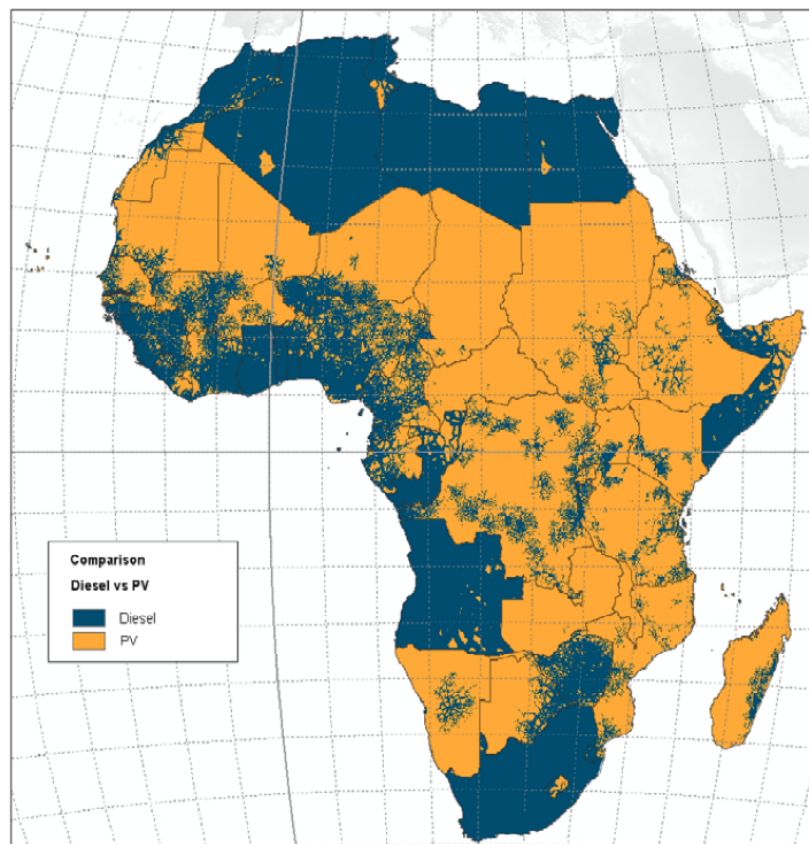


FIGURE 3.5: Comparison of diesel versus PV

It must be said that, as grid extension delivers low-cost solutions only in the case of a small area where a high number of consumers can be connected, sparsely populated areas (as the Sub Saharan ones) may become target for hybrid or PV based rural electrification development, only with the implementation of a proper financial scheme.

Doing the evaluation of which is the best solution to choice, the willingness and ability to pay the electricity by families connected to the grid is still an important factor to be determined (studies done by Szabo, Bodis, Huld and Moner-Girona

affirm that "the 25 and 30 €c threshold is the range where the PV option becomes the most attractive rural electrification technology" [53]).

3.2.2 Case study

After the description of the elements which compose Smart Grids and the relative benefits that this technology may bring to the supply of electricity and to the people to whom the implementation of this grid is addressed, we may proceed with a little review of two projects regarding the achievements obtained with the introduction of a Smart Grid.

These projects have taken place in Guwahati region (India) and in Austin (Texas); the choice of these two examples has been done in order to show the benefits which this kind of technology may bring to both developed and developing countries.

The interest for Smart Grids on the part of many nations is steadily increasing; as regards the two countries we analyzed, for example, there are various projects concerning the implementation of this new type of electric network: United States have invested in the creation of a Smart Grid in California while in several regions of India (such as Kerala, Rajasthan, Punjab and many others) these grids are already operative.

3.2.2.1 Guwahati region

The Guwahati region is located in the Assam state, in the northern east area of India.

The smart grid project is expected to cover up to 15,000 users involving a total of 90 MWh of input energy which are produced both with renewable and not renewable sources, it will cost about \$ 5 million and has a timeline of 18 months to be developed.

It involves the integration of 100 kW solar farm into the distribution network in conjunction with battery storage via a bidirectional inverter, the development of filters for reduction of harmonics injected into the grid and integrating it into

the smart meters, the development of messaging systems (for in house display and on mobile) for power consumption information and methods to reduce energy consumption.

According with Indian government [83], the benefits brought by the introduction of the smart grid are:

- Increased availability of energy during peak time;
- Revenue increase through power quality measurements and power factor penalty;
- Reduction in AT&C Losses;
- Reduction in interest payments due to deferred capital investment in sub-transmission networks;
- Improvement of availability (reduction of "customer minutes lost");
- Improved management of power procurement options;
- Unscheduled interchange using short term load forecasts;
- Power consumption information available via mobile or in house display.

3.2.2.2 Austin

The city of Austin is the capital city of Texas (USA).

The smart grid project covers up to 1 million people and 410,000 consumers on an area of about 650 km^2 , mixes nuclear, coal, natural gas, and renewable energy for a total of 2,600 MW, costs about \$ 390 million and was divided in two phases: the first has run since 2003 to 2009 ("Smart Grid 1.0") and the second has run since 2009 to 2011 ("Smart Grid 2.0").

It involved the installation of about 500,000 devices including 410,000 meters, 86,000 thermostats, 2,500 sensors, 1,700 computers and 1,000 network elements, it is expected that production will be made through renewable sources in a share of about 30% by 2020 and provides a remote control systems which enable services

like turn-on and shut-off of appliances (e.g. of air conditioning) or the remote metering.

According with the European Commission [84], the benefits brought by the introduction of the smart grid are attributable to the point of view of customers and to the one of the utility (Austin Energy).

Regarding the customers the benefits are:

- Faster notification and restoration times from outages;
- Better understanding and management of bills through usage information via a web portal;
- Ability to participate in energy efficiency and demand response programmes;
- Improvements in timeliness and accuracy of billing with fewer estimated bills;
- Access to real-time meter reads through a call to customer service or via data on a home energy display or web portal;
- Manage appliances via web portal;
- Ability to participate in alternative tariff options.

Regarding the utility the benefits are:

- Reduced need for additional generation and transmission capacity;
- Reduced operating costs;
- Improved outage management - ability to quickly determine if power is off or on;
- Reduced number of delayed and estimated bills;
- Reduced energy theft;
- Improved load profiler;

- Improved distribution load management and planning;
- Greater historical load and usage data available for better load forecasting;
- Better asset management and maintenance (effectiveness and cost reduction);
- Time-of-use, prepaid, and flat bill pricing programmes;
- Support any market price-responsive tariff requirements.

3.2.2.3 Conclusion

The benefits which have been highlighted in these case studies confirms (or, at least, can be traced to) the ones which have been exposed in Section 3.1.2.

As mentioned previously in fact, the optimization in network management, a more efficient energy use and an improved management of renewable energy sources (and their consequences) following the implementation of a Smart Grid, are elements related to energy that have an impact on performances of the electricity grid in both developed and developing countries.

Grid reliability and security is impacted, as example, as "Increased available energy during peak time" (India) or "Improved outage management - ability to quickly determine if power is off or on" (Texas);

Customer energy management opportunity is impacted, as example, as "Power consumption information available via mobile or in house display" (India) or "Access to real-time meter reads through a call to customer service or via data on a home energy display or Web portal" (Texas);

Asset and resource optimization is impacted, as example, as "Improved management of power procurement options" (India) or "Improved distribution load management and planning" (Texas);

Health, safety, and environment is impacted by the introduction, or the improvement, of renewable sources which is contemplated in both cases;

Productivity and Economic Growth is impacted, as example, as "Revenue increase through Power Quality measurements and power factor penalty" (India) or "Reduced need for additional generation and transmission capacity" (Texas).

Chapter 4

Model

4.1 Introduction

After having outlined the energetic context of the countries belonging to the African continent and described the characteristics of a Smart Grid and its benefits, we proceed with the definition of our model.

The purpose of our model is to evaluate the improvement in quality of life due to the implementation of a Smart Grid in a rural area of Sub Saharan Africa; this assessment is studied within the project Power Africa, characterized by some specific methods of financing that, as it will be described later, allow the implementation of such grid in a rural area, without impute any additional cost to the local population.

Before moving on to the description of the model it is important to underline the fact that the main hypothesis of our study consists in the existence of a rise in energy consumption resulting in the implementation of the Smart Grid in a given period of time: this increase, as it will be described below, is not only caused by a growth of the population living in the area taken into account, but also to two other factors:

- full satisfaction of the energy demand of the rural population (through the elimination of outages);

- a stimulus for the rural economy, still lagging from behind, for which an increase in energy availability leads to a consequent increase of consumption (regarding this consequence it is possible to cite a project of electrification in rural areas run by FUNAE in Mozambique where, due to a greater availability of energy, there has been an increase in energy consumption by local population because of the possibility for shops to store and freeze fresh products "making the market more competitive with prosperous business through local development" [85]).

In poor and underdeveloped areas, in fact, even a little improvement in electricity availability can free large amounts of human time and labor: in the poorest areas of the continent, people used to carry water and fuel by hand, their activities are restricted within hours characterized by sunlight and their food storage can be limited.

The utilization of refrigerators, enabled by a higher electricity availability, increases the length of time that food can be stored (virtually reducing hunger and illness), while evening lighting can extend the daylight hours for the local population, letting them to have more time for productivity.

