**UNIVERSITÀ DEGLI STUDI DI BRESCIA**

Facoltà di Ingegneria

Corso di Dottorato di Ricerca in

Metodologie e Tecniche Appropriate

nella Cooperazione Internazionale allo Sviluppo

CICLO XXIV

Settore scientifico disciplinare ICAR/03 – Ingegneria Sanitaria-Ambientale

# Appropriate solutions for cooking energy at household level in the Logone Valley (Chad – Cameroun)

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# Sommario

## Introduzione

Un adeguato accesso all'energia è un prerequisito fondamentale per un appropriato sviluppo umano. Diversi studi e rapporti di agenzie e organizzazioni internazionali (IEA – Agenzia Internazionale dell'Energia 2011, WB – Banca mondiale 2011, WHO – Organizzazione Mondiale della Sanità e UNEP – Programma Ambientale delle Nazioni Unite 2009) hanno riconosciuto il forte legame tra l'accesso all'energia e il raggiungimento degli Obiettivi di Sviluppo del Millennio (Sanchez 2010), in particolare la riduzione della mortalità infantile (Obiettivo 4) e la riduzione della povertà estrema (Obiettivo 1) (Bruce et al 2011). L'accesso all'utilizzo di tecnologie semplici e pulite che garantiscano un livello energetico minimo ma adeguato (Practical Action 2010) è un processo indispensabile per il miglioramento della qualità di vita delle popolazioni più povere.

Nel mondo quasi tre miliardi di persone si affidano ancora a combustibili tradizionali solidi per soddisfare i loro bisogni di cucina quotidiana. La maggioranza vive nei Paesi in via di sviluppo, in particolare in Cina e Africa sub-sahariana. In questi contesti il legno è spesso l'unica fonte di energia per le famiglie e le piccole attività produttive. Questo aggrava ulteriormente la pressione sulle risorse naturali che sono già pesantemente sfruttate dal settore industriale e dal commercio internazionale del legno, aggravando problemi quali la desertificazione e la deforestazione (Geist e Lambin 2002, Mahiri e Howorth 2001). La crescente scarsità di legno comporta implicazioni gravi sia per l'ambiente sia per la popolazione locale: il taglio illegale è diventata una pratica comune, i costi dei combustibili primari (legna o carbone) sono soggetti ad aumenti vertiginosi, donne o bambini devono coprire distanze sempre maggiori per raccogliere la legna necessaria per cucinare tutti i giorni. Inoltre, l'uso di combustibili solidi in fuochi aperti o in stufe inefficienti porta all'emissione all'interno degli spazi domestici di una serie di inquinanti che danneggiano la salute, condizione spesso aggravata dalla scarsa ventilazione dei locali adibiti alla preparazione dei cibi (Rehfuess et al 2011, Ezzati et al 2002). Donne e bambini piccoli, che trascorrono molte ore in prossimità della sorgente del fumo, sono i più esposti (Desalegn et al 2011). Ciò si traduce in un impatto drammatico sulla salute: in tutto il mondo quasi due milioni di morti per polmonite, malattie polmonari croniche e cancro ai polmoni sono riconducibili all'esposizione a livelli elevati di inquinamento dell'aria domestica derivanti dalla combustione di biomassa e carbone (Zhang e Smith 2003). Tali emissioni possono anche avere gravi effetti sul riscaldamento globale, contenendo sottoprodotti ad elevato potenziale clima alterante generati da processi di combustione incompleta (Smith 1994, Bailis et al 2003, Venkatamaran et al 2010, Bhattacharya e Salam 2002).

L'accesso a stufe migliorate (cioè sistemi che garantiscano una migliore combustione, una maggiore efficienza nel trasferimento del calore alla pentola, un livello minimo di emissioni dannose per la salute) è ancora molto limitato. Nei paesi meno sviluppati solo il 7% delle persone che utilizzano sistemi di cottura migliorati, rispetto al 27% delle persone nei paesi in via di sviluppo nel suo complesso (WHO & UNEP 2009). Nei programmi di cooperazione internazionale di diffusione di stufe migliorate spesso in passato si sono verificati dei fallimenti, dovuti, in parte, alla mancanza di standard e di controllo di qualità, e a scarsa attenzione alla progettazione delle tecnologie (WB 2011). Oggi, una nuova generazione di stufe migliorate avanzate a biomassa sono disponibili in commercio, così come stufe meno costose, ma comunque efficaci possono rappresentare una possibilità intermedia per garantire un accesso più appropriato all'energia domestica.

## Obiettivo della ricerca

L'implementazione di tecnologie di cottura adeguate in contesti con risorse limitate è strettamente necessario per dare una risposta concreta e sostenibile a questo problema. In particolare questo lavoro si concentra su una specifica regione, la Valle Logone al confine tra Ciad e Camerun. La ricerca è stata realizzata nell'ambito delle attività di un progetto di cooperazione internazionale allo sviluppo (ENV/2006/114-747) implementato dalla ONG italiana ACRA e finanziato dalla Comunità Europea. Dato il contesto locale ed i relativi vincoli, la sfida era di trovare le soluzioni adeguate, sotto un punto di vista tecnico, per la riduzione del consumo di legna. La parte principale del progetto si è concentrata sulla protezione delle risorse naturali, in particolare attraverso la creazione di comitati comunitari per la protezione e gestione delle foreste locali. Tra le attività del progetto, un'azione specifica è stata rivolta alla riduzione del consumo del principale combustibile domestico, il carbone di legna, che era prodotto localmente in processi di carbonizzazione a bassissima efficienza. Il tema di ricerca di questo lavoro è stato sviluppato in parallelo con le attività del progetto al fine di individuare una serie di tecnologie energetiche appropriate per raggiungere l'obiettivo della riduzione del consumo di combustibile a livello familiare. L'ambiziosa domanda di ricerca che ha guidato questo lavoro è "Quale tecnologia di cottura è appropriata per l'accesso all'energia nella Valle Logone?" La ricerca ha approfondito i risultati e gli interessi più recenti della comunità scientifica internazionale, cercando di coniugarli nel modo più appropriato con i vincoli locali dato dalla peculiarità del contesto di implementazione. Sia gli aspetti tecnologici e che quelli relativi agli impatti generati dall'utilizzo stesso delle tecnologie sono stati considerati al fine di dare una valutazione globale del sistema di cucina studiato.

## Struttura della tesi

I primi tre capitoli forniscono al lettore le basi per i casi di studio che vengono presentati in seguito. Per ogni caso di studio sono prima discussi gli aspetti legati alla tecnologia, mentre in un capitolo successivo sono presentate alcune considerazioni circa l'impatto dell'adozione di tali tecnologie. L'ultimo capitolo propone una valutazione complessiva dell'appropriatezza delle tecnologie studiate in base ai risultati ottenuti durante la ricerca.

Questo lavoro si sviluppa in otto capitoli:

I. il capitolo 1 offre una breve panoramica del settore dell'energia per la cucina domestica nei paesi in via di sviluppo. L'argomento è veramente ampio e molta letteratura scientifica è stata prodotta. Inoltre essendo un settore molto multidisciplinare, che varia dall'energia alla gestione ambientale, dalla salute all'economia, con impatti incrociati sugli aspetti sociali e influenze dei comportamenti degli utenti e delle pratiche locali, è molto difficile dare una trattazione completa e dettagliata. Questo capitolo descrive le interconnessioni tra l'accesso all'energia e lo sviluppo, la dimensione del problema a livello globale secondo i più recenti lavori pubblicati, i fattori che influenzano il consumo energetico e gli impatti principali sulle utenze.

II. Il Capitolo 2 presenta la metodologia generale adottata in questo lavoro; i metodi e i protocolli specifici utilizzati e implementati nelle diverse attività sono riportati in una sessione relativa per ogni capitolo.

III. Il Capitolo 3 fornisce alcune informazioni sul contesto studiato sia a livello nazionale che locale, la Valle Logone. In questo capitolo sono presentati alcuni dati raccolti in sito, con una descrizione dettagliata dello stato energetico delle famiglie nell'area di intervento.

IV. Il Capitolo 4 presenta i risultati di un certo numero di test eseguiti su stufe migliorate disponibili localmente che utilizzano diversi combustibili. Le due stufe scelte per la diffusione sono state incluse nell'insieme dei modelli testati. Le stufe sono state testate secondo protocolli standard internazionali, il che ha permesso un confronto con altri studi simili.

V. Il capitolo 5 riporta la valutazione dell'impatto della diffusione di un preciso modello di stufa, la stufa Centrafricain, promossa dal progetto. Impatti socio-economici, ambientali e sulla qualità dell'aria domestica sono stati quantificati utilizzando indagini mirate. Una particolare attenzione è stata data all'attività degli artigiani formati nella produzione della stufa e alle indicazioni fornite dalle utenze locali che hanno adottato la stufa.

VI. Il Capitolo 6 presenta la ricerca e lo sviluppo di una stufa pensata per recuperare la lolla di riso, una biomassa disponibile localmente che è attualmente considerata come un rifiuto. Seguendo i risultati ottenuti in itinere, diverse configurazioni sono state testate per migliorare l'efficienza della stufa. I principali risultati di questa attività (che è ancora in corso) sono riportati in questo capitolo. Il processo tecnico di ricerca e sviluppo è stato fatto in piena collaborazione con il DIMI, Dipartimento di Ingegneria Meccanica dell'Università degli Studi di Brescia, in particolare con il dott. Simone Parmigiani.

VII. Il Capitolo 7 contiene alcune considerazioni riguardo alla sostenibilità economica della stufa a lolla di riso proposta. Nonostante il processo di ricerca e sviluppo sia stato guidato da vincoli tecnici dettati dalla conoscenza del contesto locale, ed alcuni prototipi pilota siano stati riprodotti in sito, non è stato possibile diffondere la tecnologia a scala reale. Quindi, è stato elaborato un semplice modello economico considerando i principali fattori di impatto sul consumo di energia per famiglia, assumendo diversi mix di combustibile. L'obiettivo di tale valutazione preliminare è stato quello di evidenziare la soglia che rende fattibile l'acquisto e l'adozione della stufa a lolla di riso nel contesto studiato.

VIII. Il Capitolo 8 riassume i risultati delle attività realizzate, sia in loco sia in laboratorio. Un'analisi multi-criteri è stata applicata al fine di evidenziare la migliore tecnologia di cottura per il contesto locale secondo i diversi impatti che diversi sistemi potrebbero avere sull'utente. Sono state studiate quattro macro-categorie, strutturando indicatori quantificabili per gli impatti economici, ambientali, sociali e sanitari legati all'uso di una certa tecnologia energetica. I sistemi di pesi adottati sono stati scelti in modo da considerare le caratteristiche di ciascuna tecnologia in base principalmente alla loro rilevanza per le esigenze locali.

Anche se le attività di progetto hanno interessato due Paesi, Ciad e Camerun, questa tesi si concentra soprattutto sul lato del Ciad, dove un divieto governativo per la produzione e la vendita di carbone nel 2009 ha colpito duramente la popolazione locale, costringendola al passaggio ad altre fonti di energia domestica.

Diverse indagini svolte nell'ambito di questo lavoro hanno rilevato le pressoché identiche caratteristiche socio-economiche e pratiche in ambito energetico domestico delle popolazioni divise da confini amministrativi, ma appartenenti alla medesima etnia, i Masa.

## Conclusioni

Le tecnologie appropriate giocano un ruolo chiave nel rompere il circolo vizioso della povertà energetica, fornendo soluzioni intermedie per fuggire da questa condizione limitante. Attualmente ci sono molte opzioni tecnologiche che permettono di utilizzare combustibili tradizionali in modo più efficiente. L'idoneità e l'applicabilità di tali tecnologie dipende da fattori quali la disponibilità di combustibili e materiali, l'accettabilità, la convenienza e la possibilità di far fronte a piccoli investimenti iniziali per l'acquisto della tecnologia. La riduzione della disponibilità di combustibili primari rende in alcuni luoghi il passaggio alle alternative moderne un obbligo. In alcuni altri l'inconsistenza di un mercato non supportato da realistiche politiche e strategie energetiche rende inaccessibile per la maggior parte delle persone l'accesso a combustibili più appropriati, provocando il ritorno a quelli tradizionali meno costosi. In base a questi aspetti, e per la stima del numero crescente di persone che continueranno ad utilizzare biomasse per cucinare nel prossimo futuro, l'adozione delle migliori tecnologie che permettono di utilizzare persino i combustibili poveri, ma in modo conveniente, pulito e più efficiente, sembra essere un valido modo per raggiungere l'obiettivo minimo di un adeguato accesso all'energia per i poveri.

L'approccio adottato in questo lavoro è fortemente influenzato da considerazioni fatte qui sopra. Un contesto specifico, la Valle del Logone al confine tra Ciad e Camerun, è stata quello in cui sono state effettuate le osservazioni sul campo e le attività qui presentate. Nella regione di intervento carbone e legno erano i combustibili tradizionali utilizzati a livello domestico. Solo nelle aree urbane alcune famiglie ad elevato reddito utilizzavano gas per cucinare. La produzione e la vendita di carbone è stata improvvisamente vietata dal governo ciadiano nel 2009. Ciò ha avuto un effetto scioccante sui prezzi del legno che sono più che raddoppiati, da 15 franchi CFA al kilogrammo nel 2008 a 35 franchi CFA al kilogrammo nel 2010. Il progetto ha mirato alla riduzione del consumo di legna a livello familiare. La scelta di diffondere modelli a basso livello tecnologico ma ad alta efficienza è stata fatta tenendo conto delle condizioni socio-economiche della popolazione locale (capacità di investimento minima dovuta al bassissimo livello di reddito) e delle competenze e degli strumenti disponibili per le piccole officine locali (in particolare la mancanza di elettricità incide sulle capacità produttive di base).

Sono stati condotte numerose prove sul posto per valutare quale modello di stufa, in combinazione con il relativo combustibile, fosse adatto per la diffusione tra la popolazione locale. I modelli di stufa sono stati scelti tra stufe migliorate tradizionali già disponibili nella regione e testati seguendo protocolli standard riconosciuti a livello internazionale (Prove di ebollizione dell'acqua WBT e prove di cucina controllata CCT). I due modelli scelti per la diffusione (attraverso la formazione di artigiani locali) sono stati la stufa migliorata ceramica e quella Centrafricain. Entrambe sono state selezionate non solo per le loro buone (ma non "migliori" rispetto a quelle delle tecnologie disponibili più avanzate) prestazioni tecniche, ma soprattutto per l'adeguatezza al contesto locale in termini di accettabilità da parte degli utenti e di riproducibilità. Una valutazione d'impatto basata sui risultati ottenuti è stata fatta per mezzo di una serie di indagini sia quantitative (Performance Test Kitchen, monitoraggio della qualità dell'aria domestica, stime delle emissioni di $CO_2$ evitate) sia qualitative (attraverso interviste, osservazioni). L'aumento dei tassi di adozione (oltre 3500 unità vendute a marzo 2011) e l'apprezzamento da parte degli utenti indica l'adeguatezza del modello di stufa proposto al contesto locale. La riduzione dei consumi (-55% per la stufa Centrafricain rispetto al tradizionale fuoco aperto a tre pietre) e l'adattabilità alle pratiche di cucina locale sono le caratteristiche principali che gli utenti indicano come punti di forza della tecnologia. Questi aspetti sono stati fondamentali per il successo della diffusione del modello di stufa.

Parallelamente è stata portata avanti la sperimentazione di un nuovo disegno di stufa. L'input è stato dato dalla disponibilità locale di una certa biomassa di scarto, la lolla di riso, che si è pensato di recuperare come combustibile alternativo al legno per la fornitura domestica di energia. In piena collaborazione con il DIMI è stato progettata e testata una stufa migliorata per tale scopo. Questa stufa di mattoni in terra cruda è dotata di un camino e un reattore interno in rete metallica per contenere il combustibile. Tale lay-out consente un processo di combustione/gassificazione della biomassa che ne permette lo sfruttamento energetico per le attività di cucina. Un percorso rigoroso di ricerca e sviluppo è stato seguito al fine di indagare in dettaglio il funzionamento della stufa, ottenendo una configurazione finale con ottime prestazioni e affidabilità (efficienza media del 18%, basse emissioni di inquinanti sia in termini ambientali che sanitari). La stufa non è stata ancora diffusa in loco, tuttavia la progettazione del prototipo è stata sempre guidata da vincoli legati al contesto locale. Non sono stati considerati solo gli aspetti tecnici come la disponibilità materiale o le competenze tecniche degli artigiani locali, ma sono stati affrontati anche aspetti come l'adattabilità alle pratiche locali, la sostenibilità e l'accettazione da parte degli utenti. Secondo i risultati di un semplice modello economico elaborato *ad hoc*, l'introduzione della stufa a lolla di riso "*mlc (my little cookstove")* nel sistema di cottura di una famiglia è economicamente sostenibile. Tutti gli scenari elaborati mostrano come l'adozione della stufa a lolla di riso ridurrebbe in modo significativo la spesa di carburante per la casa, nei limiti della disponibilità locale di tale biomassa. L'uso della tecnologia proposta, in combinazione con una stufa migliorata a legna, fornirebbe alle famiglie un insieme di sistemi di cottura appropriati e convenienti, aumentando le opportunità di scelta della tecnologia energetica preferenziale per l'utente. Ciò risulta ancora più importante se si considera il crescente prezzo della legna osservato in sito, il che può potenzialmente influenzare negativamente i vantaggi connessi all'utilizzo delle sole stufe migliorate a legna.

Un'analisi a multi-criteri finale ha consentito di valutare l'adeguatezza delle tecnologie studiate fornendo una visione globale dei risultati ottenuti nelle diverse attività. La struttura di analisi è stata costruita allo scopo di evidenziare la migliore tecnologia di cottura per il contesto locale secondo i diversi impatti che un tale sistema potrebbe avere sull'utente. Sono state studiate quattro macro-categorie principali, strutturando indicatori quantificabili per gli impatti economici, ambientali, sociali e sanitari legati all'uso di una certa tecnologia energetica. I sistemi di pesi adottati sono stati scelti in modo da considerare le caratteristiche di ciascuna tecnologia in base principalmente alla loro rilevanza per le esigenze locali. Un'analisi di sensibilità, che ha preso in considerazione un sistema di pesi in base alle priorità elencate da un gruppo di esperti di energia domestica, ha evidenziato alcune differenze tra il punto di vista delle persone che lavorano nel settore e quello delle persone che dovrebbero adottare l'uso quotidiano della tecnologia. Per colmare questa distanza, dovrebbe essere raggiunto un insieme condiviso e adeguato delle priorità, da un lato attraverso la consapevolezza e l'educazione della popolazione locale sulla tutela dell'ambiente e della salute, in modo che anche gli impatti negativi legati a queste categorie siano efficacemente percepiti dagli utenti diretti. Dall'altro lato la facilità d'uso, l'adattabilità alle pratiche di cucina locale e l'affidabilità del combustibile e delle tecnologie sono aspetti che non dovrebbero essere trascurati, ma anzi dovrebbero guidare la progettazione di un nuovo sistema di cottura da parte della comunità scientifica.

L'analisi effettuata in questo lavoro permette di trarre alcune considerazioni finali generali. Il tradizionale modello economico di accesso all'energia, la scala energetica "*energy ladder*", come qualsiasi modello di tale genere, è verosimile fornire solo una visione limitata della realtà delle famiglie (Masera et al 2000). A causa dell'inadeguatezza di tale modello lineare nel descrivere le dinamiche di adozione dei diversi combustibili, in molti casi un approccio a "combustibili multipli" appare più appropriato. L'ampia gamma a disposizione di nuove tecnologie di cottura ha il grande potenziale di utilizzare una varietà di residui di biomassa che sono difficili da bruciare in modo pulito in stufe tradizionali. In molti luoghi nei paesi in via di sviluppo la legna è ancora il combustibile preferito, a causa di abitudini tradizionali e pratiche sociali radicate, anche se la fatica fisica e le perdite di tempo legate all'attività di raccolta o l'impatto finanziario sul bilancio delle famiglie sono di giorno in giorno sempre più elevate. Allo stesso tempo, nelle stesse aree in cui carbone e legna da ardere stanno diventando una risorsa scarsa e costosa, sistemi innovativi, come i micro-gassificatori o le stufe a combustibile alternativo acquisiranno una crescente rilevanza, permettendo di bruciare biomassa in modo pulito. Rendere disponibili tali nuove tecnologie, promuovere la ricerca e trovare le strategie di diffusione più appropriate potrebbe aiutare concretamente le persone che vivono in povertà energetica a fuggire dalla loro condizione miserabile, guadagnando l'accesso ad un portafoglio di tecnologie energetiche più ampio. L'adozione di una varietà di sistemi energetici, affidabili, comodi, puliti e a prezzi accessibili, basati sull'utilizzo di combustibili multipli, potrebbe contribuire a proteggere le fasce di popolazione a basso reddito, notoriamente le più esposte alle fluttuazioni dei prezzi dei combustibili primari. Ciò permetterebbe di individuare un nuovo primo gradino ad un livello più elevato nella visione classica della scala di energia, definendo una raffigurazione più "piatta" (Figura A). Infatti le nuove tecnologie disponibili possono ridurre significativamente il divario in materia di accesso adeguato all'energia domestica tra le classi a basso e ad alto reddito, raggiungendo un uso efficiente (e non solo efficace) della biomassa, ad un livello similare a quello dei combustibili più moderni.

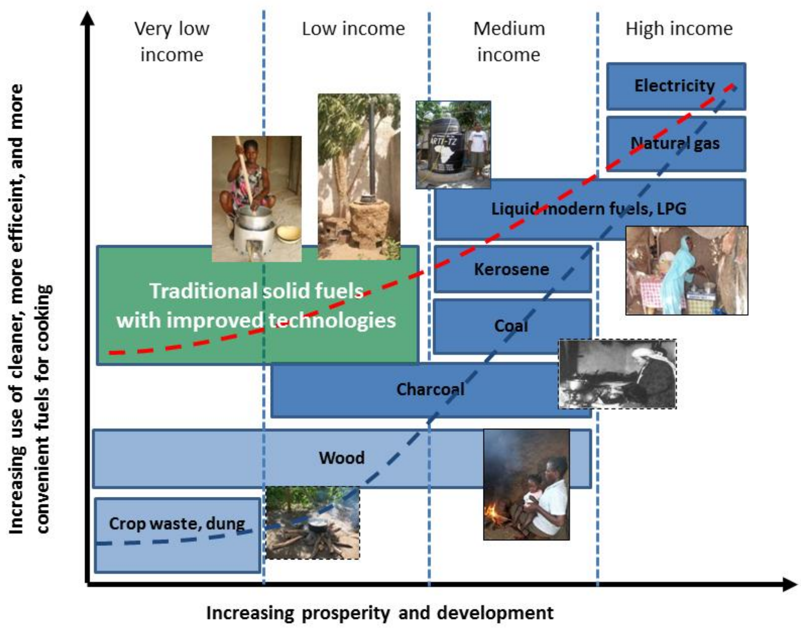



**Figura A: Paragone tra la visualizzazione classica dell'"energy ladder" e quella proposta da questo lavoro.**

## *Acknowledgements*

*I wish to thank my supervisors Dr. Mentore Vaccari and Dr. Angelo Mazzù, who guided me in the research sharing their knowledge and investigating new topics with enthusiasm.*

*I wish to express my gratitude to the Archetti family and to Prof. Carlo Collivignarelli, who gave me the chance to work on interesting topics and projects.*

*I am deeply thankful to the staff of ACRA NGO in Bongor, Yagoua, Maroua and N'Djamena for their support to my research activity and for their friendly hospitality.*

*RESOURCES*
*It doesn’t matter how many you have,*
*if you don’t know how to use them..!*

# Index

# List of figures

# List of tables

# List of acronyms

| | |
|---|---|
| ALRI | Acute Lower Respiratory Infections |
| BC | Black Carbon |
| CCT | Controlled Cooking Test |
| CDM | Clean Development Mechanism |
| CeTAmb | Centro di documentazione e ricerca sulle tecnologie appropriate per la gestione dell'ambiente nei Paesi in via di sviluppo. (Research centre on appropriate technologies for environmental management in developing countries) |
| CFA | Coopération Financière en Afrique centrale ("Financial Cooperation in Central Africa") |
| CO | Carbon Monoxide |
| COPD | Chronic Obstructive Pulmonary Disease |
| CV | Coefficient of Variation |
| CFA f | CFA franc |
| DALY | Disability-adjusted life year |
| DC | Developing Country/ies |
| GHG | Green House Gas/es |
| GWP | Global Warming Potential |
| KPT | Kitchen Performance Test |
| HDI | Human Development Index |
| HH | House Hold |
| IAP | Indoor Air Pollution |
| ICS | Improved Cooking Stove |
| IEA | International Energy Agency |
| LPG | Liquefied Petroleum Gas |
| MCA | Multi Criteria Analysis |
| MDG | Millennium Development Goal |
| *mcc* | My Chubby Cookstove |
| *mlc* | My Little Cookstove |
| NCV | Net Calorific Value |
| NGO | Non-Governmental Organization |
| PIC | Product of Incomplete Combustion |
| PM | Particulate Matter |
| R&D | Research & Development |
| UNDP | United Nation Development Programme |
| UNEP | United Nation Environmental Programme |
| WBT | Water Boling Test |
| WHO | World Health Organization |

# Introduction

An appropriate access to energy is a fundamental prerequisite for an adequate human development. Several studies and reports from international agencies and organisations (IEA 2011, WB 2011, WHO&UNEP 2009) have recognised the strong link between the energy access and the achievement of the Millennium Development Goals (Sanchez 2010), particularly child mortality reduction (Goal 4) and extreme poverty reduction (Goal 1) (Bruce et al 2011). There is an urgent need for a minimum energy access level (Practical Action 2010) promoting the adoption of improved technologies and cleaner fuels. The provision of clean and affordable household energy is a part of scaling up energy access for the poor.

In the world, almost 3 billion people still rely on traditional solid fuels to meet their daily cooking needs. The vast majority of them lives in developing Countries, in particular in China and Sub-Saharan Africa. In these contexts wood is often the only energy source for households and small productive activities. This entails a further stress on the natural resources which are already heavily exploited by the industrial sector and by the international wood trade, worsening the issues of desertification and deforestation (Geist and Lambin 2002, Mahiri and Howorth 2001). Besides, the increasing scarcity of wood leads to severe implications both for the environment and local population; illegal cutting has become a common practice, primary fuel (wood or charcoal) costs have significantly increased, women or kids have to cover longer distances to collect the wood necessary for daily cooking. Furthermore, the use of solid fuels on open fires or inefficient stoves results in large amounts of a range of health-damaging pollutants, often under conditions of poor household ventilation (Rehfuess et al 2011, Ezzati et al 2002). Women and young children, who may spend many hours in the vicinity of the smoky source, are the most exposed (Desalegn et al 2011). That results in a dramatic impact on health: worldwide almost two million deaths from pneumonia, chronic lung disease and lung cancer are associated with exposure to indoor air pollution, resulting from cooking with biomass and coal (Zhang and Smith 2003). Such emissions have also significant global warming effects, due to incomplete combustion of fuel carbon (Smith 1994, Bailis et al 2003, Venkatamaran et al 2010, Bhattacharya and Salam 2002).

Access to improved cooking stoves – i.e. stoves with improved combustion and heat-transfer efficiency and low pollutant emissions- is also very limited. In Least Developed Countries (LDCs) and sub-Saharan Africa (SSA) only 7% of people who rely on solid fuels use improved cooking stoves, compared to 27% of people in developing countries as a whole (WHO & UNEP 2009). In the past many wood cookstove programs have unperformed, due, in part, to a lack of standards and quality control, with little attention to stove design (WB 2011). Today, a new generation of advanced and more effective improved biomass cookstoves are available commercially. In addition less expensive, effective improved cookstoves are also an option to improve the energy access in these contexts.

## Research objective

The implementation of appropriate cooking technologies in contexts with limited resources is strictly required in order to give a practical and sustainable response for this issue. In particular this work focuses on a specific region, the Logone Valley at the border between Chad and Cameroun. The research was carried out within the activities of an International Development Cooperation project (ENV/2006/114-747) implemented by the Italian NGO ACRA and funded by the European Community. Given the local background and the relative constraints, the challenge was to find the appropriate solutions, under a technical point of view, for the reduction of wood consumption. The main part of the project focused on the protection of natural resources, in particular through the creation of community-based committees for the protection of the local forests. Among the project activities, one addressed the decrease of the consumption of the main household fuel, charcoal, which was produced locally from very low efficient carbonization processes. The research, subject of this work, was developed in parallel with the project activities in order to identify a pool of appropriate energy technologies to target the objective of fuel use reduction at household level. The challenging research question that drove this work is "Which cooking technology is appropriate for household energy access in the Logone Valley?". This work looked by the one side to the most recent findings and interests of the international research community, trying to the other side to conjugate them in the most appropriate way with the local constraints given by the peculiarity of the implementation context. Both technology and impact related aspects were taken into account in order to give an overall assessment of the cooking technologies studied.

## Structure of the thesis

The structure of this thesis follows the logical order presented in Figure 1. The first three chapters provide the reader with the basic background for the case studies that are presented later. For each of the two case studies the aspects related to the technology are previously discussed, while in a following chapter some considerations about the impacts related to the adoption of such technologies are presented. The final chapter propose an overall assessment of the appropriateness of the technologies studied according to the results obtained during the research.

This work is developed in eight chapters:

I. Chapter 1 gives a brief overview of the cooking energy sector in developing countries. The topic is really wide and lots of scientific literature works have been produced. Moreover, being a very multidisciplinary sector (from energy to environmental management, from health to economics, with crossed impacts of social aspects and influences of users' behaviours and practices) it is very difficult to give a comprehensive and detailed background. This chapter describes the links between energy access and development, sizing the problem at a global level according to the most recent works published. Factors affecting energy use and main impacts on the users are also discussed.

II. Chapter 2 presents the overall methodology adopted in this work; specific methods and protocols used and implemented in the different activities are detailed in a proper session for each chapter.

III. Chapter 3 gives some information about the background both at national and local level. In this chapter some data collected on site are presented, with a detailed description of the household energy status in the intervention area.


**Figure 1: structure of the thesis**

IV. Chapter 4 presents the outputs of a number of tests performed on improved cookstove available on site using fuels locally available for household purposes. The two stoves chosen for the dissemination on site were in the pool of the models tested. Stoves were tested according to international standard protocols that allowed a comparison with other similar published studies.

V. Chapter 5 reports the impact assessment of the dissemination of the Centrafricain effective improved cookstove, the model promoted by the project. Socio-economic, environmental and indoor air quality impacts were evaluated using dedicated surveys on site. A special focus was given to the manufacturing activity of the artisans trained in the stove production and to the indications provided by local householders that adopted the stove.

VI. Chapter 6 presents the research and development of a proper stove to recover rice husk, a locally available biomass, which is currently considered as a waste by local rice producers. According to results obtained *in itinere*, different lay-outs have been tested to improve the performances of the stove. The main results of this activity (that is still on-going) are reported in this chapter. The technical Research & Development process has been done in full collaboration with DIMI, Department of Mechanical Engineering of the University of Brescia in particular with Dr. Simone Parmigiani.

VII. Chapter 7 contains some considerations regarding the economic sustainability of the proposed rice husk stove. Although the R&D process was driven by local technical constraints, and some pilot prototypes were reproduced on site, any real dissemination of the stove was done. Thus, a simple economic model was elaborated considering the main factors impacting the household cooking energy expenditure, assuming different fuel mixes. The objective of this preliminary evaluation was to point out the trade-off threshold, which makes feasible the purchase and adoption of the rice husk stove in the study area.

VIII. Chapter 8 sums up the results of the research activities implemented both on site and at pilot scale. A multi-criteria analysis was also applied in order to point out the best cooking technology for the local context according to the different impacts that such a system is likely to have on the user. Thus, four main clusters have been investigated, structuring quantifiable indicators for financial, environmental, social and health related impacts of the use of a certain energy technology. The weight systems adopted were chosen in order to consider the features of each technology according primarily to their relevance to the local needs.

Although the project activities interested two Countries, Chad and Cameroon, this thesis focus mainly on the Chadian side, where in 2009 a governmental ban for charcoal production and sale hardly hit the local population, forcing a switch to other household energy sources. Several investigations and surveys conducted in this work revealed the almost identical socio-economic characteristics and domestic energy practices both in the Chadian and in the Cameroonian population, divided by administrative national boundaries, but actually belonging to the same traditional ethnic group, the Masa.

# 1. Cooking energy in developing Countries

## 1.1. Introduction

This first chapter gives a wide overview of the influence of energy in human development, in order to provide the reader with the background for the object of this work, i.e. the importance of appropriate technologies of cooking energy in developing countries. The chapter illustrates the primary role of energy access for people and their quality of life, as outlined by several international organizations like the United Nations (2009), the International Energy Agency (2010), the World Health Organization (2009) and the World Bank (2010). Often when people think to energy access, electricity is the first technology that comes to mind, but in developing Countries the issues is even at a more basic level. Access to energy at household level, in particular for cooking, is still based on rudimental technologies and poor traditional fuels. A particular focus will be given on the impacts that the use of solid traditional fuels has on users and environment.

## 1.2. Energy access

Energy is one of the basic requirements of human societies. It is vital for human life and for technological advancement. In general energy can contribute to widening opportunities and empower people to exercise choices. Without access to efficient and affordable energy sources, people living in energy poverty have very limited opportunities for economic and social advancement.

According to Sanchez (2010), energy access means the ability to satisfy basic energy needs through the use of reliable, efficient, affordable and environmentally friendly modern energy services. The same author identifies four level of energy need:

- 'Fundamental' energy needs are associated with human survival and regards heating, cooking and lighting. These needs cannot be avoided despite poverty, location, lifestyle, thus are common both to developed and developing world, to rich and poor populations.
- 'Basic' energy needs include all those functions in the previous category and, in addition, energy to provide basic services such as better health, education, communication, transports and others. Energy poverty is defined at this level.
- Energy needs for 'productive use and income generation' include all the energy uses required for production, transformation, exploitation of natural resources and the wide range of several activities implemented to gain the daily income.
- Energy for 'recreation and comfort' refers mainly to the use of radio, TV, cooling systems and other equipment usually available only for higher income families.

The definition of an adequate level of energy access is very difficult as it depends on a wide range of factors. There is no universally-agreed and universally-adopted definition of modern energy access. Moreover energy use may depend not only on the local availability and costs of the energy service, but also on the priorities and opportunities the final user sets.

At a basic level, access to energy is relevant to many dimensions fundamental for the improvement of the living conditions of poor households. The main indicators may be identified as follows:

- availability of light for some hours during the night,
- availability of fuel to prepare two typical local hot meals for all household members,
- availability of electricity for some small equipment (mobile phone, radio and/or small TV),
- safety of all the energy sources and technologies,
- impact on the family budget, in terms of expenditure, and activities, in terms of working hours.

On April/May 2011, after the publication of the Poor People Energy Outlook (2010), GIZ and Practical Action, two important international organization engaged with cooperation projects in the challenge to improve energy access for the poor, launched an e-consultancy among researchers and people working in the sector, in order to gather opinions and observations from the active web-community. The aim was to propose the Total Energy Access minimum standards at point of use. The outputs focused on the household level and they are reported in Table 1.

**Table 1: energy service and relative minimum standards according to Total Energy Access (2011)** [1]

| Energy service | Minimum standard |
|---|---|
| **Lighting** | ➢ 300 lumens at household level for at least 4 hours per night |
| **Cooking and water heating** | ➢ 1 kg woodfuel or 0.3 kg charcoal or 0.04 kg LPG or 0.2 litres of kerosene or ethanol per person per day, taking less than 30 minutes per household per day to obtain<br>➢ Minimum efficiency of improved solid fuel stoves to be 40% greater than a three-stone fire in terms of fuel use<br>➢ Annual mean concentrations of particulate matter ($PM_{2.5}$) <10 $\mu g/m^3$ in households, with interim goals of 15 $\mu g/m^3$, 25 $\mu g/m^3$ and 35 $\mu g/m^3$ |
| **Space heating** | ➢ Minimum daytime indoor air temperature of 18°C |
| **Cooling** | ➢ Households can extend life of perishable products by a minimum of 50% over that allowed by ambient storage<br>➢ Maximum apparent indoor air temperature of 30°C |
| **Information and communications** | ➢ People can communicate electronic information<br>➢ People can access electronic media relevant to their lives and livelihoods in their household |

## 1.3. Energy and development

Several studies and reports from international agencies and organizations (IEA 2011, WHO 2002, Barnes et al. 2010) underline the strong link between energy access and the achievement of the Millennium Development Goals, while literature offers a wide range of researches and evidences of the correlation between energy and development. There is considerable empirical evidence to suggest a significant relationship between access to modern energy and human development. Energy services are an essential means to support overall development. Most economic activity is not possible without energy, and no country in modern times has substantially reduced poverty without massively increasing its use of energy.

[1] http://practicalaction.org/energy-advocacy/ppeo-energy-access-standards

Economic growth creates jobs and raises incomes, even for the small and medium-scale enterprises that are the main source of jobs for the poor.

As evident in Figure 2 there is a strong link between per capita energy use and the UN's Human Development Index, HDI[2]. This has special importance in developing countries where a small increase in the per capita energy use, due to an improved access to energy services, may result in a significant increase of HDI. However, in developed countries even a big increase of energy consumption no longer contributes to an improvement of HDI (Sanchez 2010).

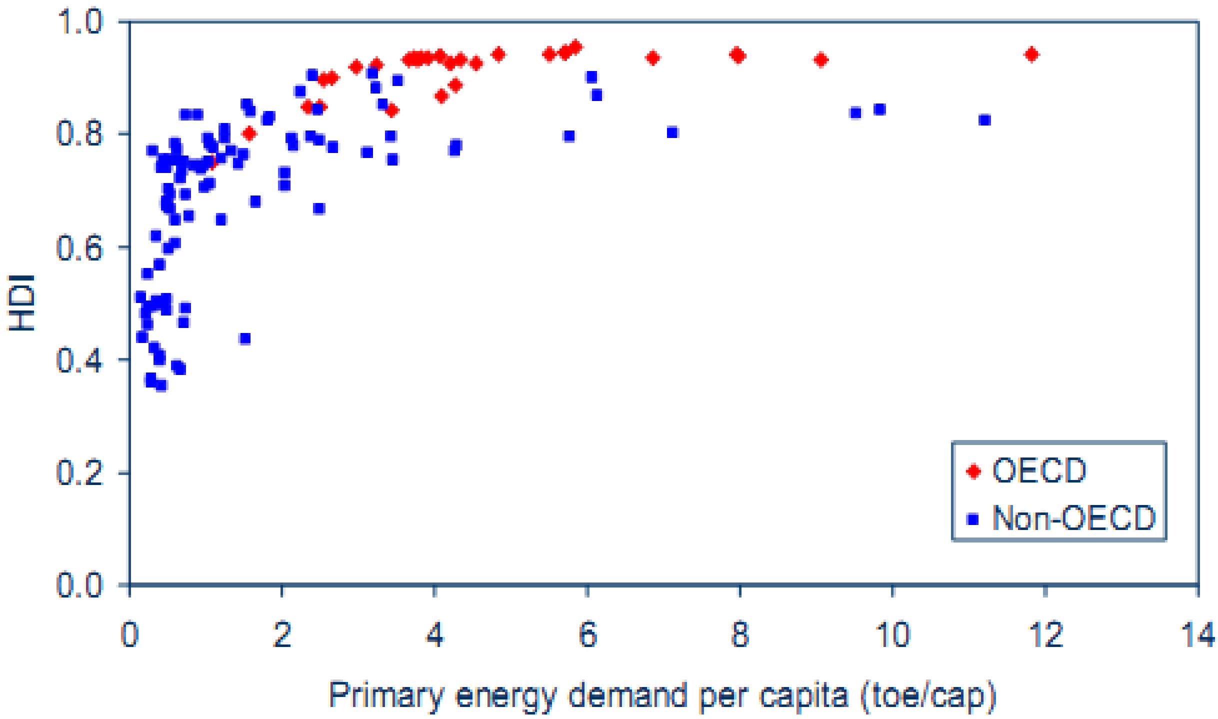



**Figure 2: HDI & Primary Energy Demand per Capita, 2002 (IEA 2004)**

The graphs in Figure 3 illustrate the link between energy access and measures of poverty reduction. Energy access is positively correlated with human development, as evidenced by the upward sloping trend in the graphs. While access to modern energy services alone is not sufficient to eradicate extreme poverty, it is a necessary condition for improving economic and social opportunities for poor men and women. Access to modern energy services improves productivity and enables local income generation by freeing up people's money and time for more productive uses that can improve human welfare (UNDP 2009).

[2] The HDI is a composite index produced by UNDP that measures a country's achievements in three key aspects of human development: longevity (life expectancy), knowledge (educational achievement), and a decent standard of living (income, measured in purchasing power parity terms). For a deeper discussion visit http://hdr.undp.org/

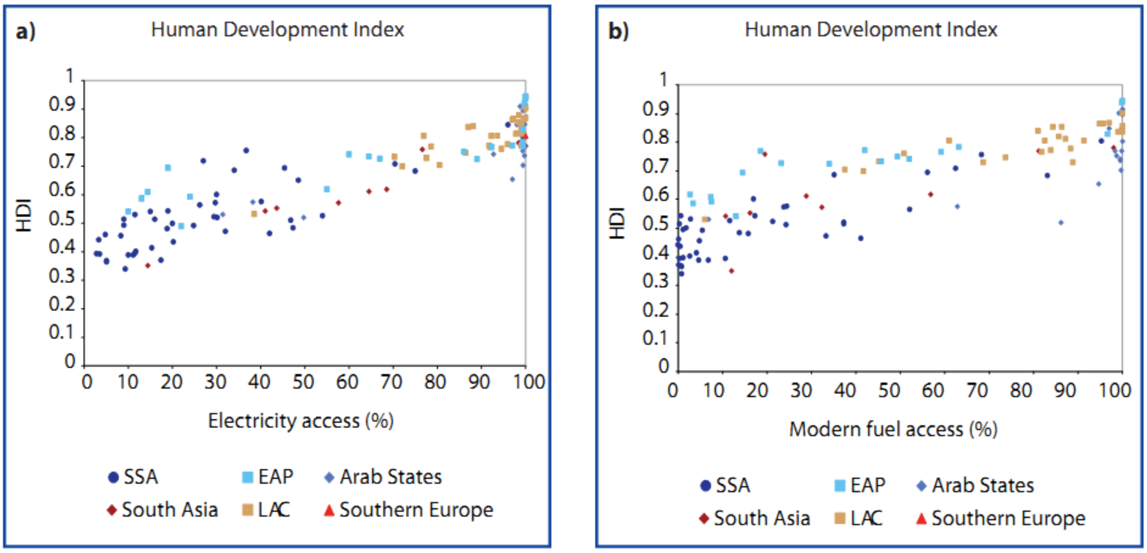



**Figure 3: Development measures and energy access (UNDP 2009)**

## 1.4. Sizing the problem

International Energy Agency (2011) estimates 1.3 billion people – over 19% of the global population – lack access to electricity and that about 2.7 billion people – some 40% of the global population – rely on the traditional use of biomass for cooking. This number is higher than previously estimated by IEA (2008) due to population growth, rising liquid fuel costs and the global economic recession, which have driven a number of people back to using traditional biomass.

Table 2 highlights that almost the totality of people without access to modern energy services lives in the developing world. The issue assumes a significant dimension in Asia and Africa, but for different reasons. In developing Asia only 19% of population is without access to electricity that implies the existence of a more or less reliable grid for the remaining 81%. In Africa the infrastructural lacks of the electric supply systems (also due to the different population density on the territory) result in a 58% of the population without access to electricity. Regarding the use of biomass for cooking, the situation is similar in the two macro-areas. While in developing Asia 54% is still relying on biomass for cooking due to the high number of people living in limited territories (India, Indonesia), in Africa, especially in the Sub-Saharan zone, 65% people still use traditional fuels mainly because of the lack of affordable and reliable alternatives.

**Table 2: Number of people without access to modern energy services, 2009 (IEA 2011)**

| | **Without access to electricity** | | **Relying on traditional biomass for cooking** | |
|---|---|---|---|---|
| | Population (million) | Share of population | Population (million) | Share of population |
| Africa | 587 | 58% | 657 | 65% |
| Developing Asia | 675 | 19% | 1,921 | 54% |
| Latin America | 31 | 7% | 85 | 19% |
| Developing countries | 1,314 | 25% | 2,662 | 51% |
| World | 1,317 | 19% | 2,662 | 39% |

Figure 4 shows the percentage of population using solid fuels in the world. Sub-Saharan Africa, South East Asia and the Western Pacific region are the most affected. Overall, wood is the most widely used solid fuel; coal is highly prevalent in China but does not substantially contribute to national household consumption in other developing and middle-income countries (Rehfuess et al 2011). In developing countries, cooking energy accounts for about 90% of all household energy consumption being the most energy intensive activity of those households. 82% of those relying on traditional biomass live in rural areas, although in Sub-Saharan Africa, nearly 60% of people living in urban areas also use biomass for cooking. The number of people relying on traditional biomass is projected to rise to 2.8 billion in 2030.

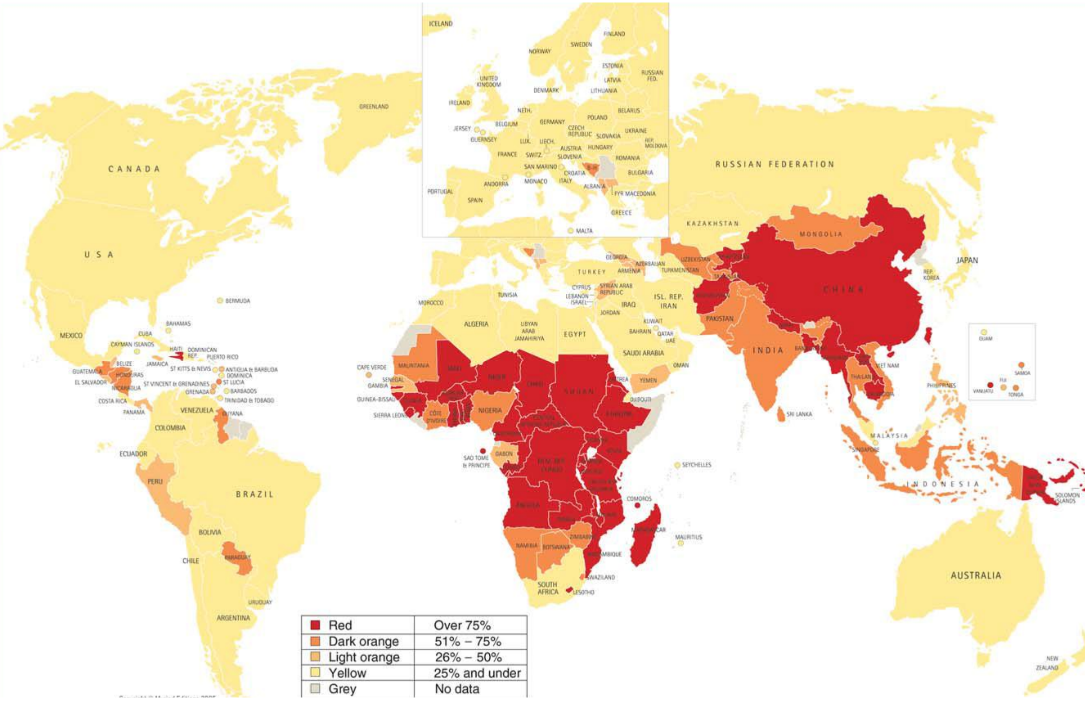



**Figure 4: Percentage of population using solid fuels, 2003 or latest available data (Rehfuess et al 2011)**

## 1.5. Factors affecting the use of cooking energy

Cooking is one of the main activities of human beings, as every person needs food to sustain its life. Focusing on the technology, two main elements compose the cooking system: the fuel and the device used to transfer energy from the fuel to the food, usually the stove. The interaction of and the issues linked to this two elements determine the cooking practices of the user. Thus a "stove" always features the combination of heat generation and heat transfer into a cooking pot. There are many different types of stoves, as a stove needs to accommodate the site-specific constellation determined by the available fuels, climatic conditions and preferences of users in the local culture. Thus stove designs reflect global diversity.

In Figure 5 most common household energy sources are grouped in three main categories: wood-fuels, other biomass fuels and non-biomass fuels. There is a wide variety of modern fuels, including natural gas, LPG, diesel and renewables such as biodiesel and bio-ethanol. In developing countries, frequently, biomass fuels are the only available energy source, especially in rural areas. These fuels include firewood, charcoal, dung and agricultural residues. Worldwide, 2.7 billion people use biomass fuels for cooking, and according to the estimation of the main international organizations involved in this issue, by 2030 more than 2.8 billion people will cook with biomass.

