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Facoltà di Ingegneria Industriale

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Improved cooking stoves: state of the art, testing and case study of environmental impact for a development project in Malawi

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Estratto in lingua italiana

L’accesso all’energia nei paesi in via di sviluppo è un problema fondamentale. Vista anche la proclamazione del 2012 come anno internazionale dell’energia sostenibile per tutti, da parte dell’assemblea generale delle Nazioni Unite, in riconoscimento dell’importanza dell’accesso all’energia per lo sviluppo economico sostenibile e per il raggiungimento degli Obiettivi di Sviluppo del Millennio [1]. Ad oggi nonostante le dichiarazioni e gli impegni presi, i numeri evidenziano una situazione drammatica: 1.4 miliardi di persone non ha accesso all’energia elettrica, un ulteriore miliardo non dispone di reti elettriche affidabili e 2.7 miliardi di persone si affidano alle biomasse tradizionali per la cottura dei cibi e l’illuminazione. Più del 95% di queste persone è concentrato nell’africa Sub sahariana o nelle zone in via di sviluppo dell’Asia e l’84% delle stesse si trova all’interno delle aree rurali.
Tale mancanze sono causa e accrescono il “development divide” che impedisce di rompere il ciclo della povertà. L’energia ha un ruolo fondamentale non solo per la generazione del benessere industriale o commerciale, ma è fondamentale per il benessere sociale ed economico: è il mezzo per alleviare la povertà, migliorare lo stato di benessere ed elevare gli standard di vita.
Al fine di rendere più immediata la comprensione dello stato di sviluppo di un paese alcune istituzioni internazionali come UNDP (United Nation Development Programme) e IEA (International Energy Agency) hanno formulato degli indicatori nell’ottica energetica ed umana. Questi indicatori sono lo Human Development Index (HDI) e l’Energy Development Index (EDI) L’indicatore che prenderemo in considerazione è l’EDI. L’EDI è stato creato nel 2004 dalla IEA in modo da capire meglio il ruolo che l’energia gioca nello sviluppo umano. Grazie a questo indicatore si possono seguire i progressi compiuti da un paese nella sua transizione verso i combustibili e forme energetiche moderne, e quindi verso l’accesso all’energia. L’EDI è costituito dalla composizione di quattro indicatori, ognuno dei quali cattura vari aspetti della povertà energetica. Questi sottoindicatori sono:

- Consumo pro capite di energia commerciale (Ec): serve a dare un’indicazione sul generale sviluppo economico di un paese
- Consumo pro capite di elettricità nel settore residenziale (EEc) : serve per dare un’indicazione sull’affidabilità del servizio elettrico e sulla capacità dei clienti di pagare per lo stesso

- Quota parte dei combustibili moderni nell'uso dell'energia in tutto il settore residenziale (ME%): indicatore che serve a mostrare il livello di accesso alle attrezzature per cucinare in maniera pulita e sicura
- Quota parte della popolazione che gode dell'accesso all'elettricità (EE%)

Descritto come si compone l'indicatore è opportuno quantificare i valori di questo indice, ed in particolare analizzarlo nelle sue componenti. Vengono quindi riportati i dati di questo indicatore e la sua scorporazione nelle sue componenti per alcuni paesi in via di sviluppo analizzati in questo lavoro.

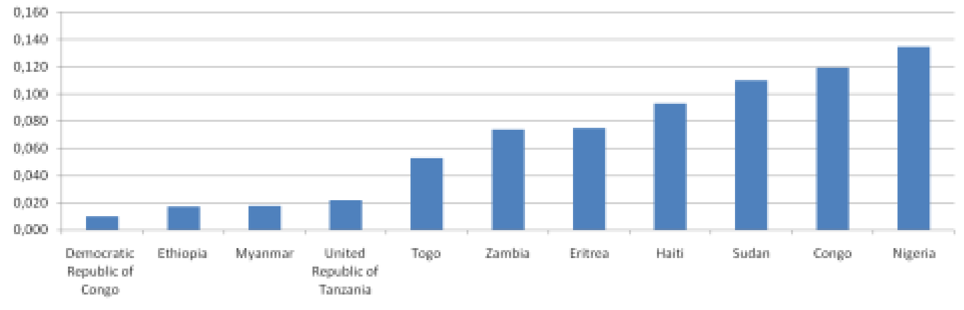

Fig 1 EDI

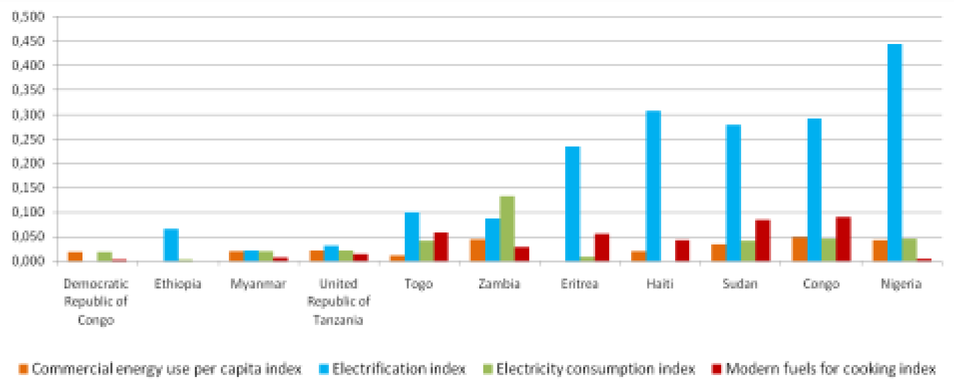

Fig 2 Componenti dell'EDI

Il valore dell'EDI di per se da un'indicazione sullo stato generale del paese (Fig 1.1), per ottenere un'indicazione più precisa sulla situazione sull'accesso all'energia è utile analizzare le sue componenti (Fig 1.2).
I problemi che si evidenziano analizzando la composizione dell'EDI sono il basso consumo di energia elettrica e di come l'accesso ai combustibili moderni sia difficoltosa e riservata ad una ristretta parte della popolazione. Quest'ultimo aspetto lo si denota in maniera chiara osservando l'esiguo valore della voce "modern fuels for coking index" nel grafico di figura 1.2. In alcuni paesi, come la Repubblica

Democratica del Congo o l'Etiopia l'indice di accesso ai combustibili moderni praticamente si azzera.
Questo significa che quasi la totalità della popolazione nei paesi in via di sviluppo fa affidamento alla biomassa tradizionale (legno e sui derivati compresi scarti agricoli) per la cottura dei cibi e l'illuminazione. Questo è stato uno spunto per poter capire i motivi e proporre una soluzione a questi problemi.
Per questo elaborato di tesi si tratterà non tanto l'aspetto dell'accesso all'energia elettrica quanto più l'utilizzo della biomassa come fonte energetica per la cottura dei cibi. E di tecnologie più moderne per l'utilizzo di quest'ultima. In particolare è stato affrontato uno studio approfondito sulle stufe migliorate.
Le stufe migliorate possono quindi essere considerate una tecnologia intermedia per il raggiungimento di una sostenibilità economica sociale e ambientale. L'adozione di stufe migliorate, sistemi energetici affidabili, puliti e a prezzi accessibili potrebbe contribuire a proteggere le fasce di popolazione a basso reddito, notoriamente le più esposte alle fluttuazioni del prezzo dei combustibili primari. La peculiarità di una stufa migliorata è quella di avere una miglior efficienza rispetto al tradizionale modo di bruciare la legna e questo comporta quindi un risparmio nei consumi. Questo aspetto ha in primo luogo un impatto ambientale in quanto si abbassa la produzione di CO_2 data dalla combustione della legna e di conseguenza si riduce il tasso di deforestazione e. L'altro aspetto da tenere in considerazione riguarda la dimensione sociale. In quanto risparmiando tempo, dovendo procacciarsi il combustibile meno frequentemente, le donne e i bambini possono dedicarsi ad attività meno fisiche e più stimolanti per poter facilitare il loro sviluppo culturale e quindi sociale. Per l'ultimo, ma non per importanza, va citato anche l'aspetto economico. In quanto spesso le famiglie sono costrette a comprare il legno da mercati tutt'altro che equi. Quindi una riduzione del consumo di legna spesso si traduce anche in un risparmio economico, con la possibilità di investire i soldi risparmiati in attività più riqualificanti.
Per affrontare in maniera lineare e completa l'argomento delle stufe migliorate si è deciso di partire da un aspetto generale sulla biomassa per poi passare al suo utilizzo nelle stufe migliorate. Completando poi l'analisi con dati sperimentali e ipotesi di scenario applicate a progetti reali.
In particolare questo lavoro di tesi è strutturato come segue:

1. Per il primo capitolo si è stata fatta un'analisi delle tipologie di biomassa e di come venga utilizzata e in che misura nei paesi in via di sviluppo e al livello mondiale, per aver un termine di confronto. Successivamente si sono analizzate le tecnologie tradizionali, quindi quelle basilari (come il fuoco su tre pietre) che vengono adottate per la combustione della biomassa. Come ultimo aspetto si è trattato il contesto tradizionale in cui viene utilizzata la

biomassa cercando di capire quali sono le conseguenze che si hanno sulla popolazione in termini sociali economici e ambientali.

2. Nel secondo capitolo si è entrati più nel dettaglio passando da una visione più generale dell'uso della biomassa all'utilizzo di quest'ultima nelle stufe migliorate. Come prima cosa si è definito cosa si intende per stufa migliorata e di come questa tecnologia possa essere usata come tecnologia intermedia tra i metodi base di combustione e un livello tecnologico molto più avanzato. Sono stati quindi definiti quali potrebbero essere i veri miglioramenti che si otterrebbero dall'adozione delle stufe migliorate. Si è poi passati ad un aspetto più tecnico analizzando le caratteristiche che rendono una stufa per l'appunto "migliorata" e quindi andando a vedere come si possa misurare questo miglioramento attraverso dei test standardizzati.

3. Il terzo capitolo è stato dedicato allo sviluppo di un database e quindi alla classificazione delle stufe migliorate. Si è fatto riferimento a due database il Clean Cookstove Catalog e l'STP inventory. L'analisi condotta è stata improntata su uno studio critico delle caratteristiche, del combustibile utilizzato e dei materiali con cui viene costruita la stufa. Una volta analizzati e discussi questi aspetti si è cercato di trovare nessi significativi che li potessero legare. In seguito in appendice verrà riportato per esteso il data base utilizzato.

4. La quarta parte di questo elaborato si è concentrato sull'aspetto sperimentale. In particolare si è voluto testare un particolare modello di stufa "Envirofit 3300", per verificarne l'efficienza e quindi il risparmi di combustibile. Per fare quest'ultimo confronto quindi si è reso necessario testare anche il cosiddetto caso base ovvero il fuoco su 3 pietre. La procedura che si è adottata per questi esperimenti è stata il Water Boling Test, un test standard, con precise regole di realizzazione. Una volta ottenuti i risultati sperimentali si è deciso di confrontarli con la letteratura presente, per poter avere un termine di paragone e poter fare un'analisi critica della discrepanza tra la sessione sperimentale e le analisi fatte in laboratorio provenienti dalla letteratura.

5. Una volta ottenuti e analizzati i dati sperimentali si è deciso di affrontare una analisi di previsione su come le stufe migliorate possano avere un impatto nel mondo reale. Per fare questo ci si è appoggiati ad un progetto reale, realizzato dall'ong COOPI, attuato in Malawi. Si sono prese le direttive riguardanti questo progetto per quello che riguardava la distribuzione delle stufe migliorate a circa 1600 famiglie. Indagando sul modello di stufa adottata e sulla modalità di distribuzione inserendo alcune variabili di progetto per rendere la simulazione più vicina alla

realtà. Una volta stabilito lo scenario si è simulato lo svolgimento del progetto e il suo conseguente impatto sulla vita del villaggio interessato. Calcolando quindi la quantità di CO_2 emessa sia con l'utilizzo delle stufe sia nel caso base (tecnologia 3 pietre), sempre curando l'aspetto ambientale si è risaliti alla riduzione del tasso di deforestazione ottenuto grazie all'implementazione delle stufe. Questa simulazione è stata ripetuta per due modelli di stufa e per ognuno di questi modelli si sono considerate le performance sia in laboratorio che sul campo.

Ripercorrendo quindi il lavoro si come il filo logico che si è seguito durante lo svolgimento è stato quello di partire da un aspetto generale dell'utilizzo della biomassa per poi addentrarsi in maniera più dettagliata nel merito delle questione delle stufe migliorate. Le analisi successive sono state più sugli aspetti tecnici e sperimentali per poi concludere con l'utilizzo di questa tecnologia nel mondo reale.
Quello che è emerso è stato in prima battuta sono state le condizioni e i metodi di utilizzo delle biomassa. Vedendo quindi come il suo utilizzo sia fortemente radicato nella cultura dei popoli dei paesi in via di sviluppo e di come questo spesso possa rappresentare una vera e propria trappola della povertà, obbligando le popolazioni che non hanno accesso a combustibili più moderni all'utilizzo della biomassa tradizionale. Questo non implica solo un ritardo nel progresso tecnologico ma un empasse di tipo sociale ed economico dal quale è difficile uscirne anche con la profusione di aiuti umanitari e incentivi. Questa fossilizzazione è anche da ricercare nelle ragioni culturali, spesso causa di rigetto nei confronti delle nuove tecnologie o sono motivo di mancata equità sociale e quindi del mancato progresso. Di questi aspetti se ne è parlato nei primi paragrafi dove si è evidenziato come la tradizione del cucinare e di come siano sempre le donne e i bambini costretti a raccogliere la legna e che quindi non riescano a dedicarsi ad attività più emancipati.
Diverse sono state le considerazioni tratte dallo studio più approfondito delle tecnologie utilizzate per la combustione della biomassa, quindi sulla definizione e sulle caratteristiche della stufe migliorate. Di come sia complesso appunto cercare una definizione che riguardi il concetto di migliorato e di come questa descrizione cambi radicalmente in funzione del luogo e del contesto a cui si fa riferimento. Si è poi visto che una stufa migliorata possa essere un vettore che porti verso l'utilizzo di strumenti più tecnologicamente avanzati e quindi all'utilizzo di combustibili meno inquinanti e più affidabili e disponibili, andando quindi a migliorare la situazione non solo ambientale o della salute degli utenti, ma anche migliorare la condizione economica e sociale degli utenti finali. Analizzando quindi le caratteristiche tecnologiche che caratterizzano una stufa migliorata è stato possibile capire quali possano essere i punti su cui agire per incrementarne l'efficienza. Per quello che riguarda questo aspetto riferito alla qualità della combustione si è parlato della forma della camera di combustione e di come in molte stufe si sia adotta la classica

forma a gomito per facilitare l'aspirazione dell'aria. Di come per avere un ulteriore risparmio della legna sia utile isolare la stufa come nel caso in cui sia costruita in metallo dove si è evidenziato che l'inserire delle intercapedini di materiale refrattario garantisce migliori performance mentre nel caso in cui la stufa sia già costruita in argilla o cemento è opportuno avere uno spesso strato del materiale di costruzione tra la camera di combustione e l'ambiente esterno. Guardando l'aspetto di una miglior salvaguardia della salute e quindi in particolare cercando di limitare il cosiddetto Indoor Air Pollution, si è visto come l'istallazione di un camino sia di fondamentale importanza. In primo luogo per portare all'esterno dell'abitazione i fumi di combustione e la fuliggine e come secondo aspetto garantire un miglior tiraggio e quindi un maggior eccesso d'aria riducendo cosi la generazione di incombusti, come il monossido di carbonio. Per capire meglio come poter quantificare il miglioramento di questa tecnologia si sono analizzati i test attualmente utilizzati per la misurazione dell'efficienza. Quello che accomuna tutti i test è l'obiettivo di riuscire a standardizzare una pratica assai variegata com'è quella del cucinare e piena di variabili incontrollabili . Il test più utilizzato per il calcolo dell'efficienza è il Water Boiling Test, ma altri test come Controlling Cooking Test mirano ad avvicinarsi sempre più al reale utilizzo della stufa, andando a simulare il vero e proprio atto del cucinare utilizzando come metro di misura i piatti tipici delle regione in cui si vuole testare la stufa. L'importanza dei risultati che si ottengono è fondamentale per poter quantificare il vero beneficio che possa portare un piano di implementazione delle stufe e quindi capire dove possano essere eventuali falle nel metodo di sviluppo.

Analizzando il database e quindi avendo avuto la possibilità di poter confrontare i diversi modelli di stufa passando attraverso le caratteristiche costruttive, i materiali e il combustibile con il quale vengono alimentate. È stato possibile capire come il materiale più utilizzato sia il metallo, in virtù del facile modo di approvvigionamento, come ad esempio il recupero da vecchi bidoni o rottami e anche dalla praticità del lavorare della semplice lamiera. In più il metallo non ha problemi di fragilità, che in condizioni di utilizzo particolari come quelle dei paesi in via di sviluppo lo rende il materiale migliore. Anche l'argilla è discretamente utilizzata in quanto la peculiarità di questo materiale è la facilità di reperimento essendo disponibile direttamente dal suolo. La pecca di questo materiale è la sua fragilità e quindi viene meno prediletta come materiale di costruzione, pur essendo più disponibile. Tra le caratteriste costruttive quella che si è riscontrata nel maggior numero di modelli è stata la portabilità della stufa. Questo fatto non deve sorprendere se si pensa che molto spesso l'atto del cucinare viene svolto all'esterno dell'abitazione, mentre quando le condizioni meteorologiche non lo consentono si porta la stufa all'interno. La portabilità è una condizione fondamentale per garantire una buona predisposizione nel cambio di tecnologia, la stufa fissa presuppone di cambiare in maniera troppo radicale il modo di cucinare e questo aspetto spesso rappresenta un

empasse difficilmente risolvibile. Passando al tipo di combustibile si è riscontrato come il legno sia universalmente il più utilizzato essendo il più disponibile in termini di costi di e di quantità e facilità nel reperimento. Altresì il carbone derivato dalla legna ha una buona percentuale di utilizzo anche se presuppone maggiori sforzi in termini di lavoro umano per produrlo e uno sforzo economico se si decide di acquistarlo. Anche gli escrementi degli animale non di rado vengono utilizzati come combustibile, soprattutto in quelle zone dove la disponibilità del legno scarseggia o il bosco è troppo lontano e quindi troppo scomodo per essere raggiunto. Incrociando tutti questi aspetti è emerso come la stufa di metallo portatile alimentata a legna sia la più diffusa, anche se comunque la terracotta o argilla combinata al legno come combustibile è comunque presente in maniera rilevante nei modelli analizzati. Diverso invece è il rapporto con in carbone e il materiale infatti si è riscontrato come solo le stufe a metallo siano alimentate a carbone, questo probabilmente dato dal fatto che questo combustibile brucia ad alte temperature e che quindi le stufe di argilla o di terracotta potrebbero avere cedimenti strutturali.
Di diverso tipo sono state le conclusioni ottenute dalla sessione sperimentale inserita in questo lavoro di tesi. La prima considerazione è lo scopo dell'ideazione del Water Boiling Test e di quali quindi siano i suoi punti di debolezza nel descrivere le prestazioni delle stufa. In quanto il WBT in effetti è una procedura che simula l'atto del cucinare, ed essendo condotto in condizioni standard e in ambiente controllato può perdere un po' di significato sul simulare l'efficienza della stufa nelle sue condizioni reali di funzionamento. Di contro per poter avere dati confrontabili tra di loro è necessario avere un protocollo standard da seguire con parametri precisi da calcolare. In questo modo si garantisce la ripetibilità dell'esperimento e si rende possibile il suo confronto con altre prove, in modo da poter avere un riscontro oggettivo sulle capacità delle stufa. Nel caso degli esperimenti riportati in questo elaborato la condizione di ripetibilità è venuta meno proprio per il fatto che sono stati fatti in ambiente esterno non controllato. Questo ha determinato una variabilità dei risultati non trascurabile, tant'è che in un esperimento il caso base, del fuoco su 3 pietre, ha avuto una performance migliore della stufa migliorata. Nel caso specifico gli esperimenti sono stati condotti in giorni diversi con condizioni meteorologiche anche molto diverse, anche con presenza di vento, che portava ad avere situazioni di alimento dell'aria della fiamma molto diverse tra loro. Un'altra variabile difficile da standardizzare e da controllare è stata il modo di alimentare la stufa e quindi di come riuscire ad ottimizzare la gestione della legna per ottenere il miglior risultato possibile, che nello specifico si tratta di raggiungere il prima possibile il punto di ebollizione ma senza sprecare combustibile e senza disperdere eccessivo calore all'ambiente. Quest'ultimo aspetto può essere limitato cambiando le caratteristiche della stufa, aggiungendo ad esempio un pot skirt, ovvero una sorta di schermatura che riesca ad indirizzare meglio le fiamme verso la pentola ed a limitare la perdita di energia. L'analisi con la letteratura

ha portato ad evidenziare sostanziali differenze tra i due set di dati. I risultati sperimentali davano un'efficienza quasi dimezzata rispetto a quella disponibile in letteratura. Analizzando le condizioni in cui sono stati svolti gli esperimenti di riferimento si è visto di come le condizioni al contorno fossero sostanzialmente diverse. L'analisi successiva ha portato ad un ricongiungimento dei due risultati capendo che le condizioni al contorno in particolare la temperatura sono di fondamentale rilevanza nella performance delle stufa. Pur gli esperimenti essendo stati fatti su una stufa con un buon isolamento e quindi una buona inerzia termica i 18 °C di differenza tra il laboratorio e le condizioni esterne sono stati molto rilevanti. Aver condotto gli esperimenti in un ambiente non controllato soggetto a repentini cambiamenti ha reso l'analisi più vicina al reale utilizzo della stufa mettendo in discussione la reale funzionalità di esperimenti fatti in laboratorio, questo se si considera che quei valori poi sono utilizzati da organizzazioni esterne per fare previsioni sugli effetti che si possono avere implementando quel particolare modello di stufa.