In order to evaluate the improvement of quality of life consequent to the implementation of a Smart Grid we used a hierarchical tree structure (which is represented in Figure 4.1) whose apex is the "Quality of life improvement" and whose branches, at the first level, are "Social aspects" and "Economy".

A different weight percent will be assigned to each of the two branches, based on the importance for the local population of the different elements in which the branches may be broken down.

Clearly there are plenty of other indicators which can be found in literature and which should be considered in order to assess the impact of a smart grid but, since our goal is to analyze only the impact on rural population, we decided to not mention them and to proceed as follow.

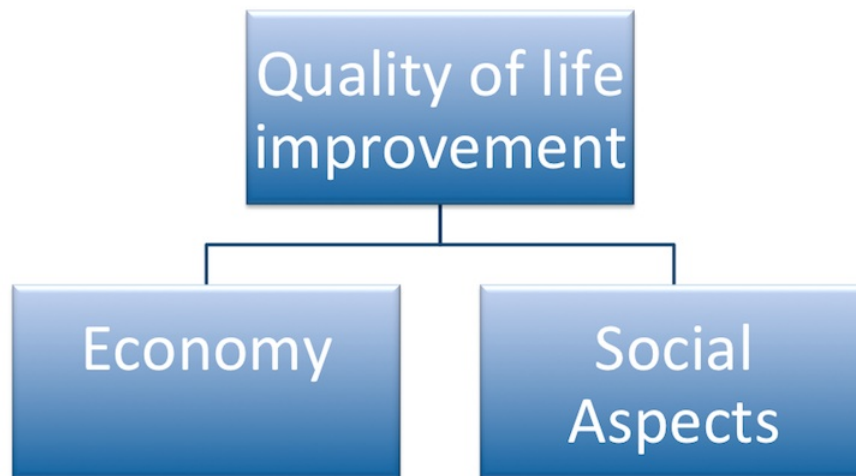


FIGURE 4.1: Hierarchical tree structure

4.2 Economy

The indicators we decided to analyze in order to assess the economic impact of smart grid's introduction are three and they reflect the effects on people living in the area where the grid is implemented.

They are related to savings on electricity costs and the economic impacts (both direct and indirect) and can be represented on our hierarchical structure as can be seen in Figure 4.2.

4.2.1 Impact on local economy

Economic impacts is a set of indexes which take into account the direct and the indirect effects on the economy related to the introduction of the Smart Grid in the rural area under consideration.

As mentioned before this branch of our model can be declined into two sub-branches: "direct job creation" and "Indirect effects on economy", described below.

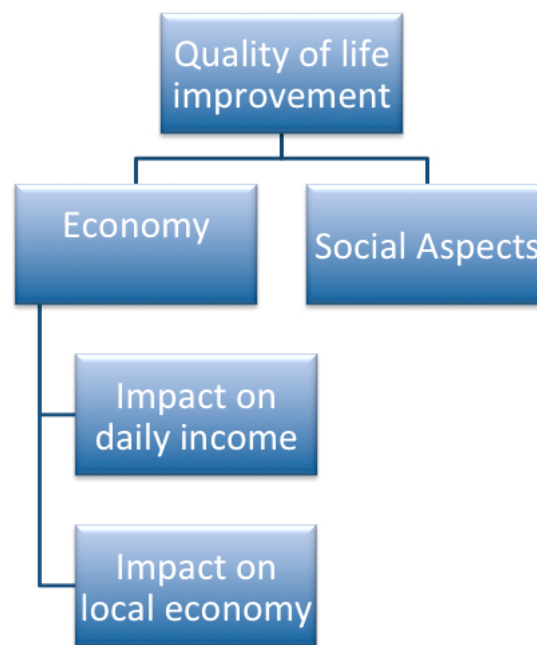


FIGURE 4.2: Hierarchical tree structure - Economy breakdown

4.2.1.1 Direct job creation

The direct job creation is as an index which counts the jobs created by the introduction of smart systems during their entire life cycle (from construction and operation till decommissioning) and assess the economic values of such jobs.

Given that the introduction of smart grids do not contemplate a wide number of new employees from the rural area under consideration (everything is managed remotely by software) we decided to not include this index in our model due to its poor impact on average quality of life improvement.

4.2.1.2 Indirect impact

The implementation of a Smart Grid in a rural setting significantly impacts the economy of the affected area: an increase in the availability of energy makes accessible to the population the electricity necessary to meet their basic needs and start (or increase) economic activities.

With regard to the indirect impact on the rural economy, it was decided to analyze

it by using the concept of Energy Intensity: the latter, calculated as units of energy per unit of GDP, measures the energy efficiency of the national economy. Through this index is therefore possible to quantify a rise of GDP of the given area in function of the electrical consumption's growth.

The consumption's growth can be determined by:

- Increment of reliability;
- Population's growth;
- New business activities.

The growth brought by the first is assessed as the difference between current demand and current availability of electrical power, because, after the introduction of smart grids, all the demand left uncovered by diesel generators will be supplied thanks to storage tools; that from the second is evaluated hypothesizing that energy consumption's and population's rises have the same growth rates over time; that from the latter element, even if it is an important component for determining the impact on economy (As example, an higher availability of energy should means that shops will be able to store and freeze fresh products making the market more competitive), is not evaluated because, according to Tanguy Bernard, researcher for World Bank, it is difficult to measure the impact of more electricity's availability on future jobs creation due to attribution difficulties of the impacts; this thesis is supported even by the club of Agencies and National Structures in Charge of Rural Electrification in Sub Saharan Africa that reports that: "the expected indirect effects [brought by an higher availability of energy] on income, health, education, agriculture, etc. are difficult to measure" [86].

4.2.2 Impact on daily income

The analysis of this index aims to assess the direct impact following the implementation of a Smart Grid, in a rural area, on the daily income of the local population.

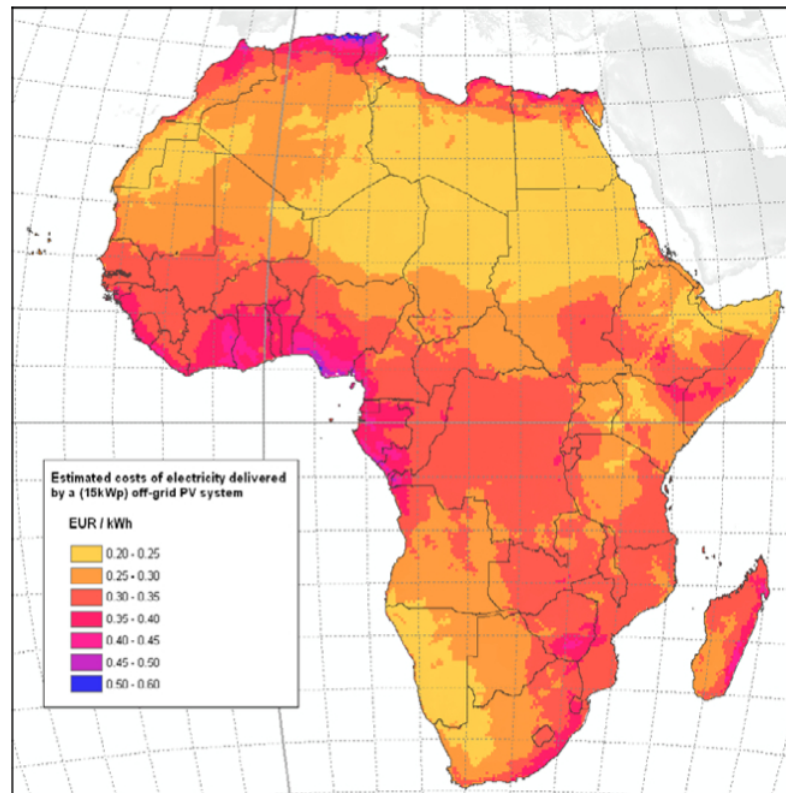


FIGURE 4.3: Costs of electricity generated with photovoltaic systems in Africa

As a proxy for the daily income we decided to use the poverty line (equal to \$1.25 per day): this choice is motivated by the fact that as many as 70% of the population belonging to Sub Saharan Africa, having at the disposal a daily income lower than the poverty line, lives in rural areas of the continent.

The analysis was then focused on the quantification of the daily savings on electricity costs, which represent the element of greatest impact on the daily income of local population as a result of the implementation of a Smart Grid in rural areas (as mentioned in paragraph 4.2.1.2, the impact on rural economy, and the consequent impact on the daily income of rural populations, is hard to quantify). The entity of savings is assumed as a monetary value weighted on kWhs (USD/Kwh) and it is calculated as difference between the cost that an inhabitant will pay per Kwh of energy produced with fuel and the cost of maintenance related to the production from renewable sources (calculated on the same quantity of energy produced). The difference is given by the storage options that will be enabled after the introduction of smart technologies which will let to use the daily energy

surplus overnight.

We assumed that costs per kWh will not change after the introduction of the smart grid since the financing method of the "Power Africa" project does not expect price growths for final users. Prices per kWhs for the different sources are shown in Figures 4.3 and 4.4.