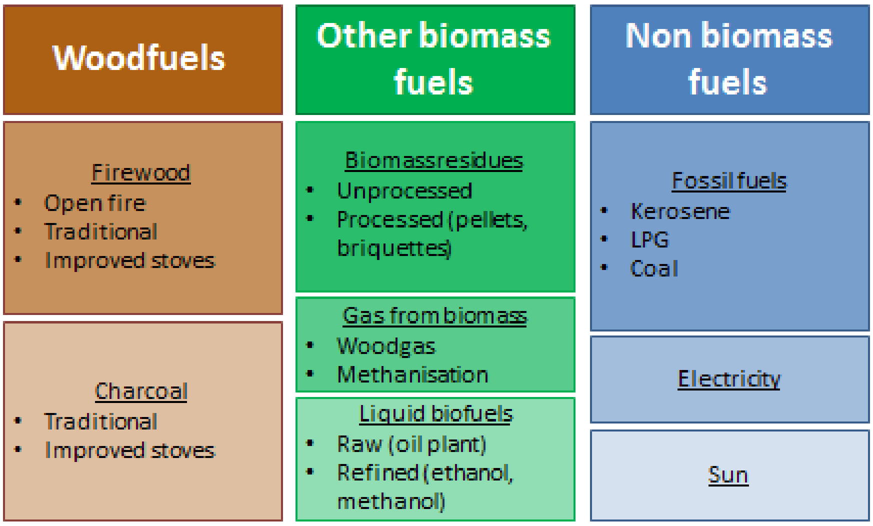



**Figure 5: sources of cooking energy**

Biomass fuels are mainly burned on inefficient open fires and traditional stoves. This results in a number of dramatic impacts not only for the users but also for the environment. In developing countries this fundamental need assumes a problematic dimension due to the lack of resources. In some cases the environment does not offer affordable and convenient energy sources, or the supply is every day harder due to impoverishment of natural resources and regional processes of desertification and deforestation. This situation may be worsened by the lack of a sustainable management of such resources. In some other cases the energy infrastructures, like markets or other delivery systems, are missing. In most of the cases the main constraint to an adequate energy access is poverty. Being poor condemns half of humanity to dependence on polluting household energy practices. Figure 6 reports the “Fuel- or Energy ladder”, a common concept in household energy analysis. The concept implies that with socio-economic development the fuel used by a household will change. The ladder model envisions a three stage fuel switching process. The first stage is marked by universal reliance on biomass. In the second stage households move to “transition” fuels such as kerosene in response to higher incomes or factors such as urbanization and deforestation. In the third phase households switch to modern fuels (Helberg 2003). Various factors will determine whether or not the household is able to move up its preferred ladder: household income and size, availability and costs of the fuel, availability and cost of the required appliances, climate, settlement size and culture and tradition. The main driver affecting the move up the ladder is supposed to be income and relative fuel price. Further, a variety of user-specific values and judgements often remain implicit (FAO 1997). Users make their own choices based on their own perceptions with regard to fuels, stoves, kitchens and related issues. With increasing prosperity, cleaner, more efficient and more convenient fuels are replacing, step-by-step, traditional biomass fuels and coal. Climbing up the energy ladder tends to occur gradually, as most low- and middle-income households use a combination of fuels to meet their cooking needs.

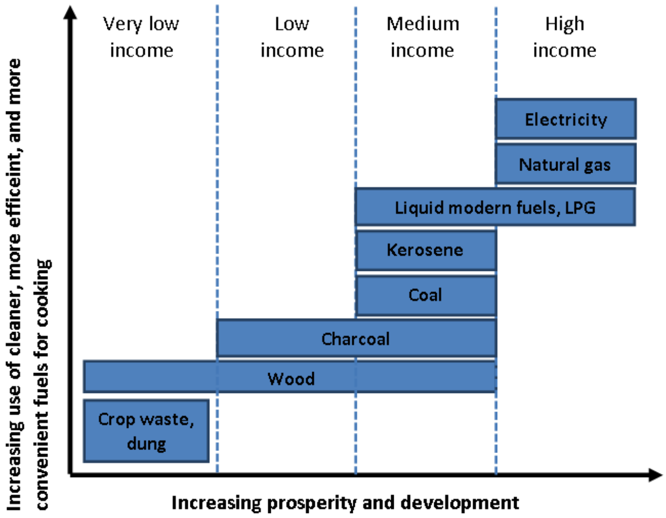



**Figure 6: the energy ladder. How the use of modern fuel is linked to income level (adapted from Rehfuess et al 2011).**

Actually this description is not exhaustive of the complexity of the fuel choice process in many contexts. A number of further factors may play a role in particular in discouraging the use of modern fuels, such as the taste and texture of food prepared, the impossibility to cook traditional receipts, the supply shortage in the market, or the large distances for retailers, which make the provision prohibitive, especially in rural areas. The new perspectives on household energy choice see it as a portfolio choice more than as a ladder. Households' energy portfolio can be described by their size, composition and diversification. A household economic model incorporating also opportunity costs (influenced by factors such as education and availability of labour and natural resources) allows studying energy use even when households use biomass they produce or collect themselves, and therefore it is hard to give a monetary value to fuel. Heltberg et al (2000) proposes that the collection and use of fuel in these cases are guided by opportunity costs that depend on the productivity of labour in fuelwood collection vis-à-vis the opportunity cost of time in alternative employment.

The role of technologies

Many factors affect the choice and the demand of energy and fuels: as shown in Figure 7 these factors can be divided in macro-categories, even if they strongly influence and interact reciprocally. Environmental factors are a main constraint.

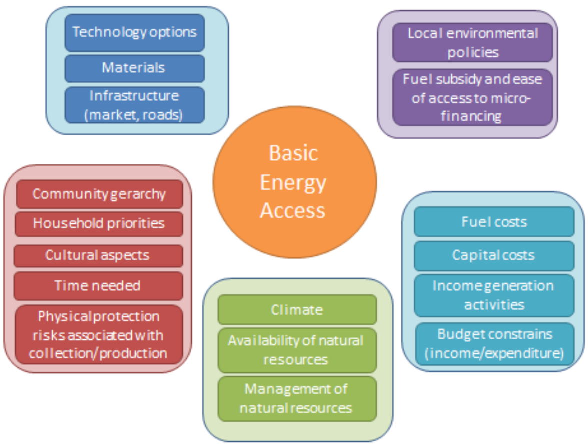



**Figure 7: factors affecting basic energy use from traditional fuels**

First of all the availability of natural resources exploitable for energy purposes affects whether people collect or purchase fuel. Furthermore the availability of fuel can vary seasonally: during the dry period people may rely on agricultural residues as a complementary fuel, while in the rainy season the conditions of roads and pathways and the moisture content of collected wood may force people to purchase dry wood or other fuels at the local markets. Moreover a cold climate implies the eventual need for heating energy, not likely to be required in warmer contexts. The management of natural resources is directly linked to their sustainable use, or, in other words, to their renewability. Also the local community structure, its control on the territory and on natural resources, supported by the presence of environmental regulations, are associated to this aspect. Often, especially in context where the wood resource is scarce, the lack of administrative or community-based surveillance of rural forests and woods leads to their overexploitation and illegal cut. This reflects in a medium term on the availability and renewability of the resource that is often already threatened by macro-scale phenomena like deforestation and climate-change driven desertification. The institutional/political background influences the access to energy also by means of some mechanisms such as the promotion of micro-financing or subsidies. This in particular may apply both to fuels and stoves. Many experiences have been made in this field to promote the dissemination of modern fuels like LPG or of a specific kind of stove within regional strategies or international cooperation projects. The supply of subsidies allows the population, in particular the low-income class, to bypass the initial capital cost, in many cases the first big barrier to the adoption of an improved cooking system, or to the affordability of a cleaner and more efficient fuel. Some concerns about the sustainability of such programs are self-evident. In several recent stove dissemination interventions, marked-based approaches are being proposed alternatively. These interventions address in an effective way the economic dimension of the action, profiting in some cases also by the carbon market mechanisms and promoting the development of a manufacturing local sector which create job opportunities for the local population. At the same time, they are unavoidably oriented towards a share of the population that is within the monetized economy. Therefore, there is a considerable risk that these actions neglect the most emarginated income class or the rural householders that collect themselves their own fuel for free and do not perceive any advantage in reducing their woodfuel consumption.

Cooking technologies can play an important parallel role in different ways:

- providing the users with fuel saving devices, more efficient in comparison to traditional ones, or
- allowing the use of alternative fuels, such as LPG (modern and clean) or agricultural residues (costless in rural areas).

Two main elements play a key role in cooking energy under a technical point of view: the fuel and the cooking system. These two technical subjects have to meet the user's cooking practices in order to be acceptable. The local cooking practices and preferences, the easiness in the use and the taste of food are only some of the aspects that are often secondary, or hard to assess, in the evaluation of a cooking energy technology. At the same time they affect significantly the adoption of a certain technology. Other social aspects occur in the way people access to basic energy: household priorities usually stated by the head of family and not by the woman who is usually in charge of the preparation of meals, social risks associated to the fuel collection activity, value of time spent in gathering wood or cooking.

## 1.6. Impacts of the use of biomass fuel

The use of biomass fuel has several impacts not only on the proper user, the cooker, but also on other members of the family/household and on the environment both at local and global level. Figure 8 summarises certain points for different categories of impact that are discussed deeper in the following paragraphs. A strong subdivision of the impacts is not exhaustive of the several reciprocal influences and correlations between social, financial, environmental and health related aspects.

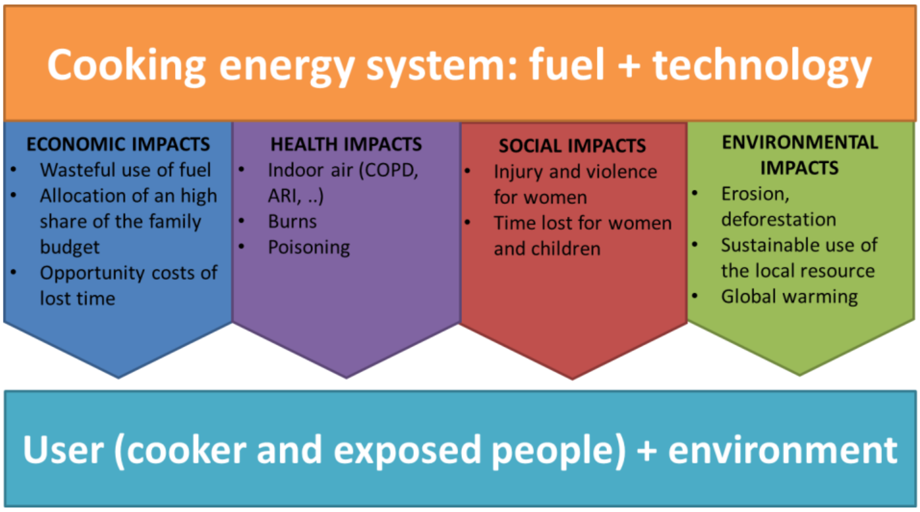



**Figure 8: different impacts of cooking energy system on the user(s) and the environment**

### 2.6.1. Economic impacts

One of the most important factors influencing options for change and methods of delivery is the close relationship between reliance on traditional fuels and poverty, as already said in the previous paragraph. This relationship operates in both directions. On the one hand, poor households do not have the financial resources and income security required to switch to more efficient, cleaner fuels and energy technologies. At the same time, the consequences of using traditional fuels – which include impacts on health, women's time and opportunities for income generation – add to the constraints on families attempting to escape from poverty.

Fuel cost is the first immediate indicator of the impact of daily cooking energy needs on the financial resources of people. Prices are influenced by several factors, such as the availability of local natural resources, the market infrastructures and the presence of specific taxation or subsidize regimes. The scarcity of wood, the so called "wood crisis", in contexts affected by deforestation is an issue pointed out by several authors since a long time (Agarwal 1986, Gorse 1985, Mgendi 2000): one of the main consequences is the increase in wood prices.

People, especially in urban areas, are forced to buy wood or charcoal as there is no other alternative. This affects mainly the lower income classes, which often need to allocate a disproportionately high share of household budgets to energy services (Modi et al 2005). A study of the IEA (2002) in some countries highlights that the percentage of household income spent on energy is significantly higher in the poorest quintile of the population. In particular, among the considered countries (South Africa, India, Ethiopia and Uganda) the difference was even more marked in the less developed countries, where the total expenditure of the poorest population reached 10-16% of the household budget, in comparison to 7-9% for the richest one.

Under the opposite point of view, fuel sale may be seen as an income opportunity for rural people. Every day many people come to urban market to sell wood gathered or charcoal produced in rural areas. The transport of solid fuels even for long distances is made convenient being the only profitable activity in certain seasons for poor farmers, or by to increasing fuel prices for middle dealers. The control on local natural resources by institutions and rural communities assumes a key role in guaranteeing and promoting measures against illegal unsustainable exploitation of forests, improving the production efficiency (for instance the carbonisation processes), equity and justice in the price paid to weak stakeholders for the goods.

### 2.6.2. Social impacts

Social aspects related to access to energy are particularly linked to various limitations and financial barriers. When financial resources are limited, the distribution of resources within the household is impacted by gender, among other factors (Chukuezi 2009). Men and women may have different priorities and the priorities of men are more likely to be taken into consideration. While women's priorities in accessing resources of energy may lie in having access to devices that facilitate domestic chores as well as those that may lead to income generation, men's priorities often differ sensitively. This is often an obstacle to the purchase of an improved cooking system or a cleaner modern fuel, which is not seen by the family budget manager as a priority. A focus on gender issues is particularly important in this sector since a disproportionate number of people living in hunger and extreme poverty are women in the rural areas. These women depend on subsistence agriculture to feed their families. It is principally the women and children who carry out task of collecting the fuels. Increasing degradation of these natural resources causes them to spend more time and physical effort finding and bringing home the fuel they need. During a typical week, family members spend a considerable amount of time collecting fuel, whether from common village land or farmer's fields. Biomass fuel collection often entails walking long distances carrying heavy head-loads and safety hazards. A WHO review of fuel-collection time and biomass energy use among 14 countries in Sub-Saharan Africa found a wide range of estimates for the number of hours spent collecting biomass energy, from a low of 0.33 hours up to 4 hours per day (Dutta 2005; WHO 2006). Moreover fuelwood is often collected on a daily basis and sometimes has no time to dry before use. This makes the use less efficient as some heat is wasted to drive the moisture out of the wood. Moist fuel results in more smoke.

There are also serious health impacts associated with burning traditional biomass fuels as discussed in the following paragraph. Open fires in the home produce unventilated smoke; women and young children, who spend many hours in the kitchens, are the most exposed to high concentration of carbon monoxide and other pollutants. The exposure increases the risk of diseases, burns to children and injuries to women from carrying wood (Hutton et al 2006).

### 2.6.3. Health impacts

Indoor biomass cooking smoke is associated with a number of diseases, including acute lower respiratory infections (ALRI), chronic obstructive pulmonary disease (COPD), lung cancer, tuberculosis, asthma, cataracts, adverse pregnancy outcomes and low birth weight, cancer of the upper aerodigestive tract, interstitial lung disease and ischaemic heart disease (Smith et al 2004, Valent et al 2004, Viegi et al 2004, Girod and King 2005, Bruce et al 2006, Ceylan et al 2006).

**Table 3: mechanisms by which some key pollutants in smoke from domestic sources may increase risk of respiratory and other health problems (Bruce et al 2002)**

| Pollutant | Mechanism | Potential health effect |
|---|---|---|
| Particulate matter small particles less than 10 microns and particularly those less than 2.5 microns aerodynamic diameter | • Acute: bronchial irritation, inflammation and increased reactivity<br>• Reduced muco-ciliary clearance<br>• Reduced macrophage response and (?) reduced local immunity<br>• (?) Fibrotic reaction<br>• Automatic imbalance, pro-coagulant activity, oxidative stress | • Wheezing, exacerbation of asthma<br>• Respiratory infections<br>• Chronic bronchitis and COPD<br>• Exacerbation of COPD<br>• Excess mortality, including from cardiovascular disease |
| Carbon Monoxide | • Binding with Haemoglobin (Hb) to produce COHb which reduced $O_2$ delivery to key organs and the developing of fetus | • Low birth weight (fetal COHb 2-10% or higher)<br>• Increase perinatal deaths |
| Benzo[a]pyrene | • Carcinogenic (one of a number of carcinogenic substances in coal and biomass smoke) | • Lung cancer<br>• Cancer of mouth, nasopharynx and larynx |
| Formaldehyde | • Nasopharyngeal and airways irritation<br>• (?) increased allergic sensitization | • (?) increased susceptibility to infections<br>• (?) may lead to asthma |
| Nitrogen dioxide | • Acute exposure increases bronchial reactivity<br>• Longer term exposure increases susceptibility to bacterial and viral lung infections | • Wheezing and exacerbation of asthma<br>• Respiratory infections<br>• Reduced lung function (children) |
| Sulphur dioxide | • Acute exposure increases bronchial reactivity<br>• Longer term: difficult to dissociate from particulate effect | • Wheezing and exacerbation of asthma<br>• Exacerbation of COPD, CVD |
| Biomass smoke (component uncertain) | • Absorption of toxins into lens, leading to oxidative changes | • Cataract |

In most of these cooking systems in developing country homes, combustion is very incomplete and results in high emissions, which combined with poor ventilation often produce very high levels of indoor pollution. Women and young children are disproportionately affected as they are exposed to levels of indoor cooking smoke, in the form of carbon monoxide and small particulates $PM_{2.5}$, up to 20 times higher than the maximum recommended levels of the World Health Organization (WHO 2005). It is widely agreed that the two major components of biomass smoke that should be monitored are particulates and carbon monoxide. Particulates are tiny particles of smoke that get deep into the lungs and make people vulnerable to respiratory infections. Carbon monoxide is a colourless and odourless gas that can lead to death in a very short period of time at high concentrations. At lower concentrations, commonly experienced in households using traditional stoves and open fires, exposure can lead to headaches, dizziness and nausea, and it is linked to low birth weight. Where coal-burning is common, oxides of sulphur may also be measured. Table 4 summarises the range of levels reported from literature studies for particulate matter ($PM_{10}$) and carbon monoxide (CO), compared to WHO Air Quality Guidelines for these substances (WHO 2005, 2010). The latest studies available in 2009, especially those epidemiological studies using very large databases and thus producing extremely high-resolution findings, suggest that the appropriate guideline level for longer-term average concentration of carbon monoxide in order to minimize health effects must be positioned below the 8-hour guideline of 10 $mg/m^3$ (WHO 2010).

**Table 4: indoor levels of $PM_{2.5}$ and CO from household use of solid fuels, compared with WHO air quality guidelines**

| **Pollutant** | **Range of measured pollution levels in home in DC studies of solid fuel use in simples stoves** | | **WHO Air Quality Guidelines (2005, 2010)** | |
|---|---|---|---|---|
| | Period | Level | Period | Level |
| Small particles ($PM_{2.5}$) [$\mu g/m^3$] | Annual | Average levels over the course of a year are expected to be similar to measured 24-hour levels | Annual mean | 10 $\mu g/m^3$ annual mean |
| | 24h | Wide range of recorder levels, from around 300 to 3,000 $\mu g/m^3$ or more. Most range from 500 to 1000 $\mu g/m^3$ | 24 hour mean ($99^{th}$ percentile: 3 days/year) | 25 $\mu g/m^3$ 24-hour mean |
| | During stove use | Mostly ranged from 300 to 20,000$^+$ although levels of 30,000 have been recorded | | |
| Carbon monoxide [$mg/m^3$]* | 24h | Generally up to 10 ppm, but can exceed 50 ppm | 24hours | 7 $mg/m^3$ |
| | | | 8 hours | 10 $mg/m^3$ |
| | During stove use | Can exceed 100 ppm | 1 hour$^+$ | 35 $mg/m^3$ |
| | | | 15 minutes$^+$ | 100 $mg/m^3$ |
| | Carboxy-haemoglobin (COHb) % | Level measured 1.5-13% | Recommended that COHb should not exceed 2.5%<br>Typical non-smoker 0.5-1.5%<br>Typical smoker 10% | |

* At 760 mmHg and 20°C, 1ppm = 1.165 $mg/m^3$ and 1 $mg/m^3$ = 0.858 ppm; at 25°C, 1 ppm = 1.145 $mg/m^3$ and 1 $mg/m^3$ = 0.873 ppm. $^+$ such exposure levels should not occur more often than one per day

Health effects are determined not just by the pollution level, but more importantly by the time people spend breathing polluted air – in other words the exposure level. Exposure refers to the concentration of pollution in the immediate breathing environment over a specified time interval. This can be measured either directly through personal monitoring or alternatively indirectly by combining information on pollutant concentrations in each microenvironment, where people spend time, with information on activity patterns (Lioy 1990). Information on activity patterns is very important for understanding the dynamic relationship between levels of pollution and behaviour. Thus, although poorly studied to date, it is quite possible that as pollution levels are reduced, people spend more time indoors or nearer the pollution source. So reducing ambient pollution will not necessarily result in a proportionate decrease in exposure, a situation that has important implications for interventions.

In developing countries, individuals are typically exposed to these very high levels of pollution for between 3 and 7 hours each day over many years (Engel et al 1998). Cultural practices common in developing countries may promote exposure of infants, women, the elderly and the sick. Since it is the women who generally cook, their exposure is much higher than men's (Behera et al 1988). Young children are often carried on their mother's back while she is cooking, so that from early infancy, children spend many hours breathing smoke (Albalak 1997).

It is estimated that smoke from cooking fuels accounts for nearly 2 million deaths annually (WHO and UNDP 2009), which is more than the deaths from malaria or tuberculosis; while these diseases are strongly focused by specific programs, and in the future the number of death related are likely to reduce, the victim diseased caused by the exposure to smoke from biomass are supposed to increase, as Figure 9 shows. By 2030 over 4,000 people will die prematurely each day from household air pollution (IEA 2011).

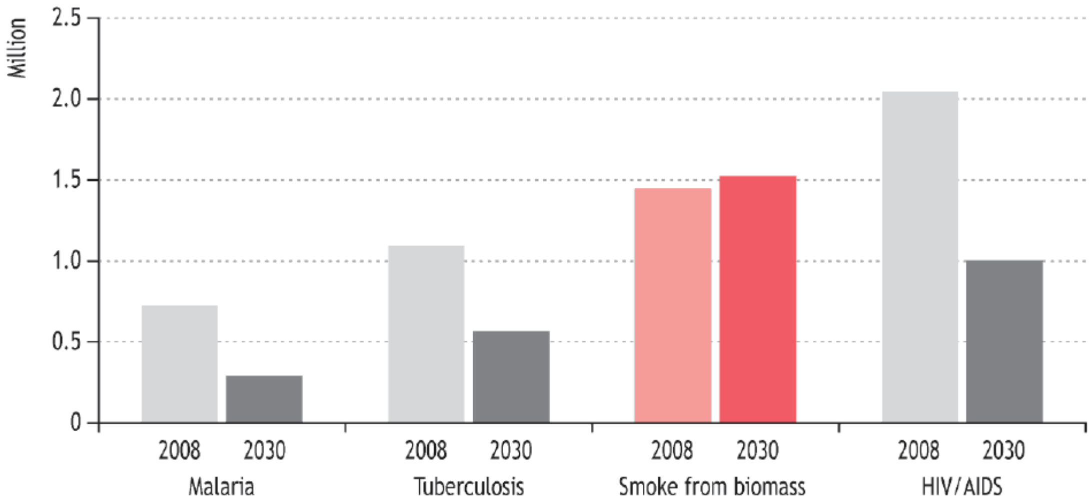



**Figure 9: premature annual deaths from household air pollution and other diseases (IEA 2011)**

The health impacts of improved stoves are difficult to model, given the lack of clear evidence in this regard. Small particles are likely to be the most harmful pollutants contained in indoor smoke, and several studies have demonstrated reductions in indoor levels of $PM_{10}$ of 80% or more where improved stoves are used (Ahmed 2005, Bruce et al 2006). However, these reductions are not a good predictor of the health impact, given possible changes in behaviour (e.g. a less smoky environment may lead to more time spent indoors) and the non-linear relationship between exposure and relative risk of health impact (the dose–response relationship is unknown for exposures to $PM_{10}$ levels above 50 µg per $m^3$). Few studies are available that link the use of a particular cooking technology to health risks over time. Fewer studies of personal exposure have been done than of area pollution, mainly because measurement of personal PM typically requires wearing a pump, a cumbersome procedure. CO can be measured more easily and has been used as a proxy: time-weighted (for example, 24-hour average) CO correlates well with PM if a single main biomass stove is used (Naeher et al 2001). A dose-response relationship for indoor air pollution (IAP) exposure and adverse health impacts is not known (Rouse 2008). Recently two studies have provided important insights into the characterization of the exposure –response relationship for the link between indoor air pollution and ALRI. A cohort study monitored 93 infants living in 55 randomly selected households in Kenya for more than two years. Exposure was assessed through continuous real-time monitoring of $PM_{10}$ and CO combined with time -activity budgets; ALRI was assessed through weekly clinical examinations. ALRI rates increased at a higher rate for $PM_{10}$ levels below 2,000 mg/m$^3$ than for $PM_{10}$ levels above 2,000 mg/m$^3$, suggesting that the exposure–response relations hip is not linear but levels off at concentrations of approximately 2,000 mg/m$^3$. The other, a randomized-controlled trial in the highlands of Guatemala, conducted repeated 48-h kitchen, bedroom, and personal samplings of $PM_{10}$ and CO for more than 500 children over an 18-month period. For a 50% reduction in personal exposure to CO, the RESPIRE trial found statistically significant reductions of approximately 25% in physician -defined pneumonia and approximately 33% in severe, hypoxemic pneumonia (Rehfuess et al 2011).

Other health risks have been identified: young children who suffer burns from falling into open fires or picking up hot fuel, cooks exposed at risk of clothes igniting. Where kerosene (paraffin) is used as a household fuel, this is frequently stored in soft drink bottles, and poisoning of young children who drink the fuel is common. Most collection of fuel is carried out by women, and school-age children are often involved. Although not well studied and quantified, there is sufficient evidence that injuries (from falling with heavy loads) and animal bites (snakes, etc.) are quite common. In some areas, particularly of political instability, women may be at risk of physical threats, assault and rape (Bruce et al 2011).

### 2.6.4. Environmental impacts

The use of traditional biomass fuel has also a significant environmental impact. An extensive local fuel collection is required to support the local market. The woodfuel demand from the growing population in the urban areas adds an increasing stress on the natural resources in the peri-urban and rural areas. It is common to find deforested areas surrounding the main urban agglomerates for a distance that increases every year. Moreover solid fuels are usually burnt in open fires and primitive stoves which are inefficient at converting energy into heat for cooking; the amount of biomass cooking fuel required each year can reach up to 2 tons per family. Where people have even any access to wood or charcoal, the use of dung and crop residues as fuels for cooking purposes takes off such fertilizer compounds from the natural soil cycle. In general, where demand for local biomass outstrips the natural regrowth of resources, local environmental problems can result such as an unsustainable exploitation of forest and the increase of soil erosion with loss of fertility. In many developing countries, forest resources are under threat from overexploitation and land-use change. Consequently, forest product supplies, environmental services (soil protection, water retention, biodiversity conservation and carbon-sequestration) and social benefits, such as cultural and spiritual values and the livelihoods of forest-dependent rural populations, are at risk.

Furthermore there is mounting evidence that biomass burned inefficiently contributes to climate change at regional and global levels. In developing countries, about 730 million tons of biomass are burned each year, amounting to more than 1 billion tons of carbon dioxide ($CO_2$) emitted into the atmosphere. Biomass fuels inefficiently burned due to incomplete fuel combustion generally release products of incomplete combustion (PIC) with a high global warming potential (GWP[3]), which linger in the atmosphere (Smith 2000, WHO 2006). These PICs include such gases as methane ($CH_4$) and nitrous oxide ($N_2O$), and fine particles in the form of black carbon (BC[4]). Some scientists now estimate that small, solid particles of black carbon are responsible for about one-fifth of warming globally and, as such, are the second-largest contributor to climate change, after carbon dioxide gas (Luoma 2010, Highwood and Kinnersley 2005). However, PICs also include organic carbon (OC), which has a cooling effect on the atmosphere. Thus, not only are potentially high levels of $CO_2$ emissions being produced in open or semi-open fires; various other products are being emitted that also affect the climate.

## 2.7. Cooking Energy and MDGs

As discussed previously, energy is indispensable for sustainable development and poverty reduction. Without access to adequate quantity and quality of modern energy services, the achievement of the MDGs will not be possible (UNDP 2007). At present, there are 1.6 billion people in the world, mostly in rural areas, who have no access to electricity. Another 2.5 billion people still rely on traditional solid fuels—wood, dung and agricultural residues—to meet their daily heating and cooking needs, having serious impacts on the environment and on people's health. This situation severely limits economic opportunities and the ability to overcome poverty. Energy, including electricity and safe cooking fuels, is among the essential infrastructure services for a productive life. The UN Millennium Project [5] proposes that countries adopt the following specific targets for energy services to help achieve the Goals by 2015.

- Reduce the number of people without effective access to modern cooking fuels by 50% and make improved cook-stoves widely available.
- Provide access to electricity for all schools, health facilities and other key community facilities.
- Ensure access to motive power in each community.
- Provide access to electricity and modern energy services for all urban and peri-urban poor.

[3] Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1).

[4] Smoke from biomass cooking emits both black carbon (BC), which is largely elemental carbon, and organic carbon (OC), where carbon is combined with other elements, such as oxygen and hydrogen. BC and OC are referred to compounds as aerosols (fine particles suspended in the atmosphere) and have a significant impact on climate. BC absorbs sunlight and has a significant net warming effect, while OC reflects sunlight back into space and has a cooling effect on the atmosphere. Both BC and OC are the components of soot, a carbonaceous substance generally defined by its means of production, incomplete combustion, rather than by its chemical or physical properties. While the emissions characteristics of biomass burning in cookstoves are considered critical for climate science, there is surprisingly little concrete scientific data on such key factors as the ratio of OC to BC (Ramanathan and Carmichael 2008).

[5] http://www.unmillenniumproject.org/reports/fullreport.htm

It is not uncommon for energy issues to be missing completely from the MDG national reports. None of the eight Millennium Development Goals specifically address cooking energy, but its importance is recognized in several documents.

Access to improved cooking fuels is necessary to ensure safe cooking of food. The creation of jobs and small business creation bring income for the handicrafts trained in the stove manufacturing; on the users' perspective, a reduced fuel need occurs in money savings. These are direct forms of poverty reduction (Goal 1). Access to electric power and improved cooking fuels lowers time spent by children (especially girls) collecting fuel-wood, thus facilitating school attendance (Goal 2). Women are often trained in the manufacturing of improved stove, in particular in rural areas, where ceramic stoves are more likely to be disseminated. Thus, women gain self-confidence and improve their status in the community. Furthermore, the reduced time spent gathering firewood and cooking and the improved conditions of kitchens where women usually cook are effects addressing the promotion of gender equality and empowerment of women (Goal 3). Reducing indoor air pollution through improved cooking fuels and stoves decreases the risk of respiratory diseases and eye infections, especially in women, and in children under five years[6]. Improved access to energy allows households to boil water, thus reducing incidence of waterborne diseases. Furthermore improved cookstoves usually are safer than open fires, reducing the risk of burns (Goal 4). Access to modern cooking fuels reduces demand for biomass, thus reducing pressure on marginal lands and forests. Improved energy services reduce indoor labour and outdoor air pollution as well as carbon emissions, in particular $CO_2$ and black carbon (Goal 7).

## 2.8. Technologies for an efficient use of biomass

There are also many technology options to use traditional fuels more efficiently. Improved technologies range from artisanal or factory-produced clay and metal stoves to solar cookers, heat retaining cookers, and stoves using green fuels such as plant oil, ethanol, or biogas. The suitability of these options depends on factors such as availability, applicability, acceptability and affordability, including access to finance to cover initial investments. The decreasing availability of existing sources of fuel makes switching to modern alternatives a necessity in some places. In some others the inconsistence of a market not supported by realistic political energy strategies makes unaffordable for most of the people gaining access to more appropriate fuels, getting back to traditional cheaper ones. According to these aspects, and to the estimated increasing number of people relying on biomass for cooking purposes in the next future, the adoption of improved technologies that allow to use even poor fuels, but in a convenient, cleaner and more efficient manner, appears to be a viable way to walk to reach the goal of minimum energy access for the poor.

There is a wide range of interventions adequate to provide people with a more appropriate access to cooking energy. Bruce et al (2011), with particular reference to indoor air pollution reduction, set three areas that can be targeted by the following interventions: reducing the source of pollution, improving the living environment and modifying the users' behaviours. Improved cooking devices (with or without flue attached) and alternative fuel-cooker combinations fall within the first of these categories.

[6] http://www.who.int/indoorair/publications/fuelforlife/en/index.html

Less than 30% of people in developing countries who rely on solid fuels for cooking (i.e., traditional biomass and coal) use improved cooking stoves. Access to ICSs is even more limited in LDCs and sub-Saharan Africa, where only 6% of people who use traditional biomass and coal for cooking have access to improved stoves (WHO and UNEP 2009). In this work the focus was pointed on improved cookstoves. There is no universally accepted definition of "cookstoves" linked to performance or technical standards.

A report of the World Bank (2011) has reviewed the cookstove intervention sector with a new look according to the recent scientific evidences on the environmental and health-related impacts. The authors propose a classification of stoves, but no measureable benchmarks are indicated for each category:

- the term ***traditional stove*** refers to either open fires or cookstoves constructed by artisans or household members that are not energy efficient and have poor combustion features.
- ***Improved cookstove*** is used in the historical sense for cookstoves installed in "legacy" programs, usually with a firebox and chimney, but without standards and with poor quality control.
- ***Advanced biomass cookstove*** refers to the more recent manufactured cookstoves, based on higher levels of technical research; these cookstoves are generally more expensive and are based on higher, but as yet not well-defined, standards that include safety, efficiency, emissions and durability; among others, they might include wood, charcoal, pellet and gasifier cookstoves.
- Finally, the ***effective improved cookstove***, cheaper but close in performance to advanced biomass cookstoves, is assembled on-site by qualified installers adhering to standards.

Sanchez (2010) propose that an 'improved energy source' for cooking is one which requires less than four person hours per week per household to collect fuel and meets the recommendations of the WHO for air quality (maximum concentration of CO of 30 $mg/m^3$ for a 24 hour period and less than 10 $mg/m^3$ for a period of 8 hours of exposure). Plus the overall conversion efficiency must be higher than 25%.

A good improved household stove, if is properly used, can save up to 60% of fuel compared to the traditional three-stone fire (GIZ 2011) and is designed to minimize the generation of products of incomplete combustion, many of which have a high global-warming potential (IPCC 2001).

# 2. Overall methodology

## 2.1. Introduction

The research was carried out within the activities of an International Development Cooperation project implemented by the Italian NGO ACRA since 2008, one year before the beginning of the PhD research presented in this thesis. This condition resulted as a main constraint in the design and development of the research, which was forced to start as an open-ended exploratory action research.

Given the complexity of the theme, both qualitative and quantitative methods from the social research literature were used, in order to gather information and data on the cooking practices and habits in a not influenced way. At the same time a rigorous scientific approach was adopted in the assessment of the technologies performances and in the quantitative evaluation of the impacts on the users. Thus, information obtained were crossed in order to have a comprehensive outlook on the several aspects of the topic and give a final assessment of the appropriateness of the intervention adopted.

## 2.2. The project

The research implemented on site is part of the memorandum of agreement signed between CeTAmb (Centre for Documentation and Research on appropriate technologies for environmental management in developing countries) and ACRA (Association of Rural Cooperation in Africa and Latin America) for the implementation of the Logone Valley project (project participatory management of forest resources in the Logone Valley ENV/2006/114-747). The project aims at:

- strengthening the forestry technical knowledge;
- promoting innovative technologies to reduce the consumption of charcoal and wood;
- developing productive activities based on the sustainable use of local trees and plants;
- increasing the awareness of the local population on the issues of environmental degradation;
- implementing a community-based monitoring system of forest resources based on participatory mapping and GIS technology.

CeTAmb was involved as technical partner with responsibility for science and technology component of the diffusion of renewable energy sources. In particular, the activities initially focused on the design, implementation and testing of a machine for the production of briquettes. This activity was changed due to factors related to the economic feasibility of the proposed action, orienting to the reduction of wood consumption at household level by means of dissemination of appropriate technologies. In particular the study dealt with increasing the efficiency of traditional cooking systems, comparing different technology options.

## 2.3. Assessment of access to cooking energy

A number of activities on the field were implemented to gain knowledge about the cooking energy issue in the local context.

Among the social research qualitative methods in this research the followings were applied:

- observation of the target groups, villages and project interventions through local field staff was used in order to gain a first impression of energy patterns. Even though not as accurate and representative as structured surveys, observations can be especially useful for preparing further scientific research (e.g. questionnaires) by providing site-specific knowledge (Trochim and William 2006).
- Focus Group Discussions allowing interviewers to study people in a more natural setting than in a one-to-one interview (Trochim and William 2006). This method was used during the workshops organized for local artisans in the production of some models of improved stove to assess their opinions by talking to various people at once in a less forced environment.

Quantitative approaches are concerned to quantify social phenomena by collecting and analyzing numerical data in a statistical reliable and valid manner.

- Semi-structured interviews were used in quantitative surveys to obtain comparable information representative for the total target group. Standard questionnaires (IEA, WHO) were adapted to fit objectives of surveys implemented on relevant assessment fields. Random samples were chosen among the population living in the intervention area. Questions were structured in order to avoid bias due to undesired effects on the respondents such as social-desirability (people tend to answer not according to their own opinion but according to social norms or what the respondent thinks would be the desired answer for the interviewer) and revised after some pilot tests.

Besides information that need to be gathered from interviews or observations, data on particular indicators were provided from local databases, statistics and registers.

## 2.4. Stove testing

Over the last thirty years there have been many attempts to develop improved stoves, but often they failed due to lacks in quality and performance control. The technical performance of stoves is tested according to internationally agreed test procedures related to energy efficiency, emission control and safe use. Historically the main focus of the performance of an energy system is given to its efficiency, an indicator that expresses the ratio of energy useful to achieve a specific task on the total energy consumed. Thus, such a parameter is too narrow to describe the effectiveness of a stove, as a number of factors beyond the stove design takes influence in similar conditions, like the quality and characteristics of the fuel, the handling of the fuel, the handling of the stove, the management of the cooking process, the environment of cooking.

With focus on relative performances of stoves, the assessment of stove efficiency is circumstantial. A clay stove is perceived as an efficient stove in households with open fire places and as an inefficient stove in households that are using an advanced improved stove. International standards on stove quality have been discussed for many years. While they are desirable to enable a global comparison of stove performances, there is a danger that cheap solutions for the very poor households are abandoned due to their low performance in relation to the global standards, when in fact they could still be a relevant improvement in comparison to the baseline situation of the poorest of the poor. That’s why a stratification of quality standards has been developed in the “Lima consensus” reached during the 2011 Forum of the Partnership for Clean Indoor Air. The consensus reached among major stakeholders in standards and testing resolved to adopt a temporary rating system of stove technologies in tiers of performance in the areas of fuel efficiency, indoor air quality, emissions of PM and CO, and safety. Each area has to be ranked separately, reflecting a sequence of evolution from Tier 0 for 'typical unimproved' to Tier 3 'to achieve significant, measurable high goals'. The new protocol should also evaluate particulate composition including black carbon, address batch-feeding stoves that are not well captured by the current protocols.

### 2.4.1. Water Boiling Test (WBT)

This laboratory-based test is designed to explore the most basic aspects of stove performance in a controlled environment. A prescribed amount of water is brought to the boil and kept simmering for a given period of time, while the fuel consumption (and recently also the emissions) is measured. As it is a short test, and the results are not highly variable, relatively few tests can give informative and quick feedback. The WBT is a useful tool in the process of stove development or when comparing very different stoves. It allows to accurately spotting the effect of small changes in stove design, fuel quality or other physical variables. It can also be used in field tests to determine whether stoves have been built to match their design criteria on cooking time, fuel use and emissions. It does not reflect field performance because the way typical local dishes are prepared can be very different from just boiling water. Currently revisions of the test protocols are being discussed, but no new protocol has yet been accepted.

### 2.4.2. Controlled Cooking Test (CCT)

Like the Water Boiling Test, the Controlled Cooking Test measures the fuel consumption of a stove for a specific standardized cooking task typical for a certain region. The CCT can be done either in a laboratory-environment or in the kitchen of a real user while the regular user operates the stove and the tester observes and records all the influencing parameters. The duration of the CCT is determined by the chosen typical cooking task. As well as being closer to day-to-day life, it allows the stove properties to be measured in a reproducible way by minimizing the influence of other factors.

### 2.4.3. Kitchen performance test (KPT)

The Kitchen Performance Test is an entirely field-based procedure that evaluates the effect of stove interventions in real-world conditions: the KPT is carried out over several days in the users' households. Fewer parameters are controllable as the tester is not present all the time during the test. It includes quantitative surveys of fuel consumption of the participating household and qualitative surveys of stove performance and acceptability. The KPT is more time-consuming, thus more expensive; however, it is the best way to monitor the stove's real impact on fuel use and cooking behaviour in the participating households. The KPT is increasingly important for projects that want to register for the voluntary carbon market to prove the actual fuel savings realized by the users in their day-to-day cooking.

### 2.4.4. Emission monitoring

Wood is chemically mainly carbon, hydrogen and oxygen. The main products of complete combustion are carbon dioxide ($CO_2$), water vapour and heat. In reality, it is difficult to achieve a complete combustion of biomass in stoves. Some stove designs have fewer emissions than others, but the fuel properties still have a big influence. Incomplete combustion results in emission of small particles, carbon monoxide (CO), nitrogen oxides ($NO_X$), formaldehyde, benzene and many other potentially harmful organic substances. In terms of health, particulate matter (PM) and CO emissions are the most important. These two pollutants are mainly measured in Emission Control Tests. Due to the nature of the fuel, wood stoves cause higher PM emissions.

Emissions can be measured either from the plume of smoke rising from the stove or at a designated point in the room that reflects the approximate position of the cook. There are a number of relatively cheap, reliable and easy to handle instruments for measuring the CO concentration from stove emissions.

There are two main types of equipment for monitoring carbon monoxide in this type of work. The first is a 'stain tube', which is a small tube, made of robust glass inside which is a sensor which changes colour with exposure to the gas. These tubes are useful if only a small number of measurements have to be made, but as they can only be used once, they are expensive for larger numbers of samples. They give an indicator of CO levels, but are difficult to interpret accurately and do not give real time data. Otherwise a real time monitoring of carbon monoxide can be used, like single gas monitors made for workplace safety. Once monitoring has taken place, data can be downloaded to a computer using a data-logger. Software enables the user to look at graphs of levels of carbon monoxide with time.

By contrast, measurement of the small respirable particles, also called particulate matter (PM), has been quite difficult until very recently. PM are aerosols comprising solids (dust, soot) and liquid droplets of tars and other combustion products (excluding water vapour). They occur in a wide range of sizes (between 0.005 µm and 100 µm in diameter) and with very different chemical compositions. The small respirable particles have more adverse effects on health as they can penetrate the lungs more deeply. Hence modern analysis methods focus only on the "fine" particles with diameters below 2.5 µm, called $PM_{2.5}$ or below 1 µm, called $PM_{1.0}$. There are two main methods for quantifying PM exposure.

- Gravimetric method - by sucking air through a filter and weighing the deposited particles on a high-precision scale. This method is labour-intensive, slow and prone to uncertainties from filter handling, transport, conditioning and weighing. However, it has been used for a long time within industrial settings and has shown to be robust if properly applied.
- Continuous monitoring of the PM concentration by using indirect techniques. A common method, used in fire detectors, measures the reflection of light by the aerosols. Based on this principle the Centre for Entrepreneurship in International Health and Development (CEIHD), University of Berkley developed a standard Indoor Air pollution Protocol. This method monitors for very fine particles ($PM_{1.0}$) and fine particles ($PM_{2.5}$).

It is agreed upon that fuel consumption and emissions of a stove must be monitored at the same time, so benchmarks for total PM- and CO- emissions of a stove during a standard performance test are being discussed: 'improved' stoves should possibly not produce more than 1,500 mg of particulate matter and 20 g of CO during a 5-L Water Boiling Test. However, this does not necessarily reflect the real exposure of the cook in the kitchen under day-to-day conditions. To determine the actual exposure levels, to which a person is subjected, involves personal monitoring, e.g. attaching dosimeter tubes (glass tubes containing chemicals which stain when exposed to carbon monoxide) directly onto the clothing of either the cook or other member(s) of the household, or lightweight electronic carbon monoxide detectors that can be worn around the neck. Although monitoring household members is technically more challenging, it gives direct information about real exposure of people to hazardous smoke.

The 2005 AQG set for the first time a guideline value for particulate matter (Table 5). The aim is to achieve the lowest concentrations possible. As no threshold for PM has been identified below which no damage to health is observed, the recommended value should represent an acceptable and achievable objective to minimize health effects in the context of local constraints, capabilities and public health priorities.

**Table 5: indoor air quality guidelines for PM according to WHO (2005)**

| $PM_{2.5}$ | $PM_{10}$ |
|---|---|
| 10 μg/m$^3$ annual mean | 20 μg/m$^3$ annual mean |
| 25 μg/m$^3$ 24-hour mean | 50 μg/m$^3$ 24-hour mean |

## 2.5. Monitoring of impacts and assessment of the appropriateness

For a "proper" impact assessment it is recommended[7] the use of a shared list of indicators, the conduction of baseline studies before project intervention and impact studies after households got access to a form of modern energy, the use of a theory based approach by applying the result chain for developing the study design, the use of a mixed methods approach. The inclusion of control groups if possible (households which do not have access to modern energy) into the baseline and impact study  In particular the use of mixed methods allows looking at things from multiple points of view (Mikkelsen 2005) capturing different effects of one intervention, assessing in multiple ways the complexity of a system, strengthening the results if these converge, limiting the bias. Quantitative impact evaluation done in experimental or quasi-experimental way is preferable to qualitative assessment.

Impact assessment in different phases of an intervention allows to monitor and to compare the results of the activities with the baseline. These include: income generation from stove production, women engaged in new activities, time and expenses saved, perceived reductions in the levels of indoor air pollution and reduction in the number of accidents. To collect empirical data on the impacts of energy projects, a wide range of methods and approaches is available. These may differ significantly in terms of time, money and expertise needed for implementation (Baker 2000).

Results Based Monitoring (RBM) is an international monitoring standard designed to monitor development results applied regularly to GIZ programmes. Results are defined as development changes that follow directly from an intervention; they can be outputs, outcomes or impacts resulting from a development intervention. RBM is a method to examine the result hypotheses in an empirical and systematic way. The two key results are usually considered to be stoves sales and correct stoves use, since all further outcomes and impacts depend on stoves on the market and their correct use. The stove effects strongly depend on the capacity of the user to achieve maximum reduction of fuel use and emissions. An interesting case is the Participatory Impact Assessment applied by ProBEC (Programme for Biomass Energy Conservation) in selected Sub-Saharan African countries, where impact assessment interviews were conducted by local stove artisans. This approach to impact assessment requires high involvement by the

[7] https://energypedia.info/

producers and creates business awareness. The results of an assessment by the manufacturers inevitably cannot be considered neutral.

The data from impact assessment can provide the starting point for an economic evaluation of the project, including a Cost-Benefit-Analysis (CBA) and a Cost-Effectiveness Analysis (CEA). Analyzing both the economic efficiency of the investments and the benefits deriving from energy efficient stoves on a macro and micro level can be helpful for further lobbying, public relations and keeping control of the project. Financial and technical criteria have generally prevailed, while the possibility of using a conceptual framework that encompasses sustainable energy development has often been neglected. In this perspective a multi-criteria approach to decision making appears to be the most appropriate tool to understand all the different perspectives involved (Kahraman and Kaya 2010).

# 3. Background: access to household energy in the Logone Valley

## 3.1. Introduction

As said in the presentation of the structure of this thesis the project activities interested two Countries, Chad and Cameroon, but this work focus mainly on the Chadian side. This chapter consists in two main parts. A first paragraph gives some information on the national context and provides with the basic data and features of the country with particular regard to the environmental and energy sector. A second part presents the results of some observations conducted on site. In particular the results of a survey involving more than 150 householders some living in the Logone Valley in both countries revealed the socio-economic patterns in the use of household energy in such a context. Moreover, the analysis of the output of the survey assessed the almost identical socio-economic characteristics and domestic energy practices both in the Chadian and in the Cameroonian population, divided by administrative national boundaries, but actually belonging to the same traditional ethnic group, the Masa.

## 3.2. The Chadian national context

### 3.2.1. Geography and climate

Chad is a country in North Central Africa measuring 1,284,000 square kilometres. Chad has four bioclimatic zones. The Northern Saharan zone averages less than 200 mm of rainfall annually. The human population is largely nomadic, with some livestock, mostly small ruminants and camels. The central Sahelian zone receives between 200 and 600 mm rainfall and has vegetation ranging from grass/shrub steppe to thorny, open savannah. The southern zone, often referred to as the Sudanian zone, receives between 600 and 1,000 mm, with woodland savannah and deciduous forests for vegetation. Rainfall in the Guinea zone, located in Chad's south-western tip, ranges between 1,000 and 1,200 mm.

### 3.2.2. Population

Chad's population is estimated at 8.1 million, based on 1993 census figures updated in 2003, with a population growth of 2.5% in 1993 (against 1.4% in 1964). There is a positive trend of urbanization, but still nearly 80% of the Chadian population is rural (PNSA 2005): about 6.5 million people live in rural settlements of less than 2,000 inhabitants.

The distribution of population within the country responds to a very variable pattern: the average density (5.7 inhabitants per km²) varies considerably from North to South (Figure 10). In the Saharan population, groups are located in small areas around the oasis, and the resulting mean density is very low. In the Sudanian zone, due to migration phenomena (not reversible) and the tendency to settle for transhumant, there is juxtaposition of indigenous people and migrants, determining a high density. Overall, excluding migration flows between counties, 50% of Chad's population lives in the Sudanian zone (which represents only 10% of the country) against less than 3% in the Saharan zone (SDEA 2003). Population densities range from 54 persons per square kilometres in the Logone River basin to 0.1 persons in the northern desert region. The capital city of N’Djamena, situated at the confluence of the Chari and Logone Rivers, is cosmopolitan in nature, with a current population in excess of 1,000,000 people. The recent growth of N'Djamena was carried out partly in areas prone to flooding. The cities of the oil region have far exceeded the growth rate of the capital in recent years. The situation of the Chadian population who lives in poverty is still a serious concern throughout the country, whether rural or urban, and still requires significant improvements, even if progress is perceptible.