Ed è stato questo lo spunto per elaborare l'analisi di scenario dell'ultimo capitolo. Questa analisi di scenario può rivelarsi un utile strumento di previsione per progetti reali, aiutando quindi gli sviluppatori a puntare su alcuni temi più rilevanti di altri. Per quanto riguarda nello specifico lo scenario è stato fatto usando lo scema di base di un progetto realizzato da COOPI secondo i criteri del PCM (project cycle management). Mentre per i le ipotesi ci si è basati essenzialmente sulla letteratura di GTZ. Le informazioni che GTZ è riuscita a trovare sul campo sono state di vitale importanza per poter introdurre ipotesi sensate, in modo da arricchire il modello. Il problema riscontrato consultando questo genere di documentazione è stata la frammentarietà con cui vengono date le informazioni e di come esse siano poco accurate e approsimative. Le ragioni di queste imprecisioni sono date dal difficile contesto in cui sono state prese le informazioni e soprattutto perché lo scopo principe di questi documenti era a titolo puramente informativo senza aver troppa cura dell'aspetto tecnico.

Comunque basandoci su queste assunzioni è stato possibile creare un modello il più fedele possibile alla realtà. I confronti tra i vari scenari e i due modelli presi in considerazione hanno fornito diverse interpretazioni dei risultati. La prima considerazione emersa è stata la miglior performance assoluta dell'Envirofit rispetto alla Mbaula. Queste migliori prestazioni sono date essenzialmente dall'importante strato di isolante che separa la camera di combustione dall'ambiente esterno ed alla marcata forma a gomito della camera di combustione, entrambe queste caratteristiche hanno un forte peso sul risultato finale. Si è riscontrato come le efficienze, per entrambi i modelli, nel caso in laboratorio siano maggiori di quelle misurate in campo. Questo come detto nei capitoli precedenti è dato dalle condizioni al contorno che negli specifici casi esaminati erano più sfavorevoli nel caso in campo, essendo le temperature di utilizzo più basse di quelle riscontrate in laboratorio. Diverse sono state le considerazioni derivate dall'analisi del combustibile risparmiato. Dove infatti è emerso come nel caso in campo ci sia un maggior risparmio di legna rispetto al laboratorio pur avendo efficienze minori. Il motivo di questo andamento è da ricercare nel caso di riferimento (fuoco su tre pietre), poiché l'efficienza del caso base risente molto del cambiamento delle condizioni esterne. Questa differenza importante nel cambio di prestazioni del caso base influenza come si è appena detto il risparmio del legno e quindi della produzione dell'anidride carbonica. Un altro aspetto da tenere in considerazione è di quanto vari il risparmio di combustibile dal caso della Mbaula al caso dell'Envirofit sempre confrontato tra le due diverse condizioni di utilizzo. Focalizzandosi su questo aspetto e analizzando i valori si vede come la Mbaula , passando dal caso in campo a quello in laboratorio, risenta di più delle cambio di condizioni esterne; riuscendo a risparmiare meno combustibile rispetto all'Envirofit.

Legno risparmiato	*Field*	*Lab*
Mbaula	32,48%	27,54%
Envirofit 3300	54,11%	53,13%

Come è mostrato in tabella la differenza tra il combustibile risparmiato tra i due casi di utilizzo è più marcata nel caso Mbaula (4,94% in meno nel caso Lab) rispetto all'envirofit (0,98 % in meno rispetto al caso lab).

Queste conclusioni sono solo date dall'evidenza numerica, per comprendere appieno le ragioni che stanno dietro a questi comportamenti si dovrebbero approfondire molti aspetti. Partendo in primo luogo dall'analisi del contesto, magari non basandosi solo su documenti ma anche con sopraluoghi per poter comprendere in maniera più approfondita gli aspetti che stanno dietro al comportamento dei paesi in via di sviluppo. In questo modo si potrebbero ottenere punti di riferimento più precisi per arricchire il modello. Per quanto riguarda la fase sperimentale, che è comunque collegata all'analisi di previsione, il miglioramento che ci si auspica è di poter avere molti più campioni per poter avere un'analisi statistica. Inoltre questi esperimenti dovrebbero essere resi più confrontabili e quindi svolti in parallelo per poter garantire uguali condizioni al contorno. Ovviamente un miglioramento di questa portata implicherebbe un grande impegno di risorse economiche e umane, ma sarebbe la strada da intraprendere per poter ottenere un lavoro che possa essere utile e utilizzabile.

Introduction

Access to energy in developing countries is a key problem. In compliance with the proclamation of 2012 as International Year of Sustainable Energy for All by the General Assembly of the United Nations , in recognition of the importance of access to energy for sustainable economic development and to the achievement of the Millennium Development Goals Millennium [1]. Nowadays, despite the declarations and commitments, the numbers show a dramatic situation : 1.4 billion people lack access to electricity , an additional one billion do not have reliable electricity grid and 2.7 billion people rely on traditional biomass for cooking and lighting. More than 95 % of these people is concentrated in sub-Saharan Africa area or developing regions in Asia and 84 % of them are located in the rural areas. Such failures are due and increase the "development divide" that prevents break the “cycle of poverty”. Energy plays a fundamental role not only for industrial or commercial sector, but it is essential for the social and economic welfare : it is the way to alleviate poverty , improve the welfare and increase the standard of living.
In order to make more immediate the understanding of state of development of a country, some international institutions such as UNDP (United Nations Development Programme) and IEA (International Energy Agency) have formulated indicators for human and energy dimension . These indicators are the Human Development Index (HDI) and the Energy Development Index (EDI). The indicator that we will consider is the EDI . The EDI was created in 2004 by the IEA in order to better understand the role that energy plays in human development . With this indicator is possible to follow the progress of a country in its transition to modern fuels and more performing way to produce energy. EDI is constituted by the composition of four indicators, each of which captures various aspects of energy poverty . These sub-indicators are:

- Per capita consumption of commercial energy (Ec): is used to give an indication of the overall economic development of a country.
- Per capita consumption of electricity in the residential sector (ECC): is used to give an indication of the reliability of the electrical service and the ability of customers to pay for the same.
- Portion of modern fuels in energy use throughout the residential sector (% ME): is an indicator used to show the level of access to cooking facilities in a clean and safe.
- Percentage of the population has access to electricity (EE%).

Described as composing the indicator is important to quantify the values of this index, and in particular to analyze it into its components. Are here shows the data of this indicator and its spin-off into its components for some developing countries analyzed in this work.

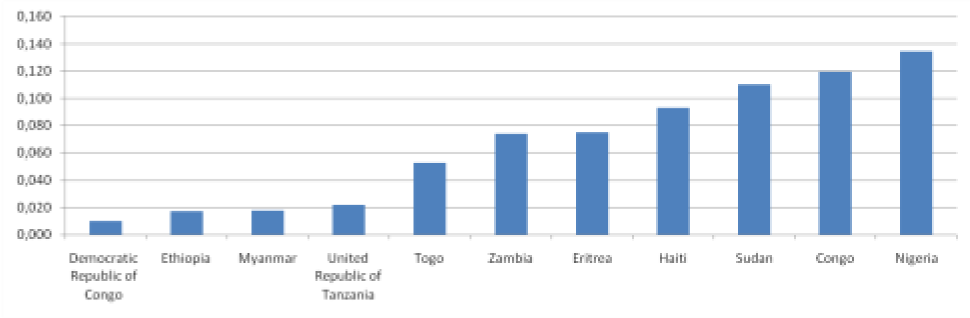

Fig 1 EDI

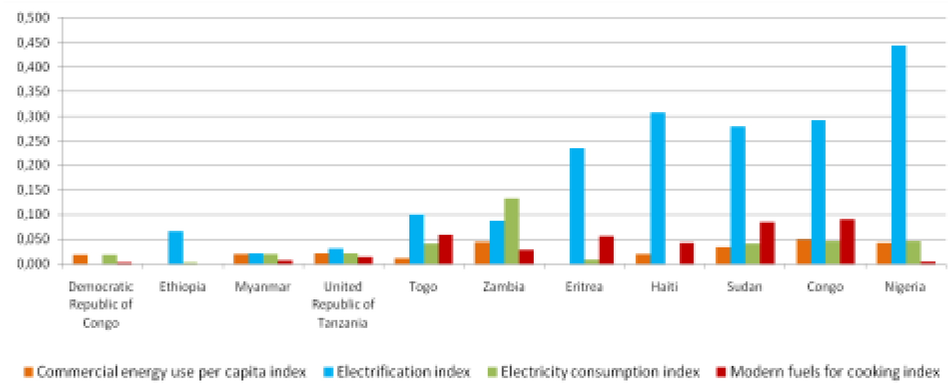

Fig 2 EDI components

The value of EDI is an indication of the general condition of the country (Fig 1), to obtain a more accurate description of the situation on access to energy is useful to analyze its components (Fig 2).

The problems that are evident by analyzing the composition of EDI are the low consumption of electricity and as access to modern fuels is difficult and restricted to a narrow part of the population. This aspect it shows clearly observing the small value of the "modern fuels for coking index" in the graph of Figure 2.

In some countries, such as the Democratic Republic of Congo or Ethiopia the index of access to modern fuels is practically zero.

This means that almost all of the population in developing countries relies on traditional biomass (wood and its derivatives including agricultural waste) for cooking. This was a starting point to understand the reasons and propose a solution to these problems.

For this thesis it will be not detailed so much the aspect of access to electricity will be given more importance to the use of biomass as an energy source for cooking. In particular it has been dealt a detailed study of improved stoves.

The improved stoves can therefore be considered as an intermediate technology for the achievement of economic, social and environmental sustainability . The adoption of improved stoves , energy systems reliable , clean and affordable could help to protect the low-income segments of the population , known to be the most exposed to fluctuations in the price of primary fuels . The peculiarity of an improved stove is to have a better

efficiency than the traditional way of burning wood, and therefore this entails a saving in consumption. This has primarily an environmental impact because it lowers the CO2 production by burning wood and consequently reduces the rate of deforestation . The other aspect to take into consideration is the social dimension. As saving time, having to procure the fuel less frequently, women and children can engage in less physical activity and more challenging in order to facilitate their social and cultural development. To the last, but not least, we should mention also the economic aspect. As families are often forced to buy the wood from markets far from equitable. So a reduction in the consumption of wood often also translates into cost savings, with the ability to invest the money saved in more re-qualifying activities.
To deal in a linear and complete the topic of improved stoves has decided to start from a general description of biomass moving to its use to the improved stoves. Then completing the analysis with experimental data and scenario assumptions applied in actual projects.
In particular, this thesis is structured as follows:

1. The first chapter is an analysis make on the types of biomass and how it is used and which developing countries and the world use it, in order to have a term of comparison. Then it was analyzed the conventional technology, the basic technologies (like fire on three stones) that are taken for biomass burning. As a final aspect was analyzed the context in which it is used traditional biomass trying to figure out what are the consequences that will have on the population in terms of social, economic and environmental issues.

2. In the second chapter it has been entered into more detail ,going from a more general use of biomass to the use of improved stoves. First of all it was defined what is meant by improved stove and how this technology can be used as an intermediate technology between the basic methods of combustion and a much more advanced level of technology . Then were defined what could be the real improvements that would be obtained by the adoption of improved stoves . Then moved on to a more technical analysis of the characteristics that make a stove for just " improved" and then going to see how this improvement can be measured through standardized test .

3. The third chapter is dedicated to the development of a database, and then to a classification of improved stoves. Reference was made to the two databases Clean Cookstove Catalog and STP inventory. The analysis was based on a critical study of the characteristics of the fuel used and the materials with which it is built the stove . Once analyzed and discussed these issues it was tried to find meaningful connections that could bind them. In the appendix will be reported to the extensive database used.

4. The fourth part of this paper is focused on the experimental aspects . In particular, we wanted to test a particular model of stove " Envirofit 3300 " , in order to verify the efficiency and thus the fuel savings . To make this comparison so it was necessary to test even the so-called base case or 3 stone fire. The procedure, that was used for these experiments, was the Water Boling Test, a standard test , with precise rules of construction. Once you have obtained the experimental results it was decided to compare them with the present literature in order to have a basis for comparison and be able to do a critical analysis of the discrepancy between the experimental session and the analysis made in the laboratory from the literature.

5. Once obtained and analyzed the experimental data it was decided to make a forecast analysis on how the improved stoves can have an impact in the real world. To do this it has leaned to a real project, implemented by the NGO COOPI, implemented in Malawi. Took the directives on this project for what concerned the distribution of improved stoves on about 1600 households. Investigating the stove model adopted and the method of distribution by introducing some design variables to make the simulation closer to reality. Once established the scenario was simulated the development of the project and its consequent impact on the lives of the village concerned. Then calculating the amount of CO_2 emitted either by the use of stoves in both the base case technology (3 stones technologies) , always taking care of the environmental aspect has been traced to the reduction in the rate of deforestation obtained thanks to the implementation of the stoves . This simulation was repeated for two stove models and for each of these models have considered the performance both in the laboratory and in the field .

1. Analysis of biomass use for energy needs in Developing Countries.

1.1. **Introduction to biomass use.**

1.1.1. Typologies of needs satisfied with biomass combustion

In this part will be discussed the principal needs satisfied with biomass combustion such as:

- cooking
- making medicine
- lighting
- heating
- protecting cattle

Cooking is the most common use of biomass combustion in developing countries that involve preparing food and heating water for cooking. In literature are reported some example of cooked meal, in specific in the west Africa the households are often involved to roasting peanuts and stepping tea [2]. The simplest way to cooking is with an open fire, for example in the Guatemala Highlands a round flat earthen or metal pan solely, locally called *Comal*, is put on the fire for cooking corn tortillas (Fig 1.1) [3].

Fig 1.1 Cooking tortillas and roasting peanuts in an open fire

a b

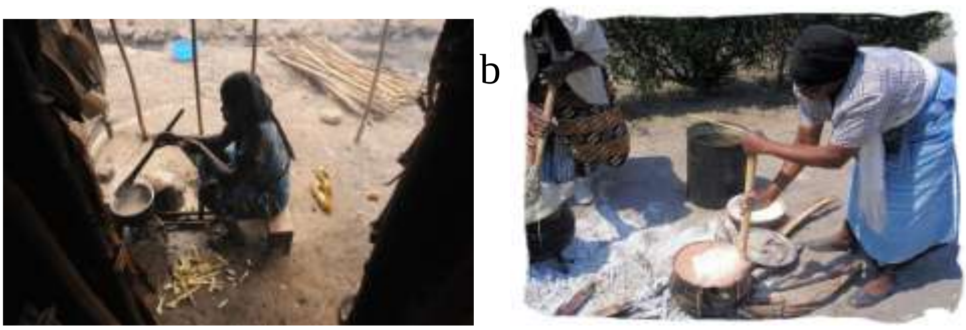

Fig 1.2 (a) Women preparing dinner on open fire. (b) Women boiling rice in a hemispherical pot

The intervals in the day of preparing food, varies in function of the country condition and food availability. In this example, the households of this village in Cambodia, prefer prepare their food three times a day for breakfast, lunch and dinner (Fig 1.2a), but some families cook twice per day, they don't prepare breakfast because they have food remained from dinner the day before [4] .The meals preparation is different during the day, two meal types are commonly eaten for breakfast and four meal types are commonly eaten for lunch and dinner, most meals include porridge. Different type of cooking request different type of pots, for making curries and rice (Fig 1.2b), pots with hemispherical bottoms and tapering tops are most suitable, meanwhile flat-bottom cylindrical pots are preferred and for boiling milk (Fig 1.3b) ,tall pots are better because their shape keeps the milk from boiling over. Also the pots material is important, in fact during high power cooking, metal pots transfer excessive heat to the food, and not uniformly so food cooked in earthen pots is more tasty and nutritious (Fig 1.3a), due to the slow and low transfer of heat to the food that they facilitate [5].

Other important aspect is the cooking location that depends on the season and cooking activities. Cooking take place outdoors or with an enclose kitchen. The kitchen was generally located in separate structure apart from the living quarters. Meals are commonly prepare in the enclose kitchen, but are prepared outside during the hottest days of the year but often hot water is prepared on an outdoors fire as showed in figures 2 and 3 the women is cooking outside, meanwhile milk is prepared indoor because is more hygienic [2].

a b

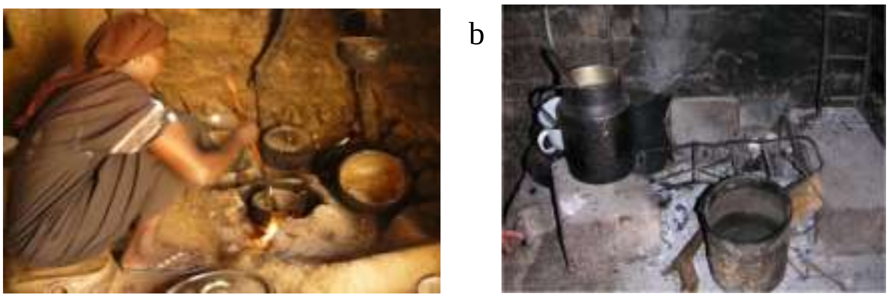

Fig 1.3 (a) Chicken prepared in a earthen stove. (b) An open-fire household uses concrete blocks and a metal rack to support pots for boiling milk

In some families the boiling water with herbs or roots is used to make homemade remedies like infusion or herbal teas, not real medicine like antibiotics. Lighting is another important aspect in the use of biomass combustion, sometimes the fire that come out below the pot can contribute to make light but typically cooking and lighting are independent. And is the kerosene the most used fuel for lighting (Fig 1.4a), only a small percentage of household use it for cooking [3].

Fig 1.4 (a) Kerosene lamp (b) An open fire used for warming and lighting

Not all the developing country are in the tropical belt, in some part of the world in the night, especially in winter, the temperature can fall down very quickly and reach low temperature , that makes necessary burn biomass for warming in order to have a comfortable indoor temperature [6], the warming is obtained with an open fire on the ground (Fig 1.4b) or keeping open the stove's door. In numerous family where there are al lot of baby child or newborn child the fire can be used to heat towels to warm the baby [3].The biomass use describe before are aimed to human use but in some rural families where cattle and buffalo are raised as draught power, therefore this animals are very important for the family subsistence, burning fuelwood is used to produce smoke to protect the animals against insects (Fig 1.5) this practice is always conducted at night time during the rainy season [4].