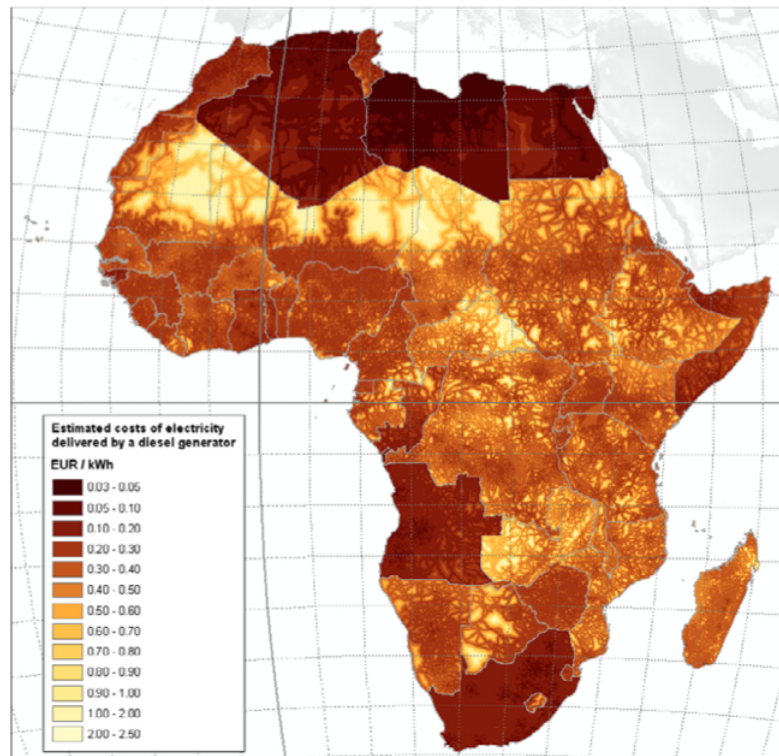


FIGURE 4.4: Costs of electricity generated with diesel generators in Africa

4.3 Social Aspects

Social aspects are very important elements in the evaluation of the introduction of smart grids in rural areas.

Such aspects, in last decades, have been the most significant criterion for a good reception of new infrastructures on the area by resident people (not only in developing countries but also for developed ones). Two indexes have been analyzed in order to better understand the social aspects: "security and reliability of energy provision" and HDI, which have been intended as follow.

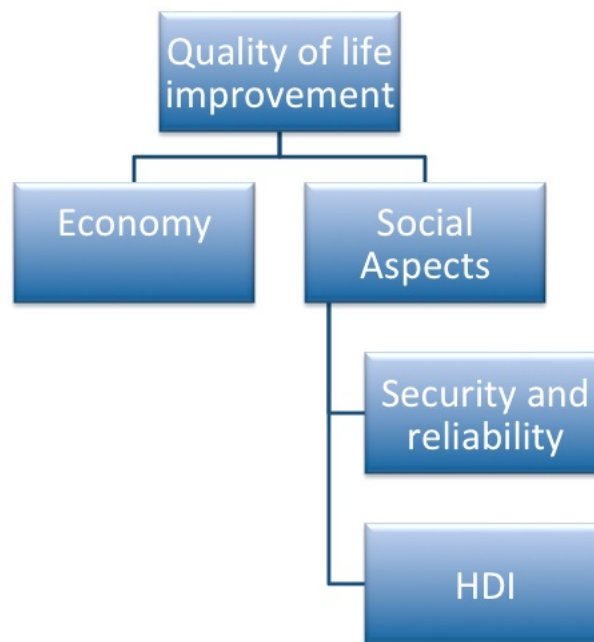


FIGURE 4.5: Hierarchical tree structure - Social aspects breakdown

4.3.1 Security and reliability of energy provision

This branch refers to the solidity of the energy system and points out the importance of the security of supply for the population living in the rural areas.

The reliability of energy provision is an important theme as it influence people's ability of accessing to energy's supply in every moment of the day, even if it is characterized by peaks in demand, in order to satisfy their needs. In fact, in moments featuring levels of energy's demand higher than its supply, there is the possibility that an outage occurs in the power grid as a result of an overload. Such contingency can be avoided, thus impacting on the quality of life of people, through the use of smart grids; in fact they allows to answer to the electricity demand of users linked to the grid by making continuous the energy supply, thanks to storage systems which are able to compensate demand's differences along the day.

4.3.2 HDI

The term HDI refers to the "Human Development Index", a statistical indicator that concerns themes like the education, the life expectancy at birth and standard of living in order to measure average achievements in human development in a society [87]; its principal aim is to classify the world's countries in four different levels of human development (Low - Medium - High - Very High) [88].

The choice of using this index in order to evaluate the impacts of the implementation of smart grids is tied to the fact that the HDI panel has been used by many researchers for measuring the effects of policies on life quality [89].

The calculation of the HDI, expressed as:

$$HDI = \sqrt[3]{LEI \cdot EI \cdot II}$$

is based on a geometrical average of three normalized indexes:

- Life Expectancy Index (LEI);
- Education Index (EI);
- Income Index (II).

If we deeply analyze each component, it is possible to note how it is directly related with energy consumption, which implies that a growth in the latter is linked to a growth of the three sub-indexes and, so, to the HDI.

It is therefore useful, in order to better understand our model, to give a brief description of the three components.

Life Expectancy Index The LEI indicator is related to the life expectancy at birth for population of the considered country; it is calculated as:

$$LEI = \frac{LE - 20}{82.3 - 20}$$

The relation between energy consumption and LEI has been evaluated by different researchers, including Chi Seng Leung [90]: he identified a positive correlation between energy consumption per capita and life expectancy at birth, by analyzing 19 countries characterized by a low level in the latter.

Education Index The Education Index is composed by two different factors: MYSI which is "Mean Years of Schooling Index" and EYSI which is "Expected Years of Schooling Index"; it is calculated with the formula:

$$EI = \frac{\sqrt{MYSI \cdot EYSI}}{0.951}$$

As highlighted by the study conducted by Mark Davis on the effects of access to electricity in Southern Africa, among the benefits brought by projects of rural electrification, there is even an improvement in education level [91] due to a better illumination of school facilities and the possibility to study even in times in which solar light does not allow an adequate illumination.

Such benefits are even been shown by ABB in its presentation of the results of the "Access to electricity" project for the electrification of rural areas in which it has been pointed out the possibility that has been given to pupils to study even during evening hours and it has been affirmed that the school enrollment in the area has doubled in only two years [92].

Finally, according to a study by Taryn Dinkelman on effects of rural electrification, a growth in energy availability and its better management in rural areas cause an increase in education demand and, consequently, to a construction of new schools (as example, in South Africa, in five years the number of schools has grown by 19%) [93].

Income Index The third element of human life on which the Human Development Index is focused is the standard of living: a decent living is the most difficult component to be measured, because its calculation requires data on access to land, credit, income and other resources. According to Eric Tollens [94],

“given the scarce data on any of these variables, we must for the time being make use of an income indicator”. For these reasons the index used in order to calculate the HDI is the Income Index: it points out the life standards of the residents of a country through the use of the GNI per capita:

$$II = \frac{\ln(GNI_{pc}) - \ln(100)}{\ln(107.721) - \ln(100)}$$

According to Todaro and Smith, the Gross National Income (GNI) is the total domestic and foreign output claimed by residents of a country, consisting of Gross Domestic Product (GDP) plus factor incomes earned by foreign residents, minus income earned in the domestic economy by nonresidents [95], so its relation with energy consumption has already been explicated in section 2.1.

4.4 Environment

It should be pointed that initially a third branch has been hypothesized, called “Environment”, whose goal was to assess the environmental impact of the implementation of the Smart Grid in the rural area; it would have been divided into two successive ramifications, “Emissions” and “Biodiversity”.

4.4.1 Emissions

Through the branch “Emissions” it is taken into account the change in the value of the emissions resulting from the implementation of the Smart Grid in the rural area under consideration. According to Chatzimouratidis and Pilavachi [96] the five most important non-radioactive emissions to consider are: non-methane volatile organic compounds (NMVOCs), carbon dioxide equivalent (CO_{2-eq}), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and particulate matter (PM). Values relating to the change of the emissions calculated in our case, consequent to a

change in consumption of the rural population as a result of the implementation of a Smart Grid, are recognized as not meaningful in order to evaluate an improvement of the quality of life, and have therefore been omitted.

4.4.2 Biodiversity

With the branch "Biodiversity" we want to identify the impact of the implementation of a Smart Grid in a rural area from the standpoint of the ecosystem; a possible loss in biodiversity could cause problems in the long term, negatively affecting the natural functioning of the ecosystems, which in many cases (such as tourism or agriculture) is a valuable, if not necessary, asset for human society. The implementation of a Smart Grid will not significantly impact on the biodiversity of the country where the investment is addressed, neither from the point of view of land use nor with regard to a possible loss of species (which is rather important in the case of realization of wind turbines, so for several species of birds the mortality rates have been increased due to collisions of the latter with the components of the wind systems).

4.5 Model's description

After having described the structure of the model that we have developed for evaluating the impacts on life quality by the implementation of smart grids in rural areas, it's therefore possible to give a more quantitative description of how it works.

First, it is necessary to proceed with a description of the initial assumptions that underlie the creation of our model.

4.5.1 Baseline scenario

The base case from which we started to carry our our analysis and suddenly created our model takes place in a rural area of the Sub Saharan region (the specific area chosen for the evaluation depends on the geographical characteristics of each country). The area considered is characterized by a surface of 100 km^2 where rural population has access to discontinuous electricity provided by several wind turbines and solar panels.