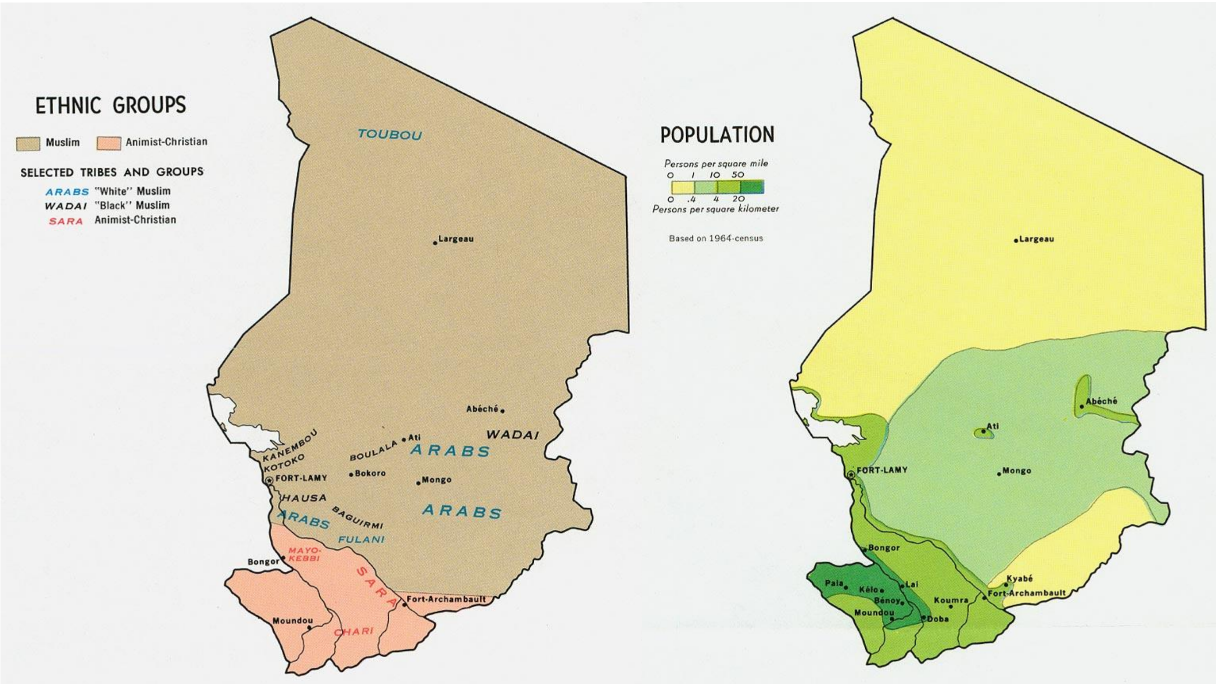



**Figure 10: ethnic groups and population density in Chad**

### 3.2.3. Socio-economic aspects

Besides oil, in Chad the national economy is primarily based on agriculture and livestock activities, concerning 80% of the population. Agro-pastoral productions taken together are involved in 38% of GDP. The country's agricultural potential is considerable, with 39 Mha of land. Floodplains, particularly extensive in the southern half of the country, contribute significantly to this potential. Agricultural systems are built around a subsistence production based on sorghum and millet, and a cash crop dominated by cotton (12% of the national area cultivated, concentrated in the Sudanian climatic zone). Other agricultural productions that have local importance are sugar, tobacco, rice and peanuts. The main constraints to agricultural development are linked on the one hand to climate, siltation and population growth, but also to low technical capacity, compounded by transport difficulties; however, civil tensions and conflicts have constituted aggravating factors. Chadian agriculture needs support for improved productivity, both for food security and commercial purposes.

The role of women in environmental management is crucial. They are involved in production activities and at all levels of domestic life, including that of energy. Women are also the targets of advocacy for water quality, hygiene and health.

### 3.2.4. Environmental issues

The national natural resource degradation is running. Population growth is high, and two conditions are of concern: poverty is very present, and the food deficit is permanent in some areas. In addition, thousands of refugees from Sudan and Centrafricain Republic moved to the East and the South of the country.

In rural areas, 30% of the population has access to a modern water point, but only 10% of the population has adequate sanitation[8]. Sewage contaminates the immediate vicinity of settlements with important implications for human health.

**Figure 11: poor water & sanitation conditions in rural and peri-urban areas in Chad**

In major cities drinking water is distributed by the STEE at a fraction of the population, while another part of the population benefits from modern water points independent by the network, there are still large areas that use traditional wells.

In N'Djamena 40% of people have a better personal sanitation (pit); moreover there are also some public toilets in town. But the conditions still leave a large place to unsafe: rainwater is very poorly drained; household waste is managed only partially; urban industrial discharges are seldom treated; in peri-urban areas informal drinking water is polluted. The health consequences are heavy; urban populations are suffering from waterborne diseases, but the relationship of cause and effect is not clearly perceived.

#### *3.2.4.1. Environmental policy, legislative and institutional framework*

Chad has endorsed the approach of sustainable development in 1995 by establishing the High National Committee for the Environment (HCNE). In an attempt to resolve the paradox between natural resources and the state of poverty and chronic food insecurity, the Special Programme for Food Security (PSSA) was launched in 1999 with these main objectives: increase of irrigated areas; intensification of agricultural production; diversification of rural incomes.

Intervention Program for Rural Development (PIDR) was formulated for the period 1999-2005 and designed as a strategic framework for the implementation of the policy of the whole sector but whose implementation has shifted. Since 2003, the national policy reference document is the National Strategy for Poverty Reduction (PRSP). This strategy aims to halve extreme poverty by 2015 addressing the following

[8] http://www.acp-programming.eu/wcm/dmdocuments/CEP%20Chad.pdf

areas: promoting good governance; ensuring growth; improve human capital; improving the living conditions of vulnerable groups; restoring and safeguard of ecosystems. In 2003 the Master Plan for water and sanitation (SDEA) was adopted. Environment does not have a clean and explicit National Strategy, so that, in terms of priority, it is weakened compared to the sectors: Water, Rural Development, Food Security, with which it is nevertheless strongly related. There is no domestic energy strategy, progress in this area have been carried out by the Household Energy Project of the World Bank led to the creation of the AEDE (Agence pour l'Energie Domestique et l'Environnement). Law 36 (1994), Law 14 (1998) and Law 16 (1999) provide a modern forest management, protection of the environment and management of water resources. But the existing texts currently are not sufficient to meet needs; a law on forest system is particularly waiting since 1999 and is still missing most of the implementing regulations to become functional. Many other areas are based on old laws.

### 3.2.5. Energy resources

Oil, high-value and strategic resource, represents also the potential for energy independence of the country. With the mining fields in the Doba region, Chad has made oil its first source of foreign exchange earnings. Various prospectings took place and new oil operations start now. Oil development in the Doba region has led to reactions from civil society and international bodies that have led to a sophisticated consideration of environmental aspects. Despite an elaborate organization, the control by the public has not yet been developed. Critical points are the measures to reduce or offset the environmental local impact of oil exploitation, as very inadequate and very limited access to information. Likely, oil use seems not to be the primary energy source to provide civil society with an adequate energy access, due to the global economic interest and to the lack of political strength and strategies to address this issue.

Electricity is used by less than 4% of the national population (up to 30% in the capital city). The costs are extremely high, especially compared to the level of life. The national STEE works very bad and service offered is not sufficient to supply all the users. Rural areas are still underserved.

Wood energy is still 98% of energy consumption at household level. The wood resources of the country have suffered very significant damage due to the considerable pressure: drought, agricultural clearing, bush fires, the impact of transhumance and collection of firewood for urban needs. Over the past 3 decades, several million hectares of forests have disappeared. In particular in the area of the capital city, N'Djamena, the increasing demand for fuel has encouraged massive unregulated firewood exploitation as a source of income, which resulted in concentric deforestation circles being pushed farther and farther away from the centre of consumption and demand.

In the 80's, the wood for the capital was taken within 25 - 50 km; the distance is now from 100 to 150 km. Between 1991 and 2001, consumption of wood energy in N'Djamena has increased at a rate of 6.3% per year. The last known annual consumption for the capital was 1.2 million cubic meters of wood equivalent (as charcoal) and 250,000 cubic meters as firewood (AEDE 2001). In Moundou the PGRN shows the equivalent figure of 360,000 cubic meters of wood equivalent of firewood per year and 100,000 in Sahr (2001). According to FAO, the amount of wood removed is already above the forest production in many areas: BET, Lac, Kanem, Batha, Mayo Kebbi, Logone Occidental, Tandjilé and of course N'Djamena. The shortage of firewood around the capital is very sensitive, a phenomenon common to other major cities situated at the gates of Sahel.

**Figure 12: wood markets in peri-urban and rural areas in Chad**

The elements of strategy that can bring solutions to this crisis of wood energy are already identified (see following sub-paragraph): re-organization of public management of forest areas, including taxation at the level of rural wood markets, improving marketing, transfer of forest management to local communities, development agro-forestry and plantations, improved stoves and other systems, development of alternative energy. For many reasons, this strategy has not been formalized, but its implementation is now urgent.

Kerosene is widely used for lighting, in particular in rural areas where hurricane lamps are common. Kerosene is a fuel used for cooking, but there is very little developed in this use. Bottled gas began to replace in the city N'Djamena a fraction of the wood energy since 1991. In two years, "butanization", which is the so-called subsidized marketing of gas cylinders of 2.75 and 6 kg (equipment and fuel), led to a significant increase in sales. But then they fell off at the end of program and of subside. In 2000 a new subside was established under the Gas Regional Programme, coordinated by the CILSS and supported by the EC. Consumption has a significant increasing trend (30% per year) since 2000. The number of gas stoves is limited, currently estimated at only a few thousand. Gas is a popular fuel in the city, but users are limited by the costs (set of the bottle and refill). Further development of the gas is hardly noticeable in other cities that N'Djamena.

Biomass and biogas are not exploited, although the energy recovery from agricultural wastes has been experienced for a long time and know-how exists. These sources can be in certain situations significant back-up energy. Other plants such as invasive plants (water hyacinth) could be used to supply units for the production of biogas (systems remain to be developed). Similarly, a significant proportion of urban solid waste could be recycled in this way. As part of PREDAS there are plans to develop production of briquettes from cotton stalks in the region of Bongor, but at the time of the study any practical evidence of such projects was found on the field.

In summary, the components of the national energy issues are many, but no clear outline of a solution to the crisis of energy wood is visible today. The reinforcement of a Domestic Energy Programme is essential and urgent. It is part of the fight against desertification. There is also need to continue to develop alternative energy sources (bottled gas) and reduce consumption (improved stoves).

Data reported in Table 6 give a profile of the socio-economic situation and of the access to energy at national level in the two Countries where the project was implemented.

**Table 6: Chad and Cameroon general country profile (WHO 20111) and access to energy status (WHO and UNDP 2009)**

| | Chad | Cameroon |
|---|---|---|
| **General country profile** | | |
| Population | 9.7 mio | 16.3 mio |
| GNI/capita | 1,280 US$ | 2,120 US$ |
| % urbanization | 25% | 55% |
| Population below the poverty line | 64% | 40% |
| Under age 5 mortality rate (/1,000 live births) | 209 | 149 |
| Life expectancy | 46 years (2006) | 51 years (2006) |
| **Access to energy** | | |
| Classification | LDC, Sub-Saharan Africa | DC, Sub-Saharan Africa |
| Numbers of deaths per year attributable to solid fuel use (2004) | 9,600 | 11,400 |
| Number of DALYs per 1000 capita per year attributable to solid fuel use (2004) | 32 | 21 |
| % of population with electricity access (rural/urban) | 29.4 (9.0/45.0) | 3.5 (0.3/16.4) |
| Fuel used for cooking (% of population) | | |
| Wood (rural/urban) | 70.8 (82.9/29.6) | 73.5 (93.9/53.2) |
| Charcoal (rural/urban) | 15.4 (8.4/39.4) | 1.7 (1.0/2.4) |
| Coal (rural/urban) | 4.9 (1.1/17.8) | - |
| Gas/Electricity/Kerosene (rural/urban) | 2.5 (1.7/5.1) | 21.4 (2.6/39.9) |
| Use of improved stoves (rural/urban) | 21.6 (23.5/14.6) | 2.6 (2.2/3.4) |

#### *3.2.5.1. Household energy strategy*

AEDE (2002) elaborated a plan for the energy supply of the city of N'Djamena. The plan pointed out also some interventions for the management of the woodfuel basin in the regions surrounding the urban area, up to the district of Bongor (240km far) in the South of the country. The plan elaborated a strategy summed up in the following points:

- reduction of wood energy demand at household level
  - wood consumption reduction through the adoption of improved stoves
  - charcoal substitution with LPG
- enforcement of the production system
  - "green village initiative": promotion of the creation of community committee to be charged of the sustainable management of the local natural resources
  - improvement of the carbonization process
- Increase the tax on coal from uncontrolled zone

Practically the political ambition aimed mainly at substituting biomass rather than making it clean and sustainable. The LPG market was strongly subsidized in the following years, but in particular in peri-urban areas the supply of modern fuels has experienced shortages and price increases, resulting in undesired mechanisms. Many households that early adopted LPG "moved down the energy ladder" and returned to cook with charcoal. The increasing demand for charcoal, which was produced in rural areas through low efficiency of carbonization processes, led in 2009 to the total ban of the production, import and sale of that fuel. This interdiction has worsened the issue of daily fuel collection for most local families, as fuel market prices have increased enormously. Any more modern alternative was likely to provide local population with an affordable and reliable energy source. LPG, even when sold at a subsidized price, resulted unaffordable for the large share of population whose subsistence economic level does not allow to have the capital cost to invest in both the gas burner and the bottle. Moreover the only available fuel was dry wood, whose price occurred in a more than double price increased from 2008 to 2010. Several local journals stated the problem caused by the ban for the local population and the consequences on the local wood market. Wood purchased in rural areas, up to 90km far, was sold in the capital city N'Djamena at a three time higher price. The values indicated by AEDE in 2002 (57 CFA francs/kg) resulted more than doubled in 2009 (121 CFA francs/kg) according to observations by the author.

## 3.3. The study area: the Logone Valley

The research leans on the activities of an International Development Cooperation project (ENV/2006/114-747) carried out by the Italian NGO ACRA and funded by the EU in the Valley of Logone River at the border between Chad and Cameroon (Figure 13): activities were implemented around the towns of Bongor and Yagoua where the project is based.

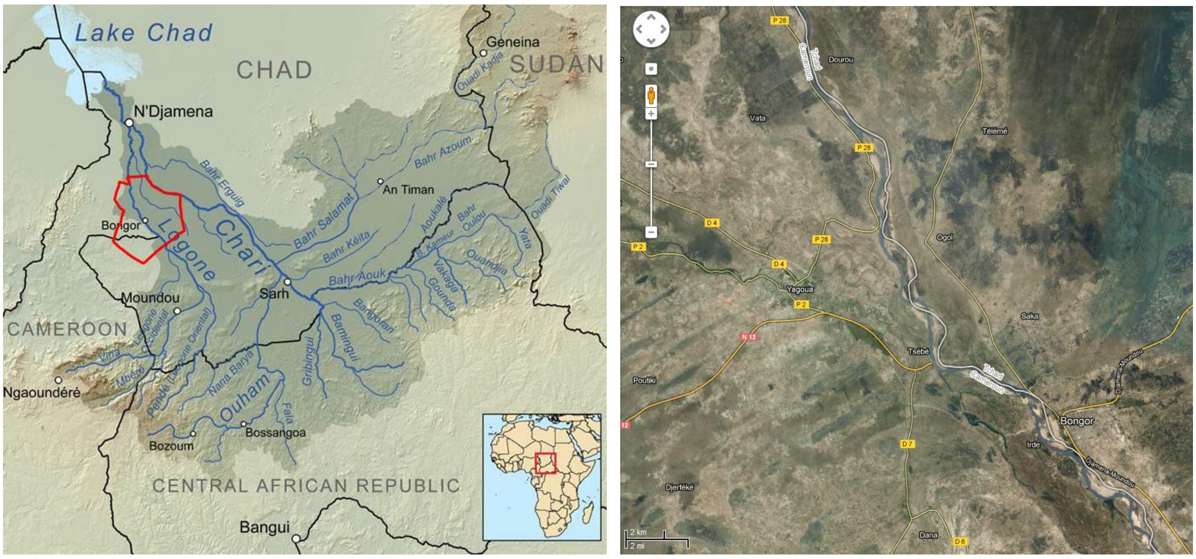



**Figure 13: the river Logone Valley and the town of Bongor (coordinates 10°16'N 15°22'E)**

At the beginning of the project (2008), in the intervention region charcoal and wood were the traditional fuels for household energy supply. Only in urban areas some people used to cook with LPG gas. Charcoal production and sale has been forbidden by the Chadian national government since 2009. In particular wood prices more than doubled, from 15 CFA francs/kg in 2008, to 40 CFA francs/kg in 2011 (according to price observations on site by the author), resulting in serious issues in fuel supply for the local population. Figure 14 shows the trend in woodfuel price observed or reported by other previous studies

(AEDE 2002), compared to the one calculated according to inflation rate provided by the World Bank website for each year. The effect of the ban of charcoal in 2009 is really clear, being the cause of a disproportionate increase of the price (+135% in the period 2008-2011).

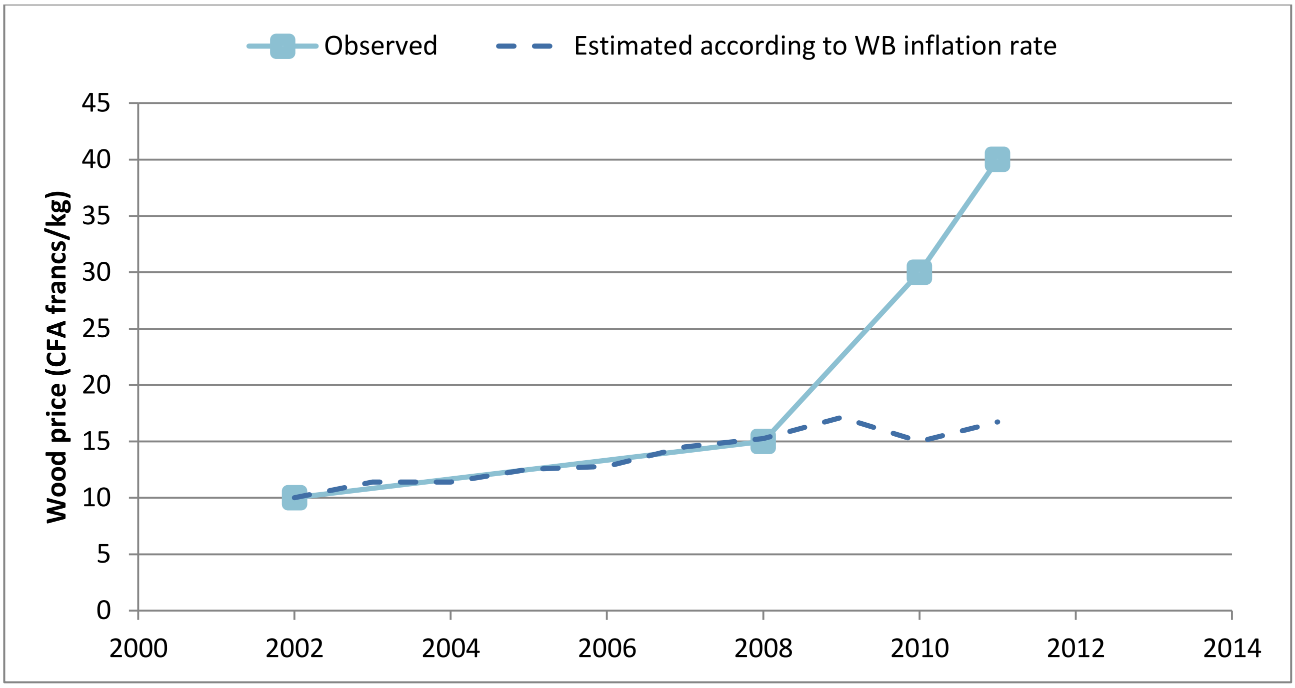



**Figure 14: differences between prices observed on site by the author and calculated according inflation rates by WB (2011)**

The project supported the creation of community based committees for the participative management of natural resources: the reduction in wood consumption for household use was one of the aims of the project. Appropriate technologies for household energy supply have been considered to achieve the objective of a reduction of wood consume. In particular the improvement of household combustion has been targeted through the spreading of existing effective improved stove models, which guarantee a lower wood consumption. The dissemination of low-technology but high-efficiency models was implemented keeping into account the socio-economic conditions of the local people (minimal investment capacity due to very low level of income) and of the skills and the tools available for small local workshops (in particular the lack of electricity limits to basic manufacturing capabilities).

According to data collected by the author in a preliminary survey on site, the vast majority of people (98%) relies on wood for daily cooking, 69% out of them use a rudimental 3-stone fire like in several other developing countries (WHO & UNEP 2009). The access to modern fuels is very limited (1.8%), even lower than the already low national average (2.5% for Chad, 2.6% for rural areas in Cameroun). In rural households, food is generally cooked on clay stoves. A family of 5-6 persons requires about 8 kg of fuel every day. Surveys showed that, on an average, the domestic fuel consists mainly of agricultural residues and cattle dung (generated in the family farm), supplemented by wood (branches of trees collected in the neighbourhood) to the extent of about 40%. Even families who can afford modern fuels, prefer to use biomass because it is available free of cost. In forested regions, the fuel is almost exclusively of wood.

### 3.3.1. The Masa ethnic group

The Masa is the main ethnic group in the intervention area, living along the riversides of the Logone. The area is an alluvial land, frequently flooded during the rainy season from May to the end of September. The climate is Sudanian-Sahelian with a maximum annual rain level of 750 mm. According to the last national census available (1993) the Masa living on the Chadian side of the Logone Valley were about 110,000; a similar population size is estimated for the Cameroonian side, but no official data are available.

The social organization is based on an extended family structure. The rural villages are constituted by independent family households, each one surrounded by the private fields where sorghum is cultivated during the rainy season and animals graze during the dry season. Sorghum and millet cultivation, livestock farming and fishing are the main productive activities.

Each patriarchal family builds its own court of households, constituted by a number of individual buildings (*ziydà*) disposed in a circular shape creating a central court, as shown in Figure 15. The single buildings are also circular based, and are connected to the other buildings by an external mud wall. Buildings are built using a mix of clay, sand and straw, but also fired or mud bricks are an option. Women live in the most internal part of the court, on the opposite side of the entrance. Every wife has her own bedroom, her kitchen (*dàfiàynà*) and her own barn (*férrà*). The fire (*gìwìnnà*) is usually outdoors, between two buildings and cover by a canopy.

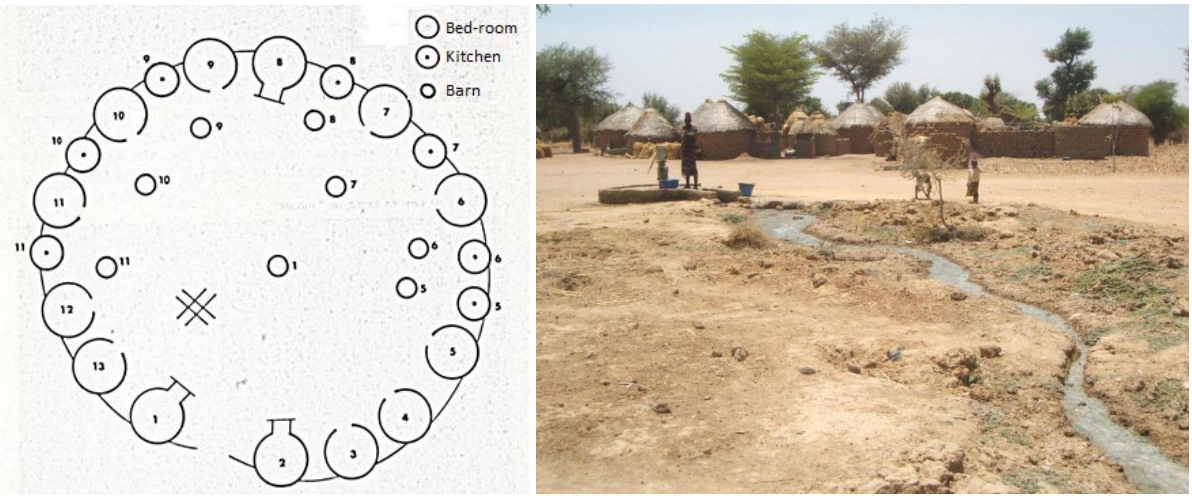



**Figure 15: typical Masa court of households drawn by Melis (2002) and observed on-site**

This situation is still typical in the rural area, where the economy is still based on a subsistence system and the monetized market is still not predominant. In the urban area the situation is significantly different, due to the fast demographic growth of small towns not followed by an adequate increase of service level. Some aspects of the rural way of life have been transported and adapted to the urban context; buildings and court spaces have been recreated but in a restricted space given by the higher population density. That often results in a number of unsafe and unhealthy practices, such as the poor management of wastewater, which are simply diverted outside the household compound, or the recovery of animals inside the living buildings, or the uncontrolled disposal and burn of solid waste just along the road. In particular, with regard to the topic of this work, the three stone fire is the most common cooking system in urban households due to the lack of a proper kitchen space and the need for daily switching the cooking place.

## 3.4. Material and methods

In order to have a deeper and more comprehensive understanding of the household energy patterns at local level a survey aimed at investigating the local cooking practices and fuel supply and consumption features was implemented using semi-structured questionnaires. This detailed survey was implemented in 2011, after the project end; nevertheless it assesses the energy access situation of the local population, having only a share of it benefited of the intervention. The householders sampled were chosen randomly among the local population during *ad hoc* field visits.

World Bank guidelines for questionnaires design in Living Standards Measurement Studies (O'Sullivan and Barnes 2007) and Standard Monitoring Packages for Household Energy Projects of the University of Liverpool (Bruce et al 2007) were taken as reference in the preparation of the survey. In order to make them understandable and appropriate to the local habits and culture, some questions were reformulated and some other were added in order to catch some peculiarities of the local context. The interviews, conducted with the unavoidable translation support of the local staff of ACRA NGO (Figure 16), consisted in five short question clusters.

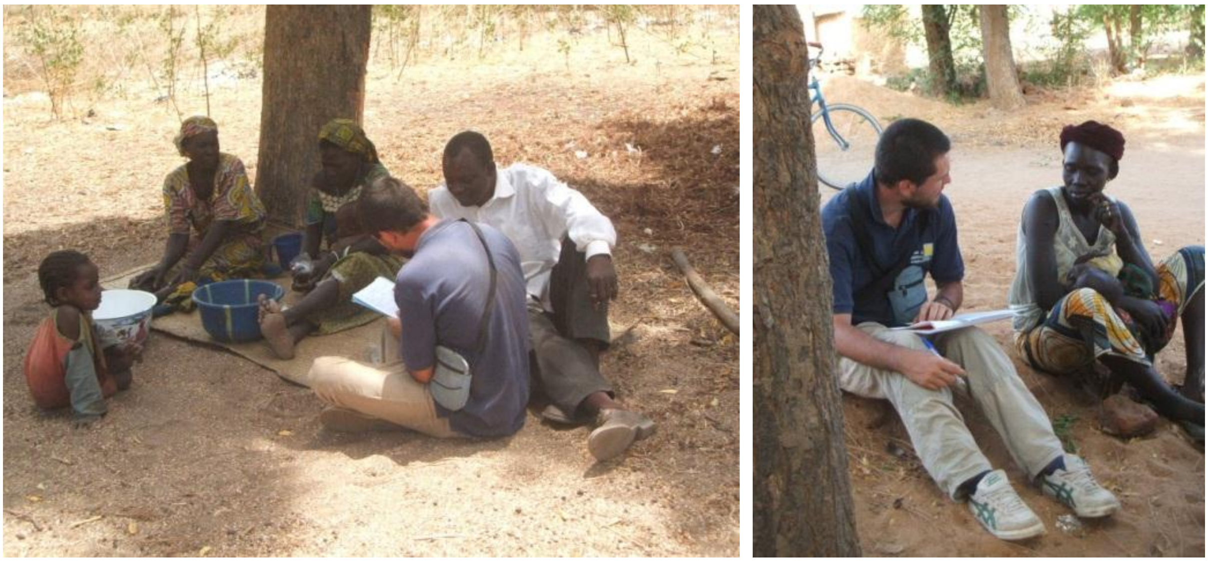


**Figure 16: semi-structured interviews to local householders**

A first one allowed gathering the household social features in terms of family size, member occupation and education, income level and productive activities. The second tranche of questions investigated the local cooking practices, thus the habits, the number of daily meals, the cooking time and the stove model used. A third group of questions aimed at quantifying the need for fuel, gathering information on the fuel provision mode, the frequency and distance for the fuel supply and the eventual fuel expenditure. The forth cluster regarded the lighting facilities and expenditure. A final checklist was included to evaluate the Energy Supply Index (EIS): this index was elaborated by Practical Action and GIZ and proposed to indicate the progress on the supply side towards the energy service standards, outlined in Table 1. The index measures the three main supply dimensions of energy access – household fuels, electricity and mechanical power – by assigning a numerical value to the qualitative dimensions of people's experience of accessing energy supplies, with 1 being the lowest and 5 the highest level of access.

**Table 7: checklist used to define the Energy Supply Index (Practical Action 2010)**

| Energy Supply | Level | Quality of Supply |
|---|---|---|
| **Household fuels** | 1 | Collecting wood or dung and using a three-stone fire |
| | 2 | Collecting wood and using an improved stove |
| | 3 | Buying wood and using an improved stove |
| | 4 | Buying charcoal and using an improved stove |
| | 5 | Using a modern, clean-burning fuel and stove combination |
| **Electricity** | 1 | No access to electricity at all |
| | 2 | Access to third party battery charging only |
| | 3 | Own low-voltage DC access for home applications |
| | 4 | 240 V AC connection but poor quality and intermittent supply |
| | 5 | Reliable 240 V AC connection available for all uses |
| **Mechanical Power** | 1 | No access to mechanical power. Hand power only with basic tools |
| | 2 | Mechanical advantage devices available to magnify human/animal effort |
| | 3 | Powered (renewable or fossil) mechanical devices available for some tasks |
| | 4 | Powered (renewable or fossil) mechanical devices available for most tasks |
| | 5 | Mainly purchasing mechanically processed services. |

Actually the EIS has been revised in the very recent last version of the Poor People Energy Outlook (Practical Action 2012), but it was not possible to ri-elaborate data gathered on field according to the new indications. Nevertheless, some interesting considerations, proposed in the following paragraphs, are meaningful and worth to be discussed. The statistical analysis of data collected was done using the SPSS software for the calculation of the analysis of correspondence, the comparison of means and the box-plot graphical representation.

## 3.5. Results

A total number of 161 semi-structured interviews were done, 115 in rural villages and 46 in urban area. On average the household was composed by 9 members (2 adult men, 3 adult women and 4 children).

### 3.5.1. Socio-economic features of the population surveyed

The socio-economic features of the population surveyed were investigated according to the information gathered in the first cluster of the questionnaire. In particular two different stakeholders were identified according to their roles in the energy management at household level. The household head is usually the man (89%), and the person in charge for the preparation of the meals and for the cooking tasks for the family (in the following called “cooking manager”) is, in the vast majority of the cases, the woman (97%).

The occupation of the household head and of the person in charge of the cooking activities (meal preparation and fuel use) is illustrated in Figure 17. In the rural area her occupation is mainly the management of the house (71%) and production of vegetables in the garden (24%), while the agricultural work in the field and the itinerant husbandry is the activity of the majority (77%) of the household heads, usually the men. In the urban area the activities are more variegated. The vast majority of cooking managers (59%) are housewives, but a significant share (17%) is professionally employed in a certain activity (secretaries, nurses, etc.). 50% of the household heads works as employee, 11% as teacher, 9% holds a commercial activity and 13% is housewife.

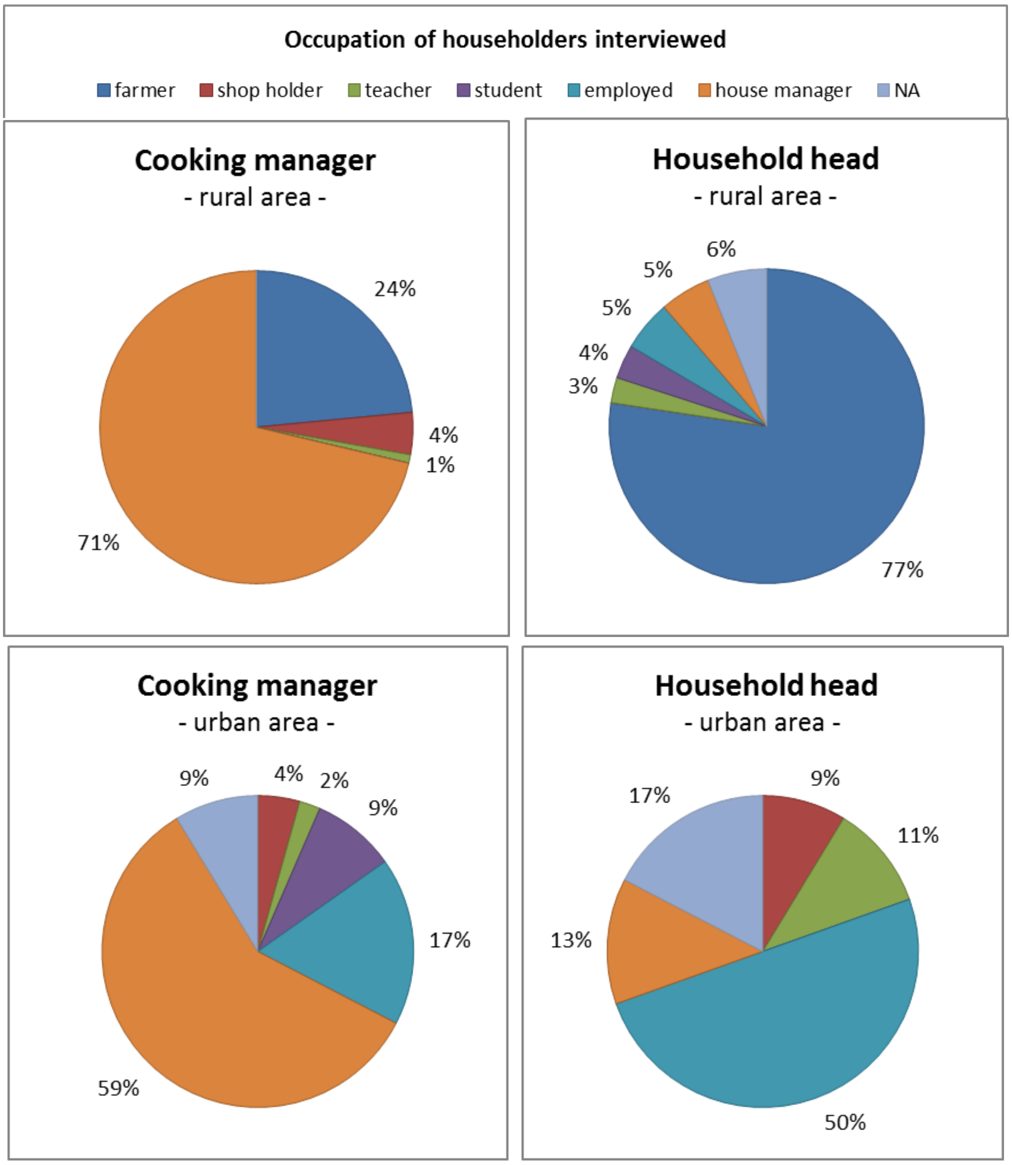



**Figure 17: occupation of the householders interviewed**

The school level, as the highest national degree of school attended, was also investigated; the outputs are summed in Figure 18. It is evident that the school level is significant lower in the rural areas in comparison to the urban one. The vast majority of rural population has a basic (26-35%) or any (50-71%) school level. In particular the school attendance is significantly lower among the cooking managers, thus the women, than for the household heads, thus the men. A similar situation can be appreciated in urban area, where, as said, the school level is higher. In particular, assigning discrete values to the school level (from 0=none to 3=superior) the average school level of the urban population is “secondary” (2.1 for household heads and 1.8 for cooking managers), while in the rural area is between “none” and “primary” (0.7 for household heads and 0.3 for cooking managers).

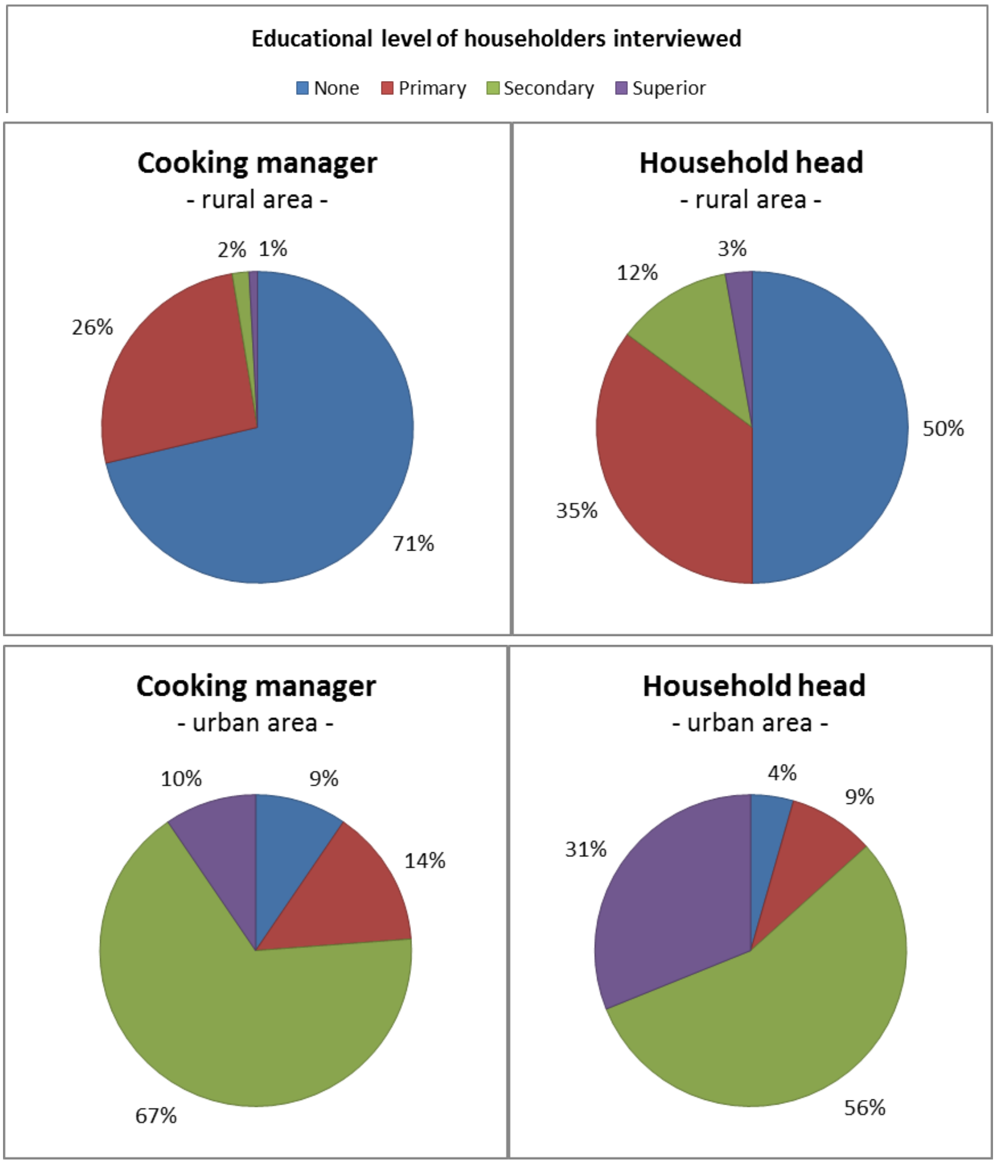



**Figure 18: educational level of the householders interviewed**

Some considerations were elaborated about the income level of the households surveyed. The interviewed was asked to give an indication of his/her average weekly income. In some cases, mainly in the rural area where agriculture is the predominant activity, the householder was not able to provide a monetized value, therefore an indirect estimation was done on the basis of the seasonal agricultural production (number of bags of pearl millet, peanut or other sellable products multiplied for their relative prices observed in the local markets) and the number of animal live stocked[9] (chickens, goats and cows). As illustrated in Figure 19, four income classes were identified. 65% of the population surveyed lives under the poverty threshold, which is 1.25 US$ per capita per day (about 600 CFA francs), 79% with less than 2 US$ per day (about 1,000 CFA francs). These impressive data are in line with the Chadian national ones (WB 2010) that assess 63% of the Chadian population living under the poverty line and 83% with less than 2 US$

[9] For each animal, its value and useful life were considered. Chicken: 1,500 CFA francs, 1 year; Goat: 10,000 CFA francs, 4 years; Cow: 110,000 CFA francs, 10 years.

per day. The average value in rural areas (345 CFA francs = 0.7 US$ per capita per day) is five times lower than the average one in the urban area (1,814 CFA francs = 3.6 US$ per capita per day).

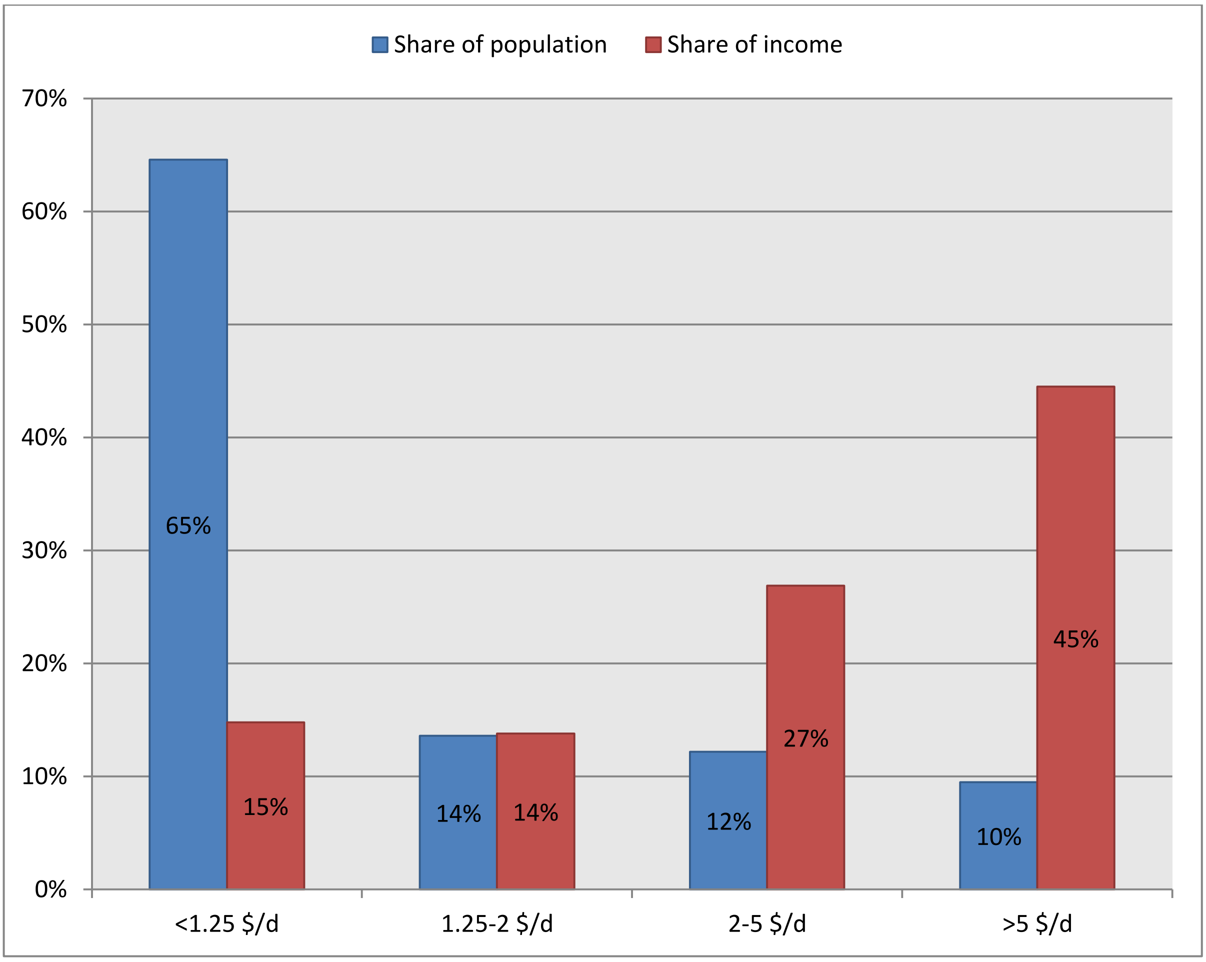



**Figure 19: classes of income per capita level of the households surveyed**

The influence on the household income level of the social data presented above was investigated. Due to high uncertainty variability of salaries for the different occupation types considered, and the weak involvement of the rural population in the monetized economy, any significant correlation between the occupation type and the income level was found. A good correlation with the school level of the household head can be appreciated in Figure 20, saying the higher school level (that probably guarantee a better occupation), the higher the income. Any similar correlation was found for the cooking manager. That may indicate that the income level of the family is strongly dependent from the activity of the man.

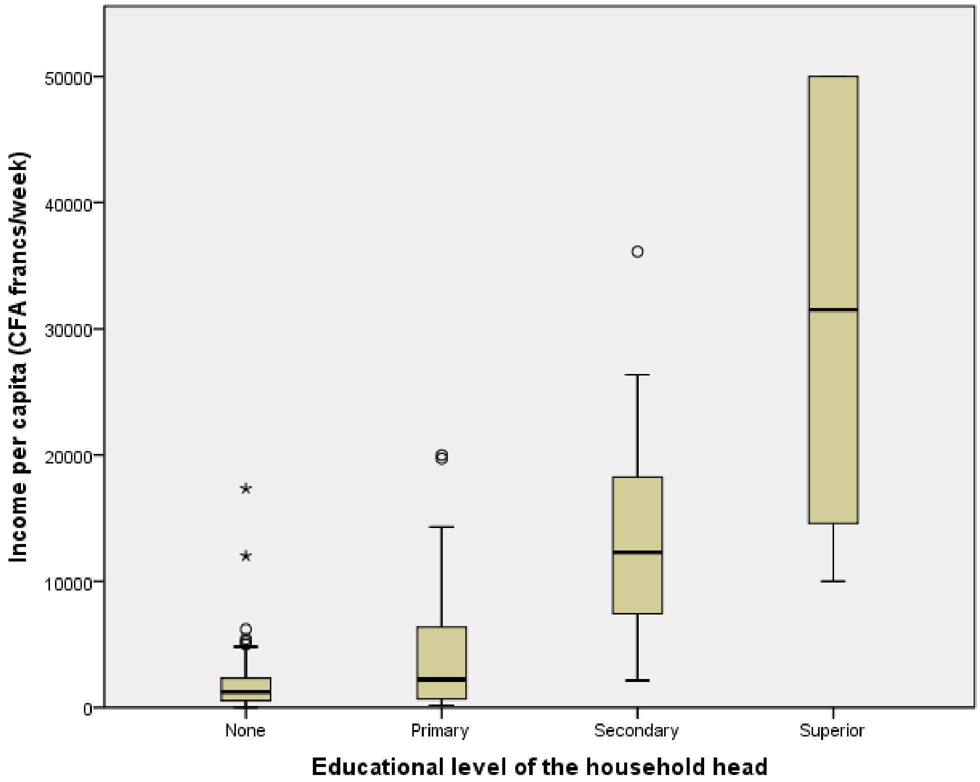



**Figure 20: boxplots of income per capita level of households surveyed according to household head educational level**

### 3.5.2. Cooking habits and fuel use patterns

The second cluster of the questionnaires investigated the cooking habits of the population surveyed.

Different cooking places were observed on site (Figure 21): outdoor at open air, under a ventilated stand or in a closed room. The choice of the place depends on the household lay-out, the season and the preferences of the cook.

**Figure 21: cooking places observed on site (outdoor at open air, under a ventilated stand, indoor in a closed room)**

Figure 22 reports the share of population cooking in different places according to a seasonal preference. It can be observed that in the rainy season (in the Logone Valley usually during from May to the end of September) the large share of the population cooks indoor (83% in the rural areas, 63% in the urban area). In the dry season the cooking outside (in open air or under a covered stand) is the preferred option (88% in the rural area, 65% in the urban area). This seasonal switch is more marked in the rural area, probably due to the household lay-out, where even having each household a dedicated building as kitchen (see Figure 15), cooking outdoor results more convenient in the hot season. In the urban areas people live in defined concessions and often have a conventional kitchen room inside the main building for both seasons.