Fig 1.5 The smoke protect cattle against insects

1.1.2. Typologies of biomass used

When considering biomass use in the residential sector of Developing Countries, usually literature refers to:

- Firewood
- Charcoal
- Animal dung
- Agricultural residue (maize cobs**)**

Firewood (Fig 1.6a) remains the primary source of fuel in all the households. This is because the cooking devices that may burn other fuel sources are either expensive or not available in the rural areas. Firewood also tend to be the available fuel source regardless of season, even though it has to be fetched from far places from the households and very frequently is the only source to burn. Not always the wood is obtained by cutting trees, often women collect the fallen branches or withered dead tree, this type of wood is called deadwood.

a b

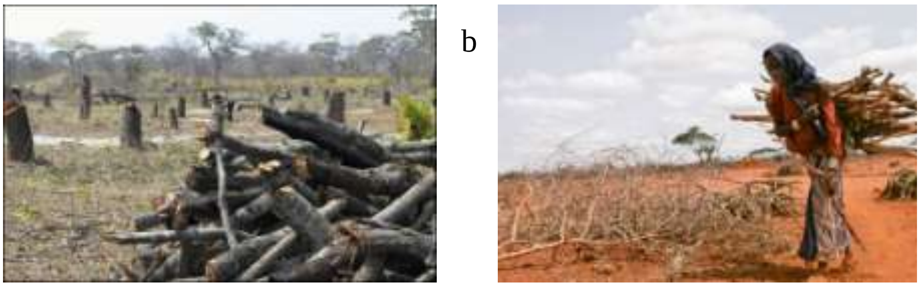

Fig 1.6 (a) Firewood wood (b) Women collect deadwood

Women collect deadwood (Fig 1.6b) in the rainy season and dry it to reduce moisture levels, the larger pieces of wood were split, dried in the sun, moisture content was an important factor in firewood preference as it affected the weight of wood when transported, fire temperature and ignitions times [7]. Generally the wood lower heating value is around the 20 MJ/ kg and this value depend of the carbon percentage in the wood [8].

The way to collect firewood varies in the different countries, a study performed in some villages in Malawi shows that the 90% of the households collect firewood for free from different places and 10% both buy and collect firewood. Of the households that collect firewood, 40% collect from public forests, 17% from private wood lots and 43% from their own farms [9].

Charcoal (Fig 1.7a) as the term suggest is a particular type of coal, is prepared (Fig 1.7b) by the strong heating of wood in closed vessel in a limited supply of air. When wood is heated strongly in a closed vessel in a limited supply of oxygen, then water and volatile material present in it get removed and black residue called charcoal is left behind. This process is called destructive distillation of wood. Another process to produce charcoal is the torrefaction, this procedure consist to heat wood between 200 °C and 300 °C in the absence of oxygen and turned into char. The torrefied wood is typically pelletised and has a higher bulk density and 25% to 30% higher energy density than conventional wood [10]. Charcoal is the most used fuel after wood, several advantages make charcoal attractive for cooking and heating, especially among the urban poor. Compared to firewood, charcoal has higher energy content, its lower heath value is around 30 MJ/kg, is less bulky, easier to transport, and more accessible and burn more cleanly. Charcoal can be purchase at the market where charcoal is readily available, and generally has a stable supply and market, relative to modern alternatives, or it can be produce, but in some poor realty the situation is opposite and charcoal is expensive, so it is used occasionally [11].

Fig 1.7 (a) Charcoal (b) Charcoal production

Less used like fuel is animal dung (Fig 1.8a), is easily affordable and available all over the year, most families own animals and use their own cattle for making cowdung cakes. Families that do not own cattle collect dung from nearby fields. In either case, however, dung availability is not sufficient, and most families purchase dung cakes at regular interval of one to two days [6]. Animal dung has a low LHV than charcoal or firewood and produce a lot of smoke, caused by the elevate moisture, so it is less used, but in some casualties is the only fuel available.

However, the households also use other sources of fuel like maize cobs (Fig 1.8b), sorghum,cassava stalks, twigs, sawdust and tea bush. The agricultural residues are seasonal, that means in some periods they are not found.

Many households use residue maize cobs but these are highly seasonal, only available soon after harvesting. Some fuel sources are place dependant, for example tea bush, pigeon pea stalks and twigs.

a

b

Fig 1.8 (a) Women make dung cakes. (b) Maize cobs residues used as fuel

1.1.3. The situation of biomass consumption at world level

There are currently about 2.7 billion people in developing countries who rely for cooking primarily on biomass, household use of biomass in developing countries alone accounts for almost 7% of world primary energy demand. Worldwide, biomass ranks fourth as an energy resource, providing approximately 14% of the world's energy needs; biomass is the most important source of energy in developing nation providing 35% of their energy [12]. There are enormous variation in the level of consumption and the type of fuel used. The vast majority of people who rely on solid fuels for cooking are concentrate is Asia and sub-Saharan Africa [13]. Almost three-quarters of those who rely on solid fuels for cooking live in Asia, with India and China accounting for 27 percent and 25 percent, respectively, of all those using solid fuels for cooking (Fig1. 9). While sub-Saharan Africa makes up 14 percent of the total population of developing countries, it accounts for more than 20 percent of people relying on solid fuels as their primary cooking fuel [14].

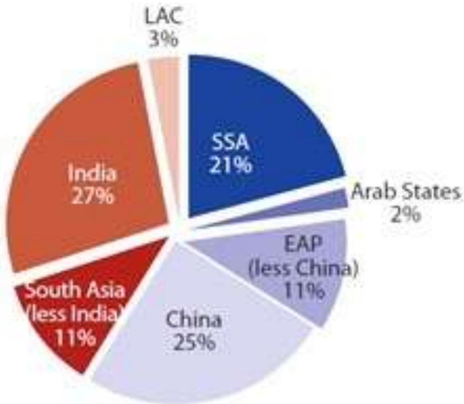

Fig 1.9 Distribution of people relying on solid fuels for cooking by developing countries

In figure 1.10 is showed how the traditional biomass is shared in the world at the residential level, the maps confirm the trend described before.

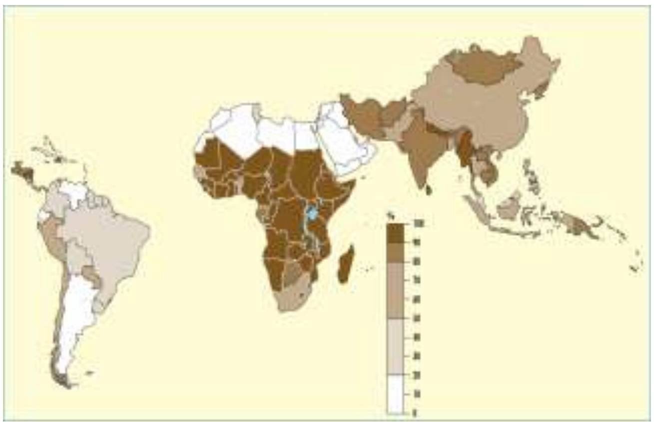

Fig 1.10 Share of Traditional Biomass in Residential Consumption by Country

Is important to pass to a energy dimension in order to have a more complete description of the biomass share, in Fig 1.11 is showed how the bioenergy is shared in the world.

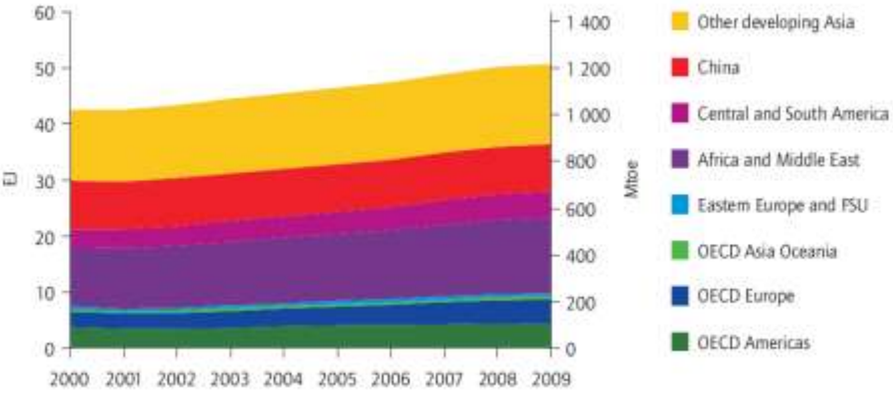

Fig 1.11 Global primary bioenergy supply

Bioenergy is energy derived from the conversion of biomass where biomass may be used directly as fuel, referred to wood, charcoal and animal dung. Figure 10 shows that bioenergy accounted for roughly 10% of world total primary energy supply, wit1h most of this being traditional biomass in non-OECD countries [10]. Figure 1.12 shows the total primary energy of biomass harvested compared with the total primary energy supply.
Bioenergy is still the predominant form of energy used by people in the less developed countries and bioenergy from biomass is about 38% of the primary energy consumption in developing countries. Furthermore, bioenergy often accounts for more than 90% of the total rural energy supplies in some developing countries. The average majority of biomass energy is produced from wood and wood waste (64%), followed by municipal solid waste (24%), agricultural waste (5%) and landfill gases (5%).

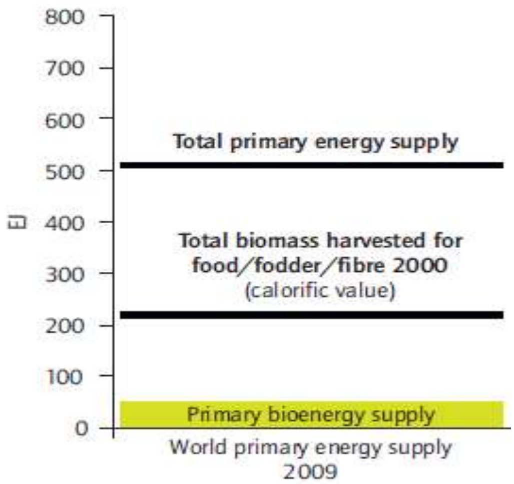

Fig 1.12 Primary bioenergy demand

In order to have an idea of the consumption of biomass in the developing countries is reported some example reached in literature. In this example is showed the biomass consumption at the residential level.

Surveys made in Chumriey Mountain demonstrates fuelwood consumption for cooking is 5.21Kg per day a family. Fuelwood consumption status for boiling water is similar to that for cooking. Households with higher income consume less fuelwood for cooking than households with lower income level. Overall average fuelwood consumption for boiling water for households per day is 2.82 Kg per day a family. The results of the study reveal that lower average consumption (4.12 Kg per day) is found in very small families while the highest average consumption is found in very large families (7.84 Kg per day). But if we consider the quantity procapita the statistical analysis demonstrate that the fuel consumption for cooking and boiling water increase in small families and decrease in large families while household size has no influence on fuelwood consumption for preparing animal food and protecting cattle from insects [4].

Another study performed in a rural isolated west African village estimate fuelwood consumption, the village's population amount a 770 people, the results are that this village consumed 234 m^3. The result of this study shows that the traditional biomass energy use is 20.6 MJ per person per day for the people that lived in a family composed of 5 members, and 10.5 MJ per capita per day for that people living in bigger family composed of 20 persons [2].

1.1.4. Selection criteria for energy sources at households level

How households select different energy sources depend from many factor, from the most practical to a cultural issue. The principal aspects described are:

- Fuel affordability
- Culinary practice
- Households income
- Seasonal variation
- Household size and head household age

Analysis to identify the determinants of fuel choice reveals that affordability plays a relevant role. In general choice of fuel for cooking and lighting purposes by the households is likely affected by a variety of factors that influence their affordability, availability (access to fuel) and awareness (about potential ill effects of specific fuels). In particular many households prefer use wood or crop residues because for this family is very difficult obtain more clean fuels. Because for example the live in isolated place or place too expensive to reach and provide modern fuels. There is also direct relationship between the fuel choice and the culinary practices. For example, studies show that the open-fire is more conductive to cooking because the large flame that envelop the pot and the temperature that is reach is higher than the LPG or kerosene's flame. So for some typical meal (like tortillas in Guatemala) the open fire is considered the only way for cooking. Other aspect is the cooking position. The squatting position that households keep cooking with an open fire is preferred for preparing meal, while the standing position required for cooking with kerosene or LPG stove is uncomfortable. This particular aspect derive from cultural behavior. For many centuries this people have cooked on the floor and change this daily routine is very hard. So this aspect can determine the choice of wood contrariwise of more clean fuels. Income could be a determinant of clean fuel expenditure share; the differences across states and between rural and urban areas in expenditure on clean fuels appears to be correlated with the state's economic status and its rate of growth over time. In rural areas the cleaner share is increasing commensurate with the economic status of the state. On the other hand in urban areas the fall in correlation over time indicates that even though the cleaner shares could be increasing over time income may not be a dominant factor for its usage [15].

In rural areas, choices are constrained by lack of access to more commercial fuels and markets for energy using equipments and appliances. Often, the choice of fuel is determined more by local availability and transition opportunity costs involved in gathering the fuel (mostly wood, dung and other biofuels) rather than household budgets constrains, pries and costs. In contrast to rural household, urban ones have a wider choice and greater accessibility to modern commercial fuels, electricity, and energy using end-use equipment and appliances and therefore greater potential for fuel switching. A survey demonstrate that household income has a positive effect on the probability of choosing clean fuel such as LPG as a cooking fuel over either firewood and kerosene. The size of household and the age of the head of the household also have a positive effect on the probability of choosing LPG, as does the household begin headed by a female. The household head begin illiterate or only having primary education increase the probability of choosing firewood or kerosene. Living in larger cities or metros also increases the probability of choosing LPG as cooking fuel [16].

The fuel choice is also influenced by the cultural aspects, for instance the source of biomass is different between younger farms and older farms. In fact the younger farms prefer cultivate crop, maize or make stover, while the older use more wood biomass [17]

1.2. **Traditional technologies used for biomass combustion.**

Here are listed the principal cooking devices, starting to the basic “three stone fire” evolving to a more complex system like the six bricks rocket stove. The term “traditional stove” often is used to indicate an open fire or the three stone fire, but this meaning can change in relation to the context, for example in India in the Bundelkhand region the traditional stove is a clay stove (Fig 1.13c), one pot size; in Africa this kind of stove is already considered an improved stove, so this classification is not absolute but it must be reported to the context [6].

- Three stone fire
- Mud stove
- Clay stove
- Six bricks rocket stove

The three stone fire (Fig 1.13a) is the most basic, but still extremely common method for cooking with biomass fuel. The three stone fire is simply an open fire, gaining its name from the stones used to hold the cook piece over the fire. The three stone fire is a traditional cooking technology, locally made, in this stove sticks of wood are burned directly under the pot which is hold by three bricks, there is no combustion chamber, no chimney so this implies a very low efficiency combustion [8].

a b

Fig 1.13 (a) Three stone fire. (b) Clay stove.

c

(c) Traditional Indian stove

Mud stove (Fig 1.14b) is used to describe any improvement form of stove compared to traditional “three stone fire”. Mud stove are usually easy to build with simple training , and material is available locally. The most basic improvement to the open fire involves filling in two sides with a mud or clay wall to prevent through-draughts, stove built of mud can also be suitable for 2 or 3 pots. Mud stove are designed primarily for firewood, but can be adapted also for charcoal [18].

Clay stove (Fig 1.13b) it is a stove with a basic combustion chamber with no chimney, it has a low cost and it can be built locally, it can use firewood, animal dung ,agriculture residue, it appears to have a life span of 4 years.

The disadvantages of this type of stove is the fragility, and produce less light adn less heat than three stone fire, however, the clay stores a lot of heat so it can be used for heating also [18].

Another simply model of traditional is the six brichs stove (Fig1.14a), as the name says, the six bricks stove is made with six bricks, which are formed so that the stove uses a rocket principle. There might also be two more bricks that are used at the stove entrance ore as an elbow. The bricks which form the combustion chamber are very lightweight, made of perlite and clay. The bricks stand on one end in a circle and are tied together with a wire. The front of stove has a hole, where the fuel is passed. To make the stove more stable and safe it can be surrounded by mud or metal. The six brick stove has very good insulation and is therefore able to burn in very hot temperature [18].

a

b

Fig 1.14 (a) Six bricks stove (b)Mud stove

1.3. **Traditional context analysis of biomass use.**

1.3.1. Economic context

The use of solid fuels inflicts high economic costs on families who can pay as much as one-third of their scarce income simply to purchase sufficient fuel to cook the daily meal. The financial toll is especially draining on the very poor, whose incomes of as little as a dollar a day must be stretched to cover basic necessities such as food, fuel, school fees, and medical care.

Other important aspect is daily time spent on collecting wood, that varies from place to place between one hour (in private areas) and 6 hours in either community forests or national forests, depending on the degree of forest degradation [19]. Time spent collecting fuel is wasted human capital time that could be better spent on income generation or other activities.

Money spent on charcoal for cookstoves may mean the loss of scarce households income to buy medicine, food or capital to start a small business. The charcoal market also offers opportunities for urban households to participate through the formation of small scale retail businesses as well as in packaging and transportation. The massive market for charcoal across much of the developing world, the manufacture, distribution, sales, and service of clean cookstoves and fuels could be a major potential source of employment in regions where jobs are scarce [20]. The charcoal market also provides urban households with an affordable, convenient and reliable source of energy and associated energy services at relatively stable prices. However, charcoal production can also have perverse effects on poverty. Charcoal production enhances social and economic security in rural areas, and is an important source of non farm income for some households which burn and sell charcoal for cash to buy grains and other households commodities when food supplies run low in the off season. Sometimes charcoal productions has negative aspects, distribution and sale provide lucrative opportunities to support rural livelihoods and household income, particularly in the agricultural off season.

1.3.2. Social context

Biomass use implies some different social problem, like health diseases caused by the air pollution or broken bones caused by falls due the bulky load, back pain due the heavy load that the women and girls are forced to carry, rape episodes are not infrequent during the way for collecting wood and animals bite are very dangerous and can cause death. Also this direct consequences is necessary to consider the time spent collecting solid fuels that imposes opportunity costs that constrain socio-economic development generally [14].

The disease burden from indoor air pollution is a consequence of exposure to the extremely toxic pollutants produced by solid fuels burned in open fires or stoves in the home for cooking or heating. The most harmful of these pollutants include monoxide and particulates. Evidence that exposure to these toxic particles at the level of exposure from cooking indoors with solid fuels have come from numerous studies associating exposure to indoor air pollution with death from certain diseases. Harm depends on human exposure to these pollutants. The level of exposure can depend on many factors including proximity to the source of the pollutants, the time exposed to the pollutants, and the intensity of the pollutants in the household. Women and children are typically more exposed than men since they are physically present for more hours and during the hours with the greatest intensity of pollutants. Children under the age of five are more subjected to acute lower respiration infections and the adults above the age of 30 are more expose to lung cancer [21].

As is described before health disease are caused by heavy load and physical work. Some estimate stipulate that by the age of 8 child can collect up to 10 kg of firewood each week, while a woman can collect around 30 kg of firewood twice weekly. The physical effects of this are manifested through superficial and deep cuts, cumulative musculoskeletal injuries and degeneration, exhaustion, broken bones and increased risk of birth complication. During the course of sourcing for firewood, women are exposed to dangers ranging from physical assault to rape. In many developing countries, women and girls trek long distance to find firewood for cooking. To avoid the heat of midday sun, may leave in the darkness of early morning and to avoid competition, they travel alone or in a small groups. While distance traveled to collect firewood may vary depending on region and area of the country, the distance traveled by women has been reported to be up to 10 miles, thereby increasing their risks for assault, and wild animal attack and danger to being bitten by snakes. In the literature it was found that in Angola the children and woman spent collecting firewood up to 7 hours per day [22]. Another survey shows that household in Tanzania time spent collecting firewood is from 0.5 to 3 hours two or three time a week [23].