A more continuous energy availability for the local people is permitted by the presence of diesel generators that allow them to take advantage of electricity produced if the renewable's one is unavailable, but has a production limit which will bring to losses in production capacity once overtaken.

The choice of technological components necessary for energy production will be made according to the needs and characteristics of the area taken into consideration.

An important element to be considered is also the efficiency of the transmission and distribution system through which electricity is provided to local population. The African continent is characterized by high percentages in loss of electricity concerning the transmission and distribution of energy: analyzing the World Bank's database concerning the Sub Saharan countries [5], the value related to the percentage of losses caused by an inefficient transmission and distribution system is on average equal to 11%, with peaks up to 48% in Congo and 28% in Namibia (while in the United States, used as proxy for the developed countries, this value reaches 6%).

These datas highlight the fact that, in this context, the implementation of a grid through which it would be possible to get a more efficient transmission and distribution and, then, an improvement in terms of energy reliability, as the Smart Grid is, may lead to significant benefits for the rural communities.

The technological components we chose in order to provide energy to local population are:

Wind turbines We chose a K-Kopron Wind30 turbine, whose specifications which we used in order to make the dimensioning are [97]:

TABLE 4.1: Wind turbines specifications

Nominal Power	30 KW
Cut-in wind Speed	3 m/s
Nominal Wind Speed	12 m/s
Maximum Wind Speed	60 m/s

Solar panels The panels we chose were Sharp ND-220E1F, the specifications which we used in order to make the sizing are: [98]:

TABLE 4.2: Solar panels specifications

Dimensions	994x1652x46 mm
Maximum Power	220 W
Encapsulated Solar Cell Efficiency (η)	15%

Diesel generators The generating sets chosen are Lombardini CGM 20LW, characterized by [99]:

TABLE 4.3: Generator specifications

Power	16 KW
Fuel consumption	4.5 l/h

The number of generators adopted is approximated to the lower entire between the ratio of the maximum peak energy demand and the generator power.

4.5.2 To-Be Scenario

The To-Be case, as difference to the baseline scenario, contemplates the introduction of a smart grid that is capable to tie together the previously mentioned elements of the grid, like solar panels and wind turbines, with storage tools, able to manage the discontinuous production of energy made through renewable sources by redistributing it during the day and to improve the efficiency of the grid itself

by avoiding outages.

In addition, another consequence of the optimization in the management of electricity generated from renewable sources after the introduction of smart grids, is also the elimination of diesel generators (and their related costs), no longer useful in order to respond to the demand for energy during the time slots uncovered by renewable sources.

This scenario also contemplates the rise of energy consumption in the area due to the growth of population (on two years term) and the growth of economic activities (which due to reasons mentioned in Section 4.2.1.2, it has not been included). We hypothesized the introduction of all tools that have been listed in Chapter 3 in order to analyze the best case since, as expected by the "Power Africa" project, the introduction of the smart elements will be totally cost-free for local population and prices for electricity will not vary after the implementation of the smart grid. It is preferable to make a separate discussion regarding the financing arrangements through which it is made available the capital needed for the implementation of the Smart Grid in the rural area taken into consideration. Our evaluation is carried out within the project "Power Africa", whose financing arrangements have been described previously in Section 2.3.2.

The "Power Africa" project intends to finance projects aimed at implementing electrical networks and systems for power generation based on the exploitation of renewable sources without allocating any extra cost to the rural population receiving the investment.

The role of the local population is therefore that of pure beneficiary, since all the costs are covered by corporations or private entities.

It should be emphasized that the focus of these funds, towards solutions which provide the exploitation of renewable energy sources, is not only due to environmental reasons, but also cultural: not yet being well established a culture of consumption-efficiency, a renewable solution where the energy source (sun, wind, etc.) does not imply a payment from those who use it, appears to be preferable to others solutions, such as diesel generators.

This method of financing is not entirely new in the African continent: some

projects aimed at increasing the degree of electrification of the area have been implemented in other rural areas of the continent, among which we can mention that of Eauxwell Nigeria ltd. aimed at the creation of mini grids for remote, rural communities in Nigeria [100].

In this Eauxwell's project, the leading water and renewable energy-engineering firm in Nigeria, the Federal Government of Nigeria has financed the installation of mini-grids, using solar panels in a rural area inhabited by 700 people.

Interesting for our study is the fact that end-users were not asked to pay any cost, but they were only required to provide land for the plants and ensure their safety. The model we propose, aimed at an evaluation from the point of view of the local population, arises within this context of financing, for which any cost related to the implementation of the Smart Grid in the rural area under consideration will be deemed.

4.5.3 Model data

Math operations which have been calculated in order to deploy the model will be examined in this section. Examples on how the model works will be analyzed afterwards in chapter 5.

4.5.3.1 Energy consumption

The input data we considered are:

TABLE 4.4: Consumption data

Per capita annual consumption	PCAC	kwh
Reduction ratio ¹	RR	percentage
Population's density	d	$\frac{people}{km^2}$
Area of interest	A	km^2
Country's Area	Ac	km^2
Country's population	Pc	number
Country's urban population	Pu	number
Daily consumption profile	DCP_i	percentage

Starting from these elements we calculated: the per capita consumption (PCC), the daily consumption (DC), the hourly usage (HU_i) and the adjusted density (Ad) as:

$$PCC = PCAC \cdot RR \quad (4.1)$$

$$DC = \frac{PCC}{365} \quad (4.2)$$

$$HU_i = DC \cdot DCP_i, \quad \text{with } 1 \leq i \leq 24, i \in \mathbb{N} \quad (4.3)$$

Because of a lack of specific data related to population density in rural areas, we approximated it considering the surface of urban areas as not significant, so we calculated the adjusted density (Ad) of population as follows

$$Ad = \frac{Pc - Pu}{AC} \quad (4.4)$$

The introduction of a smart grid will also contemplates the introduction of specific hardware (like a PLC and a computer), but the consumption of energy related to them² will be considered as negligible as they do not impact in a relevant way on total consumption.

4.5.3.2 Solar energy

The input data we considered are:

TABLE 4.5: Solar energy data

Hourly irradiation ³	HI_i	$\frac{kw}{m^2}$
Solar Cell Efficiency	η	percentage
Number of panels	$\#P$	number
Panel's dimesions	lxh	m

Starting from these elements we calculated: the panels' area (PA) and the hourly

¹In rural areas the consumption per capita are lower than the average [101]

²Assuming the use of a single PLC [102] and a computer [103], like has been done in a similar project conducted by CESI in Val Codera (Italy), consumption are lower than 300 Wh

³Missing data are estimated

production of energy from solar panels (HPS_i) as:

$$PA = l \cdot h \cdot \#P \quad (4.5)$$

$$HPS_i = PA \cdot \eta \cdot HI_i, \quad \text{with } 1 \leq i \leq 24, i \in \mathbb{N} \quad (4.6)$$

4.5.3.3 Wind energy

The input data we considered are:

TABLE 4.6: Wind energy data

Hourly wind speed ⁴	WS_i	$\frac{m}{s}$
Cut-in wind speed	CiS	$\frac{m}{s}$
Nominal wind speed	NWS	$\frac{m}{s}$
Maximum wind speed	MWS	$\frac{m}{s}$
Maximum power	MP	kw
Number of turbines	$\#T$	number

Starting from these elements the transformation function of the wind turbine and the hourly energy production from wind turbines (HPW_i) have been calculated.

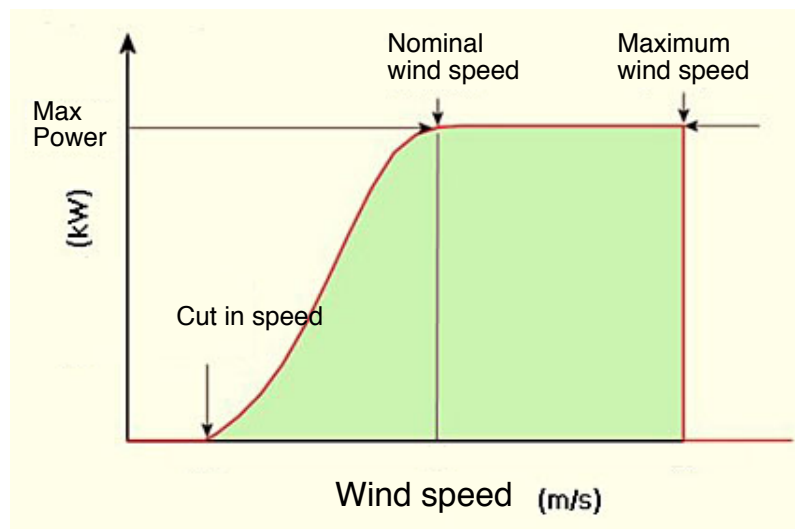


FIGURE 4.6: Wind turbines function

Firstly we designed the transformation function hypothesizing an exponential

⁴Missing data are estimated

curve between the cut in speed and the maximum speed (as can be seen in figure 4.6) and, successively, we obtained the values for (HPW_i) calculating:

$$HPW_i = f(WS_i), \quad \text{with} \quad \begin{cases} CiS \leq WS_i \leq MWS \\ 1 \leq i \leq 24, i \in \mathbb{N} \\ HPW_i < MP \end{cases} \quad (4.7)$$

4.5.3.4 Diesel production

The input data we considered are:

TABLE 4.7: Diesel energy data

Generator power	GP	kw
Number of generators	#G	$\frac{m}{s}$

Starting from these elements we calculated: the hourly renewable production (HPR_i), the maximum production with generators (GP_{max}) and the hourly production of energy from generators (HPG_i) as:

$$HPR_i = HPW_i + HPS_i, \quad \text{with } 1 \leq i \leq 24, i \in \mathbb{N} \quad (4.8)$$

$$GP_{max} = \#G \cdot GP \quad (4.9)$$

$$HPG_i = \begin{cases} d \cdot A \cdot HU_i - HPR_i & \text{if } HPG_i < GP_{max} \\ GP_{max} & \end{cases} \quad (4.10)$$

Outages In order to explain the effects on reliability of a smart greed we decided to hypothesize the possibility of outages caused by overloads on the grid.