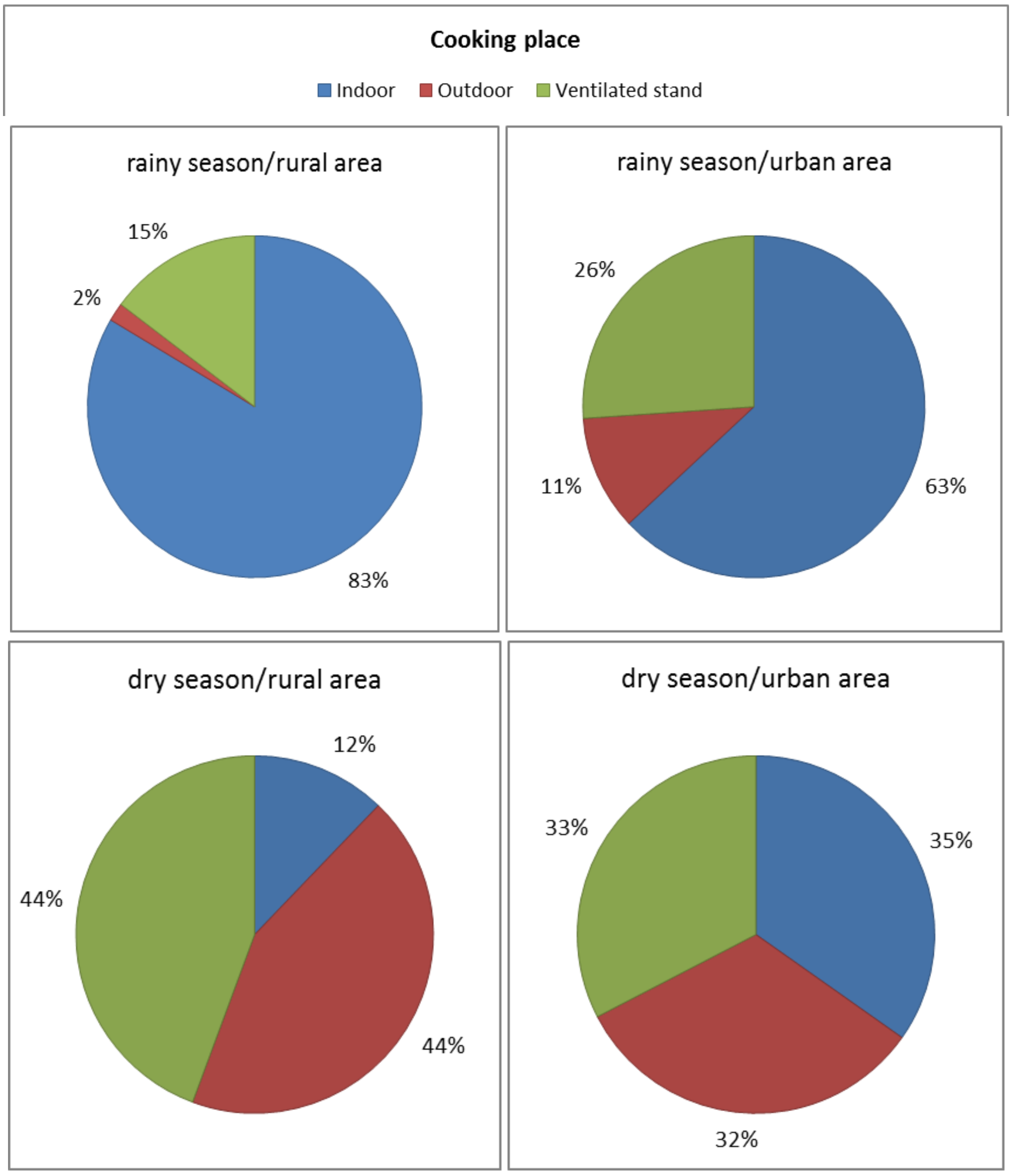



**Figure 22: preferred cooking places according to season by the householders interviewed**

As reported in Figure 23 on average meals are prepared 2-3 times per day in a household. 67% cooks 2 times in the rural areas, while 61% or urban householders cook 3 times per day. Actually the total daily cooking time is similar for the urban householder (on average 250 minutes) and for the rural ones (220 minutes).

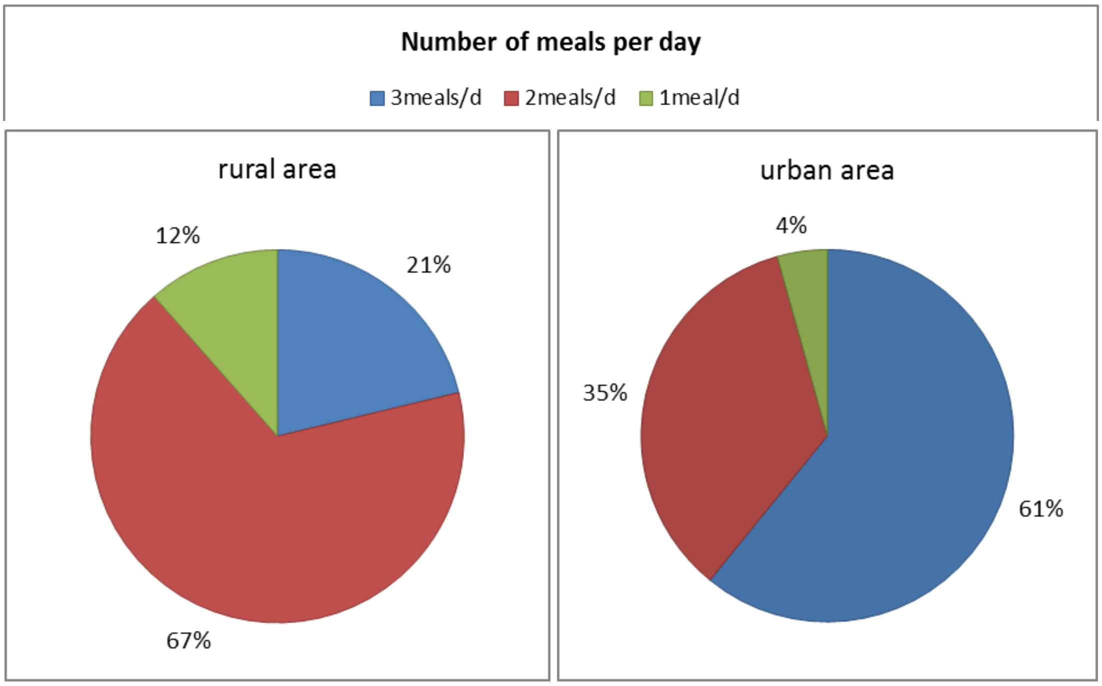



**Figure 23: number of meals per day of the householders interviewed**

A number of different stove models were observed (Figure 24). The most common system used is the three stone fire, used in 64% of the households. Some different configurations of a self-constructed fireplace were observed on site, mainly in the rural context. The traditional fireplace consists in a mud structure with a frontal inlet for the fuel and two pot places, built against a wall both indoor and outdoor. A simplified variant is the one constituted by three stones lined against the wall in order to give support to two pots. Other variants are simple mud structure supporting a single pot.

**Figure 24: stove models observed on site**

In rural areas the use of the open fire and of traditional systems, which are not or little improved, is in 95% of the population. Before the project access to improved cookstove (ICS) models was very low, in line with the national levels (see Table 6); at the time of the survey a high share of population was provided with ICS in the urban area (46%), as shown in Figure 23. That may indicate, on the one hand, the success of the intervention in the urban context, driven by some socio-economic factors; on the other hand it shows the low degree of penetration of the same action in rural areas, due to a number of barriers. Such factors are discussed with more detail in the following chapter 5. Among the 161 householders surveyed, 28% used a second stove model. In particular 78% out of these were rural householders that normally used the three stone fire, while in the rainy season used the traditional fixed system installed indoor. Only 2% used an improved stove as alternative system, and only 1% used sometimes LPG.

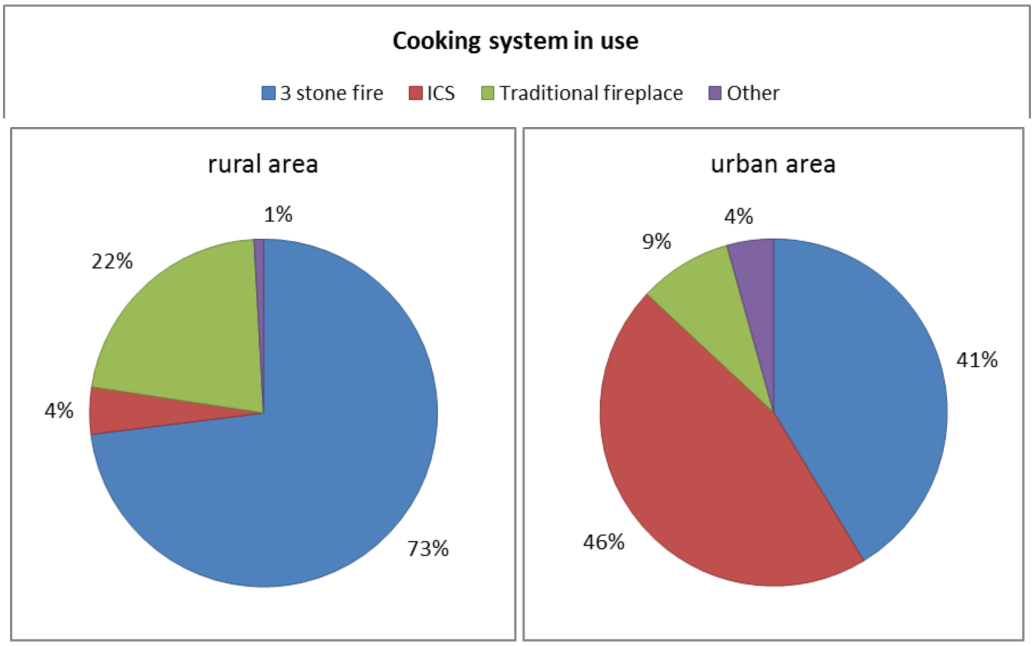



**Figure 25: cooking system used by the householders interviewed**

Figure 26 shows how the users of a certain cooking system distribute according to the educational level of the household head. While the use of traditional fireplace and three stone fire occurs mainly in households where the head has a low educational level, the use of improved systems is more typical of a higher level of education by the household head. A similar (less marked) trend can be appreciated also according to the educational level of the cooking manager. These observations may be interpreted as indicators of the importance of awareness about energy issues also at household level, that currently are understood by the more educated part of the population, but have to be understandable by the whole population in order to achieve a real development in this sector.

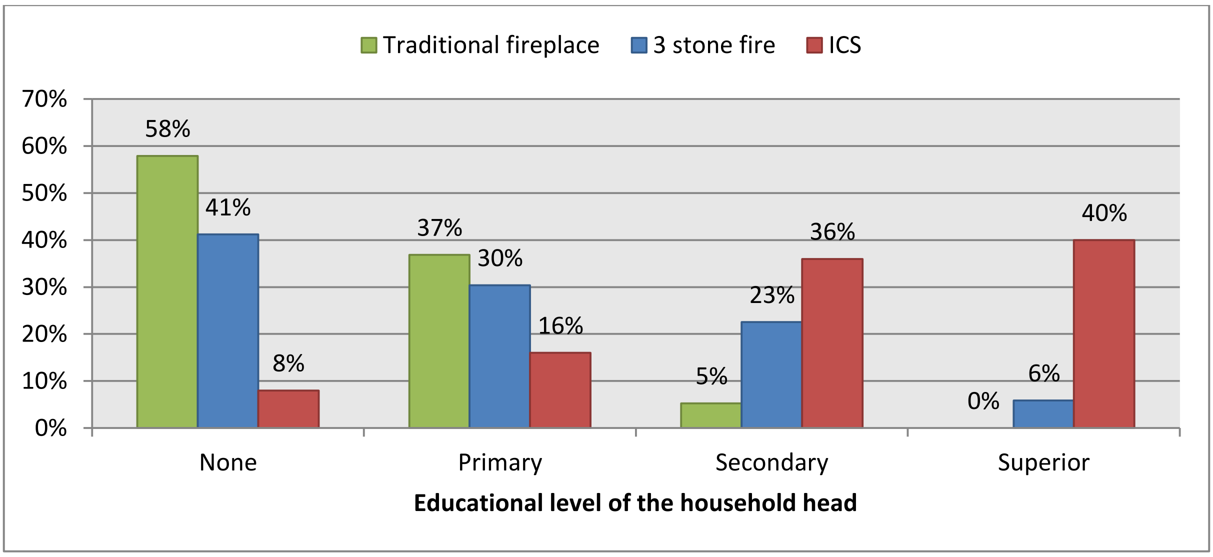



**Figure 26: distribution of the share of users of a cooking system according to educational level of the household head**

Almost the totality of householders (99%) uses wood as the main fuel for cooking purposes. 48% uses also a complementary fuel. For 76% out of these, the main secondary fuel used is millet reeds, used in the rural areas during the harvesting season, when these crop residues are easily available in the field. Charcoal (15%), petrol (6%) and LPG (2%) are the other secondary fuels, used mainly by urban householders.

Figure 27 shows the fuel supply mode in the population surveyed. There is a clear difference between the rural area, where 63% of the householders interviewed collects for free the woodfuel required for their daily cooking needs, and the urban area, where practically everyone (93%) purchase the cooking fuel. A 30% of rural people collect wood and other biomass fuel (millet reeds) during the dry season and purchase wood during the rainy season, when all the day time is dedicated to the work in the crop fields and no time is available for fuel collection. People using the three stone fire usually collect their own fuel (57%), rather than purchasing it (22%). People using an improved system usually (88%) purchase the fuel.

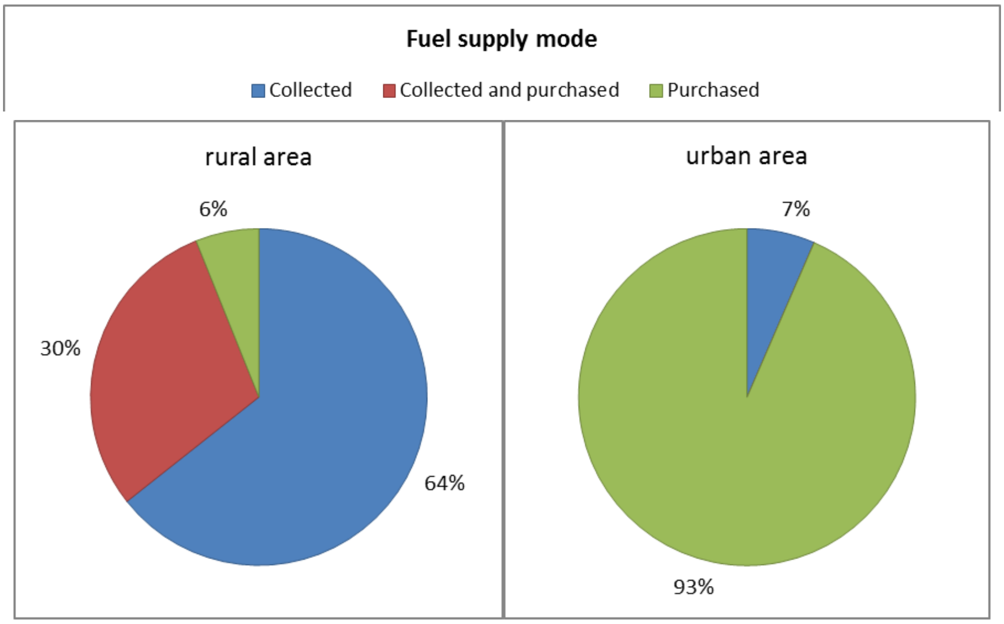



**Figure 27: fuel supply modes of the householders interviewed**

Fuel procurement happens on average two times per week, either if collected or purchased. Usually the person in charge of the fuel procurement is the women (93%), only in some cases helped by children or by the man. Regarding this aspect, there are little differences between the rural and the urban context, or according to the fuel supply mode. It can be observed that the man's involvement in the fuel procurement occurs mainly when the fuel is purchased.

Figure 28 shows the weekly burden of time and distance to be walked according to fuel supply mode. Both the distance and the time spent to gather fuel by rural users is significantly higher than for (urban) people who purchase fuel. In urban areas fuel is purchased in the local market during the weekly shopping time or brought directly to the household by the sellers: that justifies the null burden of time for the specific activity of fuel purchase. User who gather wood of other biomass fuel only during certain periods (as explained before) do not have an additional burden of time and distance, as they find the fuel directly in the field or along the way back home. The total burden of time related to household energy activities (i.e. cooking time and fuel procurement time) is therefore higher for rural (36hours per week) than for urban households (29 hours per week); this difference is significantly higher for fuel collectors, who spend 47 hours per week in the household-energy-related activities, against the 28 hours spend by wood purchaser.

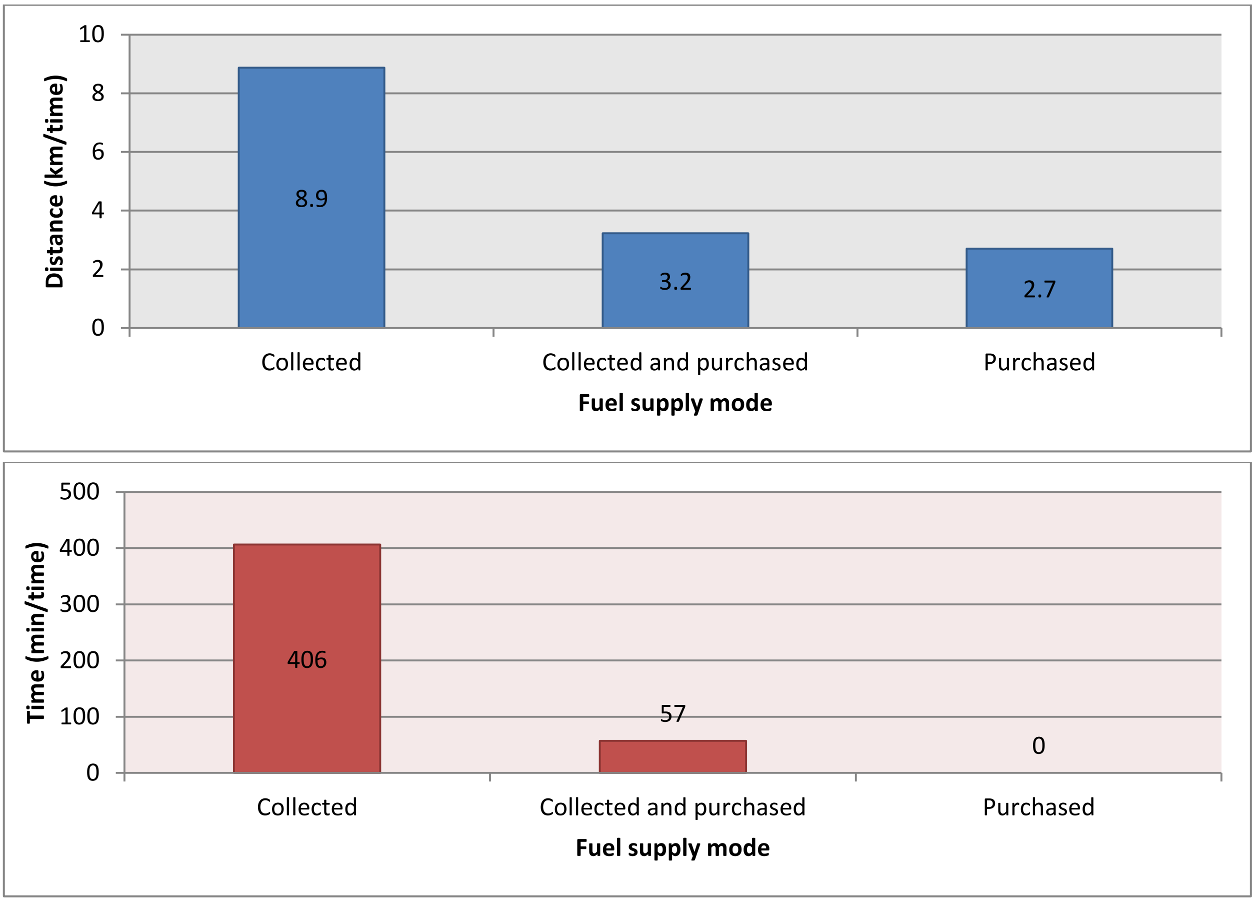



**Figure 28: burden of distance and time for householders according to fuel supply mode**

Figure 29 reports the different fuel supply modes of the householders interviewed according to their income class. The share of households relying on collection for their fuel procurement decreases with the increasing income level. Respectively, the share of population with higher income level is likely to purchase the cooking fuel, being this procurement mode more convenient and easy in comparison with the drudgery due to the collection activity.


**Figure 29: fuel supply modes of the householders interviewed according to income class**

A decreasing average fuel procurement time burden is observable with the increasing educational level of the cooking manager and of the household head, and, as shown in Figure 30, with the increasing income class. Coherently to what illustrated by Figure 29, which indicates that the purchase of fuel is perceived as more convenient in comparison to the collection, even if this is for free. Therefore, with the possibilities given by a higher income level, householders tend to switch to this “more modern” procurement mode, from that more rudimental one that implies higher time drudgery.

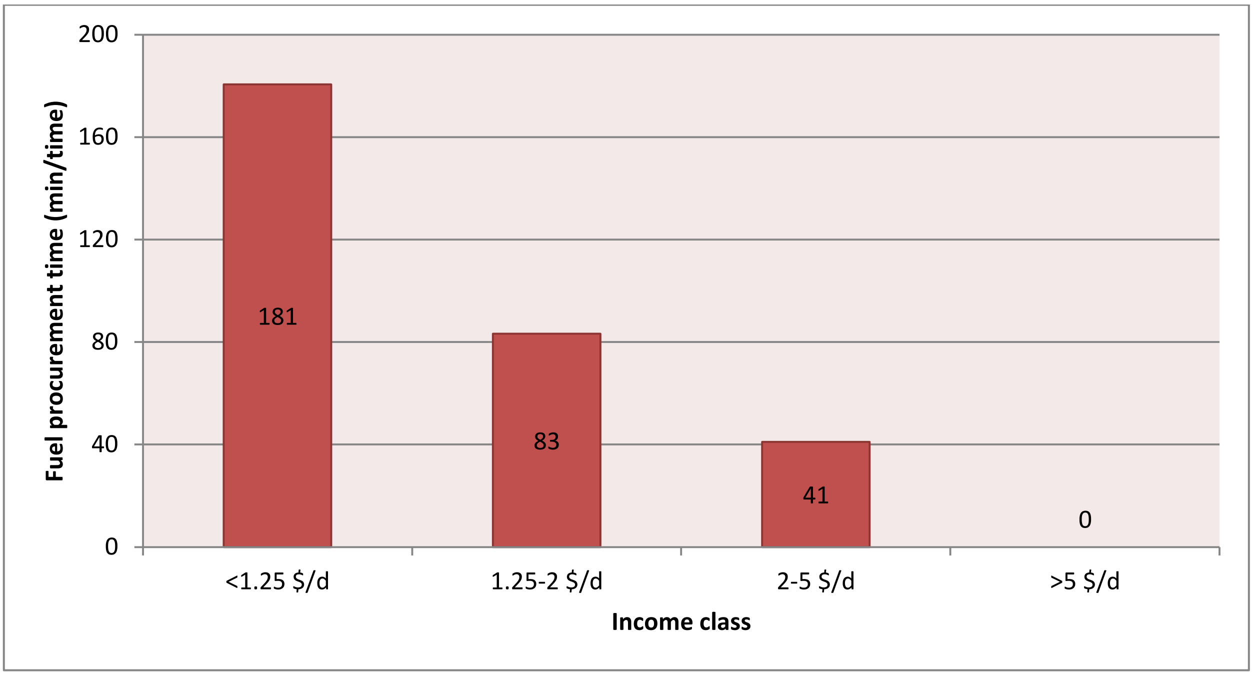



**Figure 30: fuel procurement time for householders according to income class**

Other fuel procurement patterns observed in the population sampled are:

- on average three-stone-fire and traditional fireplace users spend more time (about 2.5 hours per time) than ICS users (0.5 hours). This is likely to be linked to the different income level of these two groups, as deducible by the observations above;
- a higher fuel supply time can be observed in the population using only wood as household fuel (about 4 hours per time), while the group using supplementary fuels, in particular agricultural residues as millet reeds and charcoal (probably illegally self-produced) have a significant lower time engagement (0.5 hours per time).
- fuel supply procurement time is significantly lower when the man is in charge of this activity. That is likely to confirm that fuel collection is a woman task, while it is delegated to the man mainly when fuel is purchased (Figure 31).

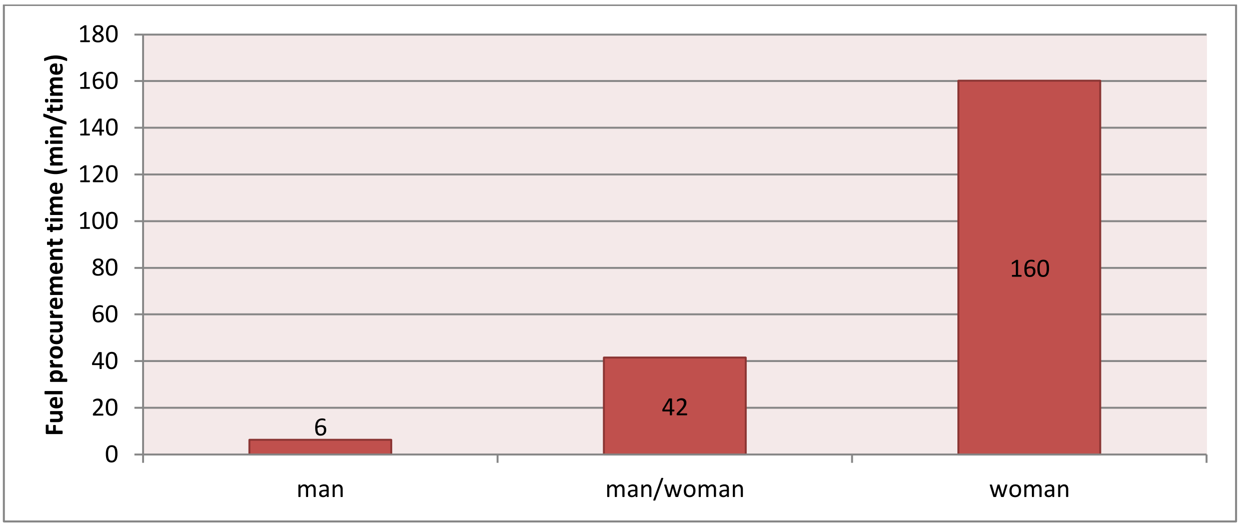



**Figure 31: fuel procurement time for householders according to person in charge of such a task**

Fuel expenditure was also investigated with a particular focus on the group of interviewed people that , partially or totally, purchase fuel. The average expenditure of the householders that only purchase fuel is 2,500 CFA francs/week. Lower fuel expenditure (540 CFA francs/week) was observed in the group that partially collect fuel; that indicates the economic advantages of such a practice in the fuel procurement. A minimal average expenditure (197 CFA francs/week) was also observed in the sub-sample households that mainly collect their fuel. That is due to the common practice of the saltuary use of petrol as emergency fuel or for fast food re-heating.

Following the fuel procurement mode, the first main influencing factor is logically the family size: the higher the number of people to cook for, the higher the fuel expenditure (likely due to higher fuel consumption). This linear correlation is shown for the surveyed sample in Figure 32.

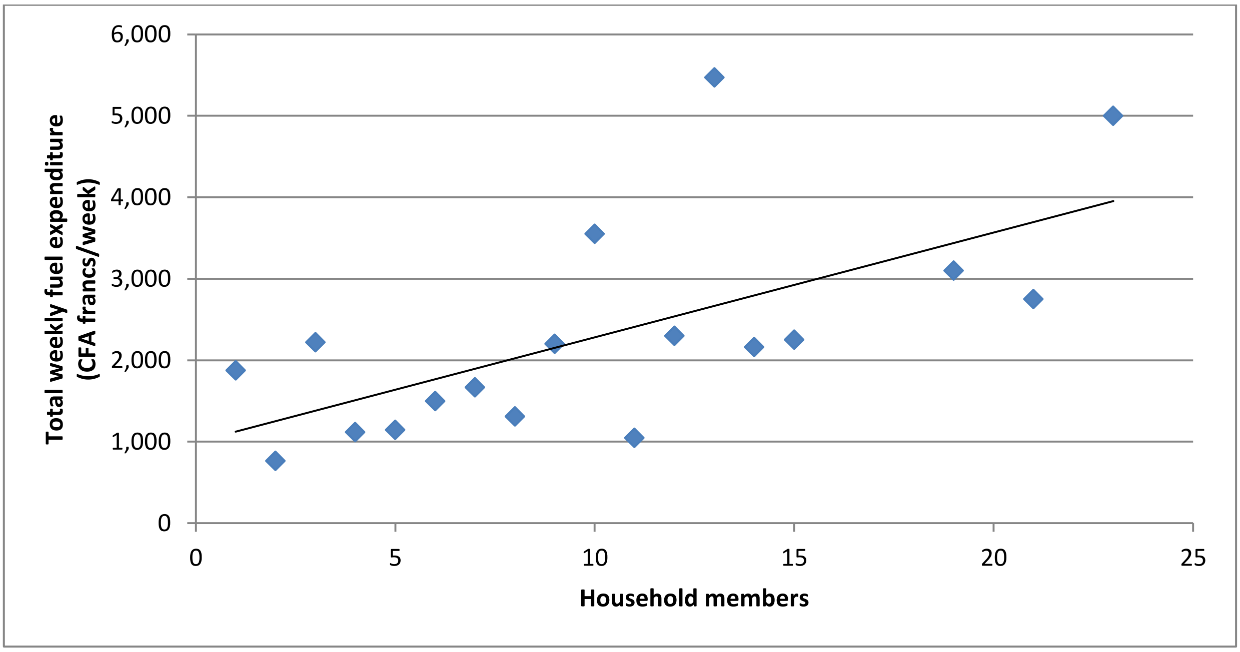



**Figure 32: total weekly fuel expenditure according to household size**

A further intuitive factor affecting fuel expenditure is the income level. As shown in Figure 33, the average fuel expenditure increases with the increase of the income level of the population surveyed. Actually this elaboration does not take in the fuel procurement mode, therefore, as shown in Figure 29, the share of low income population who collect its own fuel for free weights significantly in lowering the average fuel expenditure of the lower income classes.

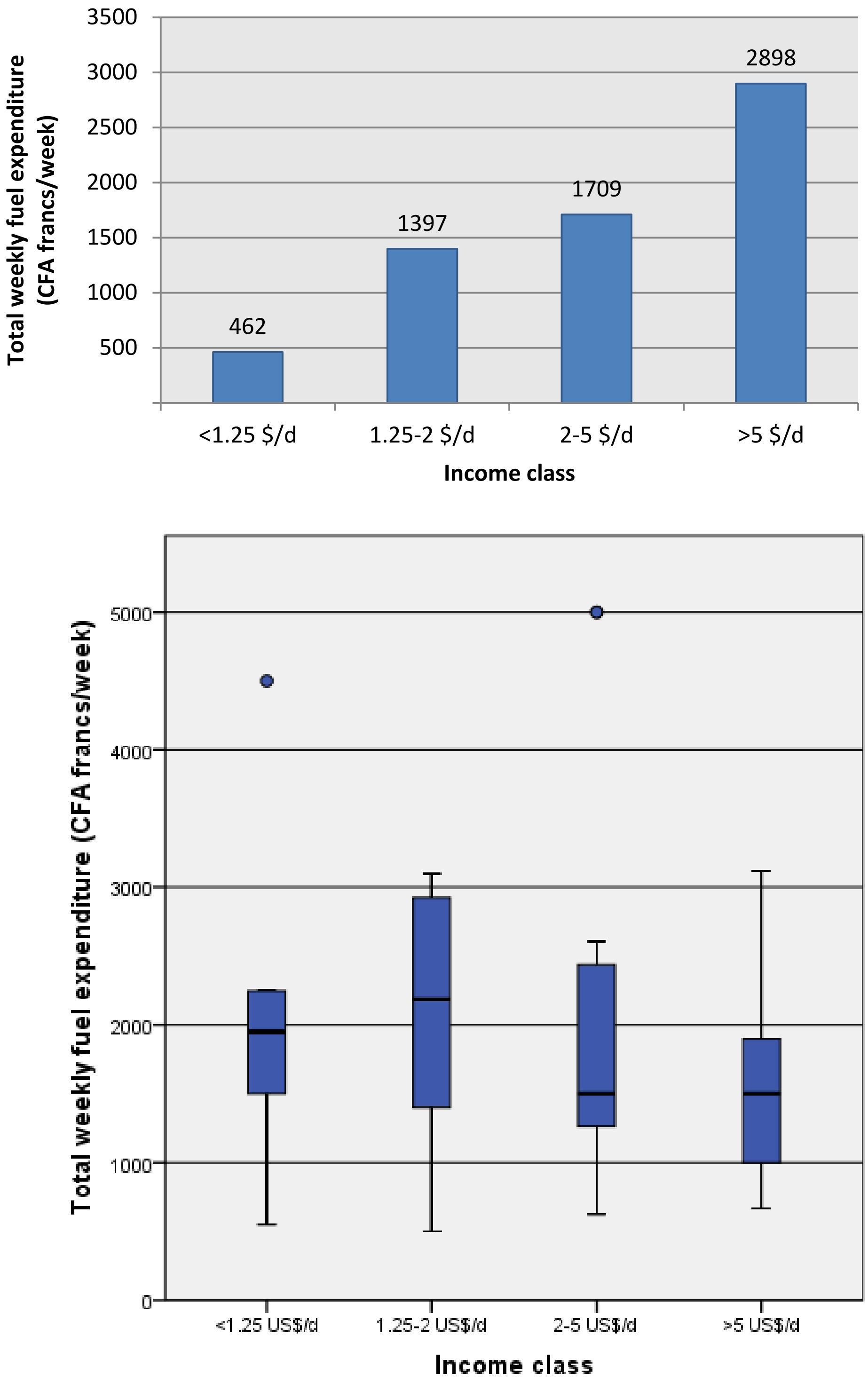



**Figure 33: total weekly fuel expenditure according to income class**

Limiting this analysis to the sub-sample of "fuel purchasers", as rendered in the graph below in Figure 34, it can be observed a substantial similar expenditure for all income classes. That may indicate that the household energy needs are almost independent from the relative income level.

Main social-economic feature influence on the total fuel expenditure was also investigated. Figure 34 shows the decreasing fuel expenditure observed in both group "Collectors and purchasers" and "Only purchasers" with the increasing educational level of the cooking manager.

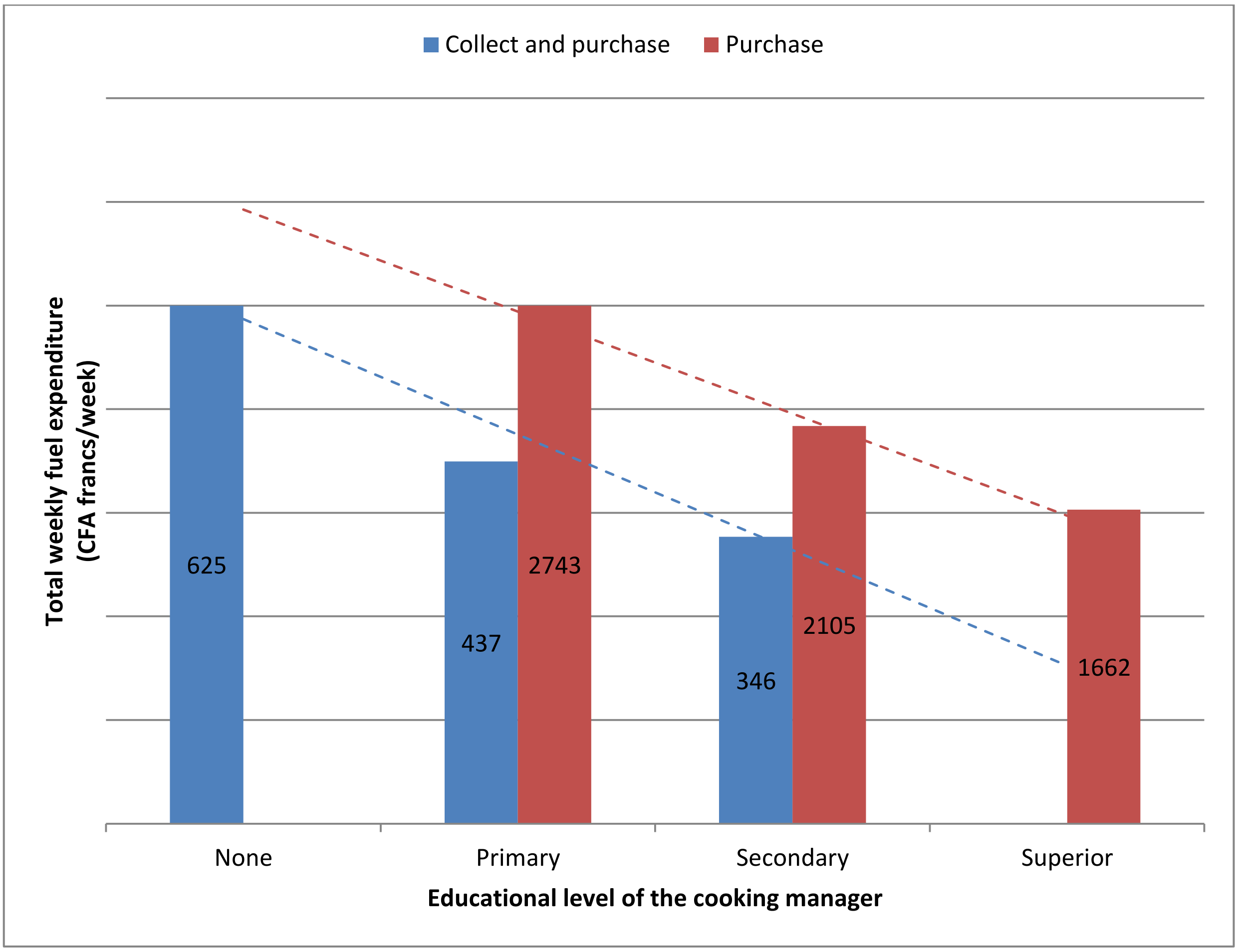



**Figure 34: total weekly fuel expenditure per household according to educational level of the cooking manager**

A similar trend cannot be observed clustering the sample according to the educational level of the household head. A lower fuel expenditure was observed in household where the head is female rather than male (-33 ÷ -70%). Other social-economic factors considered had not a noticeable influence on the fuel expenditure in the household sampled in this survey.

The influence on fuel expenditure of cooking habits and practices was also investigated. The main factor, as already discussed, is the fuel procurement mode. It is self-evident that fuel gathering has a positive impact in reducing the household fuel expenditure. Other household energy patterns that influence the fuel expenditure are the cooking system and the fuel mix in use. Figure 35 shows the ranges of fuel expenditure of the "fuel purchaser" sub-sample according to the stove model used. As desirable, the use of an improved system ranges in a lower interval in comparison to the use of the three stone fire. The average and median value of expenditure for the ICS users results equal to 1,500 CFA francs/week, while for the three-stone-fire users the median value is 2,300 CFA francs/week, while the arithmetic mean is 3,700 CFA francs/week. The higher variability of this range is likely to be imputable to the higher influence of user behaviors on fire operations, and therefore on fuel consumption, that in the improved systems is instead more limited.

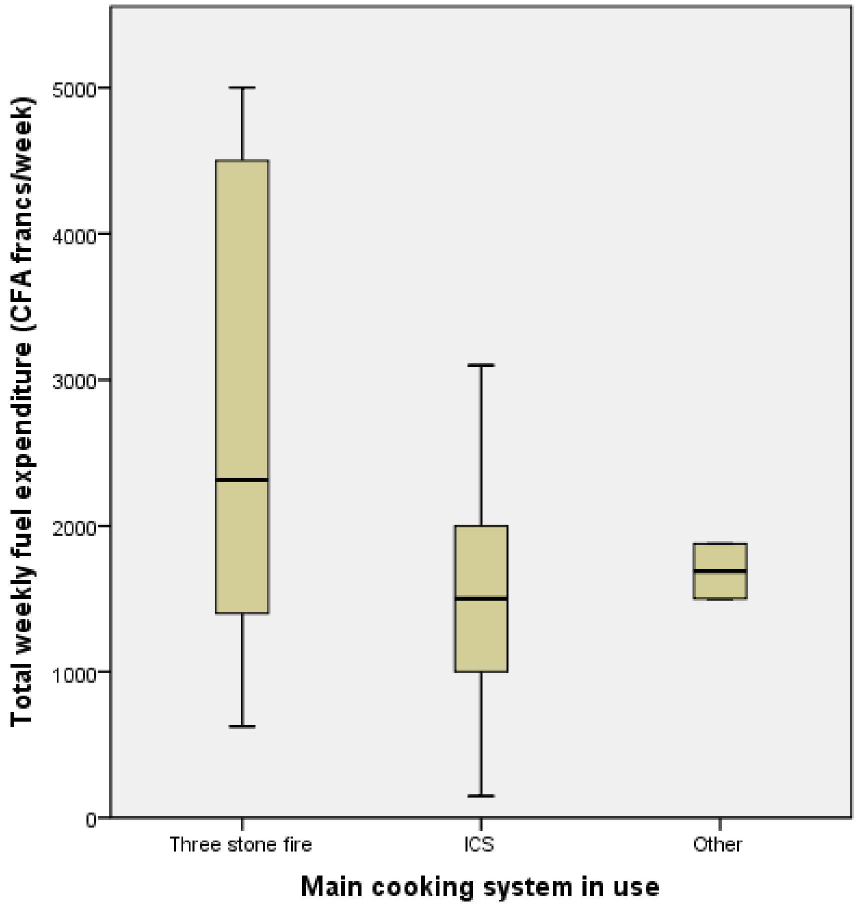



**Figure 35: total weekly fuel expenditure per household according to the main cooking system in use**

Figure 36 shows the influence of the fuel mix in use on the total household fuel expenditure. Being wood the primary fuel used by almost all the householders surveyed, some meaningful elaborations can be done according to the secondary fuel in use. In the sub-sample of householders who both collect and purchase their own fuel, the savings due to the supplementary seasonal use of millet reeds in the household fuel mix are noticeable, resulting in a total fuel expenditure 66% lower than the one registered for the complementary share group (400 CFA francs/week against 1,200 CFA francs/week). In the sub-sample of “fuel purchaser” the fuel mix is more variegated. The median were found for the more modern fuel users (LPG 3,150 CFA francs/week and petrol 2,600 CFA francs/week). In the “fuel purchasers” group the LPG, petrol and charcoal users’ median fuel expenditure result higher than the one of “only-wood users”, indicated in the graph by the two box-plots without category name. Different fuel mixes rank in an order really similar to the one of the energy ladder (Figure 6): the more modern the fuels in use in the household energy mix, the higher the relative expenditure, that may be assumed as indicator of the income level, as already discussed (Figure 33).

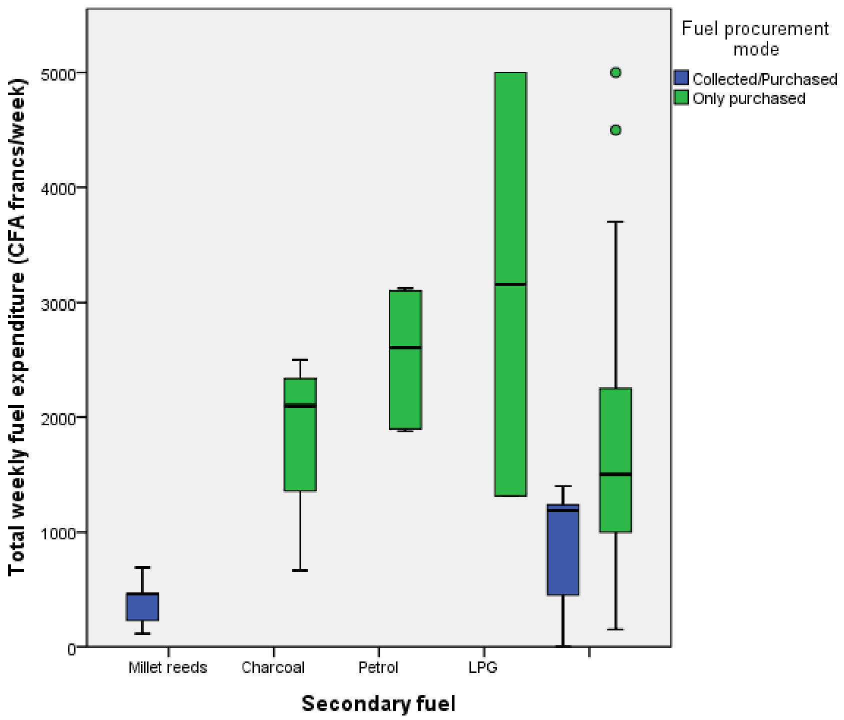



**Figure 36: total weekly fuel expenditure per household according to the fuel mix in use. The unnamed category refers to "only-wood" users**

Figure 37 reports a final elaboration done, which highlights how fuel expenditure has a significantly higher impact on the household income budget in the poorer population rather than in the richer one. This disproportion is particularly evident for the share of population living with less than 1.25 US$ per day. For this group the fuel expenditure engages on average 8-9% of the household income, while for the richest group such a budget voice accounts only for 1-2%.

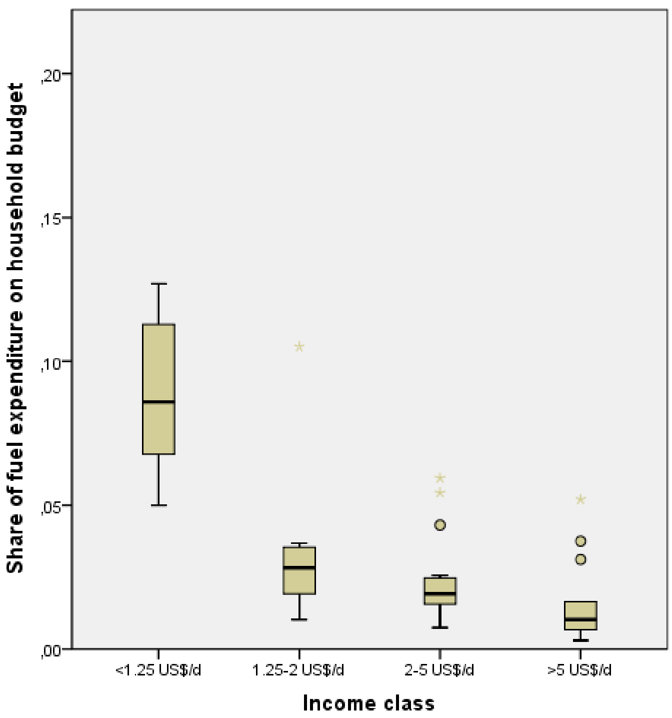



**Figure 37: share of fuel expenditure on household budget**

### 3.5.3. Lighting energy patterns

A quick assessment of the lighting system was also done, in order to have a more comprehensive view of the energy access situation at household level in the context studied. As shown in Figure 38, in the rural area petrol lamp is the most common lighting system (85%), while in the urban a more or less reliable connection to electricity is available for the majority of householders (65%). In this case a significant difference was identified between the Chadian and the Cameroonian households, in particular in the urban areas where 81% of the Cameroonian dwellers were connected to the public grid, while only 42% of the Chadian householders had a salutary access to private connections to stand-alone mini-generators. In rural areas the electricity access is significantly lower, 8% in Cameroon and 0% in Chad.

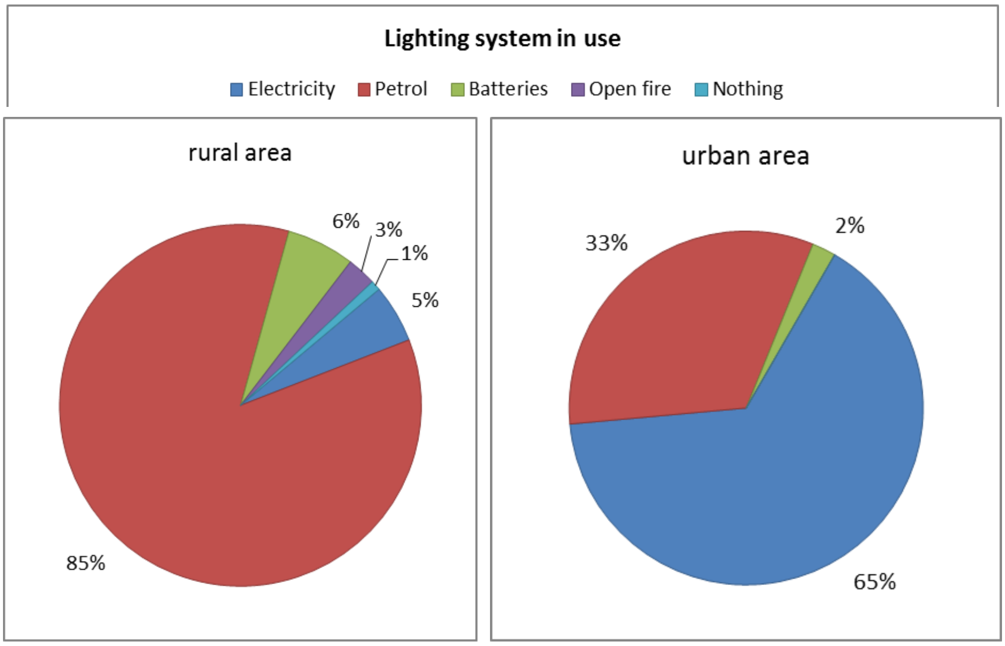



**Figure 38: lighting systems in use by the householders surveyed**

Figure 39 shows the share of population using a certain lighting device according to their income level.