In addition, young girls are often called on to assist their mothers in physically demanding fuel collection and cooking activities, preventing them from regular school attendance and the benefits of a nutritious midday meal that some schools provide [24].

1.3.3. Environmental context

Unsustainable fuelwood collection and inefficient conversion technology have serious implication for the environment, such as forest and grass vegetation degradation and localized deforestation, accelerated soil erosion and changed ecosystem substance cycle. Rapid soil degradation is a major threat to agricultural productivity, that can be set in motion by conversion of forest and grasslands to agriculture lands and the necessity to intensify cultivation on marginal lands. For example in Bangladesh due to the inefficient use of wood fuel and the rapid pace of population growth widespread destruction of forests including homestead forests has reduced the forest cover to about 8% [25]. Inefficient charcoal production from natural forest and woodlands contributes to deforestation [26].

Combustion of biomass causes emission of a number of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). the products of incomplete combustion such as carbon monoxide, methane and particulate matter contribute to the changing of the climate. Because of poor combustion conditions a significant portion of the fuel carbon became products of incomplete combustion, which general have greater impacts on climate than CO_2, but in the meantime they have greater global warming potential than CO_2 [27]. In literature it was found some experiments that reveals that the emissions, of basic three stone fire stove, are 20 mg/m^3 of CO, 145 µm/m^3 of PM_{10} for each meter cube of wood [23]. Other performance tests such as the water boiling test shows how the basic way to burn wood can be generate 51.9 mg of CO for each gram of wood and 1.6 grams of CO_2 for each gram of wood [28].

2. Improved cooking stoves.

There is no universally accepted definition of “cookstoves” linked to performance or technical standards.

A World Bank report (2011) has reviewed the classification of the stove model, assembling the categories in three type: traditional, improved and advance. [29]. The term “traditional stove” refers to either open fires or cookstoves constructed by artisans or household members, this stoves are not energy efficient and have poor combustion. For now, it is virtually impossible to use a wider set of precise measures with which to distinguish an “improved” stove from an “advanced” stove. Improved cookstove is used in the historical sense for cookstove installed in legacy programs, usually with firebox and chimney, but without standards and with poor quality control. A stove can be called an “improved cooking stove” as long as it performs better than the baseline, in the case of firewood, the three stone fire. From a technical perspective, stoves can be classified as “improved” base on some technical criteria such as: efficiency, combustion efficiency, heat and transfer efficiency, fuel consumption, fuel burn rate, time to boil (speed of cooking), emission, turn down ratio. Improvement can be on the basis of design and performance. An improved stove can be designed to improve energy efficiency, remove smoke from the indoor living space, or lessen the drudgery of cooking duties [30]. The combustion chamber also allows the stove designer to locate the cook piece for increase thermal efficiency. There exists a wide variety of stove design with varying performance. Stove efficiency and emission are very sensitive to the combustion chamber shape, material, chimney height, chimney diameter, and cook piece placement [8].

Advance biomass cookstove refers to the more recent manufactured cookstoves, based on higher levels of technical research; these stove are generally more expensive, and are based on higher, but as yet not well defined, standards that include safety, efficiency, emission, and durability [31].

2.1. Improved cooking stove as “intermediate technology”.

The improvement of the traditional stove is directly correlated to the biomass fuel change as is describe in the “energy ladder” (Fig 2.1).

The energy ladder model assumes households to mimic the behavior of a utility maximizing neoclassical consumer, which implies that they will move to more sophisticated energy carriers as their income increases. Fuel switching is a central concept in the energy transition process, referring to the displacement of one fuel to another. A move up to a new fuel is simultaneously a move away from the fuel used before. As a families gain socio-economic status they abandon technologies that are inefficient, less costly and more polluting and move from universal reliance on biomass fuels to transition fuels such as kerosene, coal and charcoal. Subsequently households switch to fuels such as LPG and electricity. The energy ladder model portrays wood as an inferior economic good, the fuels for the poor. This implies a strong correlation between income and fuel choice. A positive correlation between economic growth and modern fuel uptake.

The energy ladder also assumes that more expensive technologies are locally and internationally perceived to signify higher status. Families desire to move up the energy ladder not just to achieve greater fuel efficiency or less direct pollution exposure, but to demonstrate an increase in socioeconomic status [32].As people’s income increase, people “climb the biomass energy ladder” and turn from agricultural residue and public forest resources to fuel wood from private plantations and later to alternative and more sophisticated fuels such as biogas, LPG and kerosene [19]. with increasing income, households adopt new fuels and technologies that serve as partial, rather than perfect substitutes for more traditional ones. Furthermore, fuel switching is not unidirectional and people may switch back to traditional biomass even after adopting energy carriers.

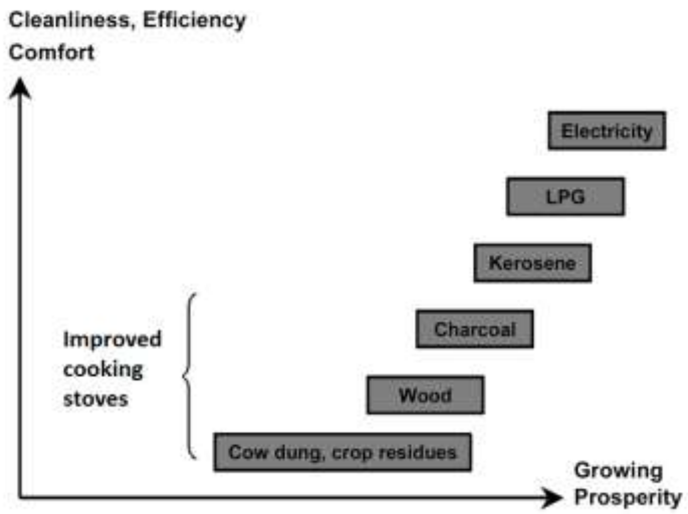

Fig 2.1 Energy ladder

This upward shift occurs most often in urban areas, because in rural areas, scarce income, combined with freely available biomass resources, leads people to continue to rely on biomass for cooking.

Changing the fuel typologies changes also the devices. The improved cookstoves are a intermediate technologies between the basilar “three stone fire” and modern stove like the LPG or kerosene stove which use modern fuels. An example of this technology transition is reported in a village in Mexico where families used exclusively fuelwood burnt with three stone fire. In this project the achievement were to change the way to cook from a exclusive use of fuelwood to an simultaneously use of fuelwood with improved cookstove and the use of LPG stove. This combination make empirical evidence of fuelwood reduction, about

10%-30%, with an correspondent reduction of air pollution and cost reduction for buy firewood. But this switching is not simple and immediate, cultural factor for example influence this transition. For instance the typical Mexican tortillas, are cooked only with the three stone fire, because the burner LPG surface is too small, this can obstacle the energy transition to more efficient and modern technologies [33].

These types of cook stoves, helps move biomass up in the energy ladder and making it closer to the liquid fuels. However users at large may find the fuel processing as a constraint in the adoption of these cook stoves. This constraint needs to be addressed for large scale adoption of forced draft cook stoves [34]. The improve cookstove help to make modern fuel more accessible or in that parts of developing world where modern fuel are not available or will not affordable in the near future can help to reduce the pressure on biomass resources[35].

Another factor impeding the movement toward more modern fuel and cooking technologies, in both rural and urban setting, is declining incomes. In Africa for example, the increase in national income has barely kept pace with population over the last decade, so some households have had to switch back from modern to traditional cooking practice [35].

2.2. Expected improvement in the traditional contexts with improved cooking stove implementation

In attempt to improve the energy efficiency of more traditional cooking methods, such as the three stone fire, emphasis has been placed on the development of suitable, energy efficient or improved cooking stove[36]. There key advantages to the use of improved cooking stoves are:

- less pressure on forest and energy resources
- reduce concentration of smoke and indoor air pollution
- money and time saved in acquiring fuel
- reduced greenhouse gases
- create skills development and job creation in the community

One of the major objective of improve stove dissemination is to reduce fuel use and thereby affect the rate of deforestation. Stoves are designed with fuel efficiency as a major goal. Improved wood burning stoves saved between 30% and 50% of the fuel used to cook with three stone fire. A study revealed that there was a less demand for fuel in improved stove compared to the traditional stove. The study showed that a family of 5 members consumed 3kg fuel daily in improved stove with compared to 4.5 kg in traditional stove with consequentially money save. Similar in Kenya indicate an average decline in daily charcoal consumption from 0.7 kg to 0.4 kg per person with an improved stove, adding up to a total yearly saving of 613 kg per family, also reported 50% fuelwood saving was achieved by household using improved stove in Malawi.

Improved cook stove reduce smoke emission and health hazards especially to the cook. In the case of chimney based ICS, the smoke from the stove is also taken out of the kitchen to keep the kitchen clean. Air monitoring research in Guatemala has indicated that improved stoves cal lower indoor PM_{10} concentration by 50% or more [26].

Another benefits is reducing cooking time, less smoke, less blackening of the cooking utensils, saving fuel, portability for portable stoves especially during rainy season[27].

Most stove users mentioned that time saving as an achievement, the users explained that the improved stove cooked faster than the traditional one. A study showed that it took only 2.25h to cook in improved stove compared to 3h in traditional stove for the same family members [26].

Improved wood-burning cookstoves can significantly decrease the global warming impact of a cooking task. In some laboratory tests, several improved biomass stoves displayed substantially reduced GWP(Global Warming Potential) compared to the three stone fire [27].

The economic evaluation of improved cook stove use assesses a money saving thanks to the fuel reduction and a income generating by selling stove. A study performed in Bangladesh shows that before the introduction of improved stoves, the contribution of respondents to their families' income was 5.01% per month, after the introduction of the improved stove their contribution increases to 5.25%. while the reasons for this increased are varied, the improved stove played an important role in saving time and gave them an opportunity to serve paid labour outside the home. The other economic achievement of stove users, always discussed in this study in Bangladesh, is income generation through construction of improved stoves. The stoves maker earned 150 taka for each stove where a monthly family income is 2500 taka [26].

2.3. **Main features of improved cooking stoves**

Technical specification and materials used in the fabrication of cook stoves influence its performance. Were analyzed some particular feature:

- Combustion chamber
- Chimney
- Air draft
- Insulation
- Types of combustion

- Pot skirt
- Way of feeding

The first component to improve is the combustion chamber(Fig 2.2 a). The basic improvement is to contain the flame with circular wall made of clay or metal. The shape of the combustion chamber should be optimized because it affects the combustion quality and stove efficiency. If the shape of the combustion chamber is not performed, is possible that some point has a low temperature, so in this corner is more probable the formation of unburned substance like carbon monoxide and HC (unburned hydrocarbon).
The most diffuse improvement of combustion chamber is L shape, adopt in the rocket stove (Fig 2.2 b). The rocket design consist in an opening on one side near the bottom of the stove for fuel to be inserted and for air to enter the combustion chamber. Draft is created by the large temperature difference between the air entering the bottom of the stove and hot combustion gases exiting from the top of the vertical combustion chamber. This particular configuration reduce drastically the CO and particulate production. The reason of this reduction is the more air quantity that flow in the combustion chamber, this cause a combustion with a large excess of air. Knowing that the monoxide carbon is an unburned product, this air excess allow the oxidation of more CO. A problem that can be found is if the draft is too strong. An excessive air flow may be too lower the flame temperature causing an decrease of the efficiency [37].

a

b

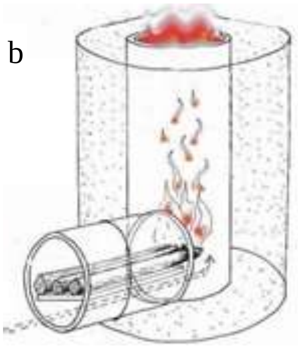

Fig 2.2 (a) Normal combustion chamber. (b) L shape combustion chamber

The stove performance can be improved by introducing a grate or holes (Fig 2.3b) because it perform several function such as injecting air below the fuel bed for better mixing of air, which is required for proper combustion of fuel. This will increase the thermal efficiency and reduce the emission from cookstove.
The cookstove efficiency can be increased by controlling air flow into the combustion chamber. Also an optimum flow rate not only enhances the efficiency and combustion temperature but also reduces the emission, which is also very important parameter. The preheating of incoming air many also improve the quality of combustion and better

thermal efficiency by raising the average temperature of the combustion chamber [38].

Chimney stoves (Fig 2.3a) have greatly reduced exposure to indoor air pollution. Any stove with a chimney reduces emission considerably. The cooks’ exposure to heat is also greatly reduced, because in chimney stoves there is no air gap between the pot and the stove. Sometimes, chimneys without dampers create excessive draft, leading to excessive combustion of fuel. The placement of a chimney does not make the smoke disappear completely. Chimney stoves are not necessarily more efficient. In fact, most often, they are less efficient. The rushing flame does not conduct heat to the pot very well. Moreover, chimney stoves are expensive. In the case of domestic stoves, the chimney sometimes costs as much as the stove [5].

a

b

Fig 2.3 (a)Chimney stove. (b) Grate and holes to improve the air draft

Insulation (Fig 2.4) and refractory quality are two important factors in stove design. Insulating bricks are refractory and withstand very high temperature, but their thermal conductivity is lower than required. They do not absorb the heat well at all. These bricks are mainly used for heat insulation. They are used on the outer side of the stove to keep heat from the combustion chamber for escaping, and to thus achieve higher thermal efficiencies[5].

For the insulation air is the best media. Even using thin metal sheets for combustion chamber, the life of the combustion chamber can be increased significantly. Even as air sucked into the combustion zone, the combustion chamber is being continuously cooled. This increases the durability of the combustion chamber. As a measure of safety from excessive heat emitted from the body of the stove, an external wall can be made out of a thin sheet or wire mesh. The surface are of contact between the hot parts and other parts of the stove should be minimum possible. The space between the inner and outer wall is often left vacant or filled with insulation material, such as broken pieces of glass, sand or ash. Ideally, the holes in the stove grate should be small, but not so big as to affect its durability. Too much or too little primary air entering the stove from below, and through the grate into the combustion chamber [5].

Fig 2.4 Insulation material

Gasification is a different way to extract energy from fuels in particular from wood a different way to burn wood. This different process needs a different type of stove. This kind of procedure implicate a particular combustion with a small percentage of oxygen. This cause the production of syngas doing a carbonification process, becoming wood in charcoal as is explained in Fig 2.5. This syngas produced is essentially carbon monoxide and hydrogen, that have and high heat value, and when it burns doesn't produce particulate or soot. The other advantage is that when the carbonification finish the result is the charcoal. This charcoal is could be used or in another traditional charcoal stove or to feed the soil. The gasification could be the best solution in order to reduce the indoor air pollution because the combustion products are only CO_2 and water, no sot, no particulate, no black smoke, but has several negative aspects. If the combustion is not controlled carbon monoxide could be formed ,as is know the monoxide carbon is very dangerous for human health, even small quantities can induce the death. Second aspect more practical and cultural is when the gasification process is started, it cannot stopped. This aspect for some households could be a problem, because maybe they have the necessity to boil some water only for a few minutes, not a constant source of heat. And they prefer start a simple fire that is more easily to prepare and is more easily to take under control.

Regulation of firepower can be difficult. Difficulties to extinguish gasification at the end of the cooking process before all fuel is consumed. Inflexibility of cooking times with batch-feeding device that cannot be refueled during operation. Require fire-starting material to initiate pyrolysis in the gas-generator [39].

Fig 2.5 Gasification process

Also the pot skirt could be a features than can permit a more high thermal diffusion on the pot. Pot skirts increase fuel efficiency dramatically (plus 6-7 %). A small fire can have a big impact if you use a pot skirt to transfer all the heat to the cooking pot [40]. The principle is very easy to describe. In stoves without potskirt part of the flame is not in contact with the pot and goes in the enviroment, this waste of heat cause an obvious decrease of the efficiency. The skirt envelops the pot and direct the flame on the pot increasing. This permit to have an high efficiency even with an not good managing of the fuel. Because some household in order to speed up the cooking extra-feed the stove and this cause high flame.

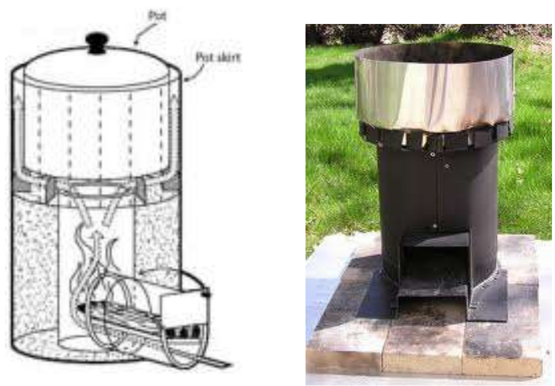

Fig 2.6 Pot skirt

Batch load that indicates the shape of the stove and the way to feed it. In fact in the stove with the batch load you can’t put the fuel with continuity, when the batch is full the stove is closed and to feed it again the pot must be moved (Fig 2.7).

Due to the shape of the combustion chamber the most used fuel is the charcoal, in order to have a slow combustion and to use the warmth from the embers. And given that the charcoal burns at high temperature the indicated material for this type of stove is metal. For how the gasification stoves works, all of this type of stove are batch loaded

Fig 2.8 Batch loaded

2.4. Performance evaluation methods for improved cooking stoves

Standard testing protocols and procedures have been under development for the past two decades based on international standards. In 1982, USAID organized a series of international conferences that resulted in some tests some in the lab and other in the field. The state intention of these protocols has been to continually evolve and improve to meet the changing needs and technology of the cookstove community. Decades of input from the field's leading experts have led to the most useful protocols for testing and evaluation. This tests validate the stove from initial optimization of the technical design all the way to what happens when cooks are using them in their homes under highly variable circumstances.

- Water boiling test (WBT)
- Kitchen performance test (KPT)
- Controlled cooking test (CCT)
- Heterogeneous testing protocol (HTP)
- Uncontrolled cooking test (UCT)

The Water Boiling Test is a simplified simulation of the cooking process. It is intended to help stove designers measure how efficiently a stove uses fuel to heat intended to help stove designers measure how efficiently a stove uses fuel to heat water in a cooking pot and the quantity of harmful emission produced while cooking. The objectives of the WBT are provide an initial assessment of stove performance, compare the effectiveness of different designs at performing similar tasks, evaluate stove changes during development, select the most promising products for field trials, ensure the manufactured stoves meet design specification. The limitation of this test is that is conducted in controlled condition so it can provide only an approximation of the cooking process. Laboratory test result might differ from results obtained when cooking real foods with local fuels, even if efficiency and emission were measured in exactly the same way for both tests. The WBT consist of three phases that immediately follow each other. First is the cold-start high power test, the test begins with the stove at room temperature and uses a pre weighed bundle of fuel. Second phase is the hot start high power that is conducted after the first test while stove is still hot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. This is particularly important for stoves with high thermal mass, since these stoves may be kept warm in practice. The last phase is the simmer test that provides the amount of fuel requires to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world.

The Kitchen Performance Test is the principal field based procedure to demonstrate the effect of stove intervention on households fuel consumption. There are two many goals of the KPT: first assess qualitative aspects of stove performance through households surveys and second to compare the impact of improved stoves on fuel consumption in the kitchens of real households. To meet these aims, the KPT includes quantitative surveys of fuel consumption and qualitative surveys of stove performance and acceptability. It is the most difficult way to test stoves because it intrudes on people's daily activities. Surveys should be happen in two stages. The goal of the first stage of the survey is to identify basic social and economic and cooking information of community families, this provides important information and it should occur before stoves are sold or distributed. The second stage of survey should be conducted about a month after the stove has been in use. This stage is important to identify the weaknesses in the stove performance as well as identify any changes in the economic or demographic status of the household [41].