They have been simulated through a random boolean variable that is equal to 1 if the outage happen or otherwise to 0; if the variable is equal to 1 all the electricity needed for the given hour is produced by diesel (within the limit imposed by the size of the generators) with consequent rise of costs and productivity losses.

Once defined the variable as

$$Out_i = rnd \text{ int} \in [0; 1], \quad \text{with } 1 \leq i \leq 24, i \in \mathbb{N}$$

the adjusted hourly production from renewables ($AHPR_i$) and from generators ($AHPG_i$) have been calculated as:

$$AHPR_i = \begin{cases} HPR_i & \text{if } Out = 0 \\ 0 & \text{if } Out = 1 \end{cases} \quad (4.11)$$

$$AHPG_i = \begin{cases} d \cdot A \cdot HU_i - HPR_i & \text{if } HPG_i < GP_{max}, \quad Out = 0 \\ d \cdot A \cdot HU_i & \text{if } HPG_i < GP_{max}, \quad Out = 1 \\ GP_{max} & \end{cases} \quad (4.12)$$

4.5.3.5 HDI

The input data we considered are:

TABLE 4.8: HDI data

Yearly human development index	HDI_y	value
Electric power consumption per capita	EPC_y	kw

Starting from these elements we obtained a 2nd degree polynomial function like:

$$HDI = f(EPC) = \alpha_1 \cdot EPC^2 + \alpha_2 \cdot EPC + \alpha_3$$

which have been derived in order to obtain a marginal growth's equation as:

$$mHDI = \frac{d \, HDI}{d \, EPC} = 2 \cdot \alpha_1 \cdot EPC + \alpha_2 \quad (4.13)$$

that will be used in order to calculate the HDI's growth brought by a given rise of energy consumption.

4.5.3.6 Energy costs

The input data we considered are:

TABLE 4.9: Costs data

Average fuel price	P_F	$\frac{USD}{l}$
Hourly fuel consumption	FC	$\frac{l}{h}$
Average renewable maintenance costs	C_{RE}	$\frac{USD}{kWh}$

The price of the energy generated with diesel (P_D) is calculated using the average fuel cost in a given country, the fuel consumption per hour and the produced kWh:

$$P_D = \frac{P_F \cdot FC}{GP} \quad (4.14)$$

4.5.3.7 Expenditures

Starting from the costs of single units of energy is possible to determine the expenditures that are necessary to our model in order to calculate the impacts of "Savings on electricity costs" and "Security and reliability".

Such expenses are:

- Costs at initial condition (C_{IC})

$$C_{IC} = \sum_{i=1}^I (HPG_i \cdot P_D + HPR_i \cdot C_{RE}) \quad (4.15)$$

- Costs at initial condition considering outages ($C_{IC, Out}$);

$$C_{IC, Out} = \sum_{i=1}^I (AHPG_i \cdot P_D + AHPR_i \cdot C_{RE}) \quad (4.16)$$

- Costs with smart grid (C_{SG}).

$$C_{SG} = \sum_{i=1}^I (HPR_i \cdot C_{RE}) \quad (4.17)$$

The differences between these costs represents the margin created by savings (Δ_S) and by reliability (Δ_R) which are determined as follows:

$$\Delta_S = C_{IC} - C_{SG} \quad (4.18)$$

$$\Delta_R = C_{IC, Out} - C_{IC} \quad (4.19)$$

4.5.3.8 Indirect effects on local economy

The indirect effects on economy, in terms of rise of GDP of the given area, is function of electrical consumption's growth.

The three determinants of this value have been listed in section 4.2.1.2 but, as we do not proceed with the evaluation of the third element because of the high difficulty of its evaluation, we decided to assess the first ones on a period of two years, in order to minimize the effects of the impact on local economy brought by new business activities in the area.

The input data we considered are:

TABLE 4.10: Indirect effects on local economy

Initial energy demand	D_0	kWh
Initial energy availability	A_0	kWh
Yearly GDP per unit of energy use	EI_y	$\frac{\text{kg of oil equivalent}}{\$PPP}$
Yearly GDP	GDP_y	\$ PPP
Average population's growth	PopG	percent

Starting from these elements we calculated: energy consumption in kg of oil equivalent (C_t), the relative rural⁵ GDP's values (GDP_t) using the trend line's function⁶

$$EI_t = f(GDP_t)$$

⁵according to Paul Dorosh and Emily Schmidtrural, rural GDP's values in Ethiopia are the 57% of total one [104] and, due to the lack of data relative to other countries, we will use the same value in our studies in Chapter 5

⁶obtained from a scatter plot presenting GDP_y on the horizontal axis and EI_y on the vertical axis

set equal to $\frac{C_t}{GDP_t}$ and the consequent difference of GDPs (ΔGDP) as:

$$C_0 = A_0 \quad (4.20)$$

$$C_t = D_0 \cdot (1 + PopG)^t \quad (4.21)$$

$$EI_t = f(GDP_t) = \frac{C_t}{GDP_t} \quad (4.22)$$

$$\Delta GDP = \frac{GDP_t - GDP_0}{GDP_0} \quad (4.23)$$

4.6 Weights assignment

In order to evaluate the improvement in the quality of life of rural population whom the investment is addressed, it is necessary to be able to quantify the importance that local residents give to each of the branches analyzed.

The criteria weights have to be specified before the overall evaluation is carried out; the importance of each criterion in each level is assessed with respect to their parent.

The choice of which are the priorities, and how much they weigh, is purely subjective as it may vary depending on the different culture, education and experience of the people. The subjectivity of the preferences which characterizes the various decision-making groups leads to different sets of weights that should therefore be examined.

Analyzing our case, regarding nations belonging to the Sub Saharan area of the African continent, a meaningful problem has occurred: the partial absence of data, such as those in the form of surveys or questionnaires, through which it would be possible to identify the weights that would reflect faithfully the priorities and preferences of rural populations in the analyzed countries.

To make our analysis possible we referred to a study conducted between 1990 and 2001 in South Africa [105]. In this report, through surveys, researchers have come to weigh the priorities for the inhabitants of the South African state: a value of 66.3% is given to the priorities identified in our model as belonging to the branch

”Social aspects”, while the remaining 33.7% is assigned to the branch ”Economy”. Through the study mentioned above it is just possible to only conjecture weights of the branches belonging to the first level of our model; priorities related to the second-level branches are hard to suggest, due to the lack of existing studies related to the implementation of a smart grid in a rural area of Sub Saharan Africa and the absence of surveys through which it would be possible to understand the relationships between the priorities of the local population represented by the branches belonging to the second level.

For these reasons we decided to weigh in the same way all the branches belonging to the second level (50% each); so, through a sensitivity analysis which will be carried out in Section 5.1.4, we will analyze the changes in the values of the quality of life improvement resulting from a modification in the weights.

Chapter 5

Case study: Mozambique

5.1 Introduction

The test through which we evaluate our model is based on data from Mozambique, in close proximity to the city of Lichinga, located at coordinates (13.16S; 35.14E). Analyzing data from various areas of the country the best solution was to implement the smart grid near the coast in order to get further potential benefits through the installation of off-shore wind turbines; but, according to the relation written by National Institute for Disaster Management of Mozambique in its "Study on the Impact of Climate Change on Disaster Risk in Mozambique" [106], the coastal zones are the most risky in terms of impact of cyclones and sea's level rise, so we decided to test the model in a less hazardous area which is preferable for investments.

The data used are relative to the day 04/30/2013.

5.1.1 Initial conditions

Values we used to carry out the testing of our model are:

Wind Speed Hourly values of wind speed of the area taken under consideration are visible in table 5.1 [107], it must be clarified that there is not the availability of all hourly data on wind speed relative to the choosen day, so the missing values were approximated randomly between 80% and 120% of the average of the maximum and minimum values of existent data since wind speed is not attributable to a known distribution:

$$WS_i = \frac{WS_i \max + WS_i \min}{2} \cdot RND \text{ with } RND \in [0.8; 1.2]$$

TABLE 5.1: Wind and solar data - Values marked with * are estimated as mentioned in section 5.1.1

Hour	HI_i	WS_i
1	0.00*	5.5*
2	0.00*	7.6*
3	0.01	5.8*
4	0.12*	6.8*
5	0.25*	7.1*
6	0.38	6.8*
7	0.50*	6.9*
8	0.61*	8.0*
9	0.73	6.2
10	0.75*	6.2
11	0.69*	5.7
12	0.56	6.8*
13	0.40*	6.6*
14	0.25*	5.1
15	0.09	7.9*
16	0.06*	5.1
17	0.03*	5.1
18	0.00	6.8*
19	0.00*	5.7
20	0.00*	5.1
21	0.00	6.2
22	0.00*	7.7
23	0.00*	8.2
24	0.00	5.6*

Solar irradiation Values related to solar irradiation in the area of coordinates (13.5S; 35.5E) have been taken from the NASA website [108]; however, values were not available for every hour of the day but every three hours: therefore it has been necessary to conjecture, starting from available data, a linearly increasing trend of values of solar radiation up to a hypothetical peak at 10 o'clock in the morning, after which we assumed a linearly decreasing trend as can be seen in Table 5.1 and in Figure 5.1.