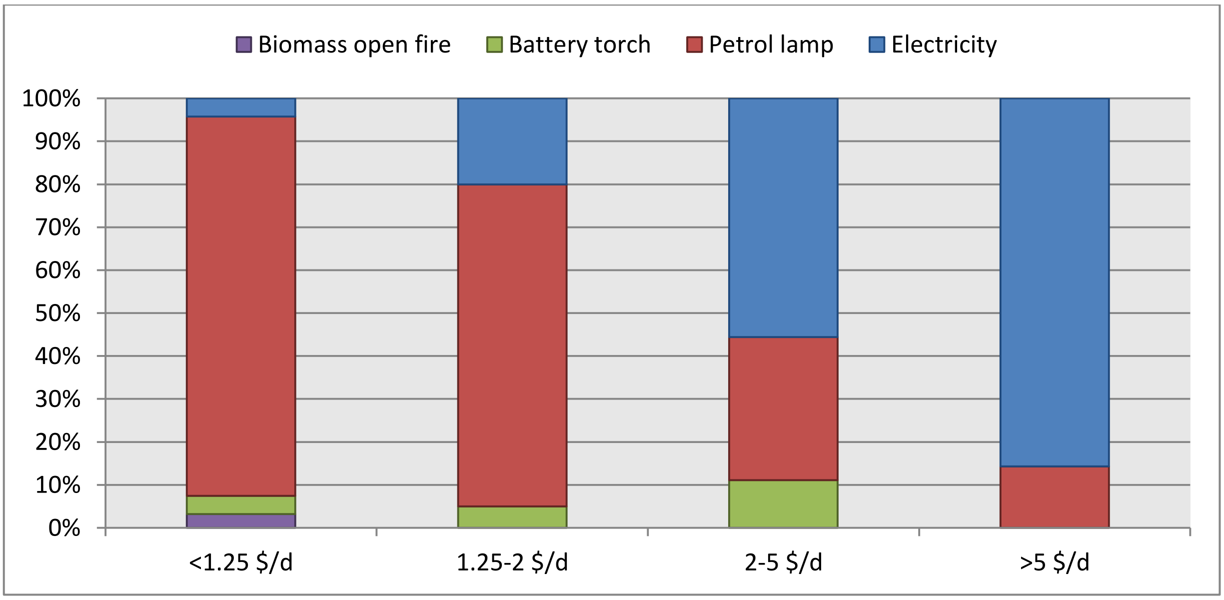



**Figure 39: share of population using a lighting device according to household income class**

The higher the income class, the higher the share of population with access to more modern lighting devices, in this case electricity; petrol lamp is the predominant mode in the lower income classes. That is due, on the one hand by infrastructural barriers (i.e in the rural areas grid connection is seldom available), on the other hand by the operating costs of the lighting device adopted. Indeed, as Figure 40 shows, the lighting expenditure strongly depends by the device used.

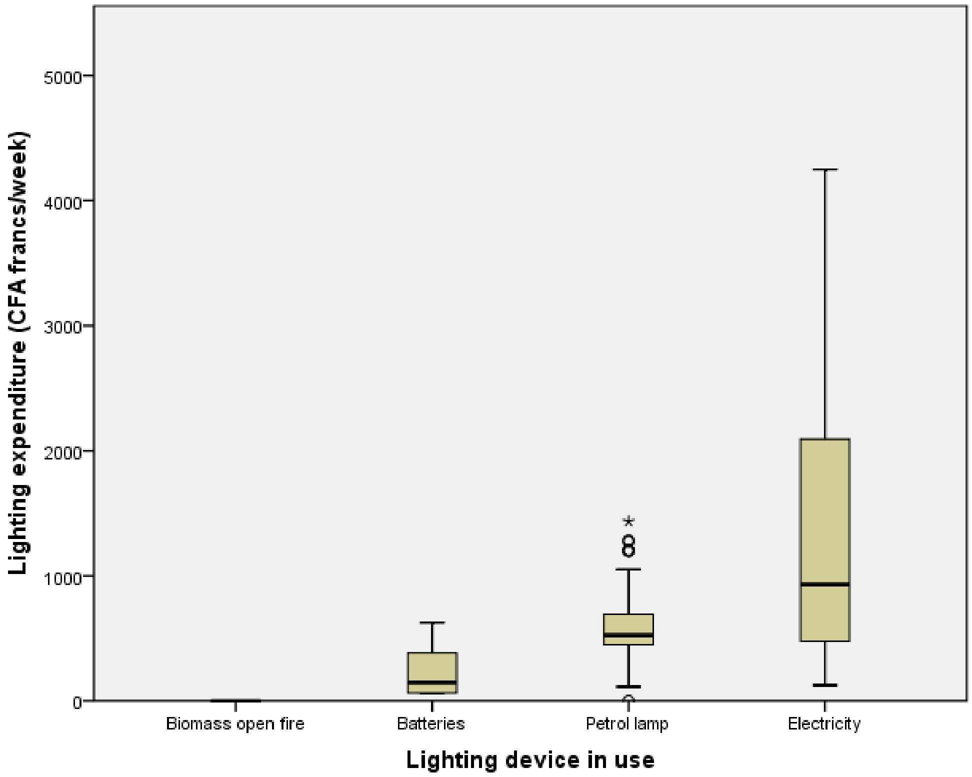



**Figure 40: lighting expenditure according to device in use in the households surveyed**

### 3.5.4. Energy Supply Index assessment

The Energy Supply Index (ESI) was assessed for each household interviewed according to answer gathered in the energy access questionnaires and observations done by the interviewer. Table 8 reports the average ESI values observed in rural and urban areas.

**Table 8: average ESI values observed on site**

| | Fuels | Electricity | Mechanic power |
|---|---|---|---|
| **Rural** | 1.31 | 1.23 | 1.03 |
| **Urban** | 2.65 | 3.04 | 2.43 |
| **Total** | 1.70 | 1.75 | 1.43 |

The average values scored in the three clusters of this index indicate the low level of energy supply of the context studied. As better detailed in the previous paragraphs, in rural areas the fuel supply consists mainly in collecting wood and using a three-stone fire, while in the urban area a certain share of the population has access to improved systems and buy wood. A similar situation has been registered with regard to electricity access, that is practically absent in the rural areas, while in urban areas, more in the Cameroonian side rather than in the Chadian one, some share of the population has access to poor quality and intermittent supply connection. Also the access to mechanical power is dramatically low, as indicated by low ESI for this aspect. That has strong implications on the productive and manufacturing activities that are seriously limited in their capacities, tools and skills. The sample clustering, according to educational level of both household head and cooking managers and income class, highlights the increasing ESI with the increasing level of attendance to school by both the key players in the energy sector at household level, as shown in Figure 41.

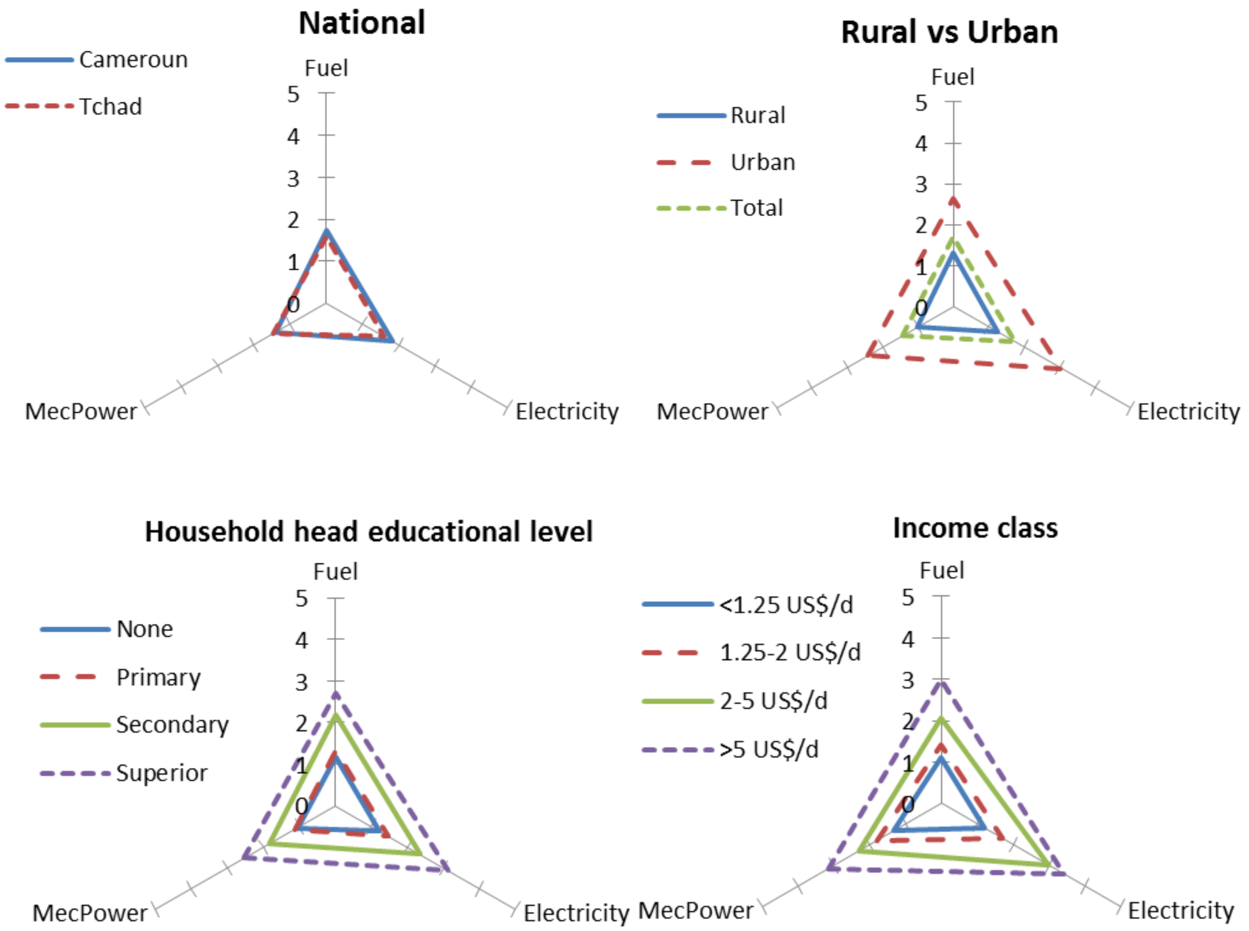



**Figure 41: ESI assessment according to different sample clustering**

Figure 42 shows the relation between the total fuel expenditure and the relative ESI values assessed for the households surveyed. It is evident that to a higher value of the index corresponds a higher median value of fuel expenditure, even if the variability of the ranges is quite high. The ESI category correspondent to the users of modern fuels shows a limited range only due to the low number of cases (therefore not really significant) registered in the survey.

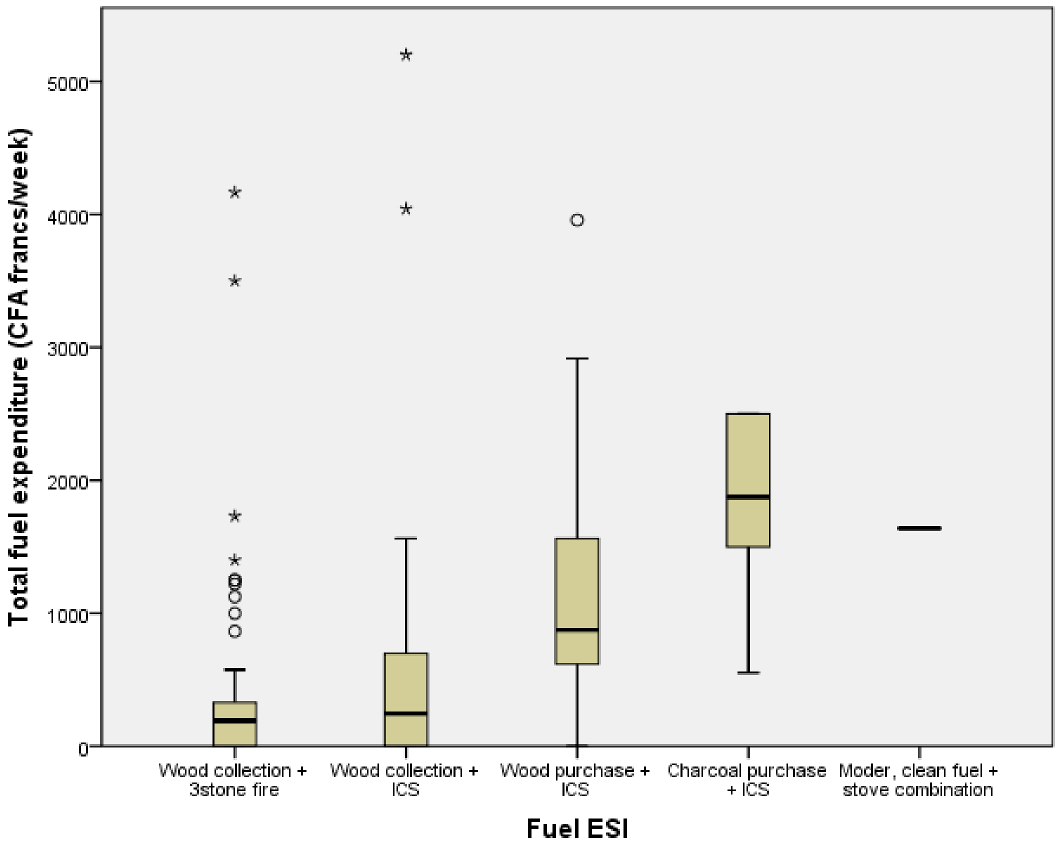



**Figure 42: total fuel expenditure according to fuel ESI values assessed in the household surveyed**

# 4. Testing improved stove models

## 4.1. Introduction

Access to improved cooking stoves– i.e. closed stoves with chimney, as well as open stoves or fires with chimney or hood - is also very limited. In Least Developed Countries (LDCs) and sub-Saharan Africa (SSA) only 7% of people who rely on solid fuels use improved cooking stoves, compared to 27% of people in developing countries as a whole (WHO and UNEP 2009). In the past many wood cookstove programs have unperformed, due to a lack of standards and quality control, with little attention to stove design (World Bank 2011). Today, a new generation of advanced and more effective improved biomass cookstoves are available commercially. In addition less expensive, effective improved cookstoves are also an option.

The aim of the research illustrated in this chapter is to identify and evaluate different stove models for safer and more efficient combustion using fuels locally available for household purposes in a sub-Saharan rural area. In particular, this chapter presents the results of several tests conducted on site by the author on two improved stoves identified for dissemination in a rural area in Chad and Cameroun. Improved models were compared to traditional cooking options (3-stone fire) and gas stove.

## 4.2. Materials and methods

### 4.2.1. Stove models tested

Two different models have been tested (Figure 43) in order to identify an improved stove, reproducible locally and affordable for the majority of the population: locally available wood stoves are described below. In order to give a complete comparison on the household energy resources available on site, also a gas-stove and the 3-stone fireplace have been tested. In particular the 3-stone fire is the traditional, most common and affordable for all cooking systems in use, while LPG is the clean modern fuel to replace solid fuels, according to national household energy supply strategies (AEDE 2002, HELIO 2009).

**Figure 43: different wood stove models tested in the study (from left: 3-stone fire, ceramic improved stove and Centrafricain improved stove)**

#### *7.2.1.1. Ceramic improved stove*

This stove is formed using moulds and standard measures, and then fired in a pottery kiln or in an open fire. The clay walls guarantee minimal insulation to the combustion chamber. Few skills are required for the self-production by users of this model, which can be easily trained. According to observations on site, prices vary between 500 and 2,500 CFA francs (0.76- 3.81 €).

A local research centre (Centre des Tecnologies Appropriates de Maroua - CTA) studied the model optimizing the design and adapting the manufacturing process to local practices. A technical manual for the reproduction of such a model has recently been written by the author in collaboration with researchers of CTA in order to standardize the dimensions (Figure 44) and the reproduction process. Within the cooperation project activities ACRA organized a one-week training for the production of this model for a group of 21 potter women.

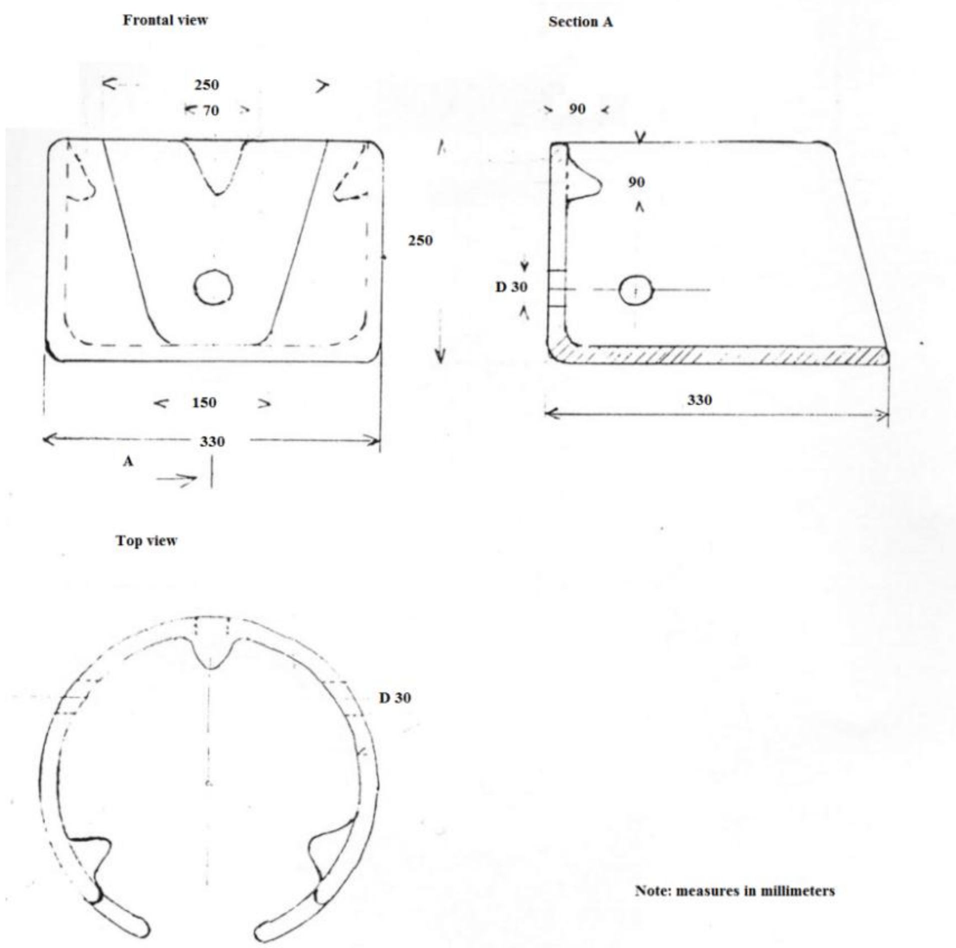



**Figure 44: technical drawing of the Ceramic stove**

### 7.2.1.2. *Centrafricain improved stove*

This stove is formed by a metallic structure assembled without welding with a 7-cm clay belt surrounding the combustion chamber (Figure 45). A good compromise between a design with smaller-mass components (to reduce absorption of heat) and acceptable durability, affordable cost and user needs meeting, as suggested by Jetter and Kariher (2009), was found with this stove model. The combination of metal and clay allows longer operational life-span in comparison with other simple ceramic models. The clay ring increases the stability, resistance and efficiency of the stove. Moreover the Centrafricain stove was designed to accommodate the local round-bottom pots, making it possible to cook according to local traditional practices. The addition of two handles ensures the portability of the stove. Formation of skilled artisans for the production of this model is needed through specific trainings. According to observations on site, prices vary between 5,000 and 7,500 CFA francs (7.62- 11.43 €).

Furthermore this model was studied by CTA and a production manual has recently been written in collaboration with the author. Two workshops for the training of local smiths were organized within the project activities.

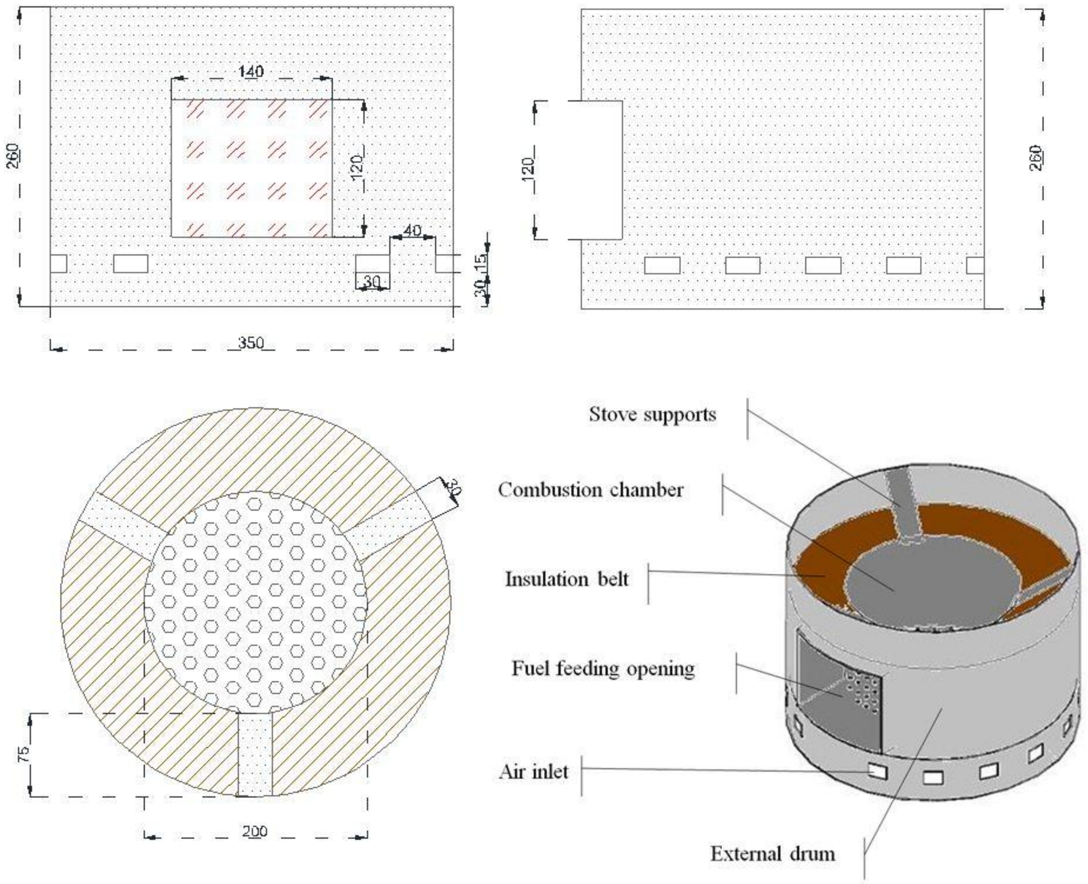



**Figure 45: technical drawing of the Centrafricain stove**

#### *7.2.1.3. 3-stone fire*

This is the traditional stove composed of three stones arranged in the form of an equilateral triangle. Depending on availability of materials, the three stones may be replaced by bricks, pieces of clay, tin cans, iron tripods or cook-pots with three feet (Westhoff & German 2005). The layout causes great heat dispersion due to no isolation of the combustion chamber: that means there is an inefficient use of great amounts of wood. Most of the households in the study area still use this rudimentary stove for daily cooking. Low performances are balanced by high flexibility, easy use of the stove and the fuel is free of cost.

#### *7.2.1.4. LPG gas stove*

According to national strategy for household energy supply (AEDE 2002), LPG gas should replace traditional fuels such as wood and charcoal. LPG gas is sold in 6-kg and 12-kg bottles at very variable prices (2,500-10,000 CFA francs for the 6-kg bottle and 10,000-12,000 CFA francs for the 12-kg bottle, according to

Boukar 2011). In fact, national butane gas imports are not sufficient to cover the whole population supply and price is not affordable by low-income households. Dedicated gas burners have been introduced in the local market to allow the switch from traditional solid fuel to modern cleaner liquid fuels.

### 4.2.2. Testing protocols

Performances of stoves vary greatly according to different operational conditions. Testing allows implementers to learn how well stoves perform and to quantify improvements in fuel efficiency (PCIA 2011). Stove Performance Tests (SPTs) were conducted according to procedures recommended in both the VITA International Testing Standards (VITA 1987) and the revised University of California at Berkeley standard testing protocol series (2003).

The full range of testing protocols available was implemented in different missions in the field in order to assess different aspects of the stoves. In particular in the first missions on the field (2009 - 2010) a number of different fuel-stove combinations were tested in order to give a full overview of the cooking options available in the local market. In particular this approach allowed to compare the energy use of stoves using different fuels, as described in the following paragraphs, but also to give a preliminary economic evaluation. In the second mission (2010) a number of controlled cooking tests were performed on some selected improved stove models, chosen for the dissemination, in comparison with the traditional local cooking system, the three stone fire. This protocol allowed to assess the wood consumption of the stoves tested in the preparation of a typical local food. A brief explanation of the procedures implemented, according to the literature reference, is given below.

#### *4.2.2.1. The Water Boiling Test (WBT)*

The Water Boiling Test (WBT) (MacCarthy 2009) evaluates stove performance while completing a standard task (boiling and simmering water) in a controlled environment to investigate the heat transfer and combustion efficiency of the stove. It is the easiest, quickest, and cheapest test to conduct, but reveals the technical performance of a stove only and not necessarily what it can achieve in real households.

The aim of the testing presented in this study was not the improvement of the stove model design: authors implemented this protocol on site in order to assess in a comparable way the performances of different fuel-stove combinations.

##### 4.2.2.1.1. Experimental procedure

Three steps compose a full WBT (Bailis et al 2007):

i. in the cold-start high-power test, the tester begins with the stove at room temperature and uses a pre-weighed bundle of wood or other fuel to boil a measured quantity of water (5 liters) in a standard pot. The tester then replaces the boiled water with a fresh pot of cold water to perform the second phase of the test;
ii. the hot-start high-power test follows immediately after the first test while stove is still hot. Again, the tester uses 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;

iii. the third phase follows immediately from the second. Here, the tester determines the amount of fuel required to simmer a measured amount of water at just below boiling for 45 minutes.

Water and fuel left, temperature of water and time are recorded at the beginning and at the end of each phase. Each stove is tested three times in order to reduce the variability of results.

###### 4.2.2.1.2. Equipment

Equipment used during the WBTs is listed below:

- scale with a capacity of at least 6 kg and accuracy of ±1 gram;
- digital thermometer, accurate to 1/10 of a degree, with thermocouple probe suitable for immersion in liquids;
- standard 7-liter pot without lid;
- timer;
- at least 10 litres of clean water for each test;
- 2 bundles of air-dried fuel-wood each weighing between 1 and 2 kg for each test;
- accessory tools to handle fire and weight hot stuff (e.g. heat resistant pad to protect scale, small shovel/spatula to remove charcoal from stove, tongs for handling charcoal, dust pan for transferring charcoal, metal tray to hold charcoal for weighing, heat resistant gloves).

###### 4.2.2.1.3. Outputs

The combination of these tests measures some aspects of the stove performance at both high and low power outputs, which are associated with the stove's ability to conserve fuel. However, rather than report a single number indicating the thermal efficiency of the stove, which is not necessarily a good index of stove performance, the WBT is designed to yield several quantitative outputs. Data measured allow calculating different outputs:

- time to boil adjusted for starting temperature to a standard 75 ºC temperature change (from 25 ºC to 100 ºC);
- burning rate adjusted for starting temperature to a standard 75 ºC temperature change (from 25 ºC to 100 ºC): i.e. rate of fuel consumption during the test time;
- specific fuel consumption adjusted for starting temperature to a standard 75 ºC temperature change (from 25 ºC to 100 ºC): i.e. the amount of fuel required to produce one liter (or kilogram) of water at ebullition temperature;
- firepower: i.e. fuel energy consumed by the stove per unit time;
- turn-down ratio: i.e. ratio of the stove's high power output to its low power output);
- thermal efficiency: i.e. ratio between heat transferred to the water to the energy consumed by burning wood or fuel.

A cross-comparison among different stove models using different fuels can be obtained considering the total energy use to complete the task of a full WBT, as suggested by MacCarty (2010):

$$\text{Energy use (kJ)} = \text{Fuel use (g)} * \text{Net Calorific Value (kJ/g)}$$

where “Fuel use” is given by sum of the average of cold- and hot-start high-power specific consumption and low-power specific consumption, multiplied for the standard quantity of water used in the test (5 L).

#### *4.2.2.2. The Controlled Cooking Test (CCT)*

The Controlled Cooking Test (CCT) is a field test that measures stove performance in comparison to traditional cooking methods when a cook prepares a local meal. The CCT is designed to assess stove performance in a controlled setting using local fuels, pots, and practices. Stoves are compared as they perform a standard cooking task that is closer to the actual cooking that local people do every day. However, the tests are designed in a way that minimizes the influence of other factors and allows for the test conditions to be reproduced (PCIA 2010). Thus, it reveals what is possible in households under ideal conditions but not necessarily what is actually achieved by households during daily use.

In this study CCTs were performed during training sessions for local handicrafts and women in the manufacturing of the improved stove models. Thus, a more practical understanding of the advantages in terms of wood consumption reduction due to the use of the promoted stove models was achieved. CCTs were repeated for 5 days employing 3 local women performing cooking task according to the local traditional practices. The typical staple food prepared was the boule, a porridge made of rice, millet or sorghum flour, served with a sauce of vegetables and meat.

##### 4.2.2.2.1. Experimental procedure

In comparison to WBT the procedure for CCT is simpler as it consists in a single cooking phase. The cooking itself should be done by a local person who is familiar with both the meal that is being cooked and the operation of the stove to be tested.

Before starting all of the preparations (washing, peeling, cutting, etc), predetermined ingredients have to be weighted. When the task is finished, time, weigh of each pot of food and weigh of remaining and unburned wood and charcoal have to be recorded.

##### 4.2.2.2.2. Equipment

Equipment used during the WBTs is listed below:

- Fuel: a homogeneous mix of air-dried fuel wood was procured.
- Food and water: like fuel, the food used was homogenous so that variability in food does not bias the results of the test.
- Cooking pot(s): the same type (size, shape, and material) of pots was used to test each stove. However, unlike the WBT, lids were used as local cooks commonly use them.
- Scale with a capacity of at least 6 kg and accuracy of ±1 gram
- Wood moisture meter
- Timer
- Accessory tools to handle fire and weight hot stuff (see paragraph 4.2.2.1.2)

##### 4.2.2.2.3. Outputs

Data measured allow calculating different outputs:

- equivalent dry wood consumed;

- specific fuel consumption: i.e. the quantity of fuel required to cook a given amount of food for the "standard cooking task". It is calculated as a simple ratio of fuel to food;
- total cooking time.

## 4.3. Results and discussion

### 4.3.1. WBTs results

Table 9 reports the results of the tests performed with the different models of stove. Similar ebullition time was recorded for the wood stove models varying between 23 and 25 minutes. Ebullition time decreases to 18-20 minutes in the hot-start phase. Gas stove shows a significant lower ebullition time needed in the cold-start test, due to the highest thermal efficiency for the gas stove. Burning rates and specific consumptions are not comparable as different fuels were used. Among wood stoves, improved models show better performances in terms of specific consumption than the traditional 3-stone fire: up to 26% less in the high power test and up to 36% in the low-power test.

**Table 9: WBTs results for the different stoves tested in the study**

| | units | 3-stone fire | Centrafricain improved stove | Ceramic improved stove | Gas stove |
|---|---|---|---|---|---|
| Fuel used | | Wood | Wood | Wood | LPG gas |
| **1. High power (cold start)** | | | | | |
| Ebullition time | min | 23 | 24 | 24 | 19 |
| Burning rate | g/min | 39 | 32 | 31 | 5 |
| Thermal efficiency | % | 17 | 16 | 18 | 61 |
| Specific consumption | g/L | 196 | 159 | 161 | 22 |
| Power | watt | 12,066 | 9,721 | 9,438 | 4,284 |
| **2. High power (hot start)** | | | | | |
| Ebullition time | min | 20 | 18 | 19 | 20 |
| Burning rate | g/min | 43 | 40 | 44 | 4 |
| Thermal efficiency | % | 16 | 17 | 16 | 75 |
| Specific consumption | g/L | 179 | 153 | 161 | 13 |
| Power | watt | 13,247 | 12,470 | 13,641 | 3,024 |
| **3. Low power (simmering)** | | | | | |
| Burning rate | g/min | 19 | 13 | 11 | 3 |
| Thermal efficiency | % | 17 | 26 | 27 | 58 |
| Specific consumption | g/L | 245 | 166 | 157 | 32 |
| Power | watt | 5,696 | 3,897 | 3,499 | 2,285 |
| Turn down ratio | -- | 2.2 | 2.7 | 2.7 | 1.9 |

The low-power phase highlights the differences between improved and not-improved wood stove models. Thermal efficiency of 3-stone fire is similar to the one in the high-power phases (17%). In contrast, the efficiency of improved wood stoves increases from 16-18% to 26-27%: that is due to the insulating clay belt of the combustion chamber, which stores heat during the first phases, improving the heat transfer to the water during the following phase. Specific consumption comparison indicates even clearly the better performances of improved models: 3-stone fire needs 245 g of fuel to keep water next to local water boiling point, while the Centrafricain and the Ceramic stoves need respectively 166 g and 157 g.

A comparison of the increase in water temperature in the two phases at high power (shown in Figure 46) shows the different behaviour of the three woodstove models tested. In the first cold start phase improved models are initially slower to transfer the heat generated by combustion to water: this is due to the heat storage materials with high thermal inertia, which insulate the combustion chamber. By the end of this phase, however, the performances of these models are better than the traditional three stone fire, which initially results in a more immediate transfer of heat to the water. In the second phase, once the work temperature has been reached, performances of improved models benefit of the contribution of insulation materials, which allow a more rapid conveyance of the generated heat to water.

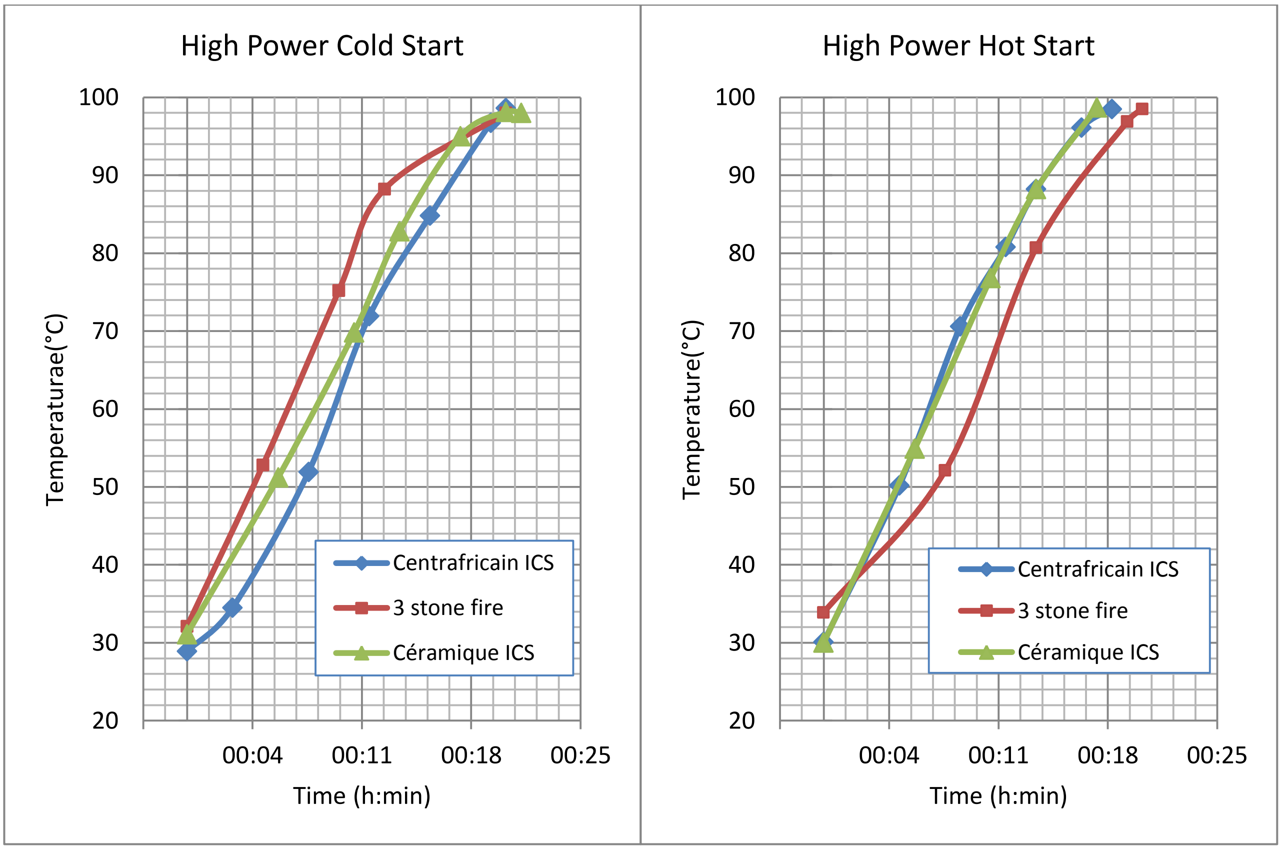



**Figure 46: comparison of HPCS and HPHS WBT phases for different woodstove tested**

#### *4.3.1.1. WBTs results: energy use*

Data reported in Table 10 show that the gas stove has the lowest use of energy (11 MJ) due to the highest thermal efficiency. Among wood-using models, the better efficiency of improved stoves (31-32 MJ) versus traditional 3-stone fire (43 MJ) is pointed once more.

**Table 10: energy use of each stove tested in the study**

| | units | 3-stone fire | Centrafricain improved stove | Ceramic improved stove | Gas stove |
|---|---|---|---|---|---|
| Fuel used | | Wood | Wood | Wood | LPG gas |
| Net Calorific Value | MJ/kg | 19.7 | 19.7 | 19.7 | 45.7 |
| Fuel use | kg | 2.16 | 1.61 | 1.59 | 0.25 |
| Energy use | MJ | 42.6 | 31.8 | 31.4 | 11.3 |

In comparison with the available literature, for proposed benchmark for wood burning cooking stoves (15 MJ to complete a laboratory 5L-WBT) (MacCarthy et al 2010) the stoves tested in this study showed a higher fuel use (respectively 32 MJ for the Centrafricain stove and 31MJ for the ceramic stove). Actually the results of tests conducted on site may be affected by several factors, such as wind conditions or other external influences that are almost absent in laboratory conditions. Comparing results in terms of reduction versus an open fire, the tested stove allowed a 25% and 26% fuel saving in comparison to the three stone fire tested in the same field conditions. Such a result is in line with energy use reduction targets proposed by MacCarthy et al (2010).

#### *4.3.1.2. WBTs results: fuel cost analysis*

The analysis of fuel cost allows for further considerations that greatly affect the real appropriateness and sustainability of a stove in the intervention context. Table 11 shows the cost of fuel consumption for each phase and the total cost to complete a full WBT according to prices surveyed during missions on site. Table 11 reports also data regarding costs of the different stoves and fuels used.

Results have only a preliminary significance, as WBTs do not give an indication of the real consumption during cooking tasks. Such preliminary elaborations can anyway give a rough indication of real costs as common cooking practices foresee often water boiling (cold-start high-power phase), simmering (low-power phase) and preparation of new courses with hot stoves (hot-start high-power phase).

The gas stove does not result anymore as the most effective option. Total fuel cost results in 0.37 €, the highest among all the models tested: such a price can only compete with other fuels in urban areas where wood results more expensive (up to 0.2 €/kg in N'Djamena, Chad capital). Improved wood stoves are the best option having the lowest fuel costs (respectively 0.09 € for the Centrafricain stove and 0.08 € for the Ceramic stove). In comparison the 3-stone fire has a fuel cost (0.12 €) 35% higher.

These considerations justify the higher initial investment cost for the purchase of improved wood stoves, which can be paid off by significant lower operation costs. Moreover, cheaper stoves experience more easily in breakdowns and need to be substituted more frequently, whereas more expensive models have longer lifespan.

**Table 11: fuel costs observed on site for different stove tested per each WBT phase**

| | units | 3-stone fire | Centrafricain improved stove | Ceramic improved stove | Gas stove |
|---|---|---|---|---|---|
| Stove cost | CFA f | 0 | 5,000 – 7,500 | 500 – 2,500 | ~8,000 |
| Fuel used | | Wood | Wood | Wood | LPG gas |
| Fuel cost | CFA f /kg | 35 | 35 | 35 | 980 |
| **1. High power (cold start)** | | | | | |
| Specific consumption | g/L | 196 | 159 | 161 | 22 |
| Fuel used | kg | 0.98 | 0.80 | 0.81 | 0.11 |
| Fuel cost | CFA f | 34.30 | 27.83 | 28.18 | 107.80 |
| | € cent | 5.23 | 4.24 | 4.29 | 16.43 |
| **2. High power (hot start)** | | | | | |
| Specific consumption | g/L | 179 | 153 | 161 | 13 |
| Fuel used | kg | 0.90 | 0.77 | 0.81 | 0.07 |
| Fuel cost | CFA f | 31.33 | 26.78 | 28.18 | 63.70 |
| | € cent | 4.78 | 4.08 | 4.29 | 9.71 |
| **3. Low power (simmering)** | | | | | |
| Specific consumption | g/L | 245 | 166 | 157 | 32 |
| Fuel used | kg | 1.23 | 0.83 | 0.79 | 0.16 |
| Fuel cost | CFA f | 42.88 | 29.05 | 27.48 | 156.80 |
| | € cent | 6.54 | 4.43 | 4.19 | 23.90 |
| **Total** | | | | | |
| Fuel use | kg | 2.16 | 1.61 | 1.59 | 0.25 |
| Fuel cost | CFA f | 75.6 | 56.4 | 55.7 | 242.6 |
| | € cent | 11.5 | 8.6 | 8.5 | 37.0 |

Figure 47 shows energy use and total fuel costs of each stove. The gas stove is the most energy-efficient, but it is not economically competitive in the study area. Improved wood stoves are characterized by significant better energy and cost-saving performances in comparison with traditional three stone fires.

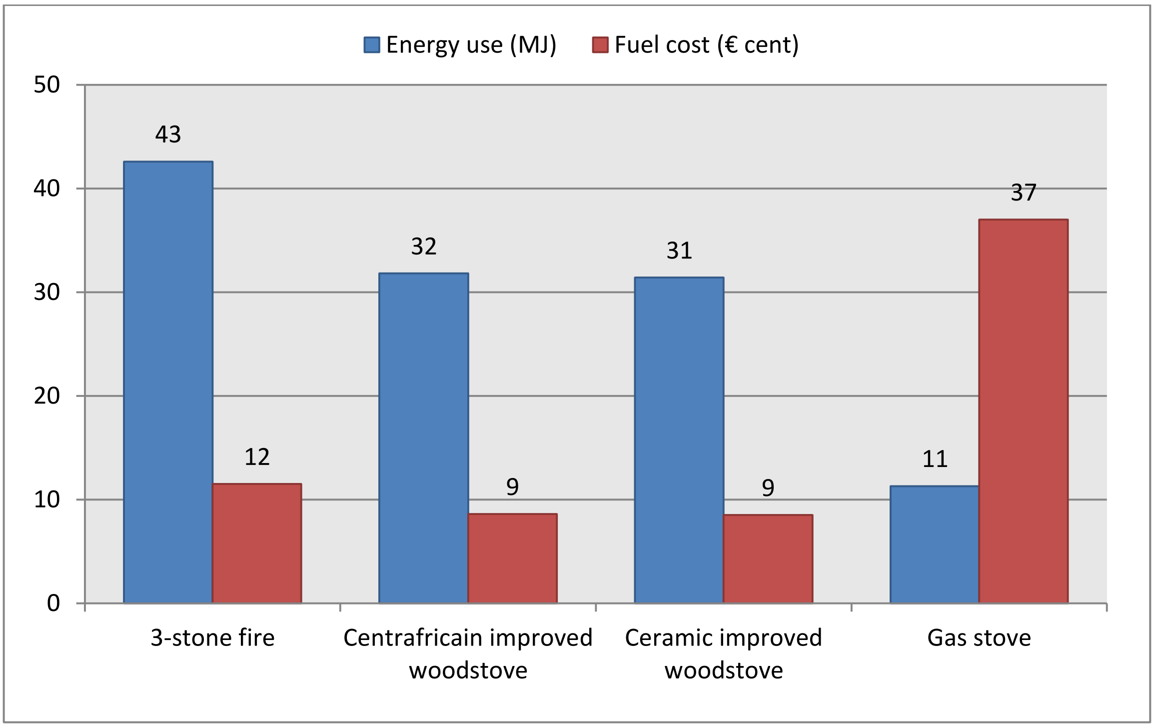



**Figure 47: energy use and fuel cost to complete a full WBT for the different stove models tested**

### 4.3.2. CCTs results

Table 12 shows the average composition of a meal prepared during the CCTs: quantities and type of food were kept as similar as possible in the different testing days in order to reduce the influence of ingredients characteristics on the results.

**Table 12: ingredients for a typical meal for CCT**

| Ingredient | Average quantity per stove | Ingredient | Average quantity per stove |
|---|---|---|---|
| Meat | 0.6 kg | Oil | 0.2 kg |
| Onions | 0.2 kg | Vegetables | 0.9 kg |
| Tomatoes | 0.3 kg | Peanut sauce | 0.4 kg |
| Rice | 0.8 kg | Water | 2.5 kg |

Table 13 shows the average output values obtained from the CCTs. The gas stove was not included in the CCT as results in WBTs already highlighted the higher fuel cost related to its use making it unaffordable for users in the local context.

**Table 13: CCTs results**

| | | Three stone fire | Ceramic improved stove | Centrafricain improved stove |
|---|---|---|---|---|
| Fuel used | kg | 2.1 | 1.6 | 1.3 |
| Specific consumption | g/kg | 434 | 330 | 282 |
| Total cooking time | h:min | 2:28 | 2:24 | 2:24 |

Results show a significant better performance of the improved models in comparison with the traditional three stone fire. Wood consumption for a meal preparation (5.9 kg) was more than 2 kg for the three stone fire, while only 1.6 kg for the Ceramic (-23%) and 1.3 kg for the Centrafricain stove (-37%). Similarly specific fuel consumption was reduced by some 24% in the tests with the Ceramic model and about 35% with the Centrafricain as illustrated in Figure 48. Total cooking time was almost the same (about 2.5 hours).

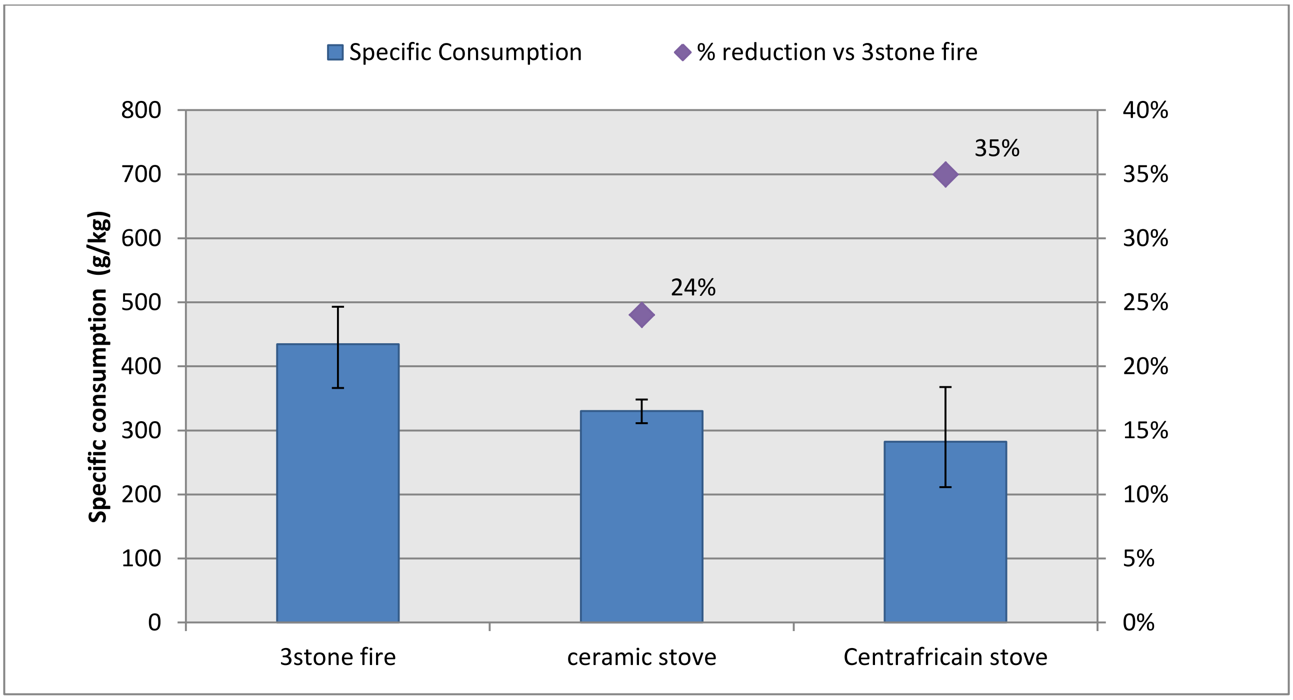



**Figure 48: specific wood consumption with different stove models according to CCTs performed**

Data gathered during the test sessions and information related to local population allowed to elaborate a stove use model in order to evaluate the wood consumption for cooking purposes in a typical household in the context studied. The average family size was assumed to be 9 people, each person consuming 0.65 kg of food daily (one meal providing 2,100 calories as suggested by the World Food Programme (2011)). The household average expenditure for cooking energy was calculated considering an initial wood price of 35 CFA francs per kilogram (updated during the stove lifespan to the current inflation rate provided by Word Bandk database), the stove selling prices (see previous paragraph) and lifespans (6 months for the ceramic stove, 48 months for the Centrafricain stove). According to the elaboration illustrated in Figure 49, having a low capital cost (1,500 CFA francs) and significant reduced wood consumption the use of the Ceramic stove occurs in a small expenditure reduction to the use of the three stone fire, due to the short lifespan caused by the low resistance of the materials. This may cause disaffection by the user and consequent dis-adoption of the technology. It has to be said that such a simple technology may be also reproducible by auto-production, removing the investment costs. Concerning the Centrafricain stove, the higher initial investment (6,000 CFA francs) is paid back within 7 months. Thanks to its longer lifespan (due to the higher quality and resistance of materials and structure) the second model shows a good performance on a medium term, resulting in higher savings of fuel and money, also in comparison with the Ceramic stove. Extending the elaboration to a longer period (5 years), the benefits of the use of the Centrafricain stove even allows for a saving equal to some 40,000 CFA francs per household, which is the 25% of the cumulative fuel expenditure per household.