The Controlled Cooking Test is designed to assess the performance of the improved stove relative to the common or traditional stoves that the improved model is meant to replace. Stoves are compared as they perform a standard cooking task that is closer to the actual cooking that local people do every day. The first step in conducting the CCT is to consult with people in the location where the stove or stoves are going to be introduces in order to choose an appropriate cooking task. After deciding on a cooking task, the procedure should be described in as much detail as possible and recorded.

Subsequently record local condition, weigh the predetermined ingredients and do all of the preparation as described by the cooking directions records.

Start with a pre-weighed bundle of fuel that is roughly double the amount the local people consider necessary to complete the cooking task. Starting with a cool stove, aloe the cook to light the fire in a way that reflects local practices. While the cook performs the cooking task, record any relevant observations and comments that the cook makes.

when the task finished remove the pot of food from the stove and weigh each pot with its food on the balance. Remove the unburned wood from the fire and extinguish it [42].

The essence of Heterogeneous Testing Protocol is to test the stove over the full range of power levels and tasks anticipated during domestic use including at least two widely used pot sizes. The HTP hypothesis that pot size may be an important performance metric for the evaluation of fuel/stove/pot combinations. The underlying proposition is that emissions might vary with power or because different pot sizes may alter the air and gas flow patterns. Accordingly, the protocol requires that the devices is operated, as per manufacturer's instruction or local fire tending practices, over a nominal range of three power settings, high, medium and low, to heat water in two significantly differ pot sizes (typically containing 5 liters and 2 liters water). Features of the test protocol require a minimum of three tests under each condition to obtain standard deviation and quality assured generalization about performance. Prior to each values using a bomb calorimeter. The procedure is divided into three phases, a high power, a medium power and a low power test begins with the pot, stove and water at room temperature.

The total emission mass per standard task was determined from the calculation of CO concentration emitted during the heating up high power phase, medium and low power setting of the stove. The HTP uses a modified carbon mass balance method of obtaining emission factors, is used an high resolution mass balance placed under the whole system to weigh the mass of fuel burned and calculating the emission [43].

Uncontrolled Cooking Test, in this method the meal is not constrained and the cook is free to prepare what they want, how they want, with the only measurement being that of the firewood used and the final mass of food cooked as part of an actual household meal. When compared with the CCT method, this should give a stronger and more representative data set with a better measure of the inherent variability as determined by real world differences in used behavior, local firewood etc. The UTC is conducted during the cooking of a number of everyday household meals. The test begin with the cook being asked to make and light a fire as they normally would, with method and start time noted and lighting materials weighed.

Results are then processed to give a specific fuel consumption, a ratio of total energy consumed to cooked food mass, and a fuel burn rate, a ratio of total energy used to cooking time [44].

3. Improved cooking stove state of the art

It is reported a database about the principal types of improved cookstoves. For this database has been referred to the Clean Cooking Catalog [40] and the STP inventory (in appendix is reported a summary table of the data base, with all the stoves model) . This database has been created first of all to have an unique documents where are storage most of the improved stove models, and second in order to permit to choose one particular model depending on the needs of the costumer. Or if the households have only some particular type of fuel or live in some particular world region, with the filter he can choose the improved cook stove more near to its needs.
The stove are listed following different parameters, the choice of this parameters has been done in order to understand the properties of each stoves. In particular the macro-categories are: material of which is composed the stove, the fuels used to feed the stoves, the geographic location where the stoves are most used and the features. This classification derive from the Clean Cooking Catalog.
This parameters have been mixed in different combination to show for each stove the different links from each parameters.
Before to read the study is required to explain each parameters in order to understand better how to read and interpret the conclusions.
The first parameter is the materials, that are:

- Bricks
- Cement
- Ceramic
- Clay
- Metal

Bricks are not a real material like metal or cement, they are made by mixing clay and sand and sun dried, but it was introduced in order to give a more complete description about the way to built a stove. Materials like cement and clay are mostly common material universal used to built stoves. Ceramic generally is not the main materials witch the stove are built. Ceramic usually is used like insulation materials to increase the stove performance. Clay is the basic material used for creating stoves, because is easily available. Many times households procure clay near the village, making sure that the clay is appropriate to built the stove and resist to high temperature, this built technique is the most old way to built stoves. The last material that is considered is metal. Metal that is often retrieved from scrap or old bins. The stove that were classified with the precedent materials are made only with that material. Then it was done another classification with the material composite, such as:

- metal&cement
- metal&clay
- metal&ceramic

The second choice parameter is the fuels use to feed the stove. This items is the most important discriminates with materials in the stove choice. From the database that this research is referred the fuels listed are:

- Pellet
- Charcoal
- Crop residues
- Dung
- wood

Pellets or briquette are made from biomass such as agricultural waste, recycled materials, or other materials such as dust. Under the right conditions, pellets or briquette can burn more efficiently than traditional biomass. They are more consistent in composition and size than traditional biomass, and a well designed stove can burn these processed fuels efficiently. After pellets is listed charcoal. Charcoal is charred wood, which has lost moisture volatile contents in the production process. The other fuels considered are crop residues, dung and wood. Mostly dung is shaped in dung cake in order to facilitate the storage and the handling. Wood as will see in the schematic is the most common fuel used in the developing countries, over the 50% of the total stove exanimate use wood as principal fuel. In the database provided by the Global Alliance for Clean Cookstove were listed others fuels such as LPG or kerosene and others but in this study it was chosen to not consider this fuels. Because this fuels are too much evolved and the most of the households in developing countries doesn't have access to this fuels. And in order to have a research more near to the field realty it is preferred to not report this type of fuels. As the material also the fuels have a mixed categories such as:

- pellets&wood
- wood&charcoal
- wood&crop residues

This combination of double fuels it was created by the database developer in order to give a more accurate way of feeding the stove. In the field all the stove can be feds with only of this fuels, because this stoves are not high technology devices and they can accept more or less all type of fuels.
The next parameter is the geographic position. This criterion has been introduced for understand where the stove are most used in the world.

In order to verify if there is a correlation between the location and the fuels used or if the geography context can influence the constructive characteristics of the stove. The region chosen are:

- Africa
- Asia
- Latin America and Caribbean

because this are the principal geographic areas were developing countries are located. The most of stove exanimate are located in Africa. That because the most of the project are develop in Africa. This means that not all the stove that are located in that region are stoves of that part of the world. For this reason the crossing research with this parameter was not done, because the results would not be a good discriminant.
As last term of comparison it has been introduced the technical and constructive characteristics such as:

- Batch load
- Side feed
- Built in place
- Ceramic lined
- Chimney
- Fan
- Natural draft
- Gasifier
- Griddle
- Multiple burners
- Portable
- Pot skirt

First of all is the batch loaded (1) that was described in chapter 2.4. It just add that all the stove with batch loaded are made in metal and the principal fuel is charcoal. As the batch load is a way to feed the stove, also the side feed (2) is a way (Fig 3.1 b). Side feed means that the feeding can be continuous. This is a typical feature of all the stove that use wood as principal fuel.
A discrimination could be whether the stove is built in place (3) or not (Fig 3.1a). This means if there is the possibility to built the stove directly in the location where it is supposed to be used. Sometimes the stoves are built by specific associations and than sold in the village. But for simpler models is more convenient to build the stove in place.
Another characteristic to give a more detailed stove inventory is whether the stove is lined of ceramic (4) (Fig 3.1c). This configuration can be chosen in order to improve the thermal isolation, but this can also increase the fragility of the structure. This can be a problem given the fact that this stove is used in developing countries where the maintenance can be difficult.

a b c

Fig 3.1 (a) Stoves built in place. (b) Side feed stove. (c) Stoves with ceramic lined

The presence of the chimney (5) can influence the draft and the air flow in order to help a more complete combustion and consequently reduce the monoxide carbon production and other pollutants. Even the indoor air pollution is influenced by the presence of chimney.
Another important characteristic is the presence of a fan (6), that can force the draft even if the chimney is not long enough to create a sufficient depression. This conformation requires a power source for the fan and because of this is more complicated and more evolved. This is the reason because this model of stove is less diffuse than the classic chimney draft. A few model of fan stove are equipped with a thermoelectric generator, this device allow to power the fan without an electric line, creating a small voltage capable to power the fan (Fig 3.2a). In the figure is possible to see the fan (orange box) powered by a thermoelectric generator. As mentioned before the air flow is an important discrimination in order to classified the stoves. Before it has been described the fan and the chimney to improve the air draft, but a large part of the models exanimate use the natural draft (7) (more than 50%). This type of stoves works with the rocket principle. This principle use the pressure differences create into the combustion chamber due the hot gases that naturally goes up, this air movement create a draft that allow the entrance of fresh air coming outside.
Gasification (8) is another characteristics presented in the inventory, the principle is already described in the past chapters. Here is shows a couple of this particular stoves (Fig 3.2b).
Another characteristic is a griddle (9) where it is possible to cook. This peculiarities is used mostly in Latin America where one of the typical food is tortillas, and this type of configuration is well developed especially for this type of dishes.

Multiple burners (10) are used in order to have the possibility to cook with more than one pot at the same time. This type of stoves are quite bulky and heavy and therefore not portable.
Important peculiarity is the portability (11) of the stove, that in some context could be determinant, for example in the rainy season it is very useful to be able to move the stove indoor, in order to protect it from the rain, especially if it is made of clay. Some families are more comfortable to cook outside the house, event to reduce the indoor air pollution. Otherwise if the stove is in clay or any other fragile material, the portability could be a disadvantage, because the possibility to break the stove increase [45].
As last characteristics is reported the pot skirt (12) describe in the previous paragraph.

Fig 3.2 (a)Thermoelectric fan stove. (b) Gasification stove. (c) Multiple burners. (d) Griddle stove

The next step was to found which of this aspects could be useful in order to understand how this parameter can influences each other. Crossing this information is useful to select a particular model of stove, with specific characteristics or built with some particular material. In this way an households or a costumer can choose the stove that is more near of its needs.
First of all it was examined which materials are more used to build the stoves. In the histogram below (Fig 3.3) is shown the number of stoves for the built material.

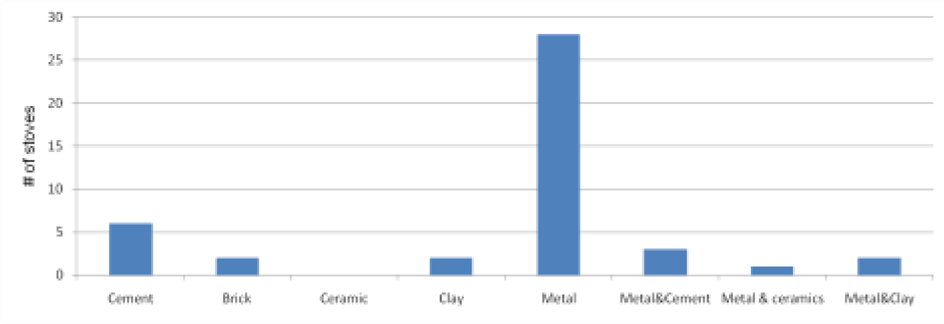

Fig 3.3   Number of stove in relation in relation with built material

Observing the plot is clear how the metal is the most used material to built the stove. In the second position there is cement, even if the difference between the two materials is very marked. The more widespread use of the metal is due to the more flexibility to the metalworking and the easiness to retrieval it. The most of metal stove are old barrels cut in the side feed shape. Or some stove are created modeling metal sheets and welded together, obtain the classical cylindrical shape. The other parameter that has been plotted (Fig 3.4) is the fuels used in each stoves.

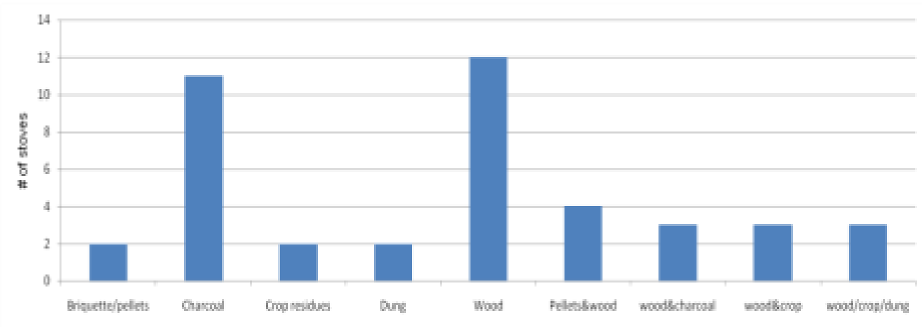

Fig 3.4 Number of stoves in relation with fuel

This plot show how the wood is the most used and versatile fuels used. This because does not require special processing. Only drying process is needed if it is too wet to be ignited. A surprising variety of wood-drying technique were observed in the study households. One way is placing the wood in the sun. Or placing it in a dry location. Another technique included above-fire rafter storage, placing wood very near the fire, and placing wood on the plancha [3].

This process And if the households use the deadwood purchase wood is very easily. This fuel is very flexible because all the stove can be fed with wood because the flame temperature is not too high to damage for example the clay. If in the stoves that use wood it is included also hybrid stoves, for example which stove that can be fed with wood&crop residues, the number of the stove that use wood increase more reaching the value of 25 models of stove that use the wood as combustible.

Charcoal that is the second fuels more used after wood, is a more esteemed fuels. The LHV of the charcoal is quite high, due the high carbon percentage inside. The stove that use this fuels are less than the wood one, this because charcoal is not always available, and producing it has a cost, and not all the households can support this expenditure. There is also technical aspects, due the high temperature of charcoal flame. Not all the materials can resist for many cycles at this temperature. In fact most of the charcoal stoves are built in metal. This aspects could be appreciate in the histogram (Fig 3.5). Where is possible to see that the wood stove are made with all the materials and how is more selective, in the choice of the stove, the charcoal as fuel. In specific there are not charcoal stove built in cement or bricks. This is due to the high temperature combustion and because the brick stove are only side-feed and are not adapted for charcoal combustion and feeding. As is know the metal is the best metal to contain the charcoal combustion, in fact this histograms shows how the metal stove are more than the wood one.

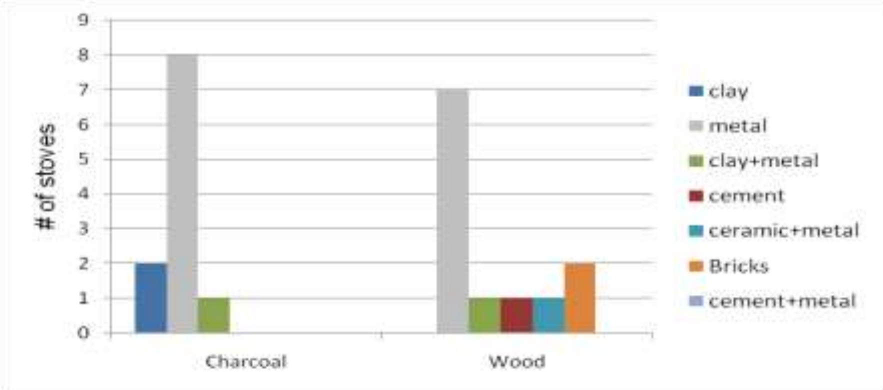

Fig 3.5 Number of stoves with different materials and fuels

Of all characteristics listed above were chosen the most significant. Like if the stove is portable, the presence of the chimney or if the stove works with the rocket effect and even if the stove use the gasification technique. First of all the portable characteristics it was crossed with the built material (Fig 3.6). Portable stoves are more than half of all the stoves examined, this is because this improved cookstoves are projects implemented in the developing countries and portable stoves are more easily to handle and carry. And for the households are more easy try a portable improved cookstove than a fixed one. Implement a fixed stove is more complicated because you should change the entire kitchen and not all of the household will agree.

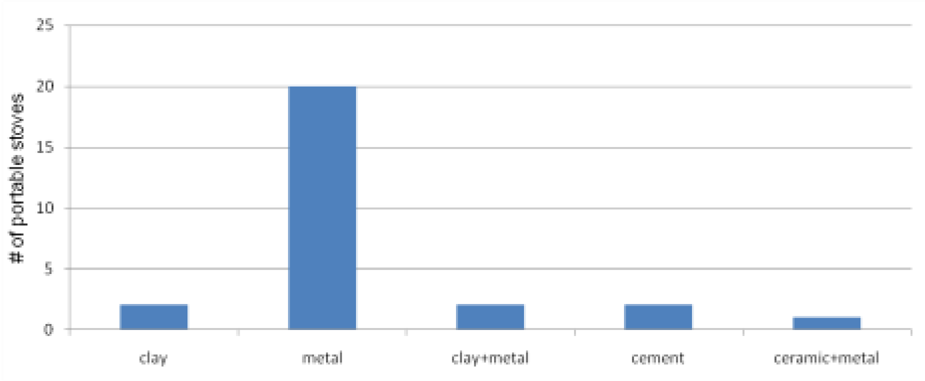

Fig 3.6 Number of portable stove with material

As well as in the general case also in portable stove metal is the most material used. That because the metal stove are more easily to handle and there is less risk of breakage. Even the plot correlating the number of portable stoves with the fuel used to feds it, maintain the same trend of the general case with all the stoves, with the wood as primary source of fuels, second the charcoal and the other fuels as minority. As said before it were examined the gasifier stoves. There are only few model of this type of stoves (8 models), and all this models are built in metal. Other important characteristics is the chimney. The stoves with this peculiarity are 17. The presence of the chimney is very important in order to reduce the indoor air pollution. Crossing the stove with chimney and the portable one, is clear how the most part of the stove with chimney is fixed and only 4 models are both chimney and portable (Fig 3.7).

Fig 3.7 Portable stove with chimney

This is because when on a stove is putted a chimney with a large probably the stove will remain in the same position forever. Mixing the gasifier characteristics with the presence of chimney the results is only two stoves have both peculiarities. Examining the built material of the chimney the trend is similar to the general case. The metal is still predominant as built material, but the difference with the cement is less pronounced as is showed in the histogram (Fig 3.8). To complete the analysis about how works the draft in the stove, it was examined the rocket stoves. The rocket stoves that are also portable are more than the half of the rocket one. And even in the rocket case metal is the main material used (Fig 3.9).

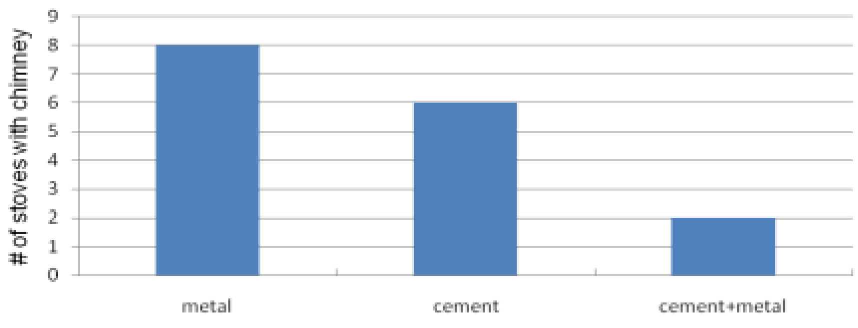

Fig 3.8 Number of chimney stove with materials

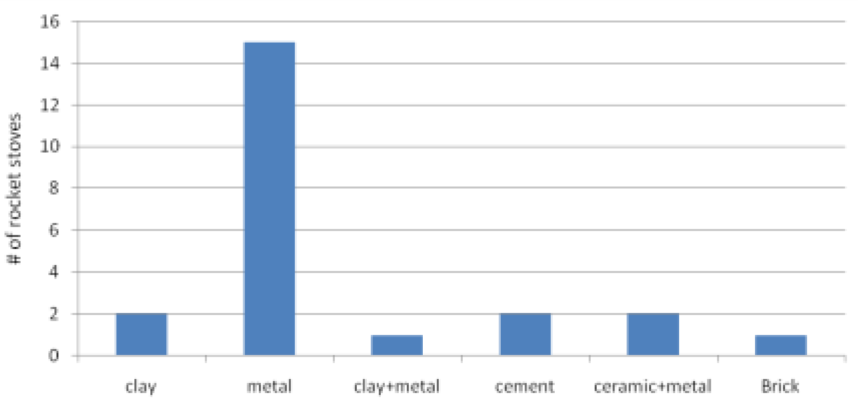

Fig 3.9 Rocket stove with materials

4. Experimental analysis

4.1. Experimental procedure

The objective of this study was to estimate the efficiency of a stove. In literature the most common test used to measure the efficiency is the Water Boiling Test (WBT), for this reason it was adopted this type of procedure in order to have a term of comparison with the results obtained. The test has been performed on a stove in particular the “Envirofit 3300” and on the “Three Stone Fire” in order to have a benchmark case.