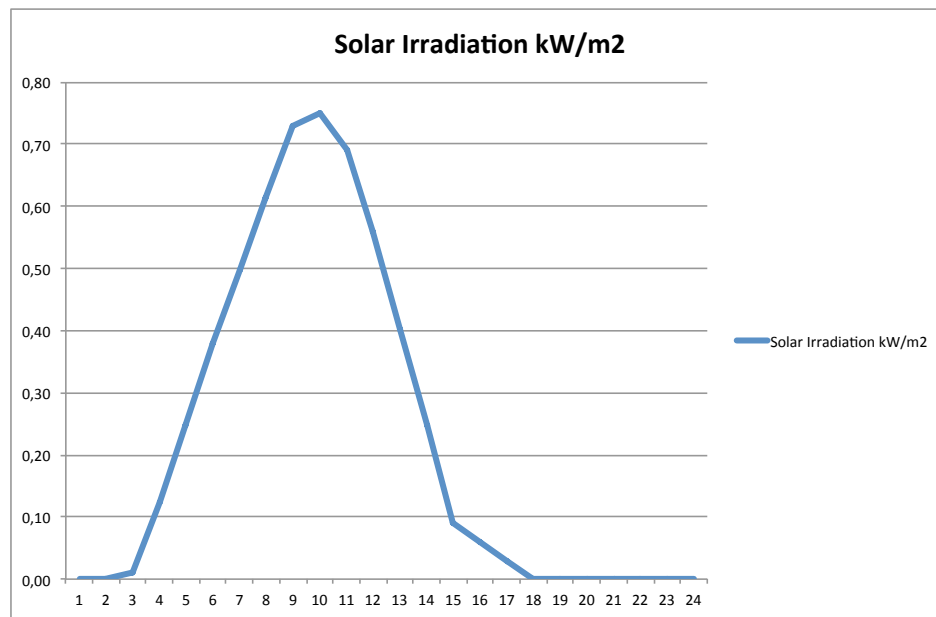


FIGURE 5.1: Solar irradiation distribution

Population density The value of population density in the state of Mozambique, taken from the World Bank's database, is equal to 23 inhabitants/ km^2 [5]; using the Formula 4.4, we obtained the value of 21.76 inhabitants/ km^2 .

Consumption per capita According to the database of World Bank [5], the average annual consumption per capita of Mozambique is equal to 447 kw; using historical data by Jin Jiaman [101], the reduction ratio for energy consumption of rural population may be approximated to 40% of the average, so we treated the annual consumption of each inhabitant equal to 178.8 kwh.

Price of electricity generated by diesel The diesel price was taken by the World Bank database, in 2012 in Mozambique it cost 1,23 \$/liter [5]; in order to enable us an assessment of the hourly cost of energy consumption derived from the utilization of diesel generators, we calculated the cost of diesel per kWh (P_D) using Formula 4.14.

Cost of maintenance of renewable energy systems In order to define the cost of operation and maintenance of systems providing renewable energy (C_{RE}) we resorted to a report conducted by Poul Erik Morthorst [109] about the costs and prices of wind turbines. According to this depth study the cost related to operation and maintenance of renewable energy systems amounts to 0.06 \$/ kWh.

Energy consumption pattern The energy consumption pattern is the profile of the electrical power's demand. Due to the lack of existing data related to Mozambique we decided to design a profile similar to the South African one, that was presented by Eskom in its "Annual Report 2009" [110]; starting from the given pattern we defined custom hourly usage percentages (as shown in Figure 5.2) and then we multiplied such shares for the daily consumption per capita which we have calculated before.

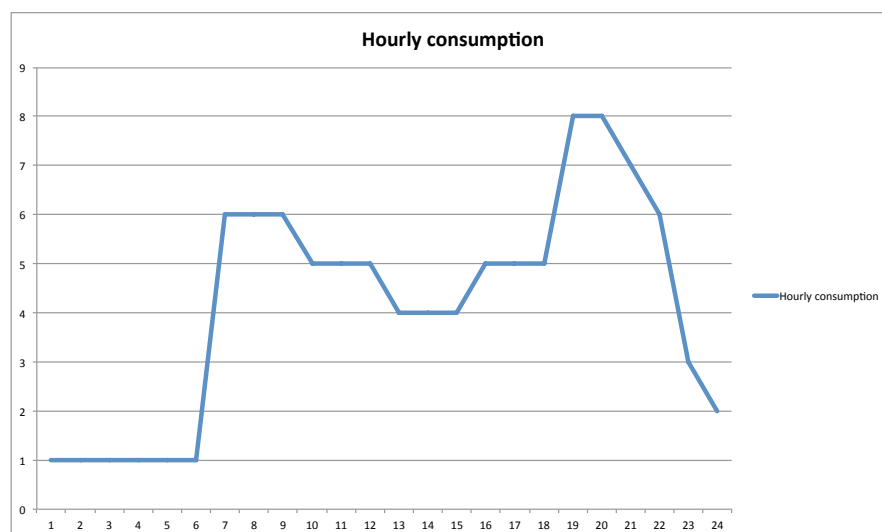


FIGURE 5.2: Custom consumption pattern

5.1.2 Results

After introducing the input data that will be used by our model, we proceed now to expose the intermediate results we obtained.

Renewable production The renewable production is calculated using Formula 4.8. The results make explicit the different behaviors of the energy sources, as can be seen in Figure 5.3 the solar energy is produced only during the day and leave uncovered the evening hours, while the wind energy is generated in the whole day but has a lower global production. The production's values, which take into consideration a loss in T&D which amounts to about 15% [5], are presented in table 5.2.

TABLE 5.2: Production with wind and solar sources

Hour	HPW_i	HPS_i	HR_i
1	2.92	0.00	2.92
2	18.80	0.00	18.80
3	3.82	1.60	5.42
4	9.50	19.75	29.24
5	12.86	39.49	52.36
6	9.03	60.84	69.87
7	10.78	79.52	90.30
8	28.89	98.20	127.08
9	5.31	116.88	122.19
10	5.31	120.08	125.39
11	3.37	110.47	113.84
12	9.50	89.66	99.16
13	7.96	64.58	72.53
14	2.08	39.49	41.58
15	26.78	14.41	41.19
16	2.08	9.61	11.69
17	2.08	4.80	6.89
18	9.03	0.00	9.03
19	3.37	0.00	3.37
20	2.08	0.00	2.08
21	5.31	0.00	5.31
22	21.87	0.00	21.87
23	34.48	0.00	34.48
24	3.20	0.00	3.20

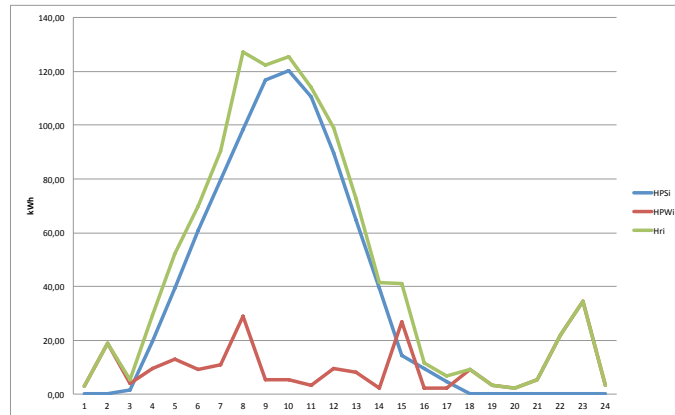


FIGURE 5.3: Production with wind and solar sources

Energy consumption The hourly usage of electricity is calculated using Formula 4.3 with the percentages shown in Figure 5.2. The consumption values are presented in Table 5.3.

TABLE 5.3: Energy consumption

Hour	DCP_i	HU_i
1	1	10.66
2	1	10.66
3	1	10.66
4	1	10.66
5	1	10.66
6	1	10.66
7	6	63.94
8	6	63.94
9	6	63.94
10	5	53.28
11	5	53.28
12	5	53.28
13	4	42.63
14	4	42.63
15	4	42.63
16	5	53.28
17	5	53.28
18	5	53.28
19	8	85.25
20	8	85.25
21	7	74.60
22	6	63.94
23	3	31.97
24	2	21.31

Diesel energy production The hourly production of energy needed to cover the gaps left by renewable sources is calculated with Formula 4.10; clearly such values are not the ones used in order to assess the savings brought by smart grids as they do not contemplate the outages (which are kept in consideration with Formula 4.12) but they must be calculated in order to define the impact in terms of reliability.

The values of the production are shown in table 5.4 and the differences between the two scenarios are made explicit by figure 5.4.