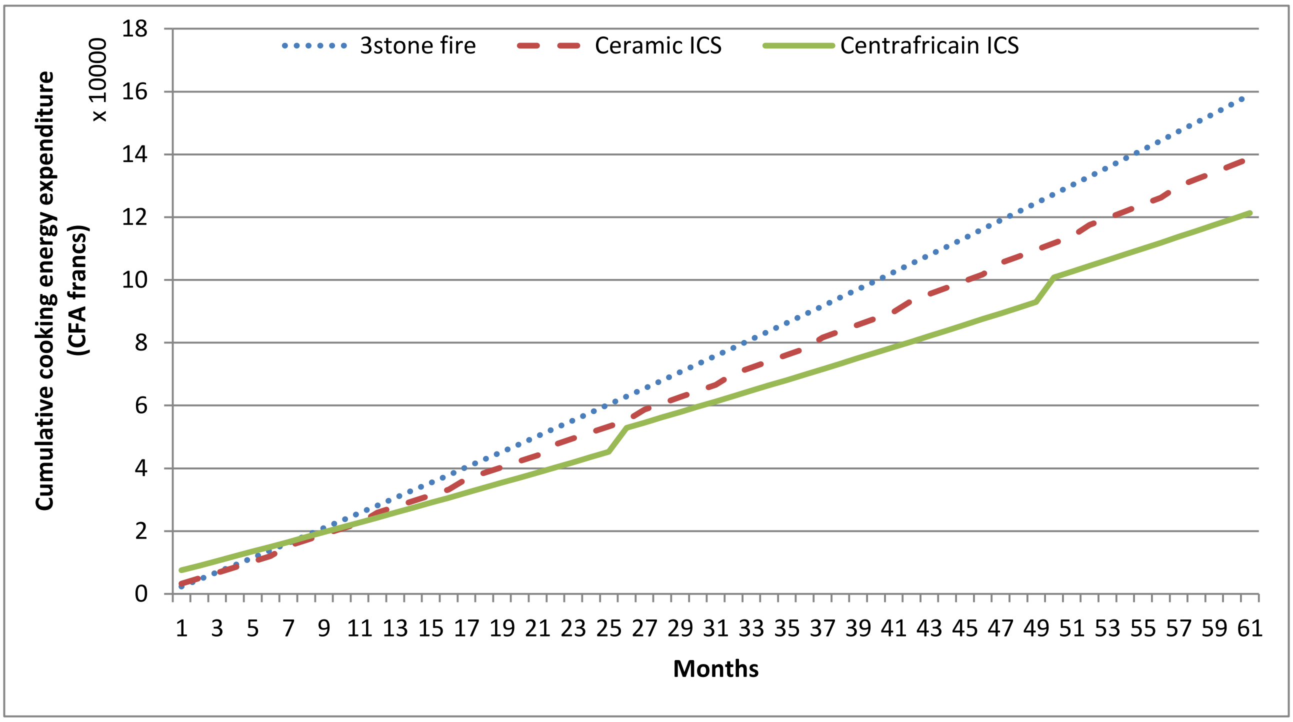



**Figure 49: 5-years household fuel & stove expenditure estimated for different stove model tested**

Data obtained were compared with other data cited in previous studies (Table 14): in particular a USAID (2010) report about the evaluation of manufactured wood-burning stoves in the Dadaab refugee camps (Kenya).

**Table 14: comparison of CCT by the author and by other reports**

| Stove model | Specific consumption | Total cooking time | Specific consumption per min* |
|---|---|---|---|
| | g/kg | min | g/kg min |
| Three stone fire | 434 | 148 | 2.9 |
| Ceramic improved stove | 330 | 144 | 2.3 |
| Centrafricain improved stove | 282 | 144 | 2.0 |
| Open fire (USAID 2010) | 295 | 54 | 5.5 |
| Envirofit (USAID 2010) | 143 | 49 | 2.9 |
| StoveTec (USAID 2010) | 136 | 50 | 2.7 |
| Philips (USAID 2010) | 159 | 56 | 2.8 |
| Vesto (USAID 2010) | 202 | 47 | 4.3 |
| Save80 (USAID 2010) | 110 | 52 | 2.1 |
| Mudstove1 (USAID 2008) | 710 | 71 | 10.0 |
| AVI3 (USAID 2008) | 801 | 67 | 12.0 |
| Tara (USAID 2008) | 608 | 85 | 7.2 |
| Mudstove2 (USAID 2008) | 372 | 65 | 5.7 |
| Six bricks (USAID 2008) | 736 | 64 | 11.5 |
| 3stone fire (USAID 2008) | 699 | 71 | 9.9 |

* output calculated by the author also for the other studies

The CCT results for a typical meal were very similar to the one used in this study: for this reason data reported from USAID are more meaningful for a comparison than data from other authors (USAID 2008). Actually the total cooking times were considerable shorter in the Kenyan case study than in the authors' test likely due to different local cooking practices. Thus, an alternative indicator, specific consumption per minute calculated as the ratio of the specific consumption on the total cooking time, was introduced in order to have a more comprehensive comparison. Data elaborated in Table 14 show that the improved stoves tested by the author result in a similar output in comparison with the best performing models tested by USAID.

## 4.4. Conclusions

A number of tests were conducted on site to evaluate which stove model, in combination with proper fuel, would be suitable for the dissemination among the local population of the Valley of Logone River (Chad and Cameroun). Models were chosen among traditional and improved stoves already available in the region.

Water Boiling Tests performed on site showed the effectiveness of improved wood stove models proposed both from an energy and an economic point of view in comparison to traditional the three stone fire that is still very common as household cooking solution in the study area. Higher values resulted in comparison to benchmarked energy use for woodstoves. That is due to the low level of technology and standardization in manufacturing process of the stoves tested. Nevertheless a lower performance can be acceptable because of a number of advantages in terms of sustainable reproducibility and adaptability to local practices.

Controlled Cooking Tests underlined even more the efficiency of the improved stove models proposed in terms of fuel savings. In particular the Centrafricain stove allows a significant reduction of wood consumption (-35%) in the preparation of a typical local meal in comparison to traditional cooking systems.

Data collected during the tests, crossed with information about the local cooking habits, allowed to estimate the impact, in terms of financial savings, for each household adopting an improved stove. The Centrafricain stove resulted being the best performing, and therefore sustainable, model, occurring in a 22% reduction of the expenditure per family for cooking purposes in a 5-year term.

According to projection by several international organizations, a wide share of global population will rely still on biomass solid fuels in 2030 (IEA and UNIDO 2010). The results of this study show that the use of improved woodstoves is likely to be a viable and sustainable option to guarantee an appropriate minimum level of energy access for cooking purposes for the poor people in developing countries, in combination with a comprehensive forest management policy in order to ensure that the fuel resource will be managed in a sustainable manner.

# 5. Assessment of the impact of the Centrafricain ICS dissemination

Further studies have been conducted to evaluate the appropriateness and sustainability of the proposed solutions in the study area: social, economic, technical, environmental and health factors must be considered to provide the local population with an effective solution to improve the household energy supply. Thus, in addition to the results of the WBT and CCT tests done on the improved stove model to assess their technical performances (whose results are presented in the previous chapter 4), some other surveys were conducted in order to assess the effective impact of the adoption of the stove on the users and on the local territory. Indeed, monitoring and evaluation of improved cookstove performance is a critical factor in program success: however, consistent evidence indicates that water boiling tests and controlled cooking tests are not stand-alone representative of stove performance during daily cooking activities (Johnson et al 2010). A number of technical factors occur in the feasibility and reproducibility of a certain technology according to local availability of materials, artisan skills and production techniques. Adaptability to local cooking practices influences greatly the acceptability by the final users and, thus, the effective adoption of the stove in the daily usage. Indeed four essential components are fundamental in the success of an energy intervention: fuels, combustion devices, applications and human factors (Anderson 2011).

In this study three sectors were considered in the assessment of the impacts the Centrafricain ICS had on the intervention context. The economic aspect is often the main force that drives the householder in the use of a fuel, as explained in chapter 4, but also in the choice of the stove. Affordability of the initial capital cost and effective fuel savings, which result in real money or in indirect costs (collection time) savings, greatly impact the possibility for users to adopt a stove and influence their preference. On the other side, health and environment related impacts were assessed even if they are usually farther from the users perceptions and needs, being related to not immediately visible effects. An overall quantification of the impact of the intervention was possible crossing data collected through surveys and tests and the total number of stove disseminated in the local context.

## 5.1. Material and methods

Table 15 sums up the methods used to assess the impact of the dissemination of the Centrafricain ICS in the Logone Valley. Each method allowed to assess a relative indicator considered meaningful for the assessment of the impact on a certain subject.

Observations and interviews are described in the overall methodology in chapter 2, while a more detailed discussion of the other protocols implemented is presented in the following paragraphs. KPT were used to quantify the real daily consumption associated to the use of the ICS in comparison with traditional cooking systems. This main output was fundamental for further considerations on the emissions related to the use of different cooking systems and the consequent impact on the household budget. Some indications on the quality of indoor air were provided by 24 hours monitoring of two main pollutants, CO and particulate matter.

**Table 15: list of indicators used to assess the impact of the Centrafricain ICS introduction**

| Impact | Subject | Indicator | Method |
|---|---|---|---|
| Technical | Artisan | Skill evaluation | Checklist |
| | Market | Availability of materials and items | Observational survey |
| Social | Household | Adaptability to local cooking practices, acceptability | Semi-structured interviews |
| Economic | Household | Wood daily consumption | KPT |
| | Household | % of fuel expenditure on household budget | KPT, semi-structured interviews |
| Health | Household | IAP reduction | IAP monitoring |
| Environmental | Household | Wood consumption reduction | KPT, CCT |
| | Project | $CO_2$ savings | AMS II.G (CDM) |

### 5.1.1. Preliminary qualitative aspects

Some considerations about the appropriateness of the Centrafricain ICS were considered fundamental at a preliminary stage. Thus, observational surveys and semi-structured interviews were posed to both the trained artisans and householders that adopted the ICS.

A technical assessment of the understanding and ownership of the manufacturing technique and procedures was done using specific checklist at the end of the training for all the artisans involved and after a period for only some among them. Indeed some of them were impossible to re-contact due to logistic issues.

A number of ICS adopters were interviewed some months after the purchase of the Centrafricain ICS in order to evaluate their opinion regarding the use of the new cooking technology. Semi-structured interviews were considered appropriate for this task in order to not influence the point of view of the interviewed in pointing out the weaknesses and strengths of the stove and their personal preferences and cooking patterns.

### 5.1.2. Kitchen performance test (KPT)

The Kitchen Performance Test (KPT) is the principal field–based procedure to demonstrate the effect of stove interventions on household fuel consumption. There are two main goals of the KPT: to assess qualitative aspects of stove performance through household surveys and 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. This type of testing, when conducted carefully, is the best way to understand the stove's impact on fuel use and on general household characteristics and behaviours because it occurs in the homes of stove users (Lillywhite 1984, VITA 1985). However, it is also the most difficult way to test stoves because it intrudes on people's daily activities. Thus, it was used as a method to evaluate the real impact of the introduction of the stove in a limited group of households.

### 5.1.2.1. KPT qualitative survey

Surveys about how people feel about the stove should happen in two stages. Both stages of the survey are adopted from the work of Baldwin and VITA (1987, 1985), with slight changes. The goal of the first stage of the survey is to identify basic social, economic and cooking information of community families. This survey provides important information and it should occur before stoves are sold or distributed. The survey may also include households that do not adopt the stove.

### 5.1.2.2. KPT quantitative survey

In order to compare two or more types of stoves, the testing phase can be carried out in two ways. It can be done by conducting daily measurements at families which use the traditional stove for a certain time (e.g. 3–7 days) followed by daily measurements of the same families using the improved stove for the same period of time. This type of test makes a comparison of the household fuel use with the old stove and with the improved stove. This is a paired-sample study with no control. Alternatively, the KPT can be done by comparing fuel consumption in two or more groups of families for a period of 3–7 days, with one group using the traditional stove and the other group(s) using the improved stove(s). This is a cross-sectional study, in which two groups of households, one using the old stove and one using the new stove, are compared at the same time. The paired-sample approach allows to avoid bias due to different behaviours, habits or socioeconomic characteristics of the two groups surveyed, being the same families involved at different times. It also permits to use a smaller sample size than the cross-sectional method for a desired level of statistical significance.

In this study a preliminary survey was conducted to assess the willingness of families to take part to the quantitative survey. At the same time a semi-structured questionnaire was used to identify the socioeconomic patterns and the cooking habits of the population. Hence a group of household that used the traditional three stone fire was selected for the KPT. Sample size was determined according to indication of Table 16 for a paired-sample test method, according to output of CCTs on detectable difference in means and pooled coefficient of variation (CV) of measurement on different stove model previously tested.

**Table 16: Sample size required for the paired-sample test method**

| Detectable difference in means | Pooled CV of measurements | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 |
| **10%** | 8 | 31 | 71 | 126 | 196 | 283 | 385 | 502 | 636 | 785 | 950 | 1130 | 1326 |
| **20%** | 2 | 8 | 18 | 31 | 49 | 71 | 96 | 126 | 159 | 196 | 237 | 283 | 332 |
| **30%** | 1 | 3 | 8 | 14 | 22 | 31 | 43 | 56 | 71 | 87 | 106 | 126 | 147 |
| **40%** | 0 | 2 | 4 | 8 | 12 | 18 | 24 | 31 | 40 | 49 | 59 | 71 | 83 |
| **50%** | 0 | 1 | 3 | 5 | 8 | 11 | 15 | 20 | 25 | 31 | 38 | 45 | 53 |
| **60%** | 0 | 1 | 2 | 3 | 5 | 8 | 11 | 14 | 18 | 22 | 26 | 31 | 37 |
| **70%** | 0 | 1 | 1 | 3 | 4 | 6 | 8 | 10 | 13 | 16 | 19 | 23 | 27 |
| **80%** | 0 | 0 | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 | 15 | 18 | 21 |
| **90%** | 0 | 0 | 1 | 2 | 2 | 3 | 5 | 6 | 8 | 10 | 12 | 14 | 16 |
| **100%** | 0 | 0 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 11 | 13 |

The person in charge of the woodfuel purchase and use was made aware on the basic test requirements, in order to avoid bias in the measurement due to uncontrollable bad user practice. The survey last for 3 days. Every day each household was visited and the weight of the wood stock and of the eventually new purchased one were noted by the testers. The woodfuel consumption was calculated by the difference between the registered weight of unused fuel and the same weight of the previous day. The same procedure was repeated the following week after providing the same families with the Centrafricain improved stove. The testers decided not to provide the users with the woodfuel for free in order to avoid consumption patterns different from normal circumstances. A compensation for participation in the KPT was considered appropriate at the end of the surveyed period after discussion with the local staff.

### 5.1.3. Indoor air pollution (IAP) monitoring

A comparative evaluation of the indoor air quality using the improved stove proposed or the traditional three stone fire was performed in order to assess also the potential impact on livelihood of the household spaces and IAP-exposure related diseases in the users. Indoor air pollution was monitored in three households out of the 9 surveyed in the KPT for a period of 24 hours. CO and $PM_{2.5}$ are the parameters real time monitored (data registered every minute) using two portable probes:

- Gasman CO monitor with data logger
- UCB monitor by University of Berkeley

Monitoring equipment was installed in the kitchen of the household, a room separated from the rest of the house. CO monitor and UCB were set up 1.5m vertically and 1.5m horizontally away from the stove and, where possible, from openings (windows or doors). The position of all the electrical equipment was chosen in order to prevent children from tampering with it and not to disturb the cooks during the use of the stove.

#### *5.1.3.1. Particulate sampling equipment*

Standard PM sampling equipment can use a pump drawing air past a cyclone that throws off the larger particles and sends the respirable particles through a filter. A small silent monitor has been developed by University College Berkeley, USA, which produces real time data. The UCB monitor relies on sensors from an inexpensive commercial household smoke detector that combines ionization chamber sensing (ion depletion by airborne particles) and photoelectric sensing (optical scattering by airborne particles) (UCB 2006).

#### *5.1.3.2. Equipment for measuring carbon monoxide*

For the purpose of this study a real time monitoring of carbon monoxide was used. Real-time gas monitors can give a digital output of CO levels at one minute (or even one second) intervals. Data can be downloaded to a personal computer. This allows peaks as well as mean values to be recorded that can in turn be related to particular events or activities. The equipment is a Gasman single gas monitor with data logger to transfer data to computer.

### 5.1.4. Emission reduction estimation

No specific in field measurement were implemented to estimate the emission reduction. The methodology recognized within the CDM protocol "AMS-II.G.: Energy efficiency measures in thermal applications of non-renewable biomass" was adopted for such a purpose, being already successfully applied in other stove projects. The technologies introduced complain the definition of "high efficiency biomass fired cook stoves", defined in the protocol as a single pot or multi pot portable or in-situ cook stoves with specified efficiency of at least 20%. The baseline emission reductions are calculated as:

$$ER_y = B_{y,\ savings} * f_{NRBy} * NCV_{biomass} * EF_{projected\_fossilfuel}$$

Where:

| | |
|---|---|
| $ER_y$ | Emission reductions during the year y in tons of $CO_{2eq}$ |
| $B_{y,\ savings}$ | Quantity of woody biomass that is saved in tons |
| $f_{NRBy}$ | Fraction of woody biomass saved by the project activity in year y that can be established as non-renewable biomass |
| $NCV_{biomass}$ | Net calorific value of the non-renewable woody biomass that is substituted (IPCC default for wood fuel, 0.015 TJ/ton) |
| $EF_{projected\_fossilfuel}$ | Emission factor for the substitution of non-renewable woody biomass by similar consumers. Use a value of 81.6 $tCO_{2eq}/TJ$ |

The protocol suggests different methods to estimate the quantity of woody biomass that is saved.

1. $B_{y,savings} = B_{old} – B_{y,new}$

Where:

| | |
|---|---|
| $B_{old}$ | Quantity of woody biomass used in the absence of the project activity in tons |
| $B_{y,new}$ | Annual quantity of woody biomass used during the project activity in tons, measured as per the Kitchen Performance Test (KPT) protocol |

2. $B_{y,savings} = B_{old}\ (1-(\eta_{old}/\eta_{new})$

Where:

| | |
|---|---|
| $B_{old}$ | Quantity of woody biomass used in the absence of the project activity in tons |
| $\eta_{old}$ | Efficiency of the system being replaced, measured using representative sampling methods or based on referenced literature values (fraction), use weighted average values if more than one type of system is being replaced |
| $\eta_{new}$ | Efficiency of the system being deployed as part of the project activity (fraction), as determined using the Water Boiling Test (WBT) protocol. Use weighted average values if more than one type of system is being introduced by the project activity |

3. $B_{y,savings} = B_{old}\ (1-(SC_{old}/SC_{new})$

Where:

| | |
|---|---|
| $SC_{old}$ | Specific fuel consumption or fuel consumption rate of the baseline system/s, i.e. fuel consumption per quantity of item/s processed (e.g. food cooked) or fuel consumption per hour, respectively. Use weighted average values if more than one type of system is being replaced |

$SC_{new}$ Specific fuel consumption or the fuel consumption rate of the system/s deployed as part of the project, i.e. fuel consumption per quantity of item/s processed (e.g. food cooked) or fuel consumption per hour respectively. Use weighted average values if more than one type of system is being introduced by the project activity

##### *5.1.4.1. Differentiation between non-renewable and renewable woody biomass*

The protocol ask to determine the shares of renewable and non-renewable woody biomass in $B_{old}$ (the quantity of woody biomass used in the absence of the project activity) the total biomass consumption using nationally approved methods (e.g. surveys or government data if available) and then determine $f_{NRBy}$ as described below. The following principles shall be taken into account.

###### 5.1.4.1.1. Demonstrably renewable woody biomass (DRB)

Woody biomass is "renewable" if certain conditions are satisfied. The woody biomass is originating from land areas that are forests or non-forest areas (e.g. croplands, grasslands) where the land area remains or is reverted to a forest; sustainable management practices are undertaken on these land areas to ensure, in particular, that the level of carbon stocks on these land areas does not systematically decrease over time (carbon stocks may temporarily decrease due to harvesting); any national or regional forestry and nature conservation regulations are complied with.

###### 5.1.4.1.2. Non-renewable biomass

Non-renewable woody biomass (*NRB*) is the quantity of woody biomass used in the absence of the project activity ($B_{old}$) minus the *DRB* component, as long as at least two of the following supporting indicators are shown to exist:

- A trend showing an increase in time spent or distance travelled for gathering fuel-wood by users (or fuel-wood suppliers) or, alternatively, a trend showing an increase in the distance the fuel-wood is transported to the project area;
- Survey results, national or local statistics, studies, maps or other sources of information, such as remote-sensing data, that show that carbon stocks are depleting in the project area;
- Increasing trends in fuel wood prices indicating a scarcity of fuel-wood;
- Trends in the types of cooking fuel collected by users that indicate a scarcity of woody biomass.

Thus, the fraction of woody biomass saved by the project activity in year *y* that can be established as non-renewable is:

$$f_{NRBy} = NRB/(NRB+DRB)$$

## 5.2. Results and discussion

### 5.2.1. KPT results

A total number of 9 households were involved in the KPT. The sample size was calculated according to indications given in the methodological paragraph (see Paragraph 5.1.2). Socioeconomic characteristics and some other information on wood consumption patterns obtained through the analysis of the questionnaires are summed up in Table 17.

**Table 17: socioeconomic patterns of surveyed household in KPT**

| | | HH1 | HH2 | HH3 | HH4 | HH5 | HH6 | HH7 |
|---|---|---|---|---|---|---|---|---|
| Woman | **Occupation** | housewife | worker | housewife | housewife | housewife | Missing information | employed |
| | **School level** | primary | secondary | superior | primary | primary | | secondary |
| Head of family | **Occupation** | retired | worker | employed | employed | employed | | employed |
| | **School level** | secondary | secondary | superior | primary | secondary | | secondary |
| Family size | **Children** | 13 | 5 | 3 | 6 | 11 | | 6 |
| | **Woman** | 1 | 4 | 2 | 1 | 5 | | 1 |
| | **Man** | 1 | 0 | 2 | 1 | 3 | | 1 |
| Income | **Income (CFA f/ month)** | 33,200 | 25,000 | 102,000 | 50,000 | 150,000 | | 110,000 |
| | **Fuel expenditure (CFA f/ week)** | 2,250 | 750 | 2,355 | 1,400 | 2,100 | | 1,650 |

According to data in Table 17, the more the income level, the more the amount spent for the purchase of daily fuel. Actually this affects in a disproportionately way on the poorest households, whose monthly expenditure for wood engages a higher share of the family budget, as shown in Figure 50.

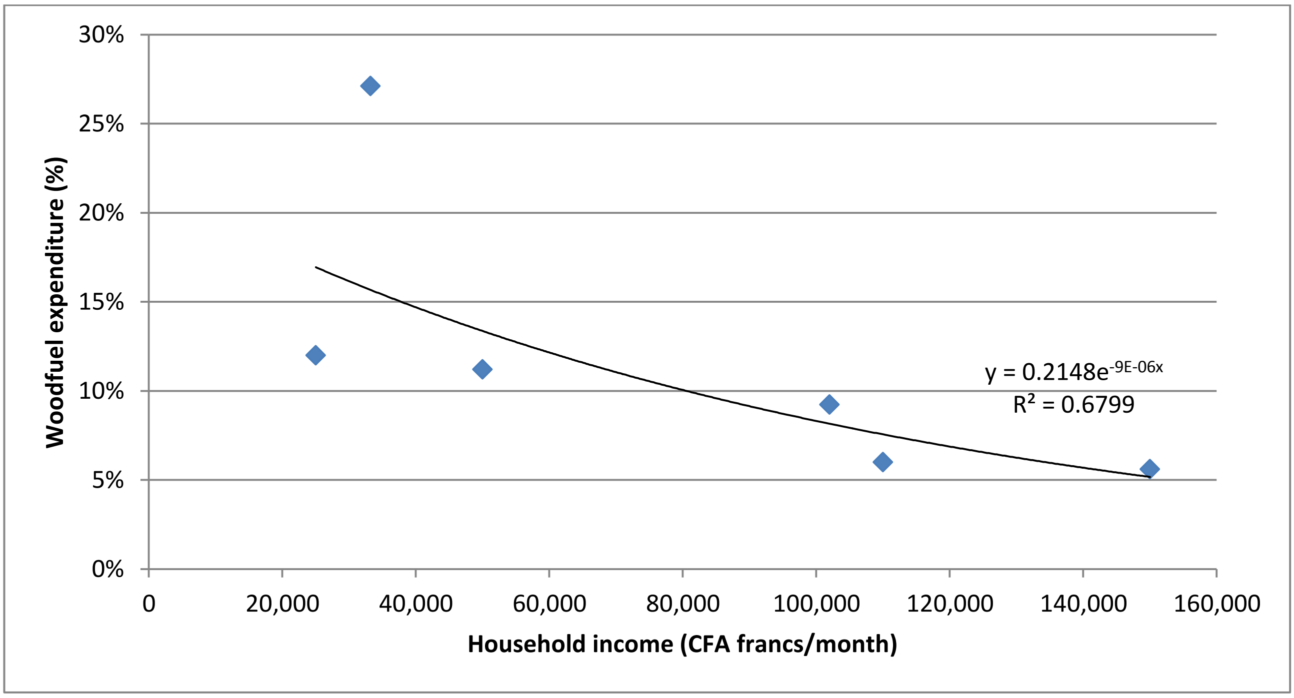



**Figure 50: woodfuel expenditure impact on household budget according to level of income**

Two households drop out the survey after the first visits, resulting in a final total number of households surveyed of 7. Table 18 shows the daily woodfuel consumption, calculated per standard person, in different households both for three stone fire and Centrafricain improved stove. Average mean resulted 1.15 and

0.51 kg/d per capita for the three stone fire and the ICS respectively. A 55% reduction in wood use can be stated by the adoption of the Centrafricain stove with to a statistical significance level equal to 90%.

**Table 18: KPT outputs**

| Household surveyed | Equivalent family members | Daily fuelwood consumption per standard person | |
|---|---|---|---|
| | | 3stone fire | Centrafricain ICS |
| | standard adults* | kg/ d p | kg/ d p |
| HH1 | 8.3 | 0.55 | 0.15 |
| HH2 | 5.7 | 1.04 | 0.68 |
| HH3 | 5.1 | 1.53 | 0.64 |
| HH4 | 4.8 | 1.01 | 0.46 |
| HH5 | 11.5 | 0.73 | 0.36 |
| HH6 | 5.6 | 1.20 | 0.87 |
| HH7 | 4.6 | 2.00 | 0.43 |
| HH8 | 6.8 | Drop out the survey | |
| HH9 | 3.5 | Drop out the survey | |

* according to Joseph (1990), for calculations of daily fuelwood consumption FAO suggests to be considered: adult man= 1person; adult woman = 0.8 person; elder= 0.8 person; child = 0.5 person.

Figure 51 shows the daily fuel consumption according to KPT outputs for each household surveyed related to its size. A less than linear decrease of wood use per person can be noticed with the increasing of the equivalent size of the family.

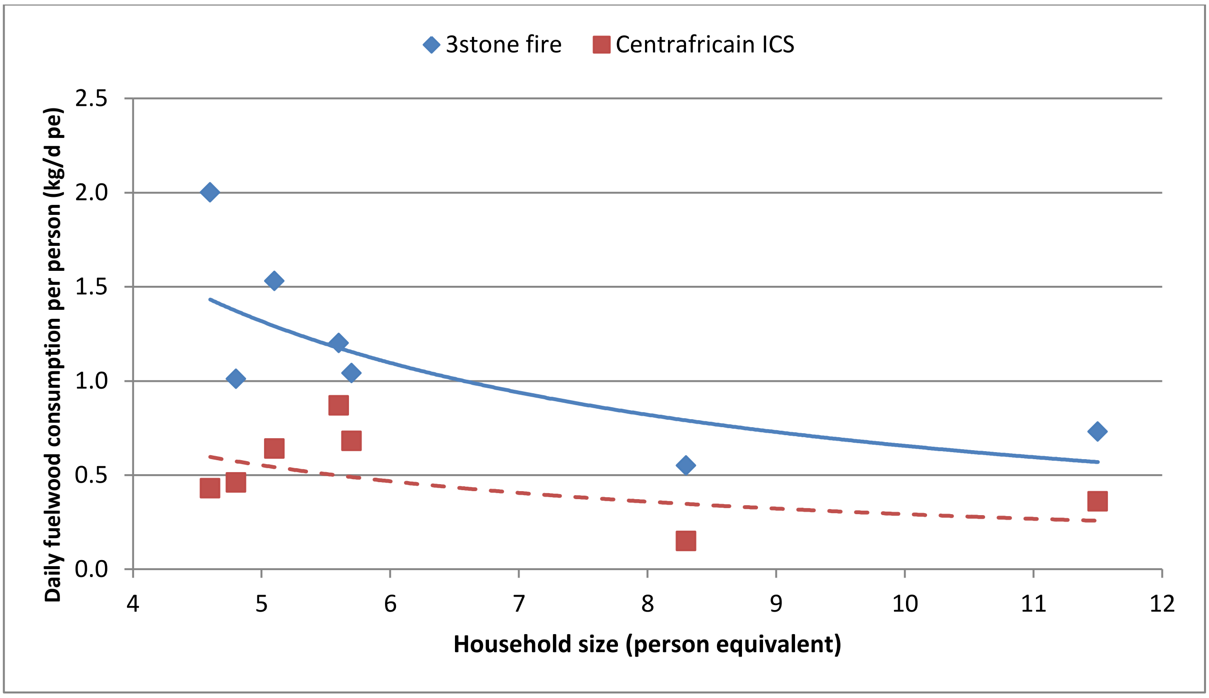



**Figure 51: daily fuel consumption vs household size according to KPT outputs**

Figure 52 shows the relation between wood consumption and income per person. The higher linear correlation law for the KPT output in the period of use of the three stone fire, in comparison with the flatter one for the Centrafricain stove may indicate a behavioural pattern in the use of the stove. Lower income people pay more attention in an efficient and low use of wood, while richer people are more wasteful in that. This results in a higher use of wood with the three stone fire, which is more energy-dispersive, and requires much more attention to gain a lower use of fuel. Otherwise the Centrafricain ICS has performances, in term of wood use, more independent from the user practices.

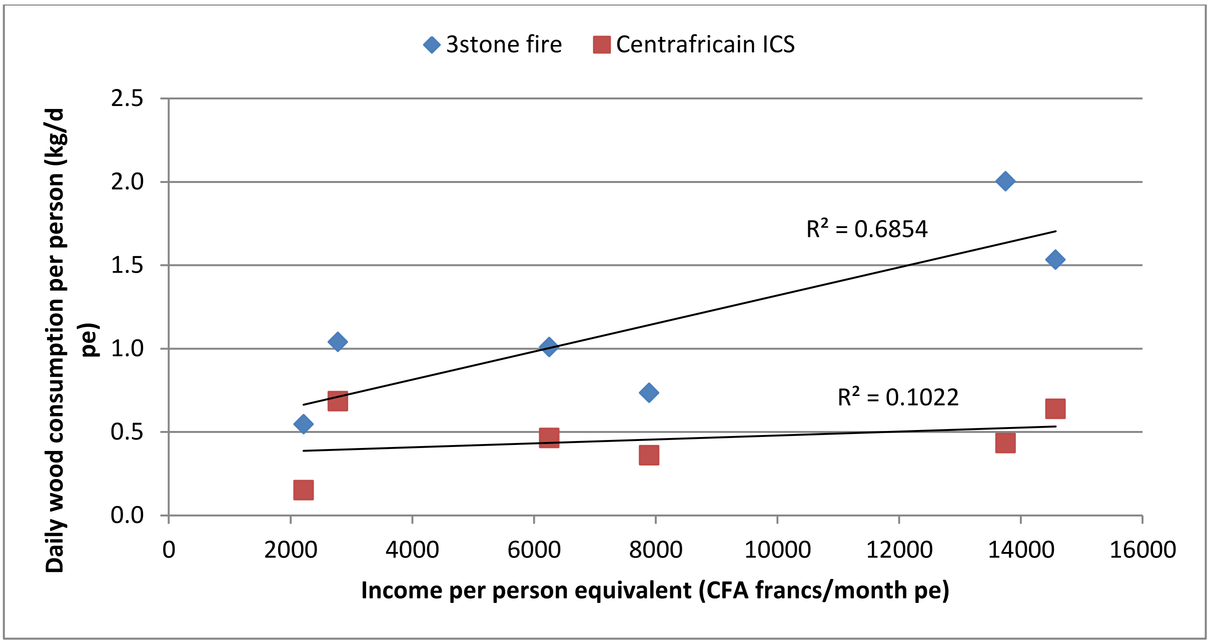



**Figure 52: daily fuel consumption versus household income per person equivalent**

Figure 53 (a, b) shows that higher reductions in wood consumption resulted in household that were more wasteful in wood use. Actually the limited number of data affects the significance of such considerations.

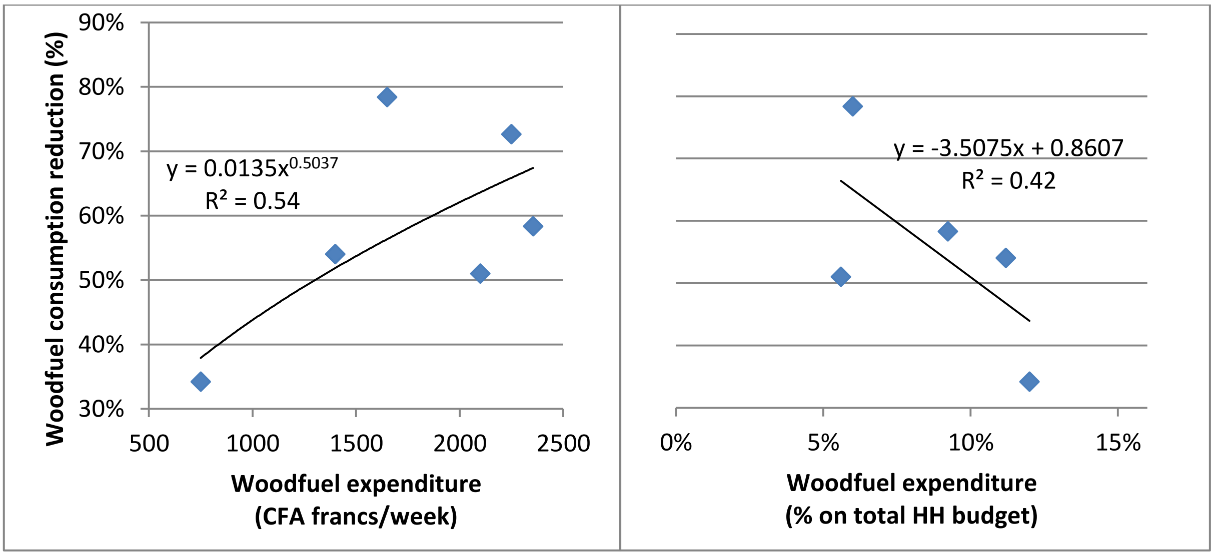



**Figure 53 (a, b): woodfuel reductions thanks to the adoption of Centrafricain ICS versus woodfuel expenditure**

### 5.2.2. Indoor Air Pollution monitoring results

Data were collected in 3 households involved in the KPT. A total number of six 24h monitoring (three for the three stone fire and three for the Centrafricain ICS respectively) were performed. Data were compared to WHO standards for IAP. The guideline value of 25 μg/m$^3$ 24-hour mean was taken as reference for $PM_{2.5}$, while for CO all the levels indicated for different periods were considered. Some differences in the cooking practices and in the number of meals prepared were noted even in the same household within the monitoring periods. Therefore, in order to avoid any bias due to particular user behaviour, cooking events were analysed specifically.

**Table 19: IAP ($PM_{2.5}$ and CO) level measured in household monitored**

| | | *WHO AQ guideline value* | Three stone fire | Centrafricain ICS |
|---|---|---|---|---|
| **$PM_{2.5}$ (μg/m$^3$)** | Arithmetic mean | *25* | 287 – 1,416 | 133 – 1,193 |
| | Meal | - | 452 – 7,344 | 271 – 2,624 |
| **CO (ppm)** | 24-hours mean | *6.1 (7 mg/ m$^3$)* | 3 - 29 | 7 - 20 |
| | Meal | - | 20 - 97 | 14 - 90 |

Table 19 shows the ranges of arithmetic means calculated for the whole monitoring period (24 hours) and for the specific cooking time. Cooking time observed in the monitoring were similar to the one observed during the CCTs (i.e. 2 - 3 hours). The level of both the parameters monitored resulted decreased by the use of the improved stove. Actually values observed do not meet the WHO indications for air quality, in particular for particulate matter, but are coherent with those indicated in literature for indoor air pollution from household fuels (Naeher et al 2007). A 30% reduction of CO indoor concentration and a 36% reduction of $PM_{2.5}$ occurred on the whole monitoring period, while no significant differences were noted during the specific meal preparation time.

Being $PM_{2.5}$ more expensive and difficult to measure rather than CO (in particular for personal exposure) according to some recent literature studies (Naeher et al 2001, Northcross et al 2010) CO measurements can be used as a proxy for $PM_{2.5}$. In the monitoring of this study the 24h mean concentration of the two parameters monitored do not show a good linear correlation, as shown in Figure 54. Otherwise, a good correlation (R2=0.85) was found between the means measured during the cooking events.

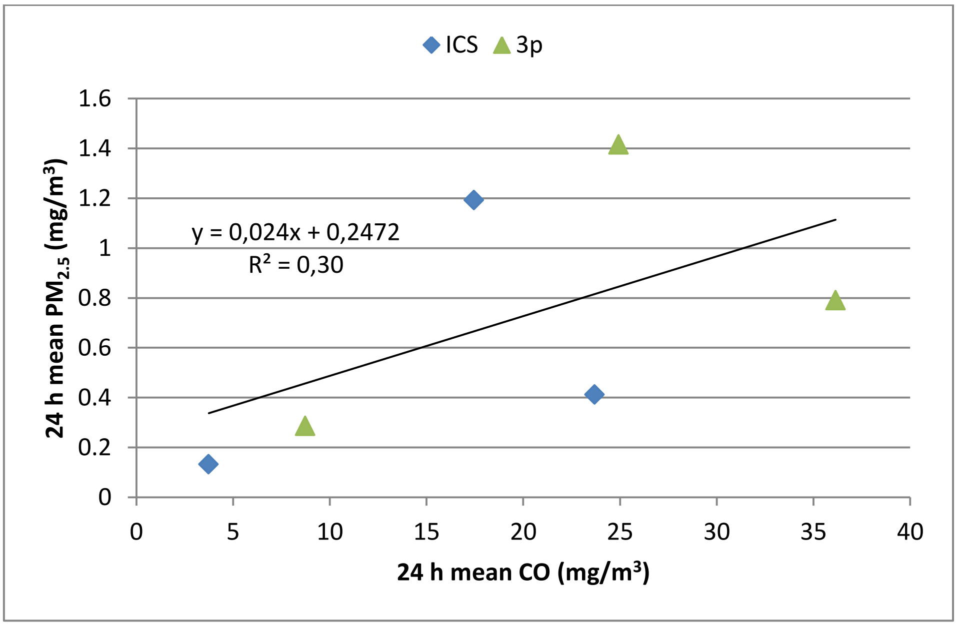



**Figure 54: mean 24 h $PM_{2.5}$ concentrations versus mean 24 h CO concentrations measured (CO was converted from ppm to $mg/m^3$ assuming an environment temperature equal to 30°C)**

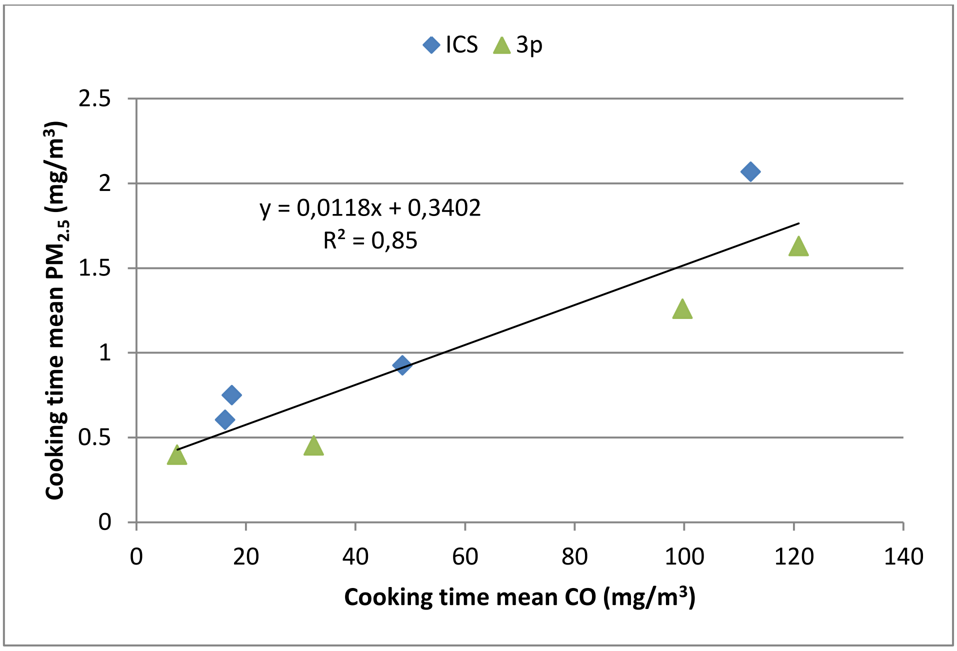



**Figure 55: mean $PM_{2.5}$ concentrations versus mean CO concentrations measured during cooking events (CO was converted from ppm to $mg/m^3$ assuming an environment temperature equal to 30°C)**

The use of the improved stove may have benefits also in terms of indoor air quality. Generally well-designed energy-efficient stoves emit very little smoke, provided that improved efficiency is due in part to improved combustion. This may result often in a relative reduction of the concentration of principal pollutants in comparison with the baseline (use of traditional three stone fire) but sometimes IAQ improvement is not enough to meet the WHO guideline values. In particular, as regards CO, regardless the stove used, the indoor average concentrations often do not meet the indications given by the WHO guidelines, as detailed in Table 20.

Table 20: share of monitoring period not meeting the WHO IAQ guidelines for CO

| Period | *WHO AQ guideline value* | 3stone fire | Centrafricain ICS |
|---|---|---|---|
| 8-hours | *8.7 ppm (10 mg/ $m^3$)* | 6-36% | 0-41% |
| 1-hour | *30.6 ppm (35 mg/ $m^3$)* | 5-36% (1-2) | 5-22% (0-3) |
| 15-minutes | *87.3ppm (100 mg/ $m^3$)* | 0-43% (0-2) | 0-12% (0-2) |

*in brackets the number of events exceeding the guideline value during the monitoring

Figure 56 shows the daily trend of the CO 1hour mean in two of the households monitored. As discussed above, the use of the improved stove may reduce in some cases the level of IAP, but not always permits to meet the WHO guideline values. In the graphs, CO peaks registered during the preparation of meals can be easily recognized. In both a reduction of their intensity can be noticed due to the introduction of the ICS. In the right graph a further pattern can be observed. While in the monitored period of use of the three stone fire only two meals were prepared, in the Centrafricain ICS one a further meal, for a total of three meals were cooked. In addition to the limited sample size, this may be a further source of bias in the evaluation of the real impact on IAQ at household level due to the introduction of the Centrafricain ICS.

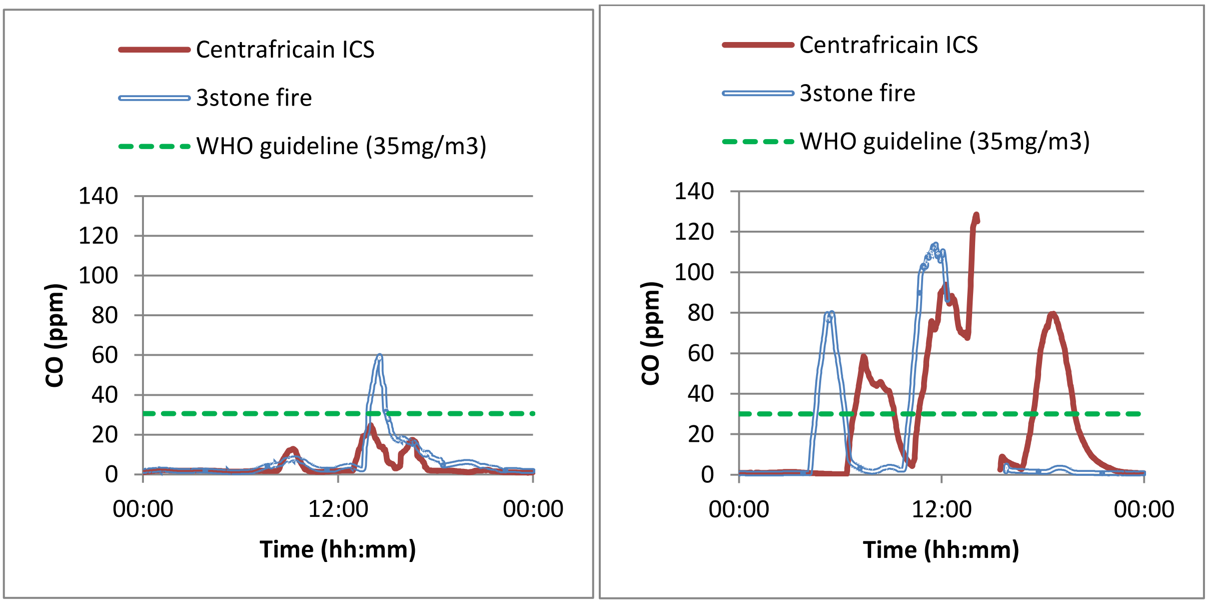



Figure 56: daily trends of CO 1hour mean in two monitored household

The monitoring campaign aimed at defining the environmental conditions of the kitchen where people used to cook. This does not necessarily reflects the impact that IAP has on a person, as it is also directly proportional to the time a person spend in a certain environment. To avoid this bias in determining the impact on the users, a single CO exposure monitoring was performed during a cooking event, in order to assess the personal exposure, i.e. the pollutant concentration at the threshold between human and environment (e.g. breathing zone). The CO monitor was applied on one of the women involved in the previous IAP monitoring phase. The preparation of the meal takes about 3 hours. During such a period CO values, reported in Figure 57, resulted very variable, according to the different activities performed by the woman. The average value during the monitoring period was equal to 52 ppm, while the median value was equal to 36 ppm. These values result within the range of average concentrations registered in kitchen monitoring, confirming the initial assumption.

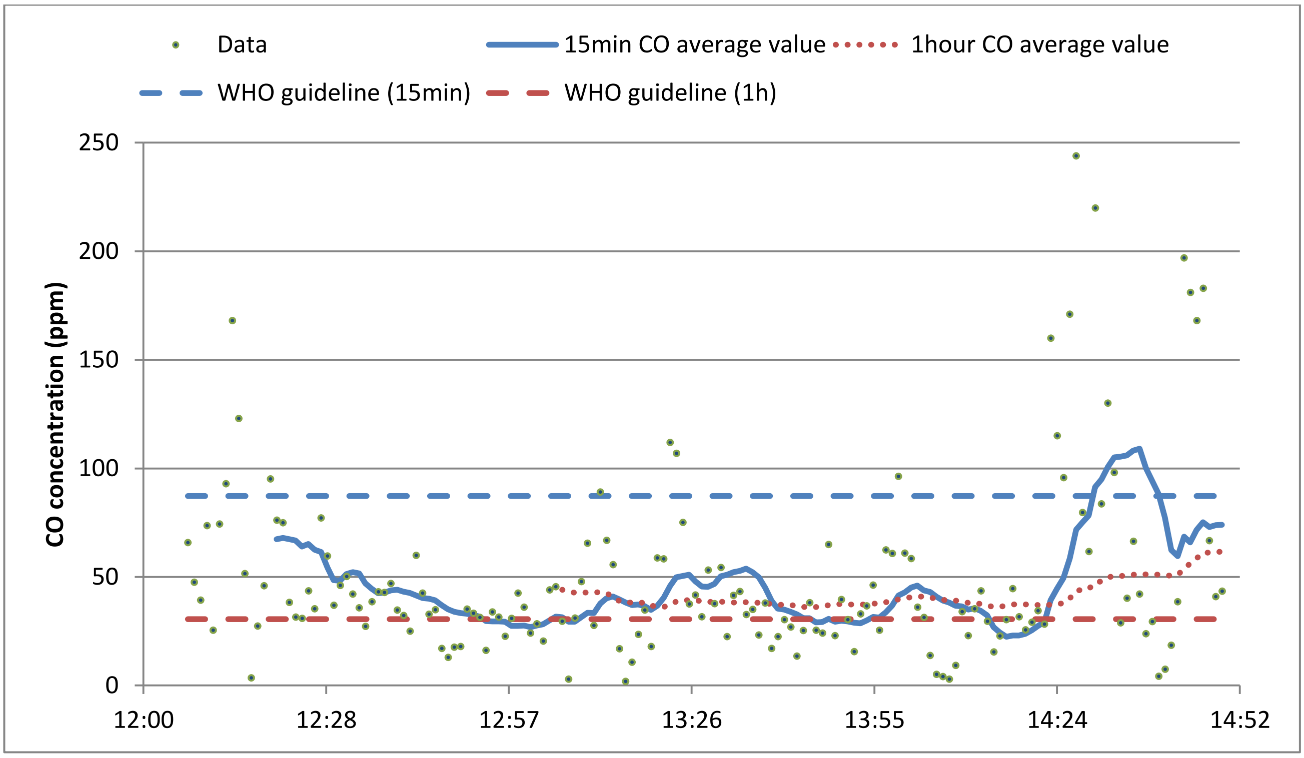



**Figure 57: CO exposure of the cook during a cooking event**

### 5.2.3. Emission reduction estimation

The outputs of the stove testing presented in the previous paragraphs were used also for the calculation of the $CO_2$ emission reduction, according to the methodology explained in the relative section and recognized in the CDM protocols and other certified standards.