In this paragraph will be explain the Water Boiling Test procedure and all the steps for each phases.

The Water Boiling Test (WBT) is a simplified simulation of the cooking process. It is intended to measure how efficiently a stove uses fuel to heat water in a cooking pot. All standardized tests involve trade-offs. When conditions are highly controlled and variability is reduced, a test is better able to detect small changes. However, a more controlled test is often less representative of actual cooking. Controlled tests are appropriate to compare various technical aspects of stove design and pre-field evaluations of performance. While lab-based tests allow differentiation between stoves, field-based tests give better indication of performance during actual use. The Water Boiling Test was developed to assess stove performance in a controlled manner, and thus it is probably less like local cooking than tests described before. Although the WBT is a useful tool for the reason given above, it’s important to remember its limitation. It is an approximation of the cooking process and is conducted in controlled conditions by trained technicians. Laboratory test result might differ from results obtained when cooking real foods with local fuels, even if efficiency and emission were measured in exactly the same way for both tests. In order to confirm desired impacts (whether it is fuel conservation, smoke reduction, or other impacts), stoves must be measured under real conditions of use.

The WBT consists of three phases that immediately follow each other. These are discussed below and shown graphically (Fig 4.1). The entire WBT should be conducted at least three times for each stove, which constitutes a WBT test set.

For the first phase “cold-start high power phase”, the test begins with the stove at room temperature and using fuel from a pre-weighed bundle to boil a measured quantity of water in a standard pot. Then replaces the boiled water with a fresh pot of ambient-temperature water to perform the second phase.

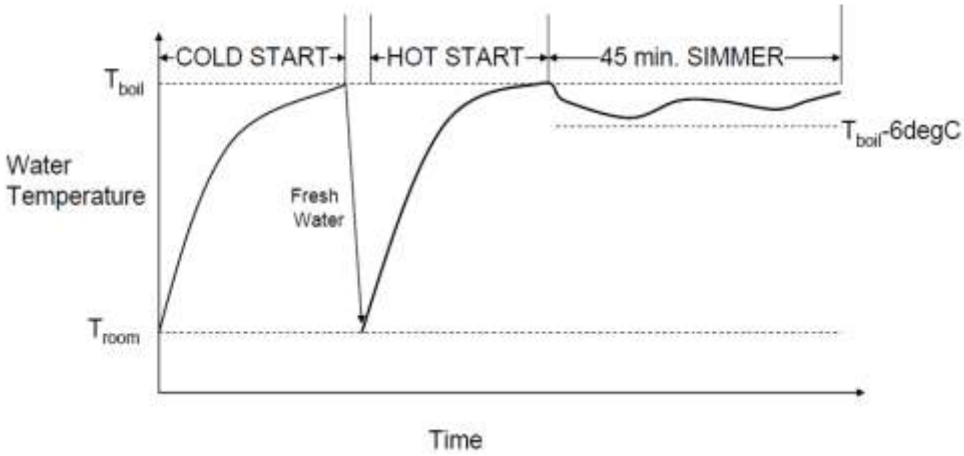

Fig 4.1 Water temperature trend in the WBT

The second phase “The hot-start high-power phase” is conducted after the first phase while stove is still hot. Again, the tester uses fuel from a pre-weighed bundle of fuel to boil a measured quantity of water in a standard pot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. This is particularly important for stoves with high thermal mass, since these stoves may be kept warm in practice.

The last phase is the “simmer phase” provides the amount of fuel required to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world. A full stove test should always include all three test phases. A quick test for a laboratory’s internal use may include only the cold-start and simmer phases if the stove has low mass (no isulation) and previous WBTs have shown that the cold-start and hot-start phases produce the same results.

Now will be explain in detail all the part of the WBT procedure.

First of all determine the type and characteristics of fuel will be used. The type, size and moisture content and the LHV of fuel have a large effect on the outcome of stove performance tests. For that reason, all tests of a single stove, or all tests to compare designs or stoves, must be done with fuel of the same type and moisture content, and similar size. Obtain all of the fuel from the same source if possible.

Determine the type of pot you will use, and record its size and shape. The common pot used are between the 7 liter and 3.5 liter capable.

It is require a thermocouple to measure the water temperature, a scale to weigh the wood, a wood moisture meter and other stuff to handle the wood and the hot char.

For the first phase the pot full of water will be placed on the stove and the fire will be started, from this moment the experiment starts.

Once the fire has caught, bring the pot rapidly to a boil without being excessively wasteful of fuel using wood from the pre-weighed bundle. When the water reaches the local boiling point will be the end of the first phase and the timer will be stopped. The procedure involves that

all the wood will be removed from the stove and extinguish the flames. After that all the charcoal from the ends of the woods will be knocked and weighted. Weigh the unburned wood removed from the stove together with the remaining wood from the pre-weighed bundle. The next step will be weight the pot.
In the second phase when the stove is warm, refill the pot with new water. The first and the second phase are conducted as the same way. The only difference is that the charcoal this time will not be weight, it will be assumed equal to the first phase. And after weighing the wood it supposed to return all the unburned wood in the stove and proceed immediately with the low power test. This last portion of the test is designed to test the ability of the stove to shift into a low power phase following a high-power phase in order to simmer water for 45 minutes using a minimal amount of fuel. The variables to measure are the same of the previously phases.
Record the weight of fuel remaining from the hot start high power phase.
Relight the hot wood that was replaced.
For 45 minutes maintain the fire at a level that keeps the water temperature as close as possible to 3 degrees below the boiling point. The test is invalid if the temperature in the pot drops more than 6°C below the local boiling temperature. After 45 take all the variables taken in the previously phases.
Now in order to understand how are the relation that were used here will be reported the variables and the equation required to calculate the efficiency and other parameters.

- fm This first parameter to bring in consideration is thee fuel consumed. This value is the mass of wood used to bring the water to boil.

- Δc This second important parameter is the net change in char during the test. This quantity is the mass of char created during the test, found removing the char from the stove at the end of the test phase.

- w_{cv} To obtain the efficiency is necessary know the mass of water vaporized. It is a measure of the water lost through evaporation during the test. It is derived subtracting the initial weigh of the pot and water minus final weigh of pot and water.

- w_r The effective mass of water boiled is the water remaining at the end of the test. It is a measure of the amount of water heated to boiling. (This parameter is used only in the efficiency equation of the simmering phase).

- f_d The equivalent dry fuels consumed adjusts the amount of dry fuel that was burned in order to account for two factors: the energy that was needed to remove the moisture in the fuel and the amount of char remaining unburned. $dryfuel = f_m \cdot (1 - MC)$

The energy that was needed to remove the moisture in the fuel is the mass of the water in the fuel multiplied by the change in specific enthalpy of water.

$\Delta E_{H2O,c} = f_m \cdot MC(4.186(T_b - T_{bfuel}) + \Delta h_{H2O,fg}$

The fuel energy stored in the char remaining is the mass of char multiplied by the energy content of the char: $\Delta E_{char} = \Delta c \cdot LHV_{char}$.

Put all this aspects together :

$$f_d = \frac{f_m\left(LHV(1-MC)-MC(4.186(T_b-T_a)+2.257)\right)-\Delta c \cdot LHV_{char}}{LHV}$$

Where MC means moisture content and Tb is the local boiling temperature and Ta is the initial water temperature

- h Thermal efficiency: this is a ratio of the work done by heating and evaporating water to the energy consumed by burning fuel. It is an estimate of the total energy produced by the fire that is used to heat the water in the pot.

$$h = \frac{4.186(T_b - T_a)(P1_i - P1) + 2260 \cdot w_{cv}}{f_d \cdot LHV}$$

where $P1_i$ is the initial weigh of the pot full of water at the end of the experiment and P1 the weigh at the beginning.

For the simmering phase there are some assumptions made in this test based on the amount of char present at the start of the simmer phase. At the end of the hot start phase, when the water comes to a boil, it is quickly weighed without disturbing the char and then the fire is tended to maintain the water within a few degrees of boiling for 45 minutes. There will be char remaining in the stove from the wood that was used to bring the water to a boil during the hot start. Removing that char from the stove, weighing it, and relighting it disturbs the fire and may result in the water temperature dropping too far below boiling. Thus, the recommended procedure is to assume that the char present at the start of the simmer phase is the same as the char that was measured after the high power cold start test. While this is not entirely accurate, the error introduced by this assumption should be minimal.

The thermal efficiency calculation for simmer is a little different than the high power calculation. For the high power thermal efficiency, the mass of water boiled is the water mass at the start of the test . For the low power thermal efficiency, the effective mass of water simmered is the average of the starting and ending water masses in the pot:

$$h_{simmering} = \frac{\frac{4.186(T_b - T_b)(P1_i - P1 + w_r)}{2} + 2260 \cdot w_v}{f_d \cdot LHV}$$

Where w_r is the mass of the water at the end of the experiment.

4.2. **Experiment performed**

In this section will be explained how the WBT procedure was applied to a real field experiments. First of all in the experiments realized were not done any emission detection. And this experiment were done in outdoors, not in a laboratory. In order to simulate with more accuracy the field conditions, where is supposed to be used. This means that all the boundary condition were uncontrolled.
The equipment used were:

- Two thermocouple model T. One to measure the water temperature and the other to measure the environment temperature.
- A scale with a 1 gram sensibility and 5kg as maximum weigh supported.
- One 3.5 liter pot made in stainless steel.
- A moisture meter.
- One metal bucket to hold the unburned wood or the charcoal and other stuff to handle hot pieces of wood and charcoal.
- One filter to separate the ash from the charcoal.
- Fir wood to feed the fire.

The first data set of the experiments were done on the Enviroft 3300 (Fig 4.1a)

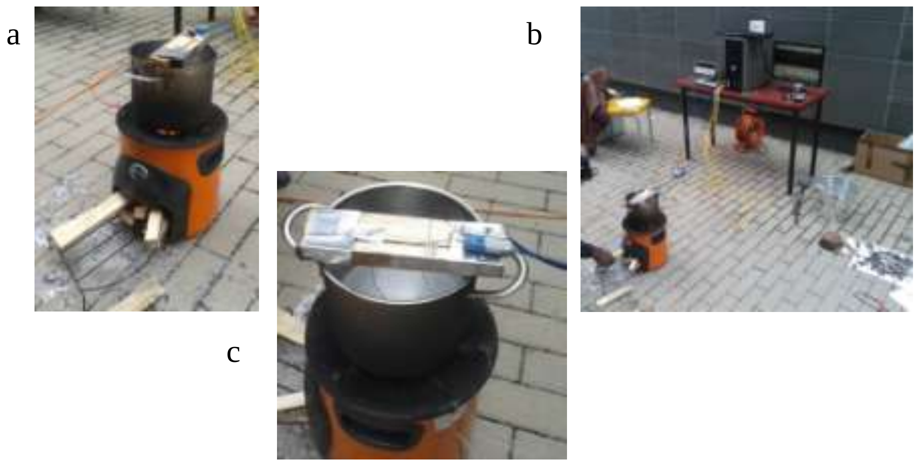

Fig 4.1 Envirofit 3300 (a) Experiments equipment (b). Simply system to handle the thermocouple

In the figure 4.1 b is possible to see all the equipments used from the thermocouple to the bucket and the PC to read the thermocouple output. In the figure are present other thermocouple used to perform an CFD (Computational Fluid Dynamics) study on the combustion chamber. In the figure 4.1 c is possible to see the thermocouple used to measure the water temperature.
The second set of the experiments were done on the "three stone fire"(3SF) (Fig 4.2) in order to have a benchmark case to figure out how the improved cook stove could be improved.


Fig 4.2 Three stone fire

All the equipment were the same of the experiment with the Envirofit 3300 in order to have a more equilibrate comparison.
For this experiments were follow the WBT procedure described before measuring all the variable needed to estimate the efficiency.
The wood used in this experiments was certificate, in specific the wood specie is Fir and the LHV is 18000 kJ/kg.
Is important emphasize the difficult found to perform this experiments. First of all the accuracy of the measurement, in order to obtain good results the way to make measures is very important. For example when was required to measure the quantity of charcoal the problem was the high temperature (that could damage the scale) and the smoke that could disturb the data detection. The greatest problem was found at the end of the second phase where timing was essential to prevent the temperature drops too and invalidate the experiment. In the simmering phase where the target was maintain the water temperature at a constant value, the management of the wood was very important. The heat flux regulation is pretty complicated, because each piece of wood when ignited generate a lot of heat and this sudden amount of heat could bring the water boiling, invalidating the experiment. The solution, in order to regulate the heat flux, it has been to cut the wood in small pieces, in this way it was possible regulate the flow of the wood more carefully. This has allowed to control the trend of the water temperature. The management of the wood is very important also in the first and second phase. In order to arrive quickly to the boiling temperature is require to feed the stove properly and in the same time

prevent that the flame don't escape from the bottom of the pot because this involves an waste of energy, in the case there not a pot skirt.
In this part will be showed the results obtained from the experiment. The total number of the experiments performed was 5. In particular 3 on the Envirofit 3300 and 2 on the three stone fire. The reason why one experiment miss on the three stone fire was time and resources. The first two experiments on the Envirofit 3300 was performed in one day but the third one was performed in another day, with different weather condition. In particular the first day the sky was cloudy while the second day the weather was sunny and windy. In a third day were performed the two WBT on the three stone fire and during this experiments the weather condition were more similar to the second Envirofit experiments with a sunny and windy day. The boundary condition are very important in order to understand differences that could be found with the literature. In the table 4.3 below are reported all the data obtained and the boundary condition of each experiments.

			WBT 1			WBT 2			WBT 3		
			Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
Envirofit 3300	boundary condition	Tamb [°C]	10	10	10	12	12	12	12	12	12
		weather condtion	cloudy	cloudy	cloudy	cloudy	cloudy	cloudy	sunny and windy	sunny and windy	sunny and windy
	varibles measured	fd [kg]	0,346	0,338	0,371	0,387	0,341	0,337	0,355	0,367	0,478
		moisture contenent	9%	9%	9%	9%	9%	9%	9%	9%	9%
		efficiency	17,60%	17,39%	15,77%	15,00%	18,55%	17,05%	18,83%	16,14%	19,17%
Three stone fire	boundary condition	Tamb [°C]	11	11	11	12	12	12			
		weather condtion	sunny and windy	sunny and windy	sunny and windy	sunny and windy	sunny and windy	sunny and windy			
	varibles measured	fd [kg]	0,602	0,648	0,430	0,464	0,605	0,673			
		moisture contenent	8%	8%	8%	8%	8%	8%			
		efficiency	11,48%	10,19%	12,71%	16,12%	10,25%	11,10%			

Table 4.1 Data set

To understand better the numbers showed in the table is possible to see the trend in the plot (Fig 4.4).

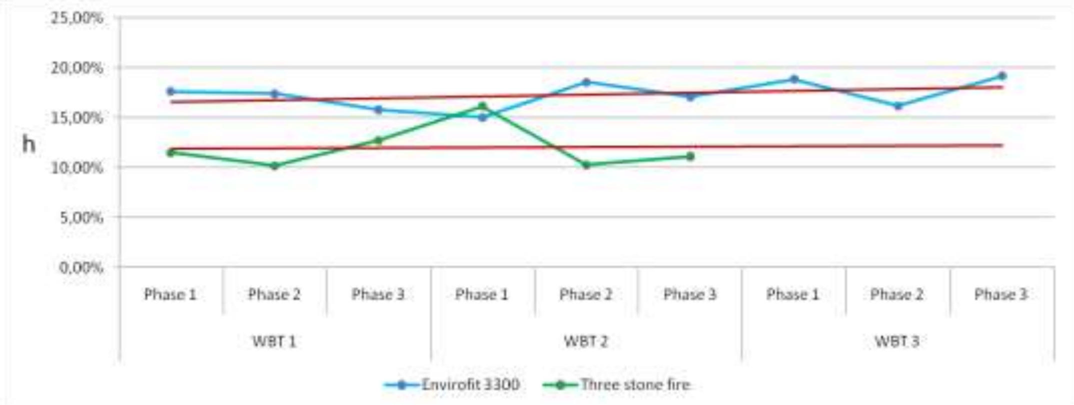

Fig 4.3 Efficiency trend

Is right give some clarification in order to understand better the data and the trend. First of all the time line, as explained before, are not the

same for each experiments. This means that the second WBT on the three stone fire was not perform in the same time of the second WBT on the Envirofit 3330, and is wrong confront point by point the two experiments.
As is shown in figure the trend is very variable in each experiments this is because the boundary condition are variable. In the phase 1 of the WBT 2 the two trend are crossing, this means that the 3SF has an efficiency higher than the Envirofit and the improvement would be negative. This out layers maybe could be caused by an error during the data collection, or a very bad wood managing in the Envirofit experiment and a very optimized wood managing in the 3SF.
For this reason is better, in order to have an idea of the improvement of the Envirofit 3300, watch the trend line (red line). The average value of the efficiency of the Envirofit is 17.28% while the average value in the 3SF is 11.98% this involves an improvement of 44%. As explained before this data are very variable, and in the average value are contained even the "out layers" that maybe can create an error in the performance valuation. For this reason it is worth report the best improvement found. In particular the highest efficiency of the Envirofit is 19.17% and the lowest 3SF efficiency is 10.19%. In this case the improvement is about 90%. This is only a consideration, as explained before the best way to understand how much is the improvement, would have more experiment in order to perform an statistic analysis. This means perform in parallel the WBT on the Envirofit and on the 3SF, in order to have the same boundary condition and repeat this procedure many times.

4.3. Comparison between experimental data and literature

In order to have a more completely comprehension of the results is necessary have different point of view. This other point of view became from the literature. To obtain this results it has been contacted another team that has performed the same experiments on the same devices and it has been consulted the data sheet of the producer of the Envirofit 3300. Here are reported the results coming from the literature and the producer[46][47].

		WBT
Envirofit 3300	Tamb [°C]	30
	moisture contenent	9,5%
	efficiency	32,6%
Three stone fire	Tamb [°C]	30
	moisture contenent	9,5%
	efficiency	14,8%

Table 4.2 Data set literature

The first comparison is about the differences of the number. For the Envirofit 3300 the efficiency become double for the average value while for the 3SF the increase is less significant. As is showed in table the boundary condition are different. In particular the literature experiments were performed with an environment temperature of 30 °C and in an lab, with controlled boundary condition that means without wind or other external agent, while the field conditions were with an environment temperature of 12 °C. In order to understand an justify this strong differences of efficiency especially on the Envirofit 3300, it was perform a study on the heat transfer and heat dissipation in the two case: in laboratory and in field. First of all it was considered the two main heat flux from the pot and from the stove (Fig 4.6).

Fig 4.4 Heat flux from the stove and from the pot

To calculate the heat loss because the lower external temperature it was decided to make a confront with the same pot and the same stove.
This calculation are conducted in the stationary case, that means in the simmering phase. This is a simplification to give an constant temperature of the pot and a constant temperature of the stove, in order to have an stationary condition and simplify the calculation.
In particular:
$\dot{Q} = S \cdot U \cdot \Delta T$ in this case the contribution considered to calculate the transmittance are the air thermal conductance of the air and the irradiance contribute. For the first contribute the it was used a correlation for vertical surface $h_{air} = 1.42 \left(\frac{\Delta T}{L}\right)^{1/4}$ (McAdams correlation).
For the radiative correlation it was used a linearization of the radiative component using T_{sky}=266.7 k giving that $h_{rad} = 4 \cdot \varepsilon \cdot \sigma \cdot T_{sky}{}^{3}$.
Finally: $\dot{Q} = S \cdot (h_{air} + h_{rad}) \cdot \Delta T$. This equation of the heat loss is the same for the pot and the stove.
The $\dot{Q}_{pot}$ and the Q_{stove} are different from the L that is the length of the S surface that exchange heat, from the surface and from the surface temperature.
This variables are reported in the table below (table 4.3).