TABLE 5.4: Diesel production

Hour	HPG_i	Out	$AHPG_i$
1	7.73	1	10.66
2	0.00	0	0.00
3	5.23	0	10.66
4	0.00	0	0.00
5	0.00	0	0.00
6	0.00	0	0.00
7	0.00	0	0.00
8	0.00	0	0.00
9	0.00	0	0.00
10	0.00	0	0.00
11	0.00	0	0.00
12	0.00	0	0.00
13	0.00	0	0.00
14	1.05	0	1.05
15	1.44	0	1.44
16	41.59	0	41.59
17	46.40	0	46.40
18	44.25	1	53.28
19	64.00	1	64.00
20	64.00	1	64.00
21	64.00	1	64.00
22	42.07	0	0.00
23	0.00	0	0.00
24	18.11	0	0.00

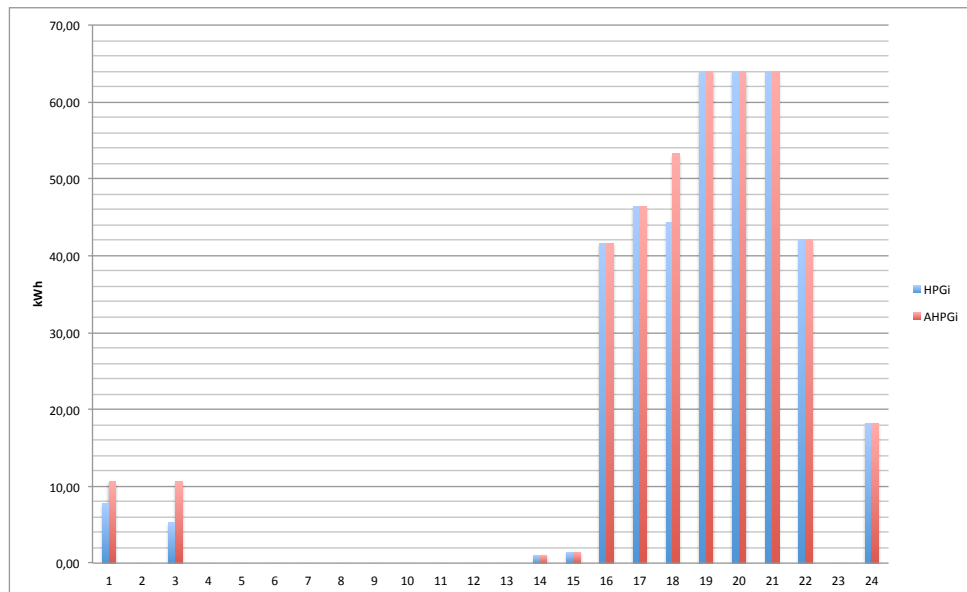


FIGURE 5.4: Production with diesel

HDI Values of HDI have been estimated using Formula 4.13. The transformation function for Mozambique has been extracted from data present in Table 5.5 (which have an R^2 index equal to 0.92873) and is: $mHDI = -12 \cdot 10^{-7} \cdot \Delta EPC_y + 0,0005$

TABLE 5.5: HDI and energy consumption

Year	HDI_y	EPC_y
1980	0.217	36
1990	0.202	40
2000	0.247	122
2005	0.287	440
2006	0.291	448
2007	0.301	450
2008	0.306	434
2009	0.312	435
2010	0.318	445
2011	0.322	447

With the growth in energy consumption resulted from our analysis (equal to 0.038 kWh per capita), the corresponding rise of the local HDI (ΔHDI) index amounts to 0.00488.

Expenditures The expenditures' values, calculated with Formulas 4.15, 4.16 and 4.17, and the consequent variations, obtained with Formulas 4.18 and 4.19, are the following:

TABLE 5.6: Costs

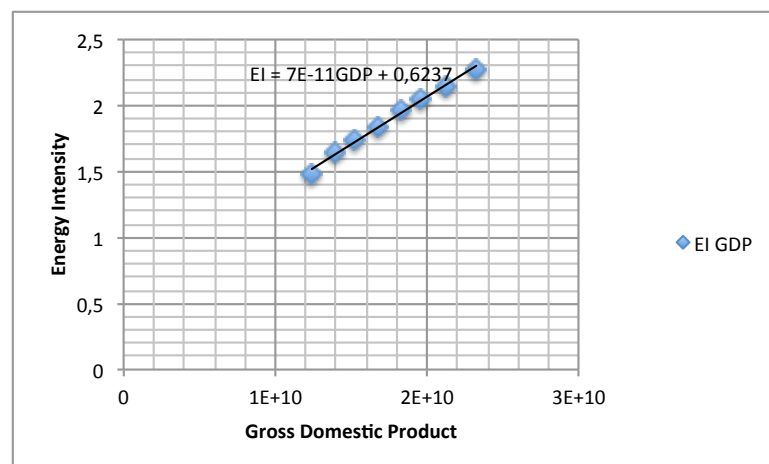
Hour	$C_{IC, Out}$	C_{IC}	C_{SG}	Δ_R	Δ_S
1	3.69	2.85	0.64	0.84	3.05
2	0.64	0.64	0.64	0	0
3	3.69	2.14	0.64	1.55	3.05
4	0.64	0.64	0.64	0	0
5	0.64	0.64	0.64	0	0
6	0.64	0.64	0.64	0	0
7	3.84	3.84	3.84	0	0
8	3.84	3.84	3.84	0	0
9	3.84	3.84	3.84	0	0
10	3.20	3.20	3.20	0	0
11	3.20	3.20	3.20	0	0
12	3.20	3.20	3.20	0	0
13	2.56	2.56	2.56	0	0
14	2.86	2.86	2.56	0	0.30
15	2.97	2.97	2.56	0	0.41
16	15.09	15.09	3.20	0	11.89
17	16.46	16.46	3.20	0	13.27
18	18.43	15.85	3.20	2.58	15.24
19	22.14	22.34	5.12	-0.20	17.02
20	22.14	22.27	5.12	-0.13	17.02
21	22.14	22.46	4.48	-0.32	17.66
22	15.86	15.86	3.84	0	12.03
23	1.92	1.92	1.92	0	0
24	6.46	6.46	1.28	0	5.18
Total	180.6	175.74	63.94	4.32	116.12

Negative values of ΔR are due to the reaching of the production limit (GP_{max}) that decreases the total amount of purchased energy because if an outage occurs it is not possible to purchase electricity produced through renewable sources.

Indirect effects on economy The values of indirect effects on economy are calculated using Formulas 4.20, 4.21 and 4.23. The equation which expresses the relation between EI and GDP in Mozambique's is $EI = 7 \cdot 10^{-11} \cdot GDP + 0,6237$, was obtained from graph in Figure 5.5 that uses data from Table 5.7.

TABLE 5.7: Values of GDP_y and EI_y

Year	GDP_y	EI_y
2004	12,398,563,785	1.52796791
2005	13,906,009,356	1.638044031
2006	15,239,549,666	1.691194782
2007	16,783,184,607	1.734643045
2008	18,279,660,001	1.829119926
2009	19,587,104,722	1.886035512
2010	21,228,677,708	1.953816934
2011	23,230,477,960	2.029738414

FIGURE 5.5: Distribution of GDP_y and EI_y

The values we obtained for GDPs in $t=0$ and $t=2$ are presented in Table 5.8 and show the positive effect that was expected.

TABLE 5.8: Values of rural GDP_y

GDP_0	251.71
GDP_2	271.54
$\Delta GDP_{0,2}$	7.88%

5.1.3 Quality of life

After having assessed the different elements which have been presented in Sections 4.2 and 4.3, we now proceed with the weighting of the different branches and the calculation of the resulting index of Quality of Life (all results, even the intermediate ones, are shown in Table 5.9).

The weights at lower level, that is the one which concerns ΔS , ΔGDP , ΔHDI and ΔR , have been decided according to what we stated in Section 4.6 and are respectively equal to 0.5, 0.5, 0.5 and 0.5. The values for Social and economy aspects, which stands at the middle level of our model, are then calculated as a weighted mean of such values.

After having obtained the values for Economy and Social aspects, we now proceed by weighting them up in order to enable the calculation of quality of life; the weights have been decided in agreement with what previously stated in section 4.6 and are respectively equal to 0.337 and 0.663.

The resulting Quality of Life improvement index is then equal to 3.41%.

TABLE 5.9: Quality of Life

ΔS	ΔGDP	ΔHDI	ΔR
4.27%	7.88%	0.15%	3.97%
0.5	0.5	0.5	0.5
Economy		Social	
6.07%		2.06%	
0.337		0.663	
Quality of Life			
3.41%			

5.1.4 Sensitivity analysis

The sensitivity analysis is carried out in order to assess the entity of the change of the value of quality of life index while varying the weights and the impact on local economy in terms of growth in energy consumption (hypothesizing a rise of consumption due to new industries in the local economy which was not considered before, for reasons explained in Section 4.2.1.2).

The values we obtained through this analysis are shown in Table 5.10 which shows on the horizontal axis the values of the consumption growth (+0%, +5%, +10%, +15% and +20%) and on the vertical axis the chosen values for the weights (in the order: ΔS , ΔGDP , ΔHDI and ΔR).

The weights used are chosen with a variation equal to $\pm 20\%$ than the average in order to study the variations of the quality of life index without making negligible (or too significant) the value obtained for a single branch.