#### *5.2.3.1. Determination of the Share of Non-Renewable Biomass*

According to AMS II.G., version 2, Non-Renewable woody Biomass (NRB) is the quantity of woody biomass used in the absence of the project activity ($B_y$) minus the DRB component, so long as at least two of the supporting indicators are shown to exist. The reason for the indicators to hold true are detailed below.

- Referring to the distance travelled for gathering fuel wood, AEDE (2002) estimated that sellers have to transport wood from farther distances due to the depletion of natural resources surrounding the capital city N'Djamena. According to interviews by the author, in the Logone Valley women selling wood stated to spend more time for gathering fuel wood and take longer distances than in the past. Thus there is an increase of distance and time used for fuel wood collection in Chad in comparison to the past.
- According to the Forest Resource Assessment Country Report (2010), carbon stocks in living forest of Chad are depleting since 1990, passing from 722 million tons in that year to 635 in 2010.

- Data collected on site by the author demonstrate the increasing trend in fuel wood prices both at national and local level. According to AEDE (2002) the cost of wood fuel per kilogram was found to be 58 CFA francs in the capital city N'Djamena. After the ban of charcoal in 2009, the actual price for a kilogram of wood fuel in 2011 was 121 CFA francs. This price indicates that the increase of wood fuel price is considerably higher than the actual inflation rate would assume.
- Trends in the type of cooking fuel collected by users do not suggest scarcity of woody biomass, being wood almost the only energy source for households. Thus, this indicator hold neutral.

The FAO Forest Resource Assessment 2010 country report has not designated any forest areas which could be classified as "Forest area under sustainable forest management". The ACRA project has promoted the creation of committee for the sustainable management of local natural resources, but those are not yet recognized at national and international level, and thus, they cannot be considered "demonstrable". It is therefore assumed that the quantity of Demonstrably Renewable Woody Biomass is zero, and the fraction of woody biomass saved by the project activity in year *y* that can be established as non-renewable is the total ($f_{NRBy} = 1$).

#### 5.2.3.2. Potential emission savings per stove

Potential emissions were calculated for the stove model promoted according to parameters presented in Table 21. CCT results were used for the calculation of the wood savings, according to the third approach suggested by the protocol. KPT outputs were considered only for the baseline quantity of fuel consumed per year, as data were available only for one out of the model proposed. Actually a higher estimation of savings would have resulted using the output of KPT also for the Centrafricain ICS, but the first approach was chosen in order to present more comparable estimations.

**Table 21: parameters used for the calculation of emission savings per improved stove**

| Parameter | Unit | Type | Description |
|---|---|---|---|
| $B_{y,\ savings}$ | tons | Calculated | Quantity of woody biomass that is saved |
| $B_{old}$ | tons | Monitored | Quantity of woody biomass that is consumed with a three stone fire in an average 7 member household |
| $SC_{new}$, $SC_{old}$ | g/kg | Monitored | Specific fuel consumption per kg of prepared meal for the three stone fire, considered as baseline system, and for the improved cooking stove models proposed, according to results of Controlled Cooking Tests |
| $f_{NRBy}$ | % | Fixed | Fraction of woody biomass saved by the project activity in year y that can be established as non-renewable biomass |
| $NCV_{biomass}$ | TJ/ton | Fixed | Net calorific value of the non-renewable woody biomass that is substituted |
| $EF_{projected\_fossilfuel}$ | $tCO_2/TJ$ | Fixed | Emission factor for the substitution of non-renewable woody biomass by similar consumers |
| $ER_y$ | $tCO_{2e}$ | Calculated | Emission reductions during the year y |

Table 22 sums up the values used for the calculations. The estimated savings per each Centrafricain ICS and Ceramic ICS are more than 1.0 and 0.7 tons per year respectively. In fact a higher value of 1.5 tons per year could be estimated for the Centrafricain ICS, assuming the outputs of the KPT.

**Table 22: emission savings estimation for the ICS model proposed**

| | | Ceramic ICS | Centrafricain ICS |
|---|---|---|---|
| $B_{y,\ savings}$ | tons/y | 0.59 | 0.87 |
| $SC_{old}$ | g/kg | 434 | 434 |
| $SC_{new}$ | g/kg | 330 | 282 |
| $B_{old}$ | tons/y | 2.45 | 2.45 |
| $f_{NRBy}$ | % | 1 | 1 |
| $NCV_{biomass}$ | TJ/ton | 0.015 | 0.015 |
| $EF_{projected\_fossilfuel}$ | $tCO_2$/TJ | 81.6 | 81.6 |
| $ER_y$ | $tCO_{2eq}$/y | 0.73 | 1.06 |

### 5.2.4. Some further considerations about dissemination

#### *5.2.4.1. Technical skill evaluation*

Artisans' skills were assessed after the trainings in order to evaluate their understanding and the ownership of the technical procedure. The technical evaluation was done using a list to check the single operation described in the manual. Three main phases were considered: folding, assembling and riveting. Each one of this phase was divided in more sub-points for a total maximum score of 10. For each operation the artisan received a point given by the trainer. The average value resulted 6/10 after the first workshop. Many difficulties for trained artisan occurred in the final assembling of the stove, in particular in the respect of details and measures. That was probably due to the low technical equipment and tools available for their activity. Given this constraint and the impossibility to provide them with useful modern tools (for instance electricity is not widely available in all the local workshops), a step-by-step illustrative manual (see Annex 2) was produced in order to guarantee with an easy guide the standardized procedure and measures. Simple tools and screens for the reproduction of the shapes were given as an incentive for the participation to the training workshop. According to visits that followed in the later months, technical skills of the more productive artisan were significantly improved, even if a rigorous ex-post assessment was not done due to the impossibility to re-contact all the trained artisans.

#### *5.2.4.2. Production*

The production trend was assessed during the different phases of the project using structured interviews to record the number of stoves sold by the trained artisans. Only the first tranche of the stoves was partially subsidized by the project (in Figure 58 the first 420 units at a discounted price of 3,000 CFA francs instead of 6,000). The number of stove sold illustrated in Figure 58 refers to the cumulative number given by each interviewed, considering as the starting point the date of the training workshop organized by the project. It was not possible to contact all the artisans trained. Indeed some of them moved to other regions in order to implement the same production in areas where such a stove model was not available in the local market. The number of Centrafricain stoves sold in the following periods by 9 out of the 17 artisans trained area was 2,944, with an average sale rate equal to 113 units per month. Number of stoves sold is not a direct indicator of the continuative adoption by the users of the stove; nevertheless, some indicators prove the success of the introduction of such a technology in the common local practices:

- the growing sale rates without the help of any subside more than doubled according to estimations based on data collected during visits to artisans, passing from 47 units/months in 2009 to 113 in 2011;
- the share of units in stock setting at about 25% of production according to observations during visits to artisans and internal reports;
- the diffusion of the model also in other regions of the country.

Graph in Figure 58 shows also the trend in sale of the Ceramic ICS (see paragraph 7.2.1.1). Actually this activity was strongly subsidized by the project, as 50 stoves were commissioned to 12 out of the 19 women trained to ease the start-up of the activity. According to sale rates observed in following visits, the diffusion of such a model results slower than for the Centrafricain ICS: in particular a significant contribution is given by the incentive of the project, whose share is greatly higher than the share sold autonomously by the women trained. This may due to the simplicity of the Ceramic ICS, not very likely to be proposed for commercialization on a large scale but more appropriate for a self-manufacturing especially in rural areas, where women own the traditional skills in ceramic production.

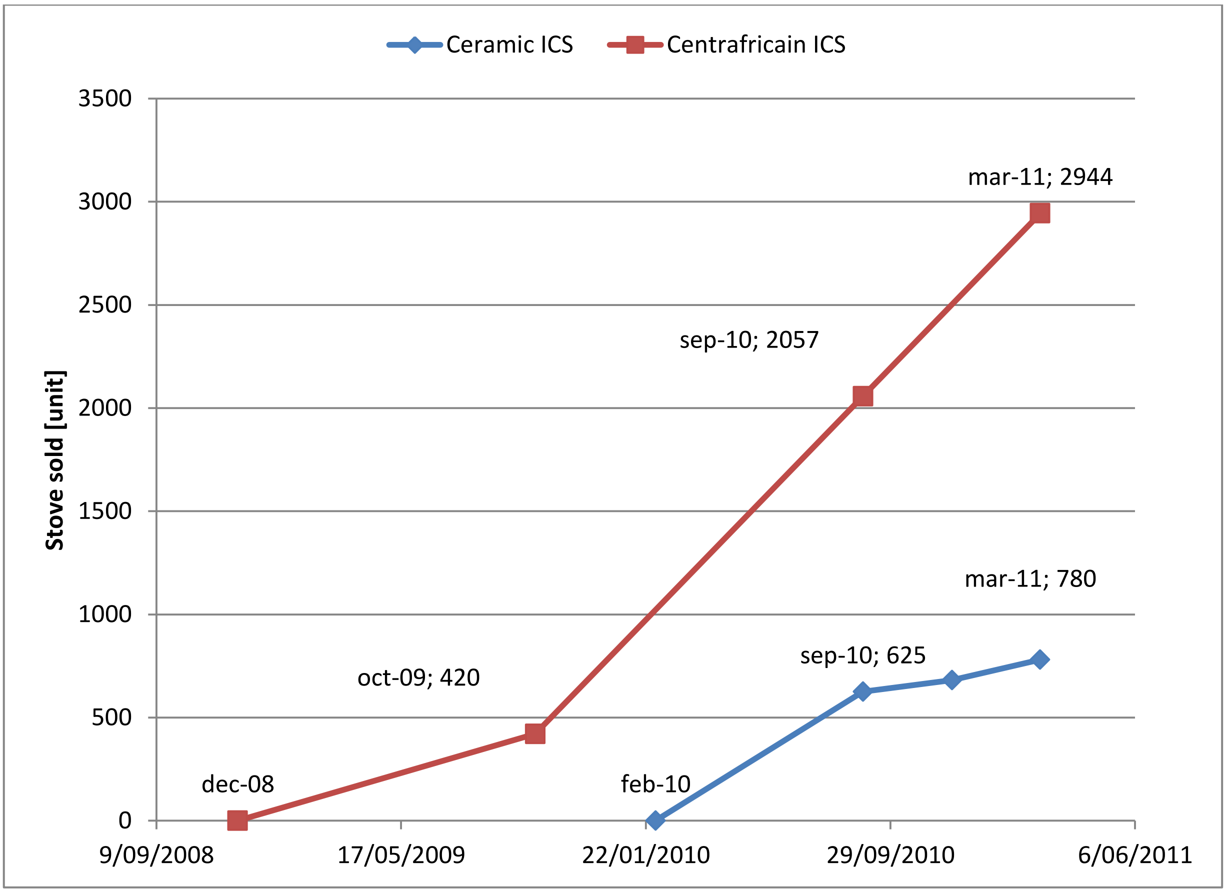



**Figure 58: ICS sale rates during different phase of project**

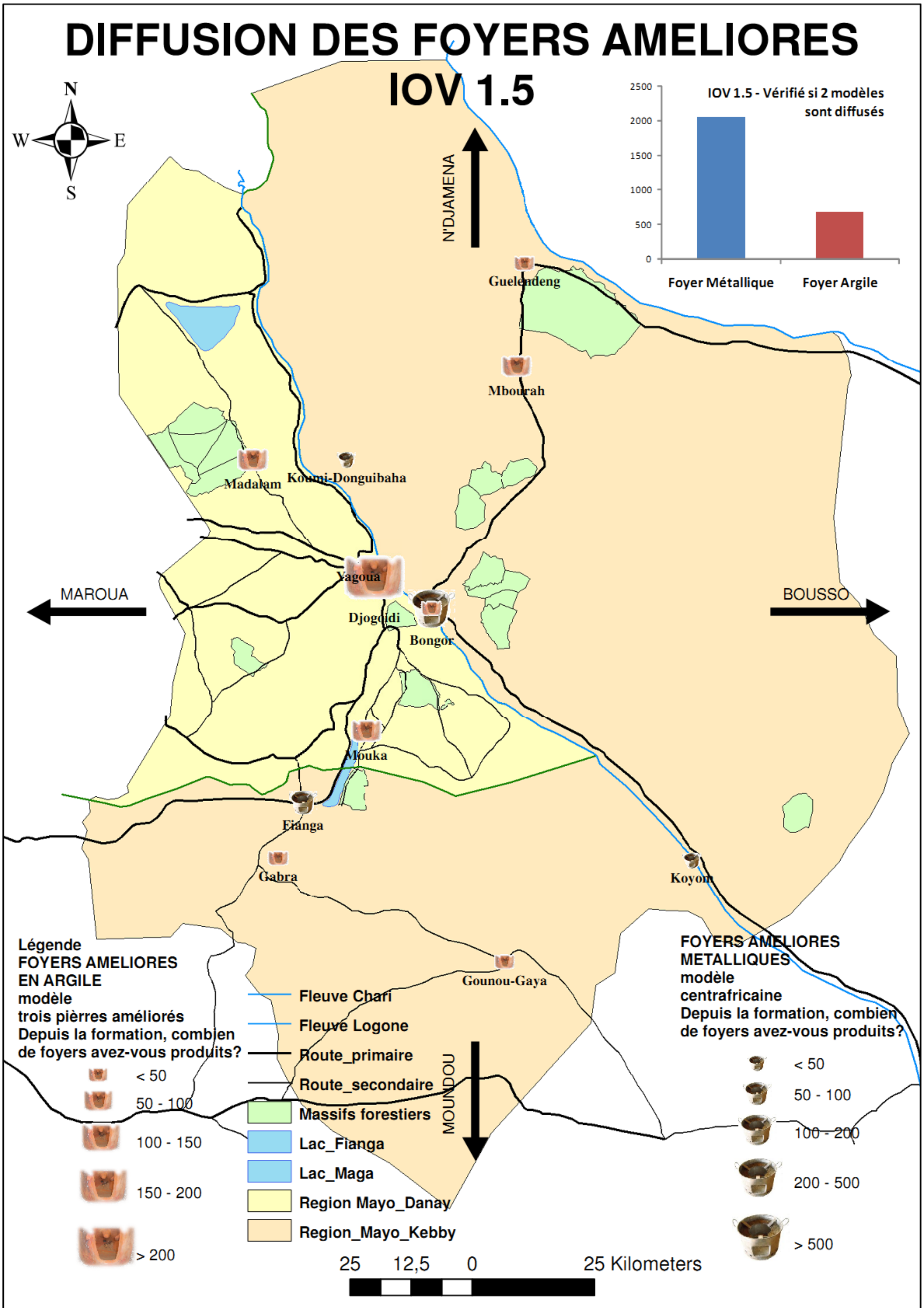



**Figure 59: diffusion of ICS promoted by the project at September 2010 (ACRA's project internal document)**

#### 5.2.4.3. *Adoption and acceptability*

Adoption and acceptability of the Centrafricain ICS was assessed through a total number of 77 semi-structured interviews in the period October-December 2009 to a sample of the early-adopters of the proposed improved stove. This survey allowed understanding some local cooking patterns before and after the adoption of the improved stove and some social characteristics of the interviewed householders. The totality of the people interviewed were women that were in charge of the daily preparation of the meals. The median size of the family was 7 people. The median age of the interviewed was 30 years: this indicates that the adoption of improved cooking system is more likely to happen where the person responsible for the cooking is young and more open to innovative improved system. Regarding the cooking practices before the adoption of the ICS, the 64% of the interviewed used the traditional three stone fire, 30% other traditional systems and 18% LPG[10]. This last output is particularly interesting because shows that some users that early switched to more modern fuels like gas went back to the use of wood pushed by convenience, ease of use, continuity with traditional practices and affordability of such a fuel. Figure 60 shows the change in cooking device used by the interviewed sample. A large share (80%) of the interviewed used the Centrafricain ICS as the only cooking device, while the remaining 20% used it in association with other systems. The share of households still using the 3stone fire, which was the majority before the intervention, reduced drastically, even if 8% of the interviewed declared still to use that rudimental system for certain preparations. The share of household that drop out the use of LPG after the adoption of the Centrafricain ICS indicates the higher convenience of such a simpler technology.

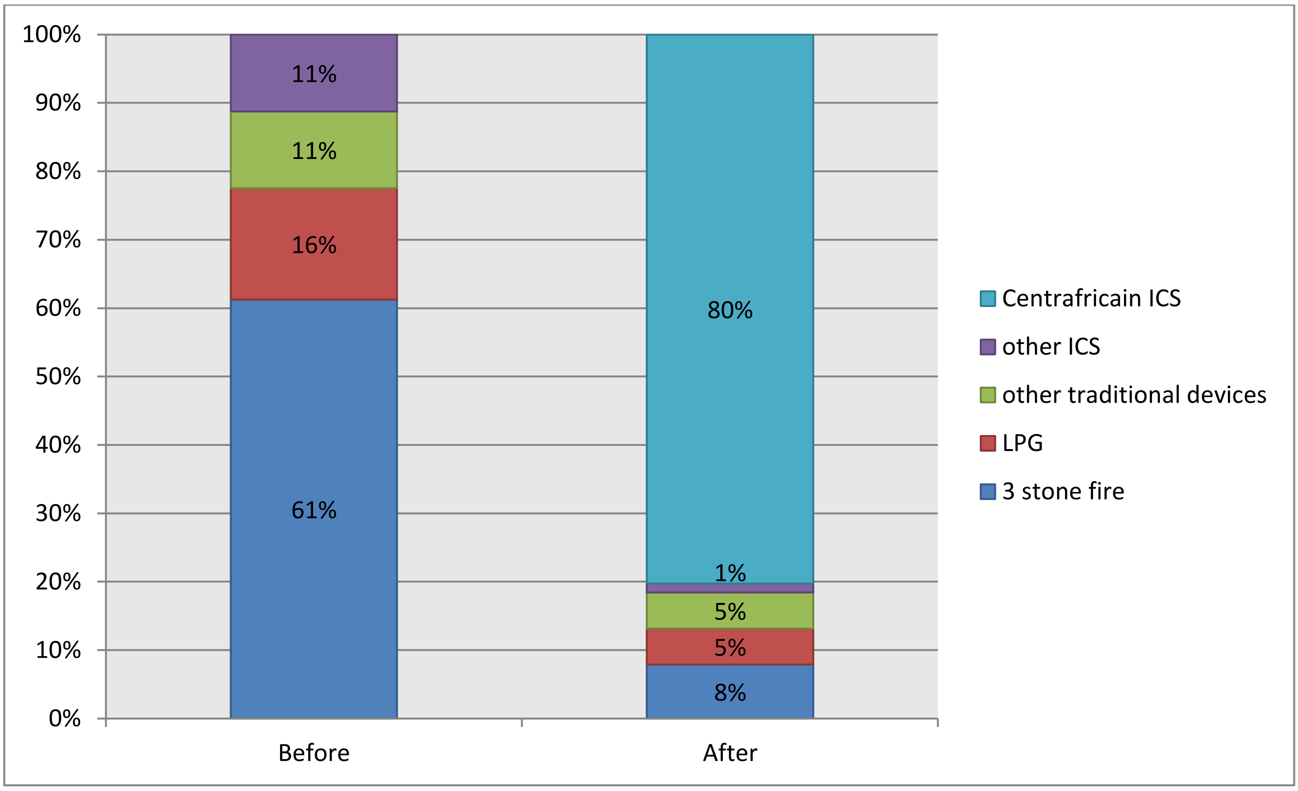



**Figure 60: cooking system used before and after adoption of Centrafricain ICS**

[10] Total sum is more than 100% because 9% of the interviewed used more than one cooking device.

The daily wood consumption per person, estimated according to declared typical fuel expenditure per week by interviewed, distributes in a lognormal way. The median value was 0.7 kg/d per person. A negatively correlation (correlation coefficient = -0.7) was found between wood daily consumption and household size. The fashion is of logarithmic type, as highlighted in Figure 61: that is, increasing the number of family members, the per capita consumption decreases in a less than linear way. Thus, there is a fixed quantity of fuel that is consumed in the activities regardless of the family size. Similarly, a nonlinear relationship between family size and total household consumption was found. In this case the correlation is positive, increasing family, the increase in consumer spending and a non-linear.

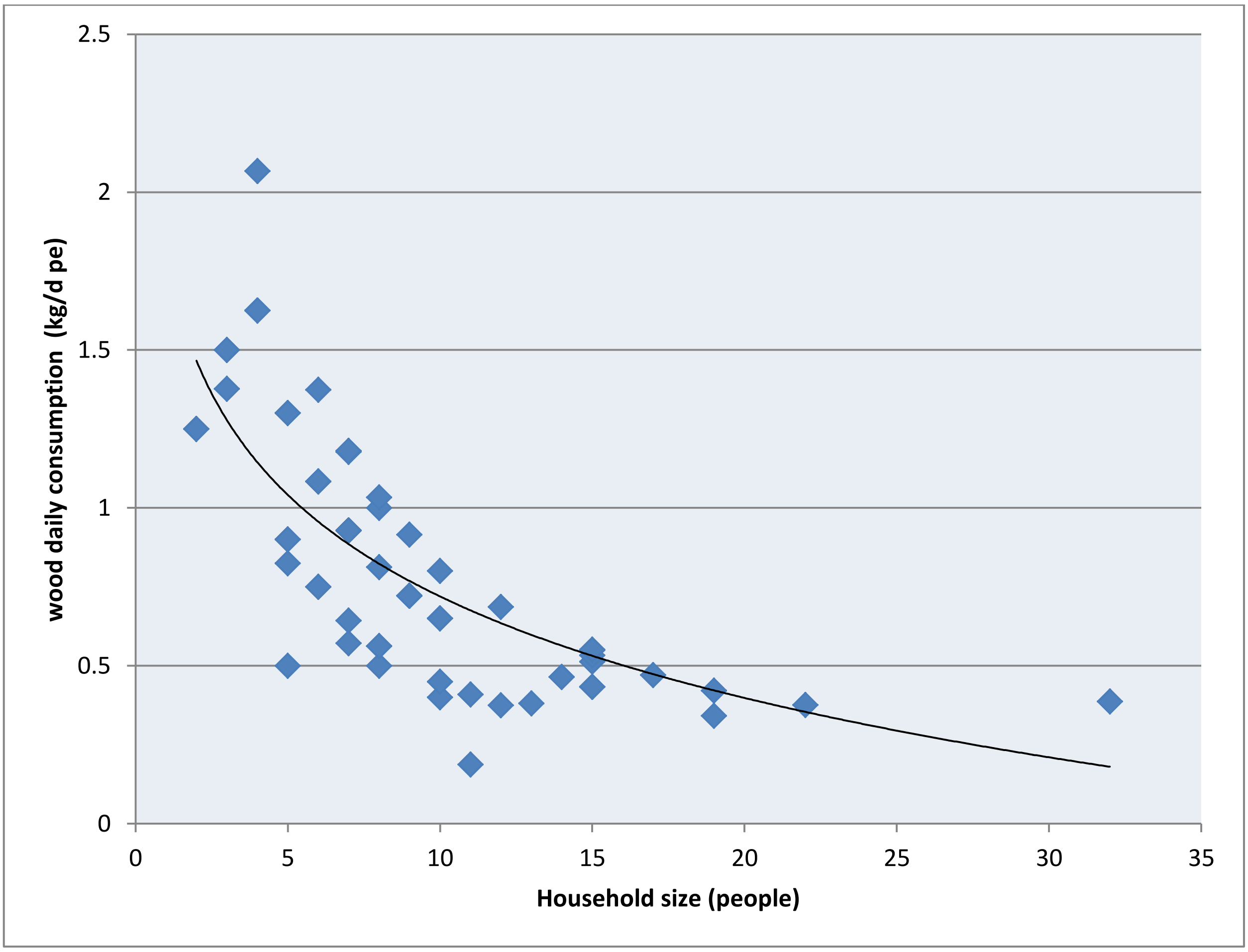



**Figure 61: wood daily consumption per person versus household size**

An open question was finally posed about the advantages perceived in the use of the Centrafricain ICS. No specific aspects were suggested by the interviewer in order to reduce possible influences in the answer. Interviewed people pointed out more than one advantage, as reported in Figure 62. The vast majority indicated the reduced wood consumption and the consequent fuel and money saving as the main advantage. A number of different aspects linked to the adaptability of the stove to local cooking practices was indicated, such as good taste of food, cooking speed, durability and transportability.

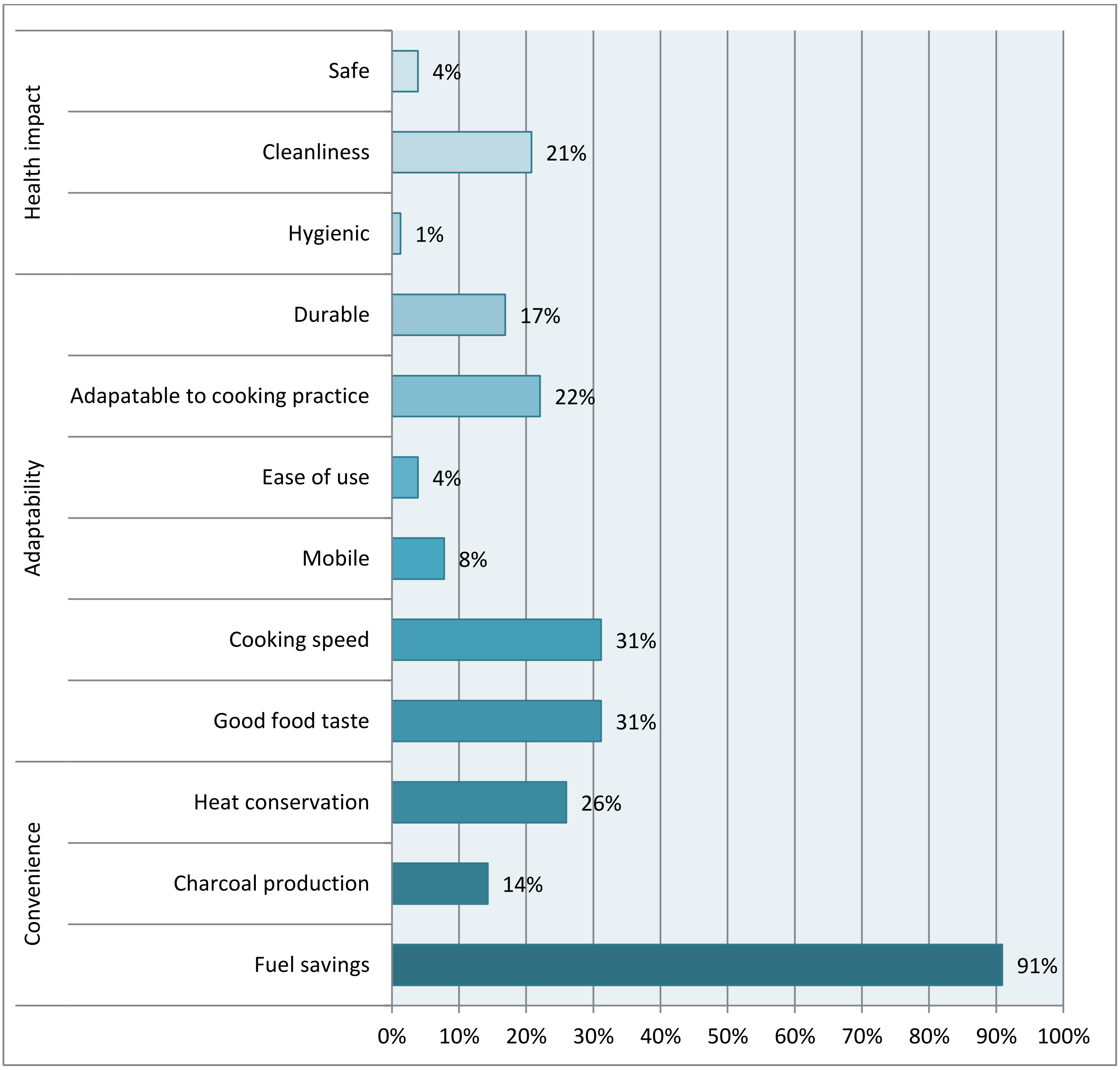



**Figure 62: advantages stated by householders that adopted the Centrafricain ICS**

### 5.2.5. Overall project impact

On the basis of the evaluation of the different impacts, some considerations can be done in order to assess the overall impact of the project. Figure 63 shows the intervention impact on the indirect beneficiaries of the project; those are the households adopting the ICS. Cumulative wood and money savings and emissions avoided due to the adoption of the Centrafricain ICS (according to the number of stoves sold observed on site in different moments of the project) can be appreciated by the differences with the baseline scenario, calculated assuming the use of the traditional three stone fire. The graphs show that the benefits of the intervention will increase significantly after the end of the intervention, according to the continuative adoption of the ICS.

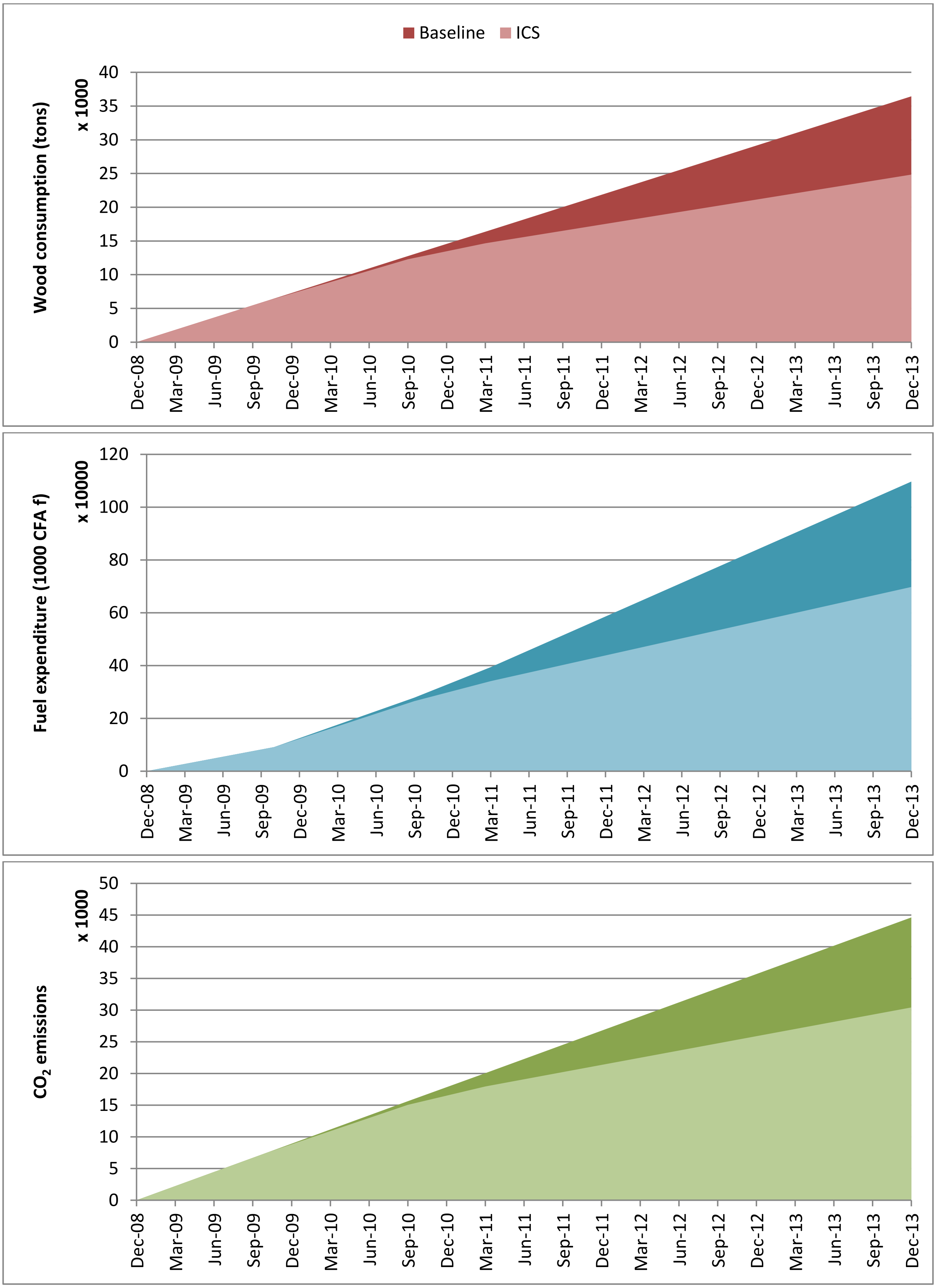



**Figure 63: Centrafricain ICS impact in terms of wood consumption, money spent for fuel expenditure and $CO_2$ emitted**

## 5.3. Conclusions

Material availability on the local market and the ownership of the manufacturing technique of the trained artisans indicates the feasibility, under a technical point of view, of the intervention proposed. The Centrafricain ICS model can be easily reproduced by the local artisans using the available tools and skills, that is really important to allow the reproducibility of the technology locally. Some issues about a more controlled quality of the production have been pointed out. Actually due to the simplicity of the stove, not a very rigorous technical standardization of the ICS is required. Some stove characteristics and measures may be improved in order to achieve even better results in terms of technical performances, even if a cost-benefits analysis of a further improvement of the technology should be done according to outputs of the local context.

Increasing adoption rates and appreciation by the users indicates the appropriateness of the stove model proposed to the local context. Fuel consumption reduction and adaptability to the local cooking practices are the main features that the users indicates as strengthens of the technology. These aspects have been fundamental for the scaling-up of the stove model. Observations on site proof the creation of a self-sustainable market and a continuative adoption by householders in particular in urban areas, where fuel is purchased. In rural areas, a lower adoption rate was observed. That is likely to be due to the fact that wood is collected for free, impacting the household activity in terms of time and not of budget. Therefore fuel saving is not seen as a priority and ICS use advantages perceived by the users reduce sensitively.

Appropriate scaling-up strategy should be planned in strict contact with the local authorities, in order to better address the cooking systems proposed to the householder needs, both in rural and urban areas.

Some scenarios show the benefits that the intervention had on the local context. These elaborations are based only on the number of stoves effectively sold according to observations done on site, thus, recent new ICS adopters are not considered in the calculation of the scenarios. According to the increasing sale rates, it is likely to assume that positive impact from the introduction of the Centrafricain ICS in terms of wood and money savings and emissions avoided could be even higher. Actually, the reduction of the environmental impact, such as the reduction of the indoor air pollution level, are aspects not really close to the sensitiveness of the users, therefore they are not likely to be used as promotion factors in the dissemination. Nevertheless the results obtained prove the appropriateness of the Centrafricain ICS also under this point of view.

# 6. Design and test of a prototype rice-husk stove

Household energy supply is a critical issue in the Valley of river Logone at the border between Chad and Cameroun. Electricity supply is not reliable in urban areas and almost always missing in the rural ones. Modern liquid fuel use is promoted by the national policies but their availability on the local market is scarce and their prices are not affordable for the majority of the population. Most of the people still rely on traditional solid fuels (mainly wood) for daily cooking using rudimental devices like 3-stone fires. That results in a very low efficiency usage of the fuel, huge health impacts for women and children exposed to harmful smokes and burning risks, increasing exploitation stress for the local natural resources threatened by illegal cut and climate change related issues. Rice husk, a waste biomass locally available, can be an alternative fuel to wood for household energy supply. CeTAmb, in collaboration with DIMI and with the support of IPS "Golgi" high-school (Brescia, Italy), is designing and testing a proper stove to recover such a biomass, which is currently seen as a waste by local rice producers.

The crude-earth brick stove is equipped with a chimney and an internal metal-net to keep biomass on the outer part of the combustion chamber. Such a lay-out allows a mix of combustion/gasification of the biomass occurring in a completely burning fire, appropriate for cooking tasks. 'Water Boiling Test' runs have been done to assess the energetic performances of the proposed stove. Efficiency, fuel consumption, ebullition time and combustion rates were calculated on prototypes built both in the laboratory of the University of Brescia and in the field during *ad hoc* missions. According to results obtained *in itinere*, different lay-outs have been designed to improve the efficiency of the stove: changes have been done in the geometric shape, primary and secondary air inlet, diameter of the central aeration channel, length of the chimney and size. Technical and economic issues have been addressed in the development of such a model; building materials have been chosen in order to guarantee a cost as low as possible, using locally available items.

## 6.1. Background

This paragraph will give a brief overview of the main issues related to the use of agricultural residues as household fuel, with particular focus on the gasifier stoves that allow a cleaner and more convenient use of such a resource. A state of the art critical review of existing technologies that use rice husk as fuel is given, in order to provide a comparison with the stove model developed in this research work. The choice of dealing with the design of a new prototype is justified not only by technological factors (such as the research of more efficient technologies) but mainly by local constraints both technical (skills, materials and resources available on site) and socioeconomic (local cooking practices, convenience).

### 6.1.1. Use of agricultural residues as fuels

The list of usable feedstock is nearly endless and depends on what is readily available in a certain location. Agricultural residues are generated in large volumes season by season and often discarded as waste - not put to use at all. Crop residues are the largest source of non-timber biomass fuel: straw, stem, stalk, leaves, husk, shell, peel, lint, stones, pulp, stubble, which come from cereals (rice, wheat, maize or corn, sorghum, barley, millet), cotton, groundnut, jute, legumes (tomato, bean, soy), coffee, cacao, olive, tea, fruits (banana, mango, coco, cashew) and palm oil.

In the developing world, most agricultural residues that are burnt as fuel are used in their natural state with some pre-treatment like drying and cutting. Compared to wood-fuels, crop residues typically have a high content of volatile matter and ash, lower density and lower energy values. Conventional 'stoves' are mostly designed to burn firewood or charcoal. The direct use of unprocessed solid biomass waste for cooking in wood-fuel stoves has some advantages and disadvantages, as shown in Table 23.

**Table 23: advantages and dis- of the use of agricultural residues as household fuel (adapted from Roth 2011)**

| Advantages | Disadvantages |
|---|---|
| • available free of cost to the poor rural families<br>• useful way to dispose of the crop residues in the field, instead of burning them in situ<br>• easy to handle and transport<br>• low impact on women's time for harvesting<br>• clean combustion in gasifier stoves | • air pollution when burned in open fires or traditional improved stoves<br>• the seasonal availability of crop residues can be a limit for its use<br>• shorter burning time<br>• very bulky (concerns in transport and storage) |

A number of technology systems are available for the energy recovery of agriculture residues. Direct combustion is a solution feasible both for unprocessed materials and after briquetting or pelletizing. Biomass gasification is a modern and convenient system which is discussed in the following paragraph.

### 6.1.2. Cooking with biomass gas

A 'biomass gas stove' is the combination of a micro-gasifier heat generator (the combustion unit) and a structure for effective transfer of the generated heat into a cook-pot (e.g. the pot-holder). It is a "gas-burning stove" that makes its own supply of gas from dry solid biomass. Gasifier stoves are currently the cleanest burning option to burn solid biomass in a cook stove. As opposed to conventional stoves, in gasifiers the creation of combustible gases from the biomass takes place in a separate location from the subsequent combustion of the gases. Thus both processes can be optimized to achieve efficient and clean utilization of the fuel.

Gasification advantages have been known for nearly two hundred years. Conventionally gasification is a well-known technology requiring a certain technical level, in particular for power generation from biomass. Several case studies can be found in literature showing the flexibility of this system, in particular for decentralized contexts in developing countries (Ravindranath 1993) and for the use of multi-fuels (Bhoi et al 2005). However, the application of gasification at sufficiently small (micro) scales appropriate for household stoves is not even three decades old.

**Table 24: advantages and dis- of the use of biomass gasifier stove (adapted from energypedia.info)**

| Advantages | Disadvantages |
|---|---|
| • cleaner burning of solid biomass<br>• more efficient use of biomass due to more complete combustion<br>• recovery of a wide variety of small-size biomass residues<br>• performance similar to biogas (but not dependent on water and bio-digester) and approaching the convenience of fossil gases<br>• 'gas' available on demand (unlike electricity or LPG that are dependent on local providers and imports, and unlike solar energy that is dependent on clear weather and daylight hours)<br>• pyrolytic micro-gasifiers can create charcoal which may be used for energy purposes or to improve soil productivity as biochar. The 'biochar' may also be used as soil amendment that can lead to improved water retention capacity and plant nutrient availability in depleted soils. | • small-sized fuel needed. Further efforts for the users for chopping and splitting for the fuel preparation<br>• most micro-gasifiers are batch-loaded and cannot be refuelled during use. Thus cooking times are predefined by the size of the fuel container<br>• not easy regulation of the heat output, unless the stove is operated with a ventilator for forced convection<br>• micro-gasifiers burn the biomass in two stages: first the gas-generator produces the woodgas, which is a thick whitish 'smoke'. The gas-burner is basically a 'smoke-burner'. This is fine, if the gas-burner operates well. Should the flame of the gas-burner go out (e.g. blown out by gusty wind), the gas-generator will still produce woodgas, which will not be burnt and then escape as thick white smoke from the stove |

### 6.1.3. Rice husk cookstoves: state of the art

Common to all fine residues is the need to get the mix of fuel to air correct. Where residues are densely packed, air cannot reach the middle of a heap of residues, smouldering occurs, along with lots of smoke. Ways must be adopted to burn this smoke before it leaves the stove. If residues are too widely dispersed, they are impractical to burn, but another approach allows fuel to trickle down, mixing with the air in the correct proportions. For residues such as rice husk, there is the added problem of low calorific value. This means that each small particle produces a lot of ash for a small amount of heat. The next paragraphs give a quick overview of existing models available for the energy recovery of such a biomass.

#### *6.1.3.1. Forced air gasifiers*

Recently, the gasification has been used to produce a very clean burning stove that uses rice husks. The more know and successful model have been developed by the research team of Dr. Alex Belonio. This is an advanced technology, as it requires a small amount of electrical power to drive a fan, so can only be used where people are able to afford the stove and where there is backup available for servicing. In the reactor, rice husks are burned with limited amount of air. This produces a gas, which is burned on the top of the stove where it behaves similarly to bottled gas and burns with a clean blue flame. At the lower end of the reactor is a fuel grate made of stainless steel, which holds the rice husks during gasification. This grate can be tipped easily to discharge char after each operation. During burning, the grate is locked into its working position. Around the reactor there is an aluminium screen to prevent accidental contact with the hot reactor during cooking (Belonio 2005). This stove technology was recently developed for operation on a continuous mode. This model has a feeding hopper and a discharge mechanism in one reactor to allow continuous feeding of rice husks and discharging of char during operation. The gas generated during the process is diverted through a duct to the other cylinder with the gas burner mounted on it. After cooking, the char is collected using a pan for proper disposal. The proto-type model of the stove has a reactor diameter of 12 cm and a height of 30 cm. A 3-watt, 12-volt DC fan supplies the air needed in gasifying rice husks. The average amount of rice husks consumed per hour of operating the stove is 1.1 kilogram with a computed thermal output of 1.19 kW. Two litres of water can be boiled using the stove within 14 minutes with a thermal efficiency of about 21%. The temperature measured beneath the pot during boiling test varies from 250 to 400°C. The expected black carbon emission is no more than 100 $\mu g/m^3$ of gas, which is almost the same with that of the batch-type rice husk gas stove. A unit of this stove costs P 2,000-2,500 (46-57 US$) depending on the kind of materials and the method of manufacturing used. This selling price is similar to the commercial units of the batch-type rice husk gas stove being produced (P 5,000 that is 113 US$). Investment can be recovered within 3 to 4 months as compared to LPG stoves (Belonio et al 2011). Figure 64 illustrates the parts of the two air forced stove models.

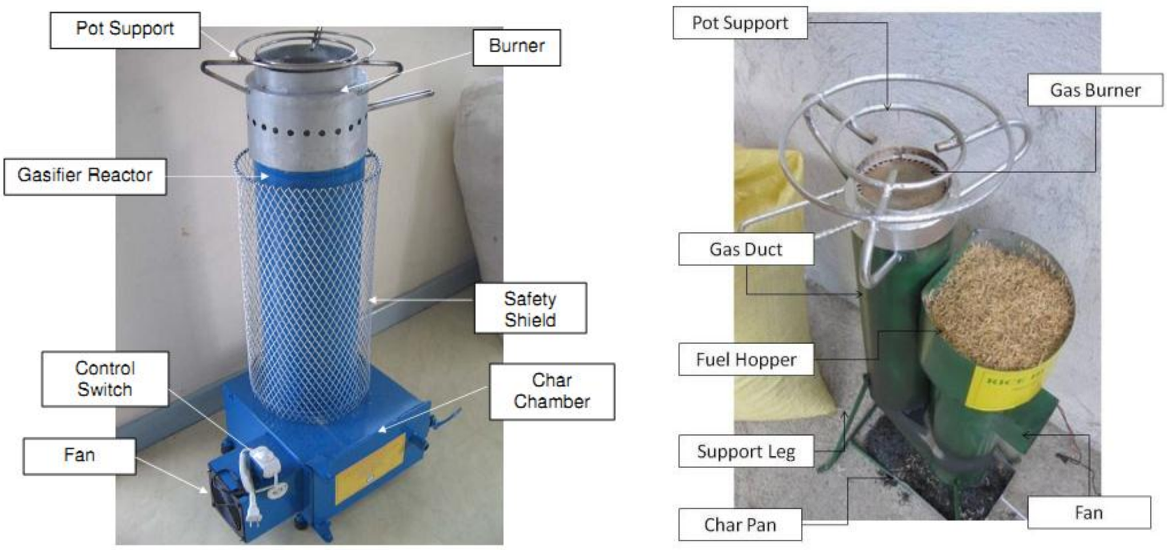



**Figure 64: parts of the batch gas stove (2005) and of the continuos flow gas stove (2011) developed by Belonio et al .**

### *6.1.3.2. Natural draft stoves*

One way to burn fine residues is to have the residues running through a funnel shape that provides a slow steady flow. With rice husk a good example is the Lo-Trau stove (also called Ipa-Qalan stove, Figure 65). It is made of sheet metal and is lightweight (2.5kg). Husk is poured between the main drum and the inner drum. The husk is ignited and burning can be regulated by the user. The combustion process can be quenched at any time by removing the inner drum.

Inspired by the Mayon volcano, the MTS stove has a 'perfect' cone design that allows the clean, efficient and convenient combustion of crop residues produced by milling the world's most important food crop. Over the past few years, 5,000 rice hull stoves have been distributed in Philippines by REAP-Canada and their local partners. REAP is now stepping up efforts to introduce this simple technology internationally.

A number of features of the stove are listed on the website of the REAP. High efficiency and clean combustion is guaranteed by swirling blue flames created from the twin primary air injectors and the extended inner cone with secondary air holes. Convenience to use, fast boiling, low cost and fuel consumption, transportability, safety and flexibility to a variety of biofuels are among the several strengths of this technology. Some concerns of this technology may be found in the continuous attention the user has to give during the operation, indeed it requires tapping every few minutes, in the stability of the structure during the meal preparation and in the control of emissions during transitory phases (ignition and extinguishment) or in case of malfunctioning.

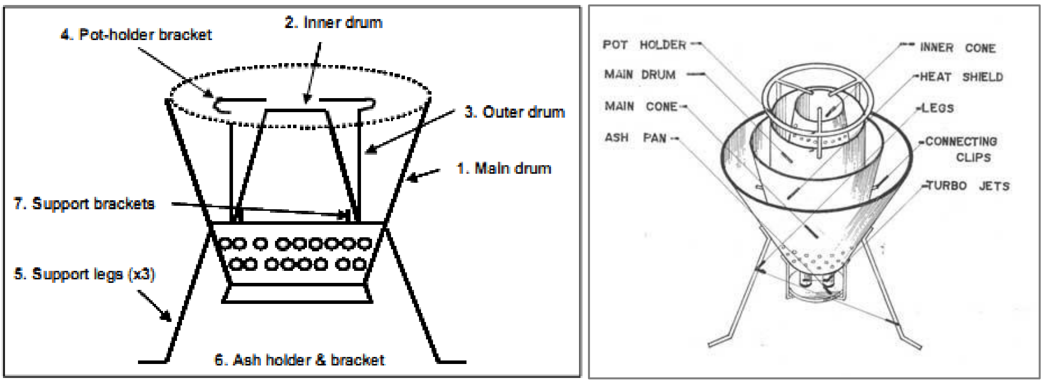



**Figure 65: Lo-Trau stove and Mayon Turbo stove**

At the Ethos conference in January 2011 a natural draft batch gasification was presented by the Georgia Tech (Paré 2011). In this model a chimney provides the necessary draft. A batch fed reactor is placed in a wooden frame under the cook top, clearly dividing the gasification zone from the heat transfer zone. Few materials are needed for this technology, resulting in a low capital cost (20 US$). Some concerns were identified by the developers of this model in the degradation of the inner metal components exposed to high temperatures. Figure 66 shows the main components and the functioning of the Georgia Tech stove.