	Pot	Stove
L [m]	0.15	0.28
S [m2]	0.09	0.18
Tsurface [°C] in the simmering phase	97	60

Table 4.3 Pot and stove characteristics

Doing the calculation the results are:

$\dot{Q}_{Stove}$ = 81.54 W → $\dot{Q}_{Tot}$ =167.37 W } this is the field case where T_{amb} = 12°C
$\dot{Q}_{Pot}$ = 85.82 W

$\dot{Q}_{Stove}$ = 47.88 W → $\dot{Q}_{Tot}$ =113.16 W } this is the lab case where T_{amb} = 30°C
$\dot{Q}_{Pot}$ = 65.28 W

The efficiency considered in the field case was 19% while the efficiency in the laboratory case was 32%. Calculating the wood that would be saved with a more warm environment the field efficiency pass from a maximum value of 19% to a value around 31% nearest to the data sheet value, and this can explain the differences between the literature and the field experiments.
Doing the ratio of the two heat power loss is possible understand how much heat is wasted in percentage because the more cold environment. The ratio is $\frac{\dot{Qlab}}{\dot{Qfield}} = 67.6\%$ .This involves more wood consumed in the field case, that became a loss of efficiency.
Otherwise with the efficiency value given by the literature the improvement became around the 120% though the producer give an improvement about of 105% assuming an 3SF efficiency about 15.8%.
As was said before the best improvement in the field case is about the 90%, compared with the 105% given by the producer is possible to see that this two values are not so far, even the boundary condition of the experiments are quite different. That is correct because the improvement in independent from the boundary condition.
Here are reported a summary table with the efficiency calculated.

Efficiency	*Field* [12 °C]	*Literature* [30°C]
Envirofit 3300	19,00%	32,00%
Three stone fire	11,00%	15,00%

Table 4.4 Efficiencys

5. Scenarios analysis for a real Improvement Cooking Stoves development project.

In this chapter will be performed forecast scenarios in order to understand how the improve cookstoves works in the real word. To help this study it was choose a real project implemented by the Ong COOPI. And applying the results and consideration gives from the experiments it has been possible make consideration more near to the real field case. The forecast study has been performed on two different type of stoves: the Chitetezo Mbaula (Fig 5.2) and the Envirofit 3300 (Fig 4.1) and for each stove it has been analyzed the field case and the laboratory case. The results of this analysis will be able to use by COOPI in order to understand better how could be the real effect of stoves dissemination. With the mathematical model modify aspects that could improve the goodness of this simulation. This study is a preliminary approach to a very complex problem, rich of variable and unpredictable situation that can change deeply the final results.

5.1. **Project structure**

As explained before the promoter of the basic project is COOPI. This project is part of a study for an Energy Facility for Malawi. The overall objective is to contribute to the improvement of access to sustainable energy services in order to reduce climate change and improve the livelihood of rural communities in Malawi. The estimates results is 9000 people (1636 households) will reduce by at least 40% wood consumption through the use of efficient energy saver stoves for cooking and will produce less smoke. Particular relevance is given to the importance to measure or at least estimate the impact of the project of the CO_2 emission reduction associated to the use of energy saving stoves, and estimate the decrease of deforestation rate due the less wood used. The duration of the project is 48 months where the stoves are distributed in 4 semesters, starting from the second semester of the first year of project. The first semester is dedicated for community sensitization about renewable energy and energy saving stoves.

5.2. **Scenario hypothesis**

In order to improve the model it has been implemented some hypothesis. This considerations were made referring to the literature, and consulting other similar project.
Are listed below the hypothesis needed to perform the scenarios.

- Type of wood burned
- Wood consumption
- Failure rate of the stoves
- Households percentage of usage

- Stove dissemination by the ONG

The type of wood is an important variable. In order to better simulate the field condition and as close as possible to realty. In this particular case the wood chosen was the Gmelina. This wood is native of Malawi and it was assumed that in this project all the households use this particular type of wood for cooking. The characteristics of this wood considered are the carbon percentage that amount about 46.7% (on dry basis) and the LHV equal to 18000 kJ/kg (both of this value are calculate on dry basis) [48].
The second hypothesis is the wood consumption. This data it was taken from the literature and represent the households wood consumption with the base technology like the three stone fire. This assessment will be used to calculate the benchmark case and is equal to 4500 kg/year for each household [49].
In order to created a more real condition as possible, it was added to the hypothesis, the failure rate of the stove. Before explain how was estimate the failure rate is necessary known that the stove chosen by COOPI to be implemented is the Chitetezo Mbaula (Fig 5.1).
To establish the failure rate it was consulted the study performed by GTZ [50], where the same stove was implemented in a village in Malawi. The data on the GTZ document were obtain with a survey in the village. Using this data it has been possible to establish the failure rate, the trend is showed in figure 5.2. In order to better understand how it was possible establish a failure rate, here are reported the initial data becoming form the GTZ document. This data were the starting point in order to have a guideline to understand how often this type of stove goes down.

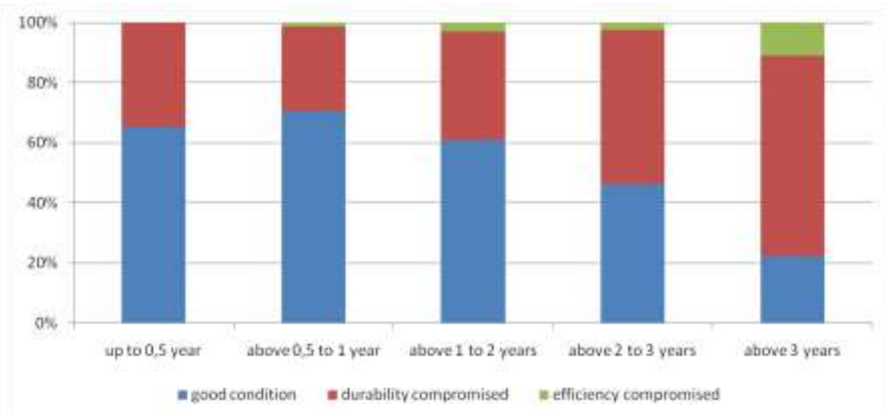

Fig 5.1Condition of the stoves according to age (GTZ document)

In this plot is showed the relative number of stoves in different operating status. If we look the percentage of stove in good condition is clear the decreasing trend with pass of the year.
This was the first data used to elaborate the failure trend showed below. Looking the increase of the voice "durability compromised" plus the "efficiency compromised" is clear the similarity with the trend calculated in the failure trend.

Fig 5.2 Chitetezo Mbaula

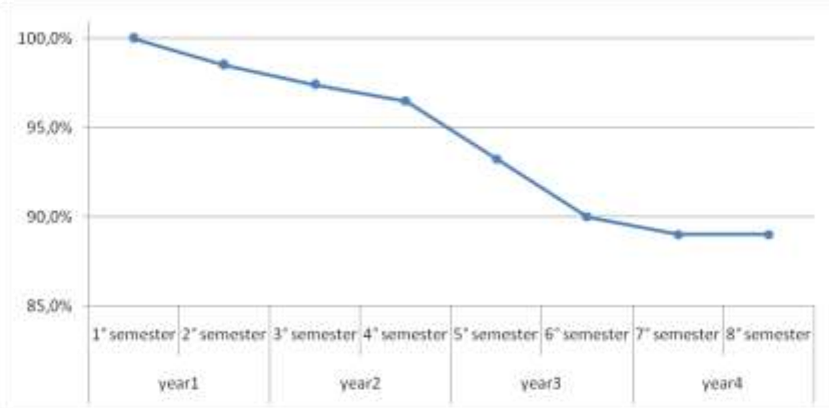

Fig 5.3 Chitetezo Mbaula failure trend

As in the bar chart on the ordinate axes there is stove percentage. In this trend the 100% implies that all the stove works properly. As time passes the percentage of stove that works properly decrease, following the data showed in fig 5.1.
As is showed the trend change gradient from the second year of the stoves life. This because form the GTZ study it was found that the lifetime of the Chitetezo Mbaula is about two years. The reason why the trend don't fall down to zero after the second year is because the ONG organized in the first semester of the project a training session, where is taught how to fix and built the stove. But the trend is more angled because the stoves rebuilt are less that the stoves distributed. In the term of failure is was considered also the efficiency decreased, this means that if a stove has an efficiency loss is considered broken and this value is included the failure value. In this way this analysis is more conservative, in order to reduce the differences between the real project and this simulation.
The number of households that decide to not use the stove even if it has been provided is an important variable. Because this can reduce significantly the effect of the projects and give inconsistent results invalidating the results. In a country like Africa, where the tradition are very strong and deeply inside in the common action such as cooking. Introducing a new way to burn wood or new devices, can create a sort of rejection of the "new". This is why COOPI has planned a sensibility session on the adoption of the improve cookstoves. In this case,

according with the GTZ documents, the percentage of family that has choice to use the stove has been to vary from an initial value of 60% for the first two years and for the last two years the percentage increase to 80%. This data were obtained with a survey performed by GTZ, during a project dissemination in Malawi on different villages (Chiwembu and Kanama). After this research the GTZ has release the results and it were used as hypothesis in this thesis. This sudden change in the CO_2 production it was fixed and the end of the second year where all the stoves are delivered, and is probable that more people had gained confidence with the stoves.
The last assumption is how the stove has been distributed in the village. Taking this information from the project instructions it has been found that the stove dissemination it was done in 4 semester starting from the second semester as explained in Fig 5.4. One tranche for each semester thus increasing the number of stove gradually.

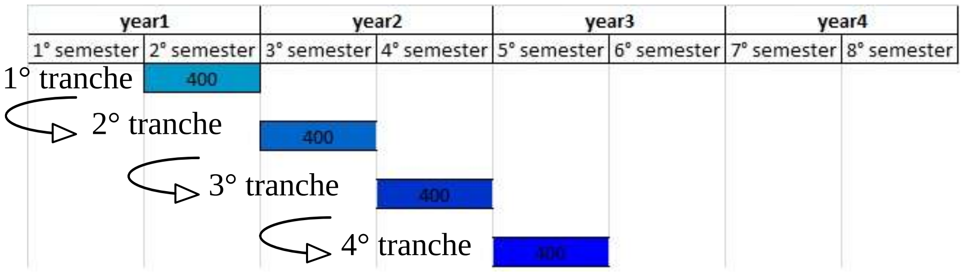

Fig 5.4 Stove distribution

The total number of stoves were about 1600, distributed in four semester this implies that each tranche was composed by about 400 stoves. The tranches are successively and every new tranche about new 400 stove were delivered. At the fourth semester all the 1600 stove will be delivered.

5.3. **Mathematical model**

To aim the objective study, then to quantify the amount of CO_2 produced and the deforestation rate, the variable calculated has been the amount of wood. This analysis has the objective to understand how much the stove can save the wood consumption against the three stone fire. To explain the calculation procedure is necessary know what variables are given from the experimental result or from literature and what variables were calculated.

Known variable:

- Wood consumption in the benchmark case (f_{m_3SF})
- 3SF efficiency
- Stove efficiency

Calculated variable:

- Stove wood consumption (f_{m_stove})
- Wood saved

To compute the wood saved the starting value were the fuel consumed with the three stone fire (f_{m_3SF} = 4500 kg/year), the three stone fire efficiency and the stove efficiency. The variable needed to calculate the wood saved is the f_{m_stove} of the stove an consequentially the wood saved is $\frac{f_{m\_3SF} - f_{m\_stove}}{f_{m\_3SF}}$.

Now the problem was how to obtain the wood consumption of the stove with the initial value explained before. In particular the issue was how calculate the wood saved starting from the efficiency.

The mathematical steps to pass from f_{m_3SF} the to the f_{m_stove} imply knowing of the efficiency of the stove and that of the benchmark case.

In order to permit to pass from the efficiency to the wood consumed it was used the WBT equation reported in the chapter 4, this imply that all the households involved use the WBT procedure to cooking.

This assumption was necessary as a buffer from the two level of technologies, having only the efficiency as known value.

The use of WBT as a model is not so far from the reality because the WBT is pretty near to the common way to cook boiling water or some soup. In figure 5.4 is reported a flowchart where are explained the steps to achieve the f_{m_stove} starting from the f_{m_3SF}.

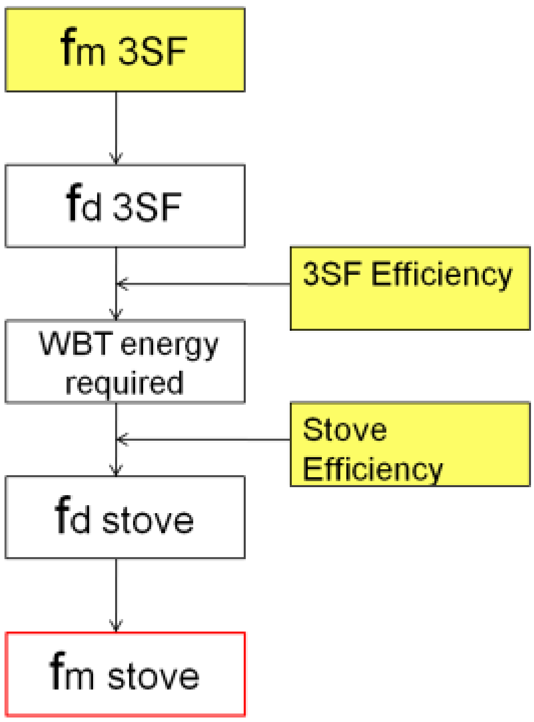

Fig 5.5 Flow chart of calculations steps

As explained before the common point from to f_m of the two technologies is the WBT, in particular the energy needed to perform a WBT.

To understand the flow chart is better known that the yellow box are the variable known form the experiments and the literature. f_m is the wood directly put in the stove, while the f_d is the mass of the wood less the moisture content and the char, as explained in the chapter 4. To derive the wood consumed from the efficiency is necessary calculate the f_d but to calculate the wood saved, as explained before, is needed the f_m. To switch from the f_m to f_d or vice versa, is needed a correction factor, derived from the experiment. The value of this factor is about 1.24. With the steps indicate in the flow chart it has been possible calculate the wood saved in each case and for each stoves.

5.4. Results

As explained before the scenarios are made with two different model of stoves. The Chitetezo Mbaula is the stove that will be implemented but in this analysis it has been introduced the Envirofit in order to implement the results obtained from the experiments and to give another point of comparison with three stone fire. The amount of wood has been calculate for each tranche of stove distributed and on each tranche it was applied all the hypothesis described before. Adding all the tranche all together is possible obtain the entire effect of the project and examining each tranche separately is possible to understand each phase of the project. To obtain the amount of CO_2 starting from the wood simply multiply for the carbon content of the wood and so dived and multiply for the molecular weight of the carbon dioxide CO_2 (44 kg/kmol) and carbon C (12 kg/kmol). This is an approximation because some part of the carbon in the wood became particulate and this product is not considered in the amount of CO2. Neglecting this part of the emission the error is practically inexistent (the ratio particulate/CO_2 is about 0.14%). Other aspects are the unburned products, such as the carbon monoxide CO. This products are unstable and in a short time becomes CO2, so even the unburned product are considered for the environmental aspect. The CO effects are not considered in this analysis where the focus is only on the environmental aspects and the health issue are not considered. After all this assumptions here are reported the plots on the CO2 trend. The two different condition analyzed were the field case and the laboratory case. This two cases differs from the boundary condition, in particular for the environmental temperature. For the field case reference was made at the environmental condition in Malawi where the average temperature is about 19 °C. For the laboratory case the environmental temperature was 30°C and all the data were available, this data was obtained contacting the team that performed the experiments. For the Mbaula stove the field efficiency was known in the literature and this value is referred to the typical condition in Malawi. Meanwhile for the Enviroft 3300 it has been necessary adapt the experimental efficiency to the Malawi boundary condition using the correlation showed in the paragraph 4.2. as in the benchmark case it was done the same adaptation. In this way the data field and the data lab are comparable, having the same references. The first step is analyzing the field trend of the CO_2 production of the two stove model.

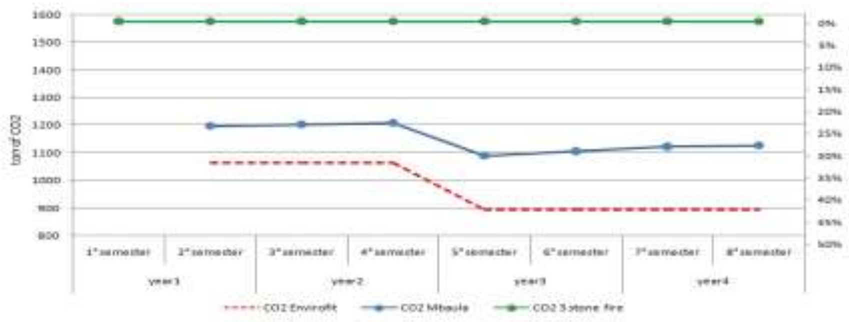

Fig 5.6 CO2 trend from one tranche in the field case

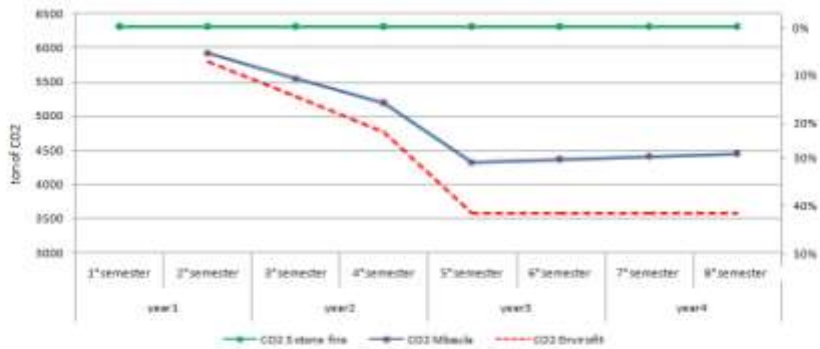

Fig 5.7 CO2 global trend in the field case

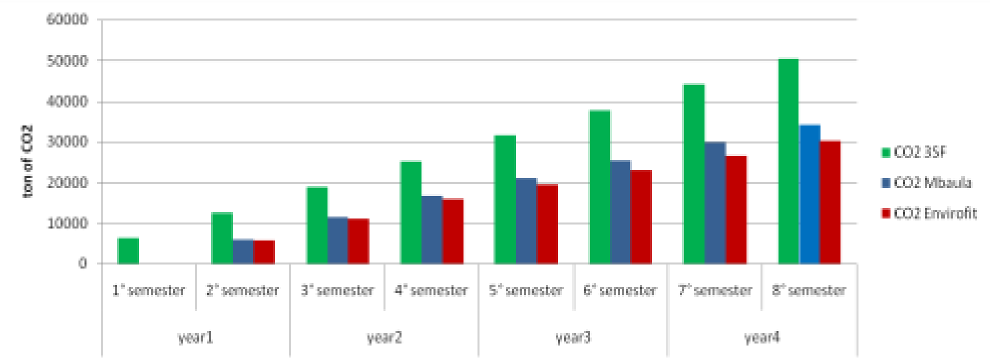

Fig 5.8 CO2 cumulative production in the field case

In the first graph are plotted the three trend of CO_2 produced from the three stone fire, the Mbaula stove and with the Envirofit stove in one tranche. On the principal axe are indicate the absolute quantity of CO_2 produced while on the second axe are indicate the relative percentage of CO_2 saved from the benchmark case (3 stone fire). The trend of the stoves start one semester later because the first training semester.The second plot represents the trend of CO2 production of the entire

project. Is clear how in the second and third semester the stoves trend are flat, changing the inclination only due the failure rate.
In the first fourth semesters the second plot in more angled because in each semester one new tranche of stove is delivered and consequentially the CO_2 decrease. In both the plots in at the end of the second year there is a strong slope changing, this because at the end of the second year it was supposed that the household percentage that use the improved cook stove pass from an 60% to a 80%. And in both plots the CO_2 production of the three stone fire is a constant value independent from any external factor. The Mbaula and Envirofit trends are slightly different. This difference is appraisable from the fifth semester to the end of the project. In this period the Mbaula increase is value because the damaging of the stove. While the Enviroft stay constant, because the Envirofit has an lifetime very high, and is very improbable that this model of stove could broke. This is due to the different material and technologies which are made the stoves. The Envirofit is made with metal and insulation material, while the Mbaula is made of clay, is obvious the different endurance to external factor such as shock or weather condition (rain).So the CO_2 production doesn't change, the only effect that affect the Envirofit is the people usage. In both the plot is possible to see the disparity of CO_2 production between the Envirofit and the Mbaula. This is because the efficiency differences of the two models. This can be seen in the cumulative plot (Fig 5.7) where at the end of the project the CO_2 produced is lower in the Envirofit. In order to have a better idea of the numbers here is reported a small table where are listed the principal data.