TABLE 5.10: Sensitivity analysis results - Table

Series Number	Weights	+0%	+5%	+10%	+15%	+20%
1	0.5 0.5 0.5 0.5	3.41	4.32	5.23	6.14	7.05
2	0.5 0.5 0.3 0.7	3.92	4.83	5.74	6.65	7.56
3	0.5 0.5 0.7 0.3	2.91	3.82	4.73	5.63	6.54
4	0.3 0.7 0.5 0.5	3.66	4.93	6.20	7.47	8.75
5	0.3 0.7 0.3 0.7	4.16	5.44	6.71	7.98	9.25
6	0.3 0.7 0.7 0.3	3.15	4.42	5.70	6.97	8.24
7	0.7 0.3 0.7 0.3	2.66	3.21	3.76	4.30	4.85
8	0.7 0.3 0.3 0.7	3.68	4.22	4.77	5.31	5.86
9	0.7 0.3 0.5 0.5	3.17	3.72	4.26	4.81	5.35

The values presented in Table 5.10 makes evident that the increase of energy consumption has a positive effect on the quality of life index with every weights' combination; it was expected since every branch, which has been analyzed previously in model's description, is positively correlated to consumption as it was demonstrated in Chapter 4.

Analyzing the graph in Figure 5.6 is possible to note that all curves have a linear dependency from energy consumption, even if with a different slope. This is due to the value of GDP, in fact, as it is calculated with Formula 4.22, its value is directly impacted by energy consumption in a positive way (a growth in energy consumption implies a growth of the value of GDP and vice versa).

So, the relation between energy consumption and GDP, make us able to create three different tiers of curves:

- Tier 1: is represented by the curves with the highest slope (equal to 1.272), which are the ones with the weight for ΔGDP set equal to 0.7 (series number 4, 5 and 6);

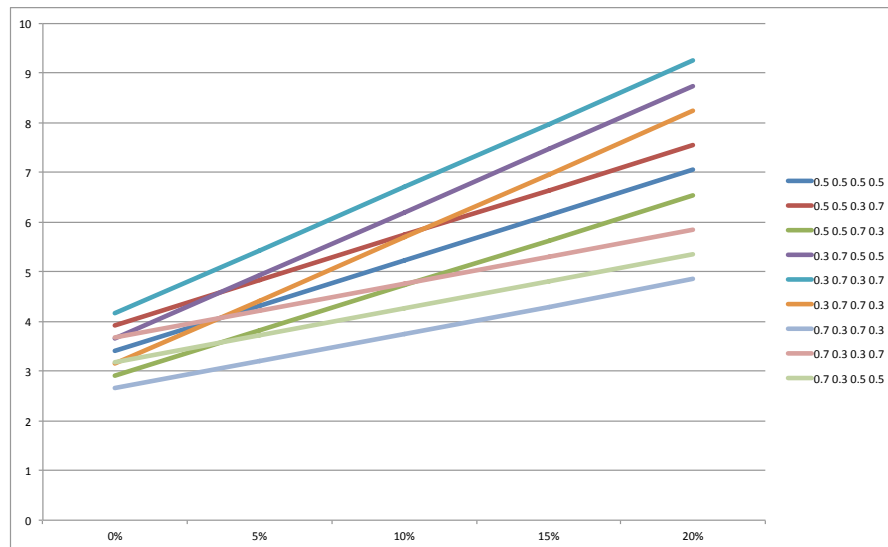


FIGURE 5.6: Sensitivity analysis results - Graph

- Tier 2: is represented by the curves with a medium slope (equal to 0.91), which are the ones with the weight for ΔGDP set equal to 0.5 (series number 1, 2 and 3);
- Tier 3: is represented by the curves with the lower slope (equal to 0.545), which are the ones with the weight for ΔGDP set equal to 0.3 (series number 7, 8 and 9).

Another relevant thing, made explicit by this analysis, is the importance of the value of ΔHDI : even if its value is function of energy consumption, it still remains significantly lower than the others (ΔS , ΔGDP and ΔR) because, as it is calculated with Formula 4.13 which considers the per capita consumption, it needs a huger growth of energy consumption in order to vary¹ and, so, the weight assigned to it have a substantial impact on the value of the quality of life index being responsible for the height of the intercept of the curve. This is evident in Figure 5.6 where series number 3, 6 and 7, which have the weight for ΔHDI set equal to 0.7 (making it more relevant), are the lower of the previously mentioned tiers, while curves of the series 2, 5 and 8 (which have the lower weight for ΔHDI , set equal to 0.3) are the higher of the same tiers.

¹about 200%

Regarding the values of ΔS and ΔR it should be said that they are not relevant in the sensitivity analysis as ΔHDI and ΔGDP are: their values both do not have an impact on the slope of the curves and have a very marginal effect on the intercept.

The first is because their values are not directly impacted by variations of energy consumption (as they are calculated in our model) so, a growth of the latter does not implies a variation in the firsts; the second is due to the fact that their values are very close to the one of the quality of life calculated in Section 5.1.3 so, the variation of the assigned weights have a very marginal impact on the final value of the index.

Chapter 6

Conclusions

To sum up, our thesis was focused on the evaluation of the impact which the implementation of a smart grid can have in a rural area of Sub Saharan Africa: both themes (geographical and technological) that have been treated, result to be particularly actual and important.

The African continent, in last years, is attracting the attention of many countries, especially United States of America and China, whom are investing their funds with the aims of create new infrastructures, improve life conditions and stimulate economic growth of countries belonging to the continent, rich of energetic resources, but which are exploited in a small share, and characterized by relevant potential development opportunities in the future.

Regarding the technological theme which has been treated in our thesis, related to smart grids, it has been highlighted how it is not only an important subject in first world's countries (as example, the United States of America which are investing in their own grids for making them "smart", in order to integrate renewable source's solutions into their existent networks), but also in developing countries, like the African ones; the latter, characterized by percentages of electrification still extremely limited, particularly high losses related to systems for transmission and distribution of power and a high potential of renewable sources (which should be able to satisfy their electrical needs) are excellent potential targets for smart grids implementation.

These statements are supported by results generated as output of the model which we have developed; it is important to underline that the topics which have been analyzed in this thesis have had a poor commitment till now: in fact it has not been possible to rely neither on an high amount of quantitative data related to similar cases, nor on surveys conducted among the rural population of Sub Saharan Africa through which it would have been possible to identify the preferences and priorities (if not in a partial way).

The structure of our model relies on a hierarchical tree structure in which the first level of resolution is composed by two branches, "Economy" and "Social aspects", that represents the macro-categories of the elements impacted by smart grids' introduction. It has been considered even a third macro-category, the "Environmental" one, but its effects were not considered because they were not bringing relevant variations to the quality of life of people living in rural areas (the implementation of a smart grid does not impact on the biodiversity of the considered area and will not bring an important decrease of GHG's emissions).

The "Economy" branch is used in order to evaluate the economic impact of the implementation of a smart grid: it is broken up in two sub-branches, "Impact on daily income" (which uses the poverty level of \$1.25 as proxy of daily income) and "Impact on local economy" (which uses the variation of GDP per capita as proxy for its evaluation).

The "Social Aspects" branch, instead, is focused on the social impact of the smart grid: it is divided in two sub-branches too, "Security and reliability" (which evaluates the impact on living standards of rural population brought by a more reliable grid) and "HDI" (an index which assesses the life expectancy, the education level and the living standard).

While applying the model on a real case, a rural area of Mozambique, and making a sensitivity analysis in order to assess the impact that a rise in energy consumption and a variation of sub-branches' percentage weights can have on our "Quality of life" index, it has been possible to draw conclusions regarding the implementation of a smart grid in a rural area of Sub Saharan Africa.

Since considered elements are related to electricity consumption in a positive way,

the impact on the quality of life of rural population results to be always positive with values ranging between 2.66% in the worst case and 9.25% in the best case. It is important to underline that this results depends on an hypothesized rise of energy used by rural population in the To-Be scenario: in fact the implementation of a smart grid will not bring only a better efficiency in energy supply and utilization, but also a growth of energy consumption trough which it is possible an improvement of rural economy that is still backward (as mentioned before, the availability of artificial lights during evening hours and refrigeration systems able to conserve food are two elements which can significantly impact the development of rural economy).

As regards variations of consumption consequent to the implementation of a Smart Grid, it is still important to highlight that our model does not consider those related to a growth of the local economy, significant but hard to be quantified; due to their positive correlation with the quality of life improvement, the value of the latter would be higher than the one we calculated.

However it is important to stress the fact that the positive impact that we have calculated it is obviously influenced by the financial scheme which is adopted: working within the Power Africa project, which aims to the electrification of rural areas of Sub Saharan Africa, implies the use of a scheme that has no direct impact on the autochthonous population (i.e. no extra-fees are imputed to the ones that benefit from the investment).

In the case of the presence of a different financial scheme, that may charge additional costs for the local population, the value of the percentage improvement of the quality of life would be obviously affected by it: in our model this extra-cost would directly impact on the branch "Impact on daily income".

It is evident, trough our analysis, how a smart grid could bring to relevant improvement in the quality of life of rural population of Africa; smart grids turn out to be a clever choice in an area characterized by a huge renewable potential and a share of people that is reached by electricity still too low to allow an economic development.

Finally it is important to underline that an adequate financial scheme for the investment, like the one represented by the "Power Africa" project, is preferable since it does not looms over the income of some of the poorest populations in the world, leaving to local population only the burden of maintenance costs which can be considered as negligible.

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