Field	Mbaula	Envirofit 3300
Efficiency	20,65%	27%
Wood saved	40,00%	54,11%
CO2 produced	40492 [ton]	36441 [ton]
CO2 saved	19,70%	27,70%

Table 5.1 Stoves performance in field

Now will be analyzed the laboratory case. The typologies plots are the same of the field case: CO_2 production in one tranche, CO_2 production in the entire project and the cumulative production.

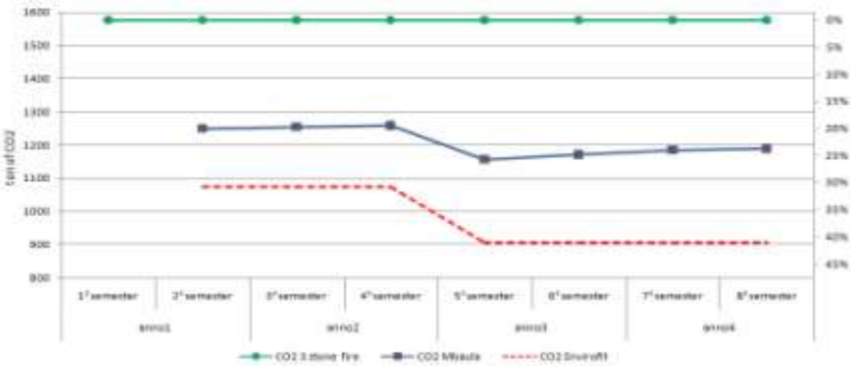

Fig 5.9 CO2 trend from one tranche in the lab case

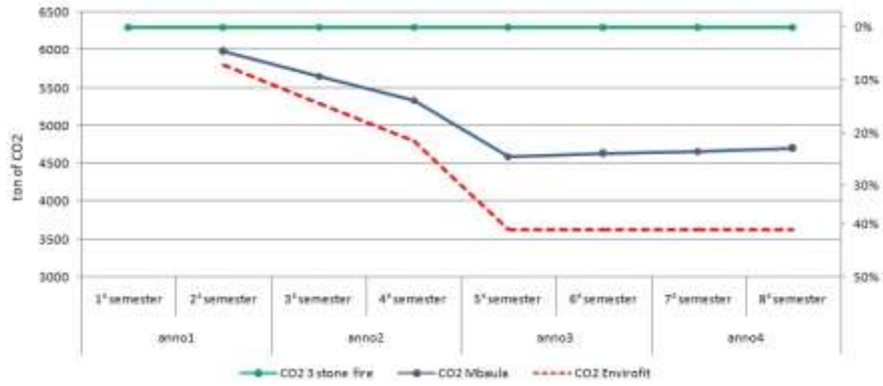

Fig 5.10 CO2 global trend in the lab case

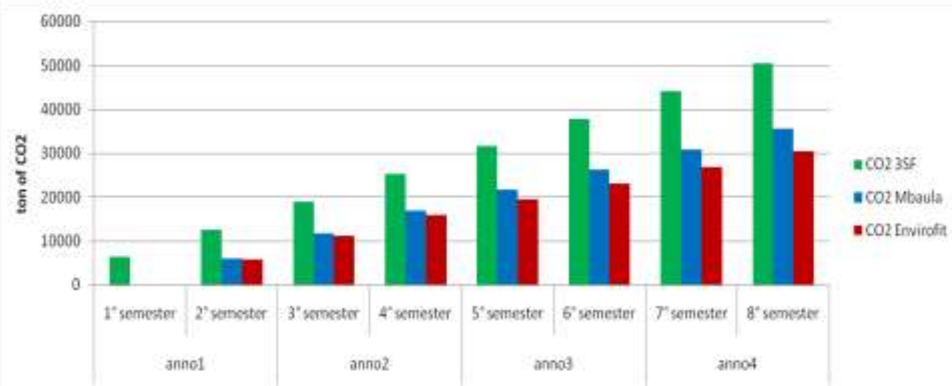

Fig 5.11 CO2 cumulative production in the laboratory case

As in the field case here are reported the principal values.

Lab	Mbaula	Envirofit 3300
Efficiency	22,90%	32%
Wood saved	34,50%	53,13%
CO2 produced	41859 [ton]	36695 [ton]
CO2 saved	17,00%	27,20%

Table 5.2 Stoves performance in laboratory

The trend in the laboratory case and in the field case are the same. The difference is in the values, and in the improvement and then in the CO_2 saved. This is clear in the plot looking the distance between the trend of Mbaula and the Envirofit to the benchmark case, watching the second axe. This differences are caused by the different boundary condition existing in the field case and in the laboratory case.
In particular is interesting analyzing this differences, showed in the table below.

CO_2 saved	*Field*	*Lab*
Mbaula	19,70%	17,00%
Envirofit 3300	27,70%	27,20%

Table 5.3 CO2 saved

Is clear how the Envirofit is more performing than the Mbaula saving more CO_2. Observing the data is clear how the Mbaula save less CO_2 than the Envirofit passing from the field case to the lab case. The reason could be found in the differences of efficiency compared with the benchmark case.

Efficiency	*Field* [19 °C]	*Lab* [30°C]
Envirofit 3300	27,00%	32,00%
Mbaula	20,65%	22,90%
Three stone fire	12,39%	15,00%

Table 5.4 Efficiencys

The differences between the field and the lab are strongest in the three stone fire and in the Envirofit, while the changing boundary condition has less effect in the Mbaula stove. This is the cause of the different value of CO_2 saved in the field and lab case. In order to understand how works the correlation between the boundary condition and the efficiency of different devices with different construction materials, it should have more data obtained with more experiments performed with the same boundary condition.
After the CO_2 analysis it was perform a study about the woodland saved with adoption of improved cookstoves. This calculation was performed starting from the wood consumed value derived from the forecast scenario. Knowing the wood density and the woodland density (measured in cubic meter per hectare) it was possible to calculate the woodland area deforested. The difference between the woodland destroyed of the three stone fire and of the improved cookingstoves gives the area saved with using the improved stoves. Here are reported the results obtained.

Woodland saved [ha/ year]	*Field*	*Lab*
Mbaula	64,00	55,20
Envirofit 3300	90,10	88,48

Table 5.5 Woodland area saved

Where the wood density is 442.5 m^3/kg [51] and the woodland density is 51.2 m^3/ha [52] and in the entire Malawi the annual area lost because the deforestation is 33000 ha per year [53].

6. Conclusions

The line of reasoning that has been followed during the development of this work was to start from a general appearance of the use of biomass and then going into more detail on the substance of the issue of improved stoves. Subsequent analyzes have been more on the technical aspects and experimental then conclude with the use of this technology in the real world.

What emerged was the conditions and methods of biomass use. Seeing as its use is so deeply rooted in the culture of the peoples of the countries in the developing world and how this can often be a real trap of poverty , forcing people who do not have access to the most modern use of biomass fuels traditional. This not only implies a delay in the progress of technology, but a kind of social and economic impasse from which it is difficult to get out even with the profusion of humanitarian aid and incentives.

Several considerations have been taken from the more detailed study of the technologies used for biomass burning, and then on the definition and characteristics of improved cooking stoves. It is then seen that an improved stove can be a vector that leads to the use of the most technologically advanced tools and therefore the use of cleaner fuels and more reliable and available, then going to improve the situation not only environmental or health users, but also improve the economic and social condition of end users. Then analyzing the technological features that characterize an improved stove was possible to understand what might be the points on which act to increase efficiency . For that concerns this aspect refers to the quality of the combustion is mentioned the shape of the combustion chamber and as it is in many stoves uses the classic form elbow to facilitate the entrance of air. Of how to obtain a further saving of firewood is useful to isolate the stove as in the case in which it is built in metal where it is explained that the insert of the interspaces of refractory material gives the best performance, while in the case where the stove is already built in clay or cement is appropriate to have a thick layer of insulation between the combustion chamber and the external environment . Looking at the appearance of a better protection of health and therefore, in particular, trying to limit the Indoor Air Pollution , it is seen as the installation of a chimney is of main importance. First to bring outdoor the combustion smoke and soot and as second aspect ensure a better draw, and therefore a greater excess of air thereby reducing the generation of unburned , such as carbon monoxide. To better understand how to quantify the improvement of this technology, we analyzed the tests currently used for measuring efficiency. What all this tests have in common is the goal to be able to standardize a practice quite varied as that of act of cooking. The test most commonly used for the calculation of the efficiency is the Water Boiling Test, but other tests such as Controlling Cooking Test aim to get closer and closer to the actual use of the stove, going to simulate the actual act of cooking using as a yardstick the typical dishes of the region in which you want to test the stove . The importance of the results obtained is crucial to quantify the real benefit that it can bring a plan to implement the stoves and then figure out where they might be flaws in the method of development.

Analyzing the database, and then having had the chance to compare different models of stove going through the construction features, materials and fuel with which they are supplied. It was possible to understand how the most used material is metal, due of the easy way of purchase, such as recovery from old cans or scrap and also the convenience of the work of simple sheet metal. Even the clay is discretely used, as the peculiarity of this material is the ease of retrieval being available directly from the soil. The problem of this material is its brittleness and therefore is less favored as a construction material, although is longer available. Among the constructive particularities that which was found in the most number of models was the portability of the stove. This fact is not surprising when you consider that very often the act of cooking is done outside the house, and when the weather conditions do not allow it, moves to the stove inside. Turning to the type of fuel it was found as the wood is being used worldwide as the most available in terms of costs and of quantity and ease to finding. Also the charcoal made from wood has a good percentage of use, even if requires more effort in terms of human labor economic effort and if it is decide to buy it. Even animal dung often are used as fuel, especially in those areas where the availability of wood is scarce or the wood is too far away and therefore too uncomfortable to be achieved. Crossing all of these aspects has emerged as the portable metal stove fed with firewood is the most common, although still clay combined with wood as fuel is still present in a significant way in the models analyzed. Different however is the relationship with the material with coal and in fact it was found that only the metal stoves are feed by coal, this is probably due to the fact that this fuel burns at high temperatures and therefore the stoves of clay may have structural failure.

Different types were the conclusions obtained from the experimental session included in this thesis . The first consideration is the purpose of the ideation of the Boiling Water Test and which are therefore in its points of weakness in describing the performance of the stove. As the WBT in fact it is a procedure that simulates the act of cooking , and being conducted under standard conditions and in a controlled environment, may lose some meaningful information on the efficiency of the stove in its actual operating conditions. On the other hand in order to have comparable data between them is necessary to have a standard protocol to follow with precise parameters to be calculated. This ensures the repeatability of the experiment and makes possible its comparison with other evidence, in order to have an objective on the capabilities of the stove. In the case of the experiments reported in this paper the condition of repeatability has failed, just for the fact that have been made in external environment not controlled. This has

resulted in a significant variability of the results. Some variable are difficult to standardize and control like the way to feed the stove so as to be able to optimize the management of the wood to obtain the best possible result. The analysis of the literature has led to highlight substantial differences between the two sets of data. The experimental results gave an efficiency almost halved compared to that available in literature. By analyzing the conditions under which the experiments were carried out reference is seen as the boundary conditions were substantially different. The subsequent analysis has led to a reunion of the two results, understanding that the boundary conditions in particular temperature are of fundamental importance in the performance of the stove. Have conducted experiments, in an uncontrolled environment subject to rapid change has made the analysis closer to the real use of the stove questioning the real functionality of experiments done in the laboratory. This when you consider that those values are used by external organizations to make predictions about the effects that can be had by implementing that particular model of stove.
And this was an hint to process the scenario analysis of the last chapter. This scenario analysis can be a useful forecasting tool for real projects, thus helping developers to focus on some issues more relevant than others. Regarding specifically the scenario was done using the base of a project made by COOPI according to the criteria of the PCM (project cycle management). As for the hypothesis was based primarily on the literature of GTZ. The information that GTZ was able to find on the field have been of vital importance to be able to introduce sensible hypothesis, in order to enrich the model .
Relying on these assumptions, it was possible to create a model as close as possible to reality. Comparisons between the various scenarios and the two models considered have provided different interpretations of the results. The first consideration emerged was the best absolute performance compared to the Envirofit with the Mbaula. These best performance are given essentially by the important layer of insulation separating the combustion chamber from the external environment and the elbow shape of the combustion chamber, both of these characteristics have a strong weight on the final result . It was found as the efficiencies, for both models, in the laboratory case are higher than those measured in field. This as mentioned in the previous chapters is due by the boundary conditions in the specific cases examined were more unfavorable in the case in the field, since the operating temperatures was lower than those observed in the laboratory. Several considerations have been derived from analysis of the fuel saved. Is emerged as in the field case there is a greater saving of wood compared to laboratory while having efficiencies minors. The reason for this trend is to be found in the reference case (three stone fire), since the efficiency of the base case suffers a lot of change in external conditions. This important difference in the change in performance of the base case influence as we have just said the saving of the wood and then the production of carbon dioxide. Another aspect to consider is

how many fuel was saved from Mbaula case to Envirofit case, always compared between the two different conditions. Focusing on this aspect and analyze the values you see as the Mbaula, from the event field to the laboratory, affected more than the change in external conditions, managing to save less fuel than the Envirofit.

Wood saved	*Field*	*Lab*
Mbaula	32,48%	27,54%
Envirofit 3300	54,11%	53,13%

As is shown in the table the difference between the fuel saved between the two use cases is more pronounced in the case Mbaula (4.94 % less in the case Lab) compared all'Envirofit (0.98) % less than in the case lab) .
These conclusions are only numerical dates from the evidence, to fully understand the reasons behind these behaviors should investigate many aspects. Starting from the analysis of the context, maybe not relying only on documents but also with scout in order to understand in greater depth the issues that are behind the behavior of countries in the developing world. As regards the experimental phase, which is still connected to the analysis of prediction. The improvement is that it is hoped to be able to have many more samples in order to obtain a statistical analysis. Furthermore, these experiments should be made more comparable and then carried out in parallel in order to ensure equal boundary conditions. Obviously, an improvement of this magnitude would involve a large commitment of financial and human resources, but it would be the way to go in order to get a job that will be useful and usable.

7. Appendix

Stove name	Materials					Fuels				
	Cement	Bricks	Ceramic	Clay	Metal	Briquettes/Pellets	Charcoal	Crop residues	Dung	Wood
100 Liter Institutional Cookstove					X	X				X
5 Star Stove Basic					X	X				
5 Star Stove Upgrade					X	X				
60 Liter Institutional Cookstove					X	X				X
Advent				X	X					X
ARTI Bhayalaxmi	X				X			X	X	X
ARTI Grihalaxmi	X				X			X	X	X
ARTI Laxmi	X				X			X	X	X
Belonio					X			X		
Berkeley-Darfur Stove V.14					X					X
BioLite CampStove					X	X				X
BioLite HomeStove					X			X	X	X
CCS922A					X		X			
CCS922B					X		X			
DA Anandi	X							X		X
DA DC-I	X								X	X
DA DC-II	X								X	X
DA Laxmi	X								X	X
DA SARAL	X								X	X
DA Sukhad	X								X	X
DA TARA 101					X					X
Dos por Tres (2x3)										X
Ecocina										X
ECO-KALAN-C				X			X			X
Ecostufa										
Envirofit B-1200					X					X
Envirofit CH-2200					X		X			
Envirofit CH-4400					X		X			
Envirofit CH-5200					X		X			
Envirofit G-3300			X		X					X
Envirofit M-5000			X		X					X
Envirofit Z-3000			X		X					X
Iron Man					X					
Jinqilin CKQ-80I					X			X		
Mayon Turbo								X		
Mbabula				X	X		X			
Mbaula Green					X		X			
Moto Stoves							X			
Mwoto Quad2 Stove.					X					X
Onil										X
Oorja						X				
Philips HD4008					X	X				X
Philips HD4012					X	X				X
Quick Mami	X									
Rocket Stove										
Square John	X									
Standard Eco-Kalan				X			X			
StoveTec										X
StoveTec GreenFire							X			X
Zoom Dura					X					X
Zoom Dura Lite					X					X
Zoom Jet					X		X			
Zoom Plancha					X		X			X
Zoom Relief					X					X
Zoom Stove Z-WCC26					X		X			X
Zoom Versa					X		X			X
Zoom Versa Lite					X		X			X
Six Bricks		X								X

Stove name	Characteristics												
	Batch loaded	Built in place	Ceramic lined	Chimney	Fan	Gasifier	Griddle/Plancha	Multiple Burners	Natural draft	Portable	Pot skirt	Side-feed	Thermoelectric generator
100 Liter Institutional Cookstove				X					X		X		
5 Star Stove Basic		X		X	X	X				X			
5 Star Stove Upgrade				X	X	X				X			
60 Liter Institutional Cookstove		X								X	X		
Advent									X	X		X	
ARTI Bhayalaxmi		X											
ARTI Grihalaxmi		X											
ARTI Laxmi		X		X									
Belonio						X				X			
Berkeley-Darfur Stove V.14					X	X		X	X	X	X		
BioLite CampStove													X
BioLite HomeStove					X				X				X
CCS922A					X								
CCS922B					X								
DA Anandi		X		X									
DA DC-I		X		X									
DA DC-II		X		X									
DA Laxmi		X		X									
DA SARAL		X		X									
DA Sukhad		X		X									
DA TARA 101										X			
Dos por Tres (2x3)		X		X			X		X			X	
Ecocina							X		X			X	
ECO-KALAN-C									X	X			
Ecostufa				X			X		X	X		X	
Envirofit B-1200									X	X		X	
Envirofit CH-2200	X									X			
Envirofit CH-4400	X									X			
Envirofit CH-5200	X									X			
Envirofit G-3300									X	X		X	
Envirofit M-5000									X	X		X	
Envirofit Z-3000									X	X		X	
Iron Man		X		X					X	X		X	
Jinqilin CKQ-80I				X			X						
Mayon Turbo									X	X			
Mbabula	X									X			
Mbaula Green	X		X			X				X	X		
Moto Stoves	X					X				X			
Mwoto Quad2 Stove.	X					X				X			
Onil							X						
Oorja										X			
Philips HD4008						X				X			
Philips HD4012						X				X			
Quick Mami									X	X		X	
Rocket Stove		X							X	X		X	
Square John									X	X		X	
Standard Eco-Kalan									X	X			
StoveTec									X	X		X	
StoveTec GreenFire									X	X		X	
Zoom Dura			X						X	X	X	X	
Zoom Dura Lite			X						X	X	X	X	
Zoom Jet	X		X						X	X			
Zoom Plancha				X			X		X			X	
Zoom Relief			X						X	X	X	X	
Zoom Stove Z-WCC26									X	X		X	
Zoom Versa			X						X	X	X	X	
Zoom Versa Lite									X	X		X	
Six Bricks									X	X		X	

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