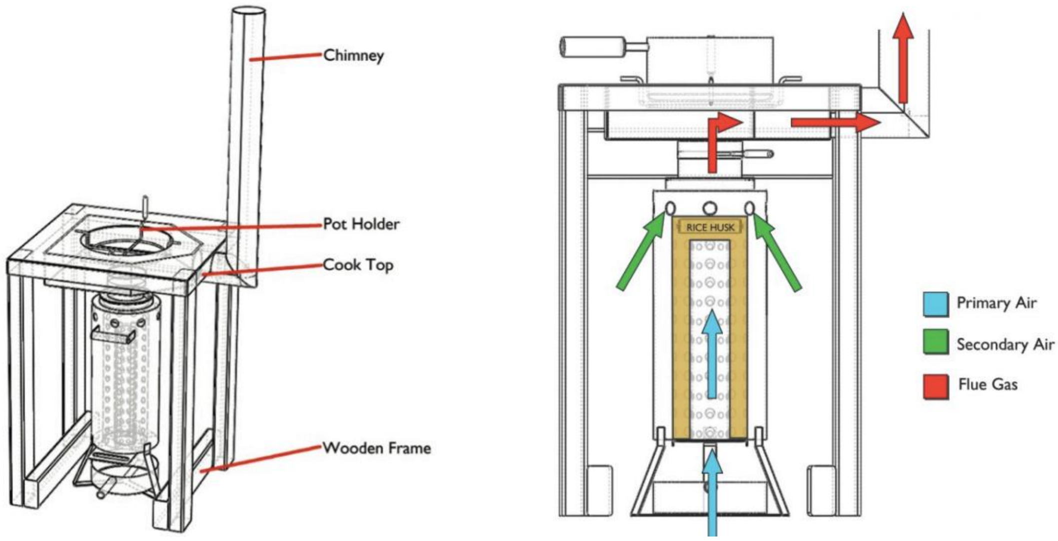



**Figure 66: Georgia Tech natural draft batch gasifier (adapted from Paré 2011)**

The presented state of the art about rice husk burners for household cooking shows that there is only some scientific studies and few published researches on this topic. A clean and reliable gasification of rice husk can be achieved using air forced technologies. Such a solution results very appropriate in contexts like the developing Asia, where the need for alternative fuels meets a technological level that allows a proficient and convenient exploitation of rice husk.  On the other side, in contexts such as the sub-Saharan Africa there are many constraints to the introduction of the same technologies. The lack of commercial, infrastructural and technical background, together with the low investment capacity of the population, limit the adoption of electricity supplied technologies. More simple systems, such as the natural draft stoves, appear more appropriate. In particular, as shown in Figure 67, unit costs per power output for existing rice husk stoves are generally lower for natural draft systems. At the same time, having such stoves lower technological levels, they do not always guarantee an appropriate and reliable operation. Continuous quasi-gasification stoves, such as the Turbo-Mayo, may incur in the emissions of products of incomplete combustion in case of malfunctioning, require frequent tapping by the user during the use and are likely not to be enough stable during the “vigorous” preparation of African meals. Natural draft batch gasifiers give a partial solution to these concerns, having a more solid structure, a stable (even if limited by initial fuel charged) functioning and being equipped with a chimney for smoke withdrawal. At the same time their disadvantages are the limited operation time (dependent of the initial batch), the need for period maintenance of chimneys, the difficult air regulation. The model presented in this work is a natural draft quasi-gasifier designed in its first version in 2008 by researchers of the University of Brescia and developed in the following years within the activities of this project. Georgia Tech is the most similar existing prototype model even if the evolution of this stove followed an independent design pathway.

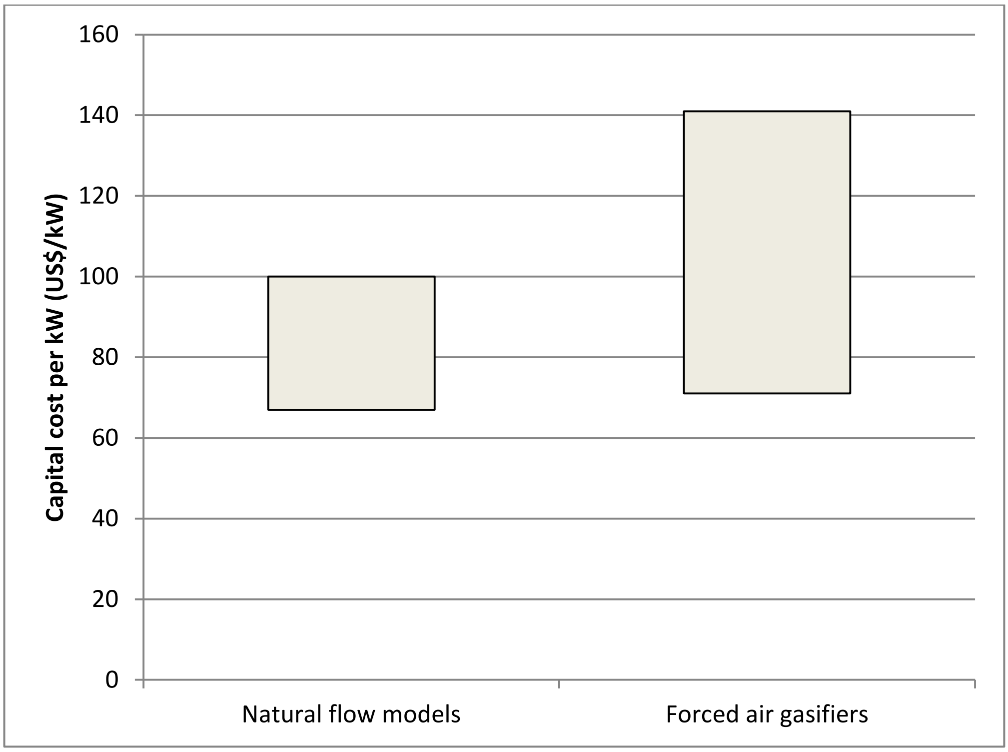



**Figure 67: capital cost per power output for existing rice husk stove models**

### 6.1.4. Justification for the choice

In the local context agricultural residues, mainly rice husk, are often burned in open-air by the farmers to clear the lands or just to dispose them. This is a common practice that generates uncontrolled dangerous emissions, while wasting a potential energy resource. A number of studies assessed the environmental impact in terms of Green House Gas (GHG) emissions related to the common practice of open burning of rice husk heaps or fields (Bhattacharya et al 2000). Pathak and Wassman (2007) indicate the burning of rice straw as the second major source of GHG contributing 13% of the average GWP (Global Warming Potential) emissions with the current farmers' practice in various districts in India. In particular $CH_4$ and $NO_2$ emissions from open burning contribute largely to the current GHG emissions (Thao et al 2011). Therefore, ceasing open burning alone has a large GHG mitigation potential. Indeed according to the potential amounts of residues that can be made available for energy purposes and the resulting fossil-fuel or non-renewable biomass replacement from utilization of these residues, greenhouse-gas emission mitigation can be estimated according to a number of published methodologies (Bhattacharya et al 1999).

The choice of the design of a new prototype is justified not only by environmental and technological factors (such as the research of more efficient technologies) but mainly by local constraints both technical (skills, materials and resources available on site) and socioeconomic (local cooking practices, convenience). The dissemination of low-technology but high-efficiency models was implemented according to the socio-economic conditions of the local people (minimal investment capacity due to very low level of income) and of the skills and the tools available for local small workshop (in particular the lack of electricity on the Chadian side shows up in very basic manufacturing capabilities). Moreover the experimentation of new stove models were studied in order to provide the local population with alternative fuel stove to partially cover their daily energy needs.

## 6.2. Materials and methods

### 6.2.1. The stove

#### *6.2.1.1. General concepts*

The task of burning rice husk for cooking purposes is not so simple with the constraints of this context. Heat generation from rice husk cannot be achieved efficiently with a simple 'direct' combustion. Proper gasification, with the aid of forced air, would be the best technical way, but this work has focused on an intermediate solution, where rice husk in part burns 'directly' and in part is gasified to burn just above, where secondary air enters the combustion chamber. A small starting fire (using a little amount of wood or charcoal) is placed in the centre of the combustion chamber and this allows the process to start.

No available or reliable electricity prevents the possibility to use fans or blowers, while some draft is fundamental for operation. This natural draft is provided by pressure gradient given by the height of the chimney if the pot is sealed in its proper position. In the meantime the chimney withdraws the smoke from the cooking position. This is a benefit for the user's health, but the chimney must be installed properly, to prevent accidents, and users must be trained for a proper cleaning and maintenance, which often is not already embedded in local knowledge and habits. The choice of using unprocessed rice husk derives mainly from the difficulties encountered trying to briquet it, but assessing a technique to use unprocessed rice husk can bring along a great practical advantage. The choice of using crude-earth bricks, besides for their local availability, provides different heat losses in comparison to a metal structure, much more heat is accumulated in the structure, but it is radiated much more slowly. This choice highly limits the portability of the stove. Inside the combustion chamber a metal-net structure allows the air to flow through the rice husk and various geometries and dimensions for this structure and the secondary air inlet have been tested. This solution is batch fed and is intended to run for 70-80 minutes without any further operation, besides an eventual air regulation. The first half of the run is a high power phase, while the second half is suitable for simmering. This makes this solution appropriate for boiling but much less for frying.

Two stove sizes[11] and many internal configurations (for the rice husk and the air flows) have been examined and tested, while few characteristics were kept as a base line: the external structure is made of crude-earth bricks, the internal geometry is manufactured with some metal-net and there must be a chimney. This should allow the technology to be locally reproducible and as cheap as possible, even if this comes along with intrinsic efficiency limitations.

##### *6.2.1.2. Prototype evolution*

The first prototypes have a square-base and hold 6-8 kg of rice husk. Given the overall dimensions are less than 1 $m^3$ plus the 2 m chimney, in the following chapter this model is identified as the large one and it was called *mcc* (*My Chubby Cookstove*). A large central metal-net keeps the rice husk on the external part of the combustion chamber, while the primary air enters from a horizontal duct placed at the bottom of the combustion chamber. The secondary air duct is placed horizontally just below the pot. The top of the stove is made of a metal plate, that could be suitable to cook meat, but is not so appropriate for boiling.

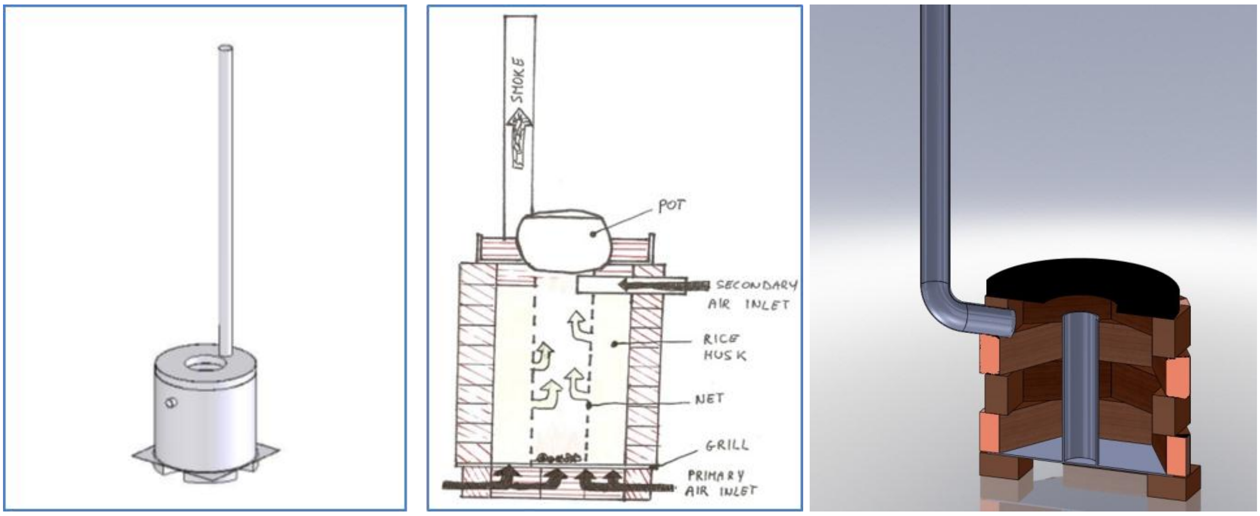



**Figure 68: axonometric view, conceptual scheme and 3D section of the proposed rice husk stove**

This solution has then changed, keeping the same overall dimensions. A metal-net has been placed on the bottom of the new round-based structure, eliminating the horizontal primary air duct. The metal plate top has then been changed with a crude earth solution, embedded in a barrel-top structure. This allows a better insulation and provides some wind protection for the pot. The secondary air is still brought from a

[11] The large one was nicknamed *my chubby cookstove* (mcc), the small one was called *my little cookstove* (mcc)

horizontal duct just below the pot, but many tests were performed regulating the secondary air flow and preheating it. This showed that, besides the draft, this was the crucial point.

#### *6.2.1.3. Final design: the "mlc" rice husk stove*

Another set of much smaller prototypes was then developed. Keeping the scheme, shape and proportions of the larger one, the 'single household' size holds 1-1.5 kg of rice husk. This smaller solution does not require a top and the wind protection can be very high, dipping almost the whole pot in the stove. Lower ducts for primary air were added, keeping also the bottom net. This showed that more air entering laterally, besides the one drafted through the bottom net, greatly helps the combustion. This insight has led to the actual solution, with a metal-net basket placed in the centre of the combustion chamber. The rice husk is kept in an annular position by the net, while air can flow freely through the central channel or in the most external annular section. Part of this air serves as primary air; part can reach the upper part of the combustion chamber as secondary air, which is hence preheated.

### 6.2.2. Testing protocol

The methodology of the Research & Development (R&D) of a new stove model was structured according to four main objectives, which can be set in a hierarchically order.

- A reliable operational functioning: working with a fuel like rice husk, which is difficult to burn especially in a natural draft system, the stove functioning had to be monitored continuously. Temperature of the flame, of the outlet flue and in different points of the fuel batch, CO and $O_2$ levels in the outlet flue where controlled in order to understand the operation of the stove and the special sequence of gasification/combustion processes inside the combustion chamber.
- A good efficiency in fulfilling a determined task: the Water Boiling Test (WBT) was chosen as the most appropriate protocol to consider as reference in this R&D phase. This laboratory-based test is designed to explore the most basic aspects of stove performance in a controlled environment. Some modifications had to be done to the procedure in order to fit the requirements of the batch system to be tested.
- A neutral contribution to IAP: the prototype was equipped with a chimney in order to provide the natural draft required for the operation of the quasi-gasification processes inside stove and also to withdraw the smoke from the cooking environment. Levels of IAP were verified according to monitoring protocols suggested in literature (see paragraph 5.1.3).
- A safe use: safety of the prototype was assessed through an international procedures (Johnson et al 2005) recently adopted as official by the international stove research community (Lima consensus 2011)

Once a reliable operation was achieved working on different system lay-outs, the functioning was optimized in order to increase the thermal efficiency. IAP levels were monitored in some of the last tests.

The equipment used in the prototypes testing is listed in Table 25 according to its specific task.

**Table 25: equipment used for the stove testing**

| Task | Parameters | Description | Equipment |
|---|---|---|---|
| Continuous operational monitoring | Temperature , pollutants concentrations in flue | Continuous logging of temperature (flame, batched fuel, flue) and flue emissions ($CO$, $O_2$, $NO_X$, $SO_2$) | • K-type thermocouples<br>• BST100 combustion analyser<br>• Testo 350MXL gas analyser<br>• DAQ module |
| WBT | Time, fuel weight, water temperature | Pre and post measurement of metrics required for the calculation of the WBT outputs | • Typical equipment of a WBT (see paragraph 4.2.2.1) |
| IAP assessment | CO and $PM_{2.5}$ indoor concentrations | Continuous logging of IAP in a closed room at a standard distance from the stove (see paragraph 0) | • CO Gasman monitor<br>• UCB monitor |
| Safety | Superficial temperatures, geometric features | Summarized safety evaluation procedures according to Johnson (2006) | • Thermo camera |

#### *6.2.2.1. Modified WBT testing protocol*

Performances of stoves vary greatly according to different operational conditions. Stove Performance Tests (SPTs) were conducted according to procedures recommended in both the VITA International Testing Standards (VITA 1987) and the revised University of California at Berkeley standard testing protocol series (2003). The Water Boiling Test (WBT) evaluates stove performance while completing a standard task (boiling and simmering water) in a controlled environment to investigate the heat transfer and combustion efficiency of the stove.

Three steps compose a full WBT:

i. in the cold-start high-power test, the tester begins with the stove at room temperature and uses a pre-weighed bundle of wood or other fuel to boil a measured quantity of water (5 litres) in a standard pot. The tester then replaces the boiled water with a fresh pot of cold water to perform the second phase of the test;
ii. the hot-start high-power test follows immediately after the first test while stove is still hot. Again, the tester uses 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;
iii. the third phase follows immediately from the second. Here, the tester determines the amount of fuel required to simmer a measured amount of water at just below boiling for 45 minutes.

Water and fuel left, temperature of water and time are recorded at the beginning and at the end of each phase.

Being a batch fed solution the designed stove cannot be tested properly according to the original protocol. Indeed we adapted the testing procedures in order to meet the characteristics of the designed solution and to assess properly the operating parameters, without veering off the original protocol's guidelines. In particular the calculated outputs were kept as close as possible to the original ones. The modified testing protocol consists in a single phase procedure: the fuel load is batch fed at the beginning. Time is counted when the pot is posed on fire. The test ends when all the fuel is consumed. The ebullition time refers to the moment when water temperature reaches the maximum temperature. All other outputs are calculated on the total testing time.

## 6.3. Results

Laboratory tests have been carried out in Brescia in open field to assess the efficiencies of the various solutions. The very first prototype was built with fired bricks and had efficiencies far below 5%. A significant first improvement was achieved introducing some modification. In particular:

- square base was substituted by a round base to allow a more uniform distribution of temperature inside the combustion chamber;
- primary air inlet was changed switching from a horizontal duct linked with the central vertical duct, to a metal-net on the bottom of the combustion chamber. That allowed air to flow also through the fuel, supplying the required air according to a more uniform distribution;
- a secondary air duct was added at the top of the combustion chamber in order to supply the air required for burning the gas produced by the quasi-gasification of the rice husk;
- the top metal-plate was substituted with a upper cover realized using the bottom of a drum and filled with the same material used to manufacture the crude-earth bricks. That reduced the heat losses through the metal layer and the escape of smoke from the spaces created by its thermal deformation.

### 6.3.1. Large stove test results

Initially, comparative efficiency tests were carried out on the larger model, to evaluate different sizes for primary and secondary air inlet, giving some insight on the required proportions between the two air flow rates. Tested primary air diameters are: 7.5 cm, 10 cm and 13 cm. Secondary air diameters are: 4.2 cm and 3.3 cm. A first testing campaign (18 tests) was performed in winter season and repeated in summer (6 tests). Indeed first results were not very encouraging being similar to the ones obtained with the very first prototype. It was though that ambient temperature acted as determinant factor in the first test session, thus, a summer testing campaign was scheduled. These tests showed an overall better operation of the stove. Easier ignition, more reliable and constant functioning, lower smoke emissions, faster ebullition times were generally observed. That could be explained by the initial temperatures closer to the working temperature of the stove. In fact any great improvement in the thermal efficiency was observed.

Table 26 sums up the average values for thermal efficiency of both the preliminary testing campaigns; single test results are tabled in the Annexes 3. A similar testing campaign was performed also during a mission in Chad.

**Table 26: Average thermal efficiency in different combinations of primary $\Phi_p$ and secondary $\Phi_s$ air ducts (in brackets the number of tests performed) reported during the preliminary testing campaigns**

| | | Diameter of primary air duct $\Phi_p$ | | | |
|---|---|---|---|---|---|
| | | *5.0 cm* | *7.5 cm* | *10.0 cm* | *13.0 cm* |
| | | *Winter session* | | | |
| **Diameter of secondary air duct $\Phi_s$** | *4.2 cm* | NA | 5.0% (3) | 6.3% (3) | 5.3% (3) |
| | *3.3 cm* | NA | 4.4% (3) | 5.1% (5) | 4.8% (3) |
| | | *Summer session* | | | |
| | *4.2 cm* | NA | 5.9% (2) | 5.2% (2) | NA |
| | *3.3 cm* | NA | 6.0% (2) | 3.8% (1+2*) | NA |
| | | *On site session* | | | |
| | *2.8 cm*[+] | 5.8% (3) | 4.9% (1) | NA | NA |

*2 tests out of 3 did not provided with data, due to malfunctioning; [+] tests performed on site (Chad)

Some influence between the ambient temperature, and thus the one of inlet air and the flow of primary air needed may be found comparing the results obtained. Indeed, the higher the ambient temperature the smaller the diameter of the primary air duct. Actually, given the not very consistent trend and the little differences observed, some significant structural modifications were introduced to the model configuration.

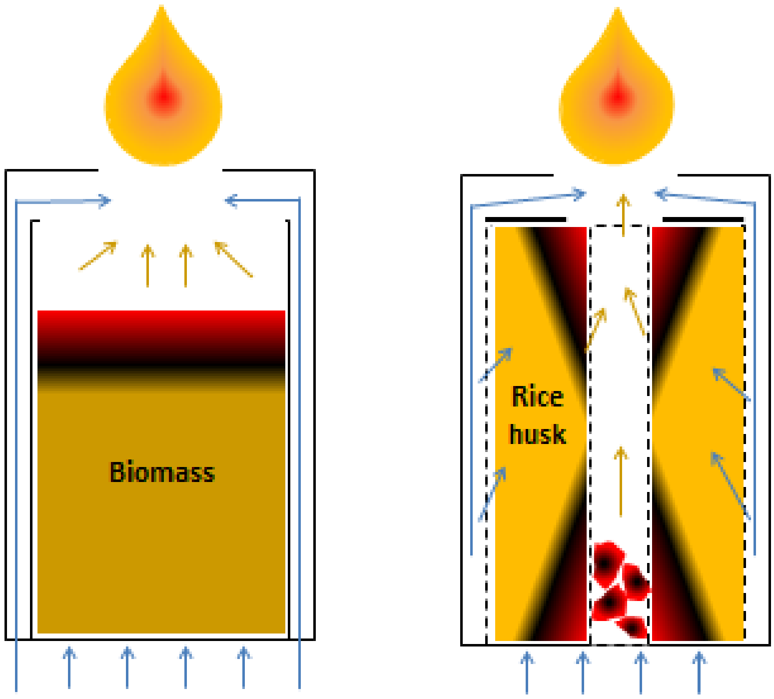



**Figure 69: conceptual scheme of the reactor of a natural draft TLUD gasifier (adapted from Anderson 2011) and of the "my little cookstove *mlc*" rice husk proposed**

Some inspiration was taken from the conceptual operation of TLUD micro-gasifiers, as presented in Figure 69 . The introduction of a fuel reactor made with metal net allows creating a gap with the internal walls of the combustion chamber. So, it results in a secondary air channel from the bottom, as in TLUD micro-gasifiers. That result in a more uniform distribution of secondary air at the top of the fuel reactor, where the combustion processes are wanted to happen. Secondary air is no more fed from the relative duct, resulting furthermore in a material cost saving. Moreover the metal-net let some air flowing also from the lateral surfaces of the fuel reactor, providing a more punctual distribution of air required for the gasification process into the fuel. A further advantage of the introduction of the fuel reactor is the easier fuel charge and ashes discharge. Such an operation was quite laborious in the previous configuration of the stove.  The fuel reactor (Figure 70) is a metal-net cylinder, 0.5 m high, with a 0.4 m diameter. Initial fuel charge is some 3 kg of not compacted rice husk.

**Figure 70: charged fuel reactor inside the combustion chamber and exhausted ashes after combustion**

An intensive monitoring of temperatures inside the combustion chamber was done during each test; typical run of temperatures on different points of the combustion chamber during the operation of a water boiling test is presented in Figure 71. In addition to a thermocouple logging the temperature of flame, six other probes were installed at three different heights (respectively 10, 20 and 30 cm from the bottom of the fuel reactor) and at two different distances from the centre (respectively 4 and 8 cm). Some patterns can be identified as typical in the run of temperatures inside the combustion chamber according to measurements done in several tests. Initially the temperatures increases in the bottom zone of the fuel reactor, where rice husk is heated by the pilot flame produced with a little amount of charcoal. In these zones very high temperatures (up to 1,000 – 1,100 $^oC$) are reached. In a second moment the temperature at the top of the fuel reactor increases, probably due to the heat irradiation from the combustion area where the flame is produced by the mixing of the burnable gas produced and the secondary air. Finally also the middle part of the fuel reactor is involved in the heating, reaching the temperatures required for the gasification processes (500-600$^oC$).

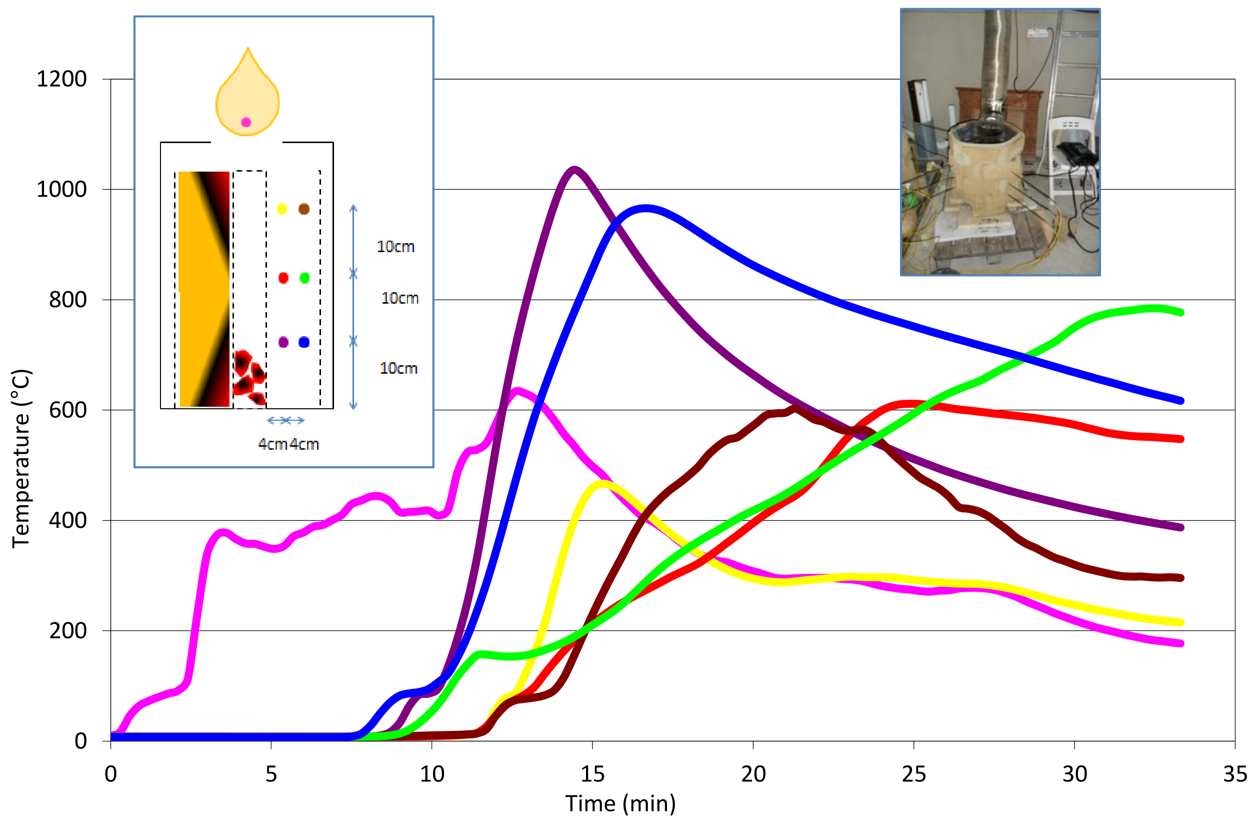



**Figure 71: typical run of temperatures on different points of the combustion chamber during a test**

The gasification processes that are likely to happen inside the combustion chamber are strongly related to the air flows. A high air excess is required due to the specific characteristics of the fuel use, rice husk. At the same time a too strong draft forced by the chimney height risks not to give appropriate time and velocity for the gasification reaction to happen at molecular level and to withdraw too fast gas rich in burnable components without burning them usefully. By the other side a too weak draft is likely not to pass through the rice husk due to the high head losses and to occur in malfunctioning in the stove. Thus, the height of the chimney was varied in order to study the effect of the natural draft on the stove operation. Table 27 reports the outputs of the test performed with different lay-outs.

**Table 27: Average thermal efficiency in different combinations of primary air $\Phi_p$ and chimney heights (in brackets the number of tests performed) reported during the testing campaigns**

| | | **Diameter of primary air duct $\Phi_p$** | | |
|---|---|---|---|---|
| | | *5.0 cm* | *7.5 cm* | *10.0 cm* |
| **Height of the chimney** | *1.5 m* | NA | 6.9% (1+1F*) | NA |
| | *2 m* | F | 7.2%(3) | 6.8% (3) |
| | *3 m* | F | 7.6% (3) | NA |
| * F = test failed | | | | |

The best average thermal efficiency was observed for the stove configuration with a 7.5 cm diameter of the primary air duct and a 3 m chimney. The increase of the chimney height, and therefore the natural draft, occurred in an overall better operation of the stove. In particular during all the time of the test, functioning resulted more reliable and stable. A secondary positive effect was on the quality of indoor air. The level of CO and $PM_{2.5}$ measured in a closed space, properly created, resulted within the guidelines values suggested by the WHO for the indoor air quality. As an instance, Figure 72 shows the different level of 15 minutes average CO indoor concentrations reached during tests with different chimney heights. The 3m-chimney layout guarantees a stable low level of CO in the testing space. Only a little increasing in the ignition phase can be observed, but greatly within the guidelines. Otherwise the 1.5m- and the 2m-chimney layouts occur instead in a not optimal operation and therefore in a high level of indoor emissions due to malfunctioning of the natural draft. While with the 2m-chimney layout guideline value is exceeded only for 12 minutes, the average concentrations registered during the test with the 1.5m-high chimney are almost always above the limit suggested. A top value of thermal efficiency was registered in the test with the 3m-high chimney (9.1%), while, for the other configurations, values were resulted lower (6.5%). This indicates that a proper configuration of the natural draft is required to achieve a good operational performance of the stove and of the smoke withdrawal function of the chimney.

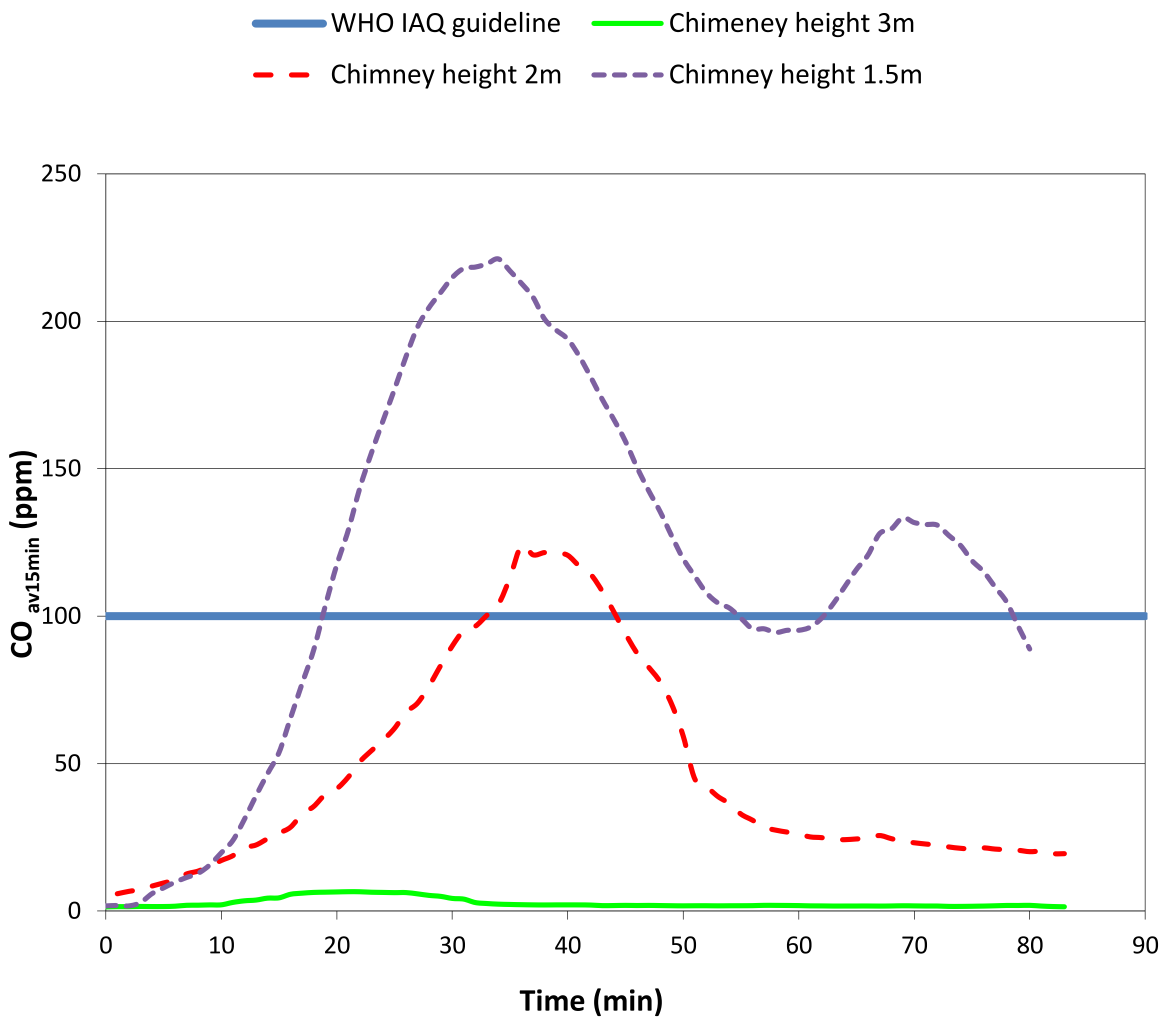



**Figure 72: average 15min indoor CO concentrations measured during tests with different chimney height**

#### 6.3.1.1. Further improvements under study

Some further improvements are currently under study, in order to investigate the optimal chimney configuration (section and height) to guarantee the adequate natural draft to the designed quasi-gasification system. Moreover, a ring reduction was introduced at the top of the fuel reactor in order to concentrate the burnable gases produced by the quasi-gasification process. Hole size was taken half the diameter of the fuel reactor (50%*(0.4 m)=0.2 m), as similarly indicated for micro-gasifiers. Many of the indications obtained from the big size model were used also in the development of the small size one, and vice versa.

### 6.3.2. Small stove test results

A smaller size model was designed according to some considerations done during the development of the first prototype. Certain advantages were likely to be achieved with comparison to the large model:

- being the structure less massive, the heat losses due to the absorption of the brick walls (but also the thermal inertia) are reduced;
- the heat exchange surface with the pot is proportionally higher, that is likely to result in a more effective use of the fuel batch loaded. It is important to ensure that both combustion efficiency and heat transfer efficiency are improved when designing a stove, in order to achieve good performance;
- the dimension is more appropriate for a family use, resulting less bulking in the kitchen space;
- less construction materials are required, thus the cost is likely to be lower. That makes the stove more affordable and, thus, it avoids an eventual barrier to the dissemination on site.

#### 6.3.2.1. Preliminary design tool

A simple design tool was used to size the small prototype. The tool was structured in order to give preliminary indications of the size of a prototype capable to boil 3 Litres of water, according to the testing protocol defined. The net energy input needed was calculated, according to the formula suggested by the WBT protocol, as the sum of the sensible heat required to bring the water to boil and the latent heat to vaporize the steam:

$$\Delta E_{net} = W_{eb} c_{p_{H_2O}} (T_{eb} - T_{eb}) + W_{evap} \Delta h_{H_2O}$$

In the preliminary design, efficiency values considered were in the range 20-30%, lower than best performing improved wood cookstoves, but quite optimistic considering the not easy task to burn rice husk and the results of the test on the large prototype. As shown in Figure 73 an effective reduction in fuel use can already be obtained working on realistic efficiency ranges, more than setting unachievable efficiencies for the technology proposed.

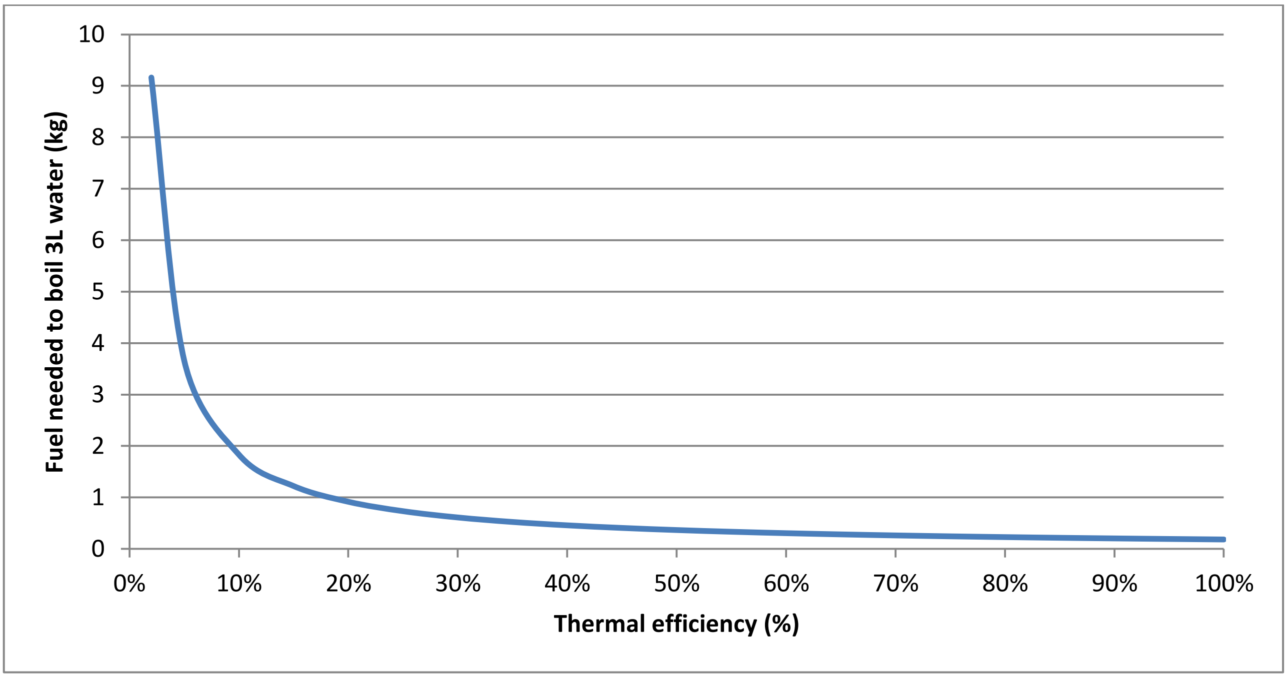



**Figure 73: fuel required for boiling 3L water versus thermal efficiency according to the design tool proposed**

Total energy input was calculated assuming a desired stove thermal efficiency.

$$\Delta E_{tot} = \frac{\Delta E_{net}}{\eta}$$

Weight of fuel needed, and therefore the capacity of the batch reactor, was calculated considering the calorific value of the rice husk (Paré 2011):

$$F = \frac{\Delta E_{tot}}{NCV}$$

Calculated the amount of fuel needed, the geometric size of the batch reactor was calculated considering the low bulk density of the rice husk. Fuel needed ranged among 0.8 and 1.2 kg. In Table 28, the values assumed in the preliminary design of the *mlc* rice husk stove are reported. Fixed the height of the cylindrical reactor equal to 24 cm, due to construction constraints, the section diameter ranged 18-23 cm.

**Table 28: parameters considered in the sizing tool and value assumed in the preliminary design**

| Parameter | Unit | Description | Value assumed for the design |
|---|---|---|---|
| $T_{eb}$ | °C | Operational temperature | 10-30 |
| $T_{eb}$ | °C | Local ebullition temperature | 100 |
| $W_{eb}$ | kg | Mass of water to be boiled | 3 |
| $W_{evap}$ | kg | Mass of water to be evaporated | 20%$W_{eb}$= 0.6 |
| $c_{p_{H_2O}}$ | kJ/kg°C | Water specific heat | 4.186 |
| $\Delta h_{H_2O}$ | kJ/kg | Water latent heat at 100°C and $10^5$ Pa | 2,260 |
| $\eta$ | % | Thermal efficiency of the stove to be designed | 20-30 |
| NCV | kJ/kg | Net calorific value of fuel used | 12,540 |
| ρ | kg/$m^3$ | Low bulk density of fuel used | 70-110 |

According to calculation outputs and indication from the experience done with the large stove model, a number of versions of the small model were designed and tested. A full overview of all the tests performed is reported in the Annexes 3. A deeper discussion of the evolution and of the technical reasons that addressed the Research & Development of this prototype can be found in the PhD thesis by Dr Simone Parmigiani member of the DIMI (Department of Mechanical Engineering of the University of Brescia) partner of the research (Parmigiani 2012).

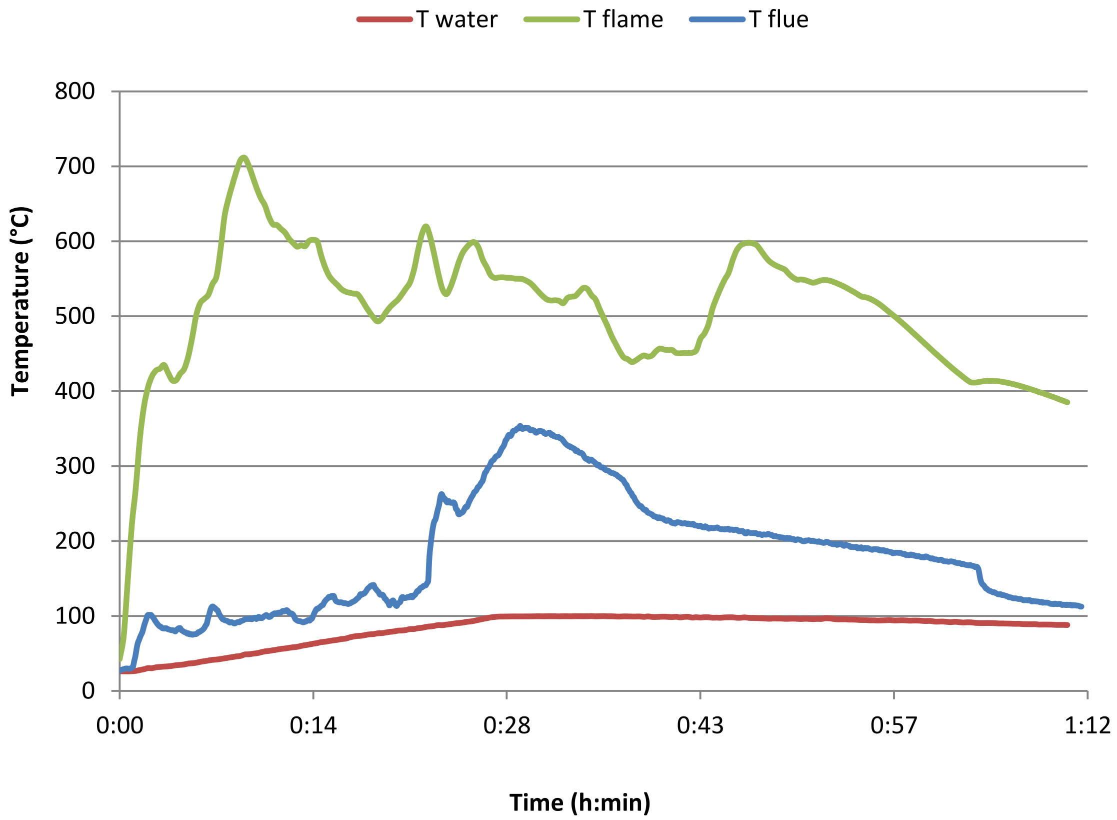
The final version had these geometrical features:

- quasi-cylindrical combustion chamber, realized with 6 crude-earth brick (30 cm x 15 cm x 5 cm), resulted with a height of 40 cm and a diameter varying in the range 28-33 cm;
- the top hole was sized to fit a 7L pot with a diameter of 24 cm; pot was surrounded by a 2 cm thick, 5 cm high layer made of the same mix of the bricks. This layer had a further function of protection from cooling effect of wind in case of outdoor cooking;
- a 1.75 m high, Φ80 iron chimney is connected to the combustion chamber with a 90°C elbow;
- 4 half bricks raise the structure and allow air flowing from the bottom;
- a 5 cm diameter central metal-net duct;
- a 24 cm diameter and a 25 cm height metal-net fuel reactor;
- a 24 cm diameter upper gas concentrator, with a 12 cm diameter central round hole.

#### *6.3.2.2. Stove operation*

The understanding of the operation of the stove was achieved through the interpretation and elaboration of temperature runs in tests varying a number of parameters and configurations. All features and outputs of configurations tested are reported in the Annexes 3. Figure 74 shows a typical temperature and emission run during a WBT.

Flame temperature grows up immediately after ignition up to high values (600 - 700°C). This is mainly due to the charcoal combustion. Temperature gradually rises in the fuel reactor, increasing the share of biomass at an adequate temperature for the gasification reactions. With the consumption of the initial igniting charcoal, the flame temperature decreases. This is the only phase during which some white smoke is observed sorting from the top of the chimney. Once the entire fuel reactor reaches the working temperature, flame temperature shows a second peak, reaching similar values to the first part of the stove. In this phase a too fast and wasteful burning of the fuel occurred. The regulation of the draft closing by half a butterfly valve on the chimney permits to reduce the instant firepower, extending the batched fuel duration. In correspondence with the increase of temperature, oxygen level in the flue reduces, passing from 18% to a final value of 12-13% during the most powerful phase. In the same phase an increase in the concentration of CO gas, up to 1% (1,000 ppm), was observed in the flue. Nevertheless emission values measured resulted slightly higher compared to the ones of more modern technologies available in the developed world market (where emission limits and minimum combustion performances are tight, see for instance Carvalho et al 2011). Also other pollutants such as $NO_x$ and $SO_2$ were seldom analysed, resulting always plenty within European standards, taken as a conservative reference given the lack of a sector regulation for the context studied.



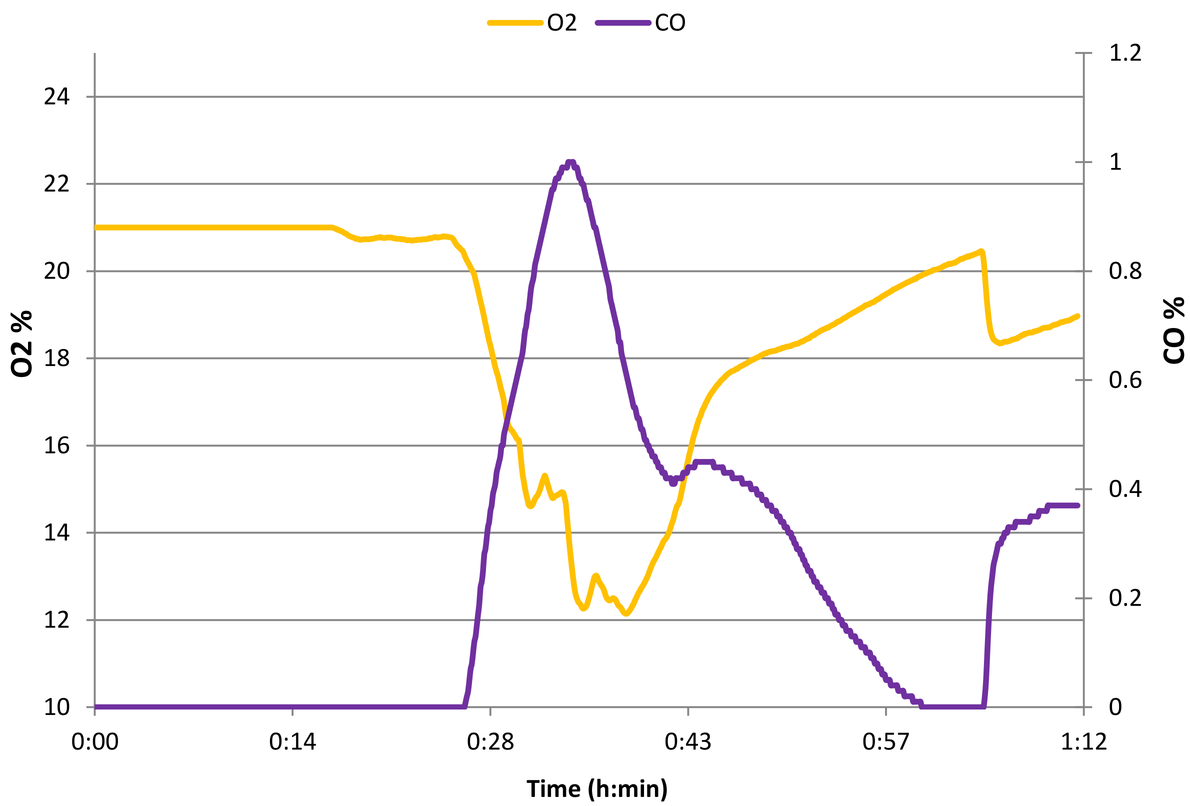




**Figure 74: Typical runs of water, flame and flue temperatures during a WBT and CO and O2 concentrations in the flue**

Thus, according to observations during the runs, the *mlc* stove is supposed to operate as a dual stage process (Figure 75). In the first phase a small quantity of charcoal (usually not more than 50 grams) is ignited inside the central duct. The small amount of charcoal that is used for the ignition of the stove plays a key role for a good operation, even if it does not give a considerable contribution to the overall efficiency (an excessive quantity of charcoal resulted often in a counterproductive effect on the operating of the stove). The pilot flame works as the spark of the process: rice husk is heated by the gasification/combustion process of the charcoal, but biomass temperatures are still too low for the gasification reaction to happen. With the increase of temperature inside the fuel reactor, due to the natural draft that sucks hot air in a radial direction, the gasification process starts. Hot flues enriched with burnable volatiles (passing through the rice husk, now at working temperature) are channelled in the external gap up to the top of the reactor. Here they burn meeting a flue of fresh hot air rising up from the central duct, which in this second stage works as secondary air, being almost free for the gradual consumption of the charcoal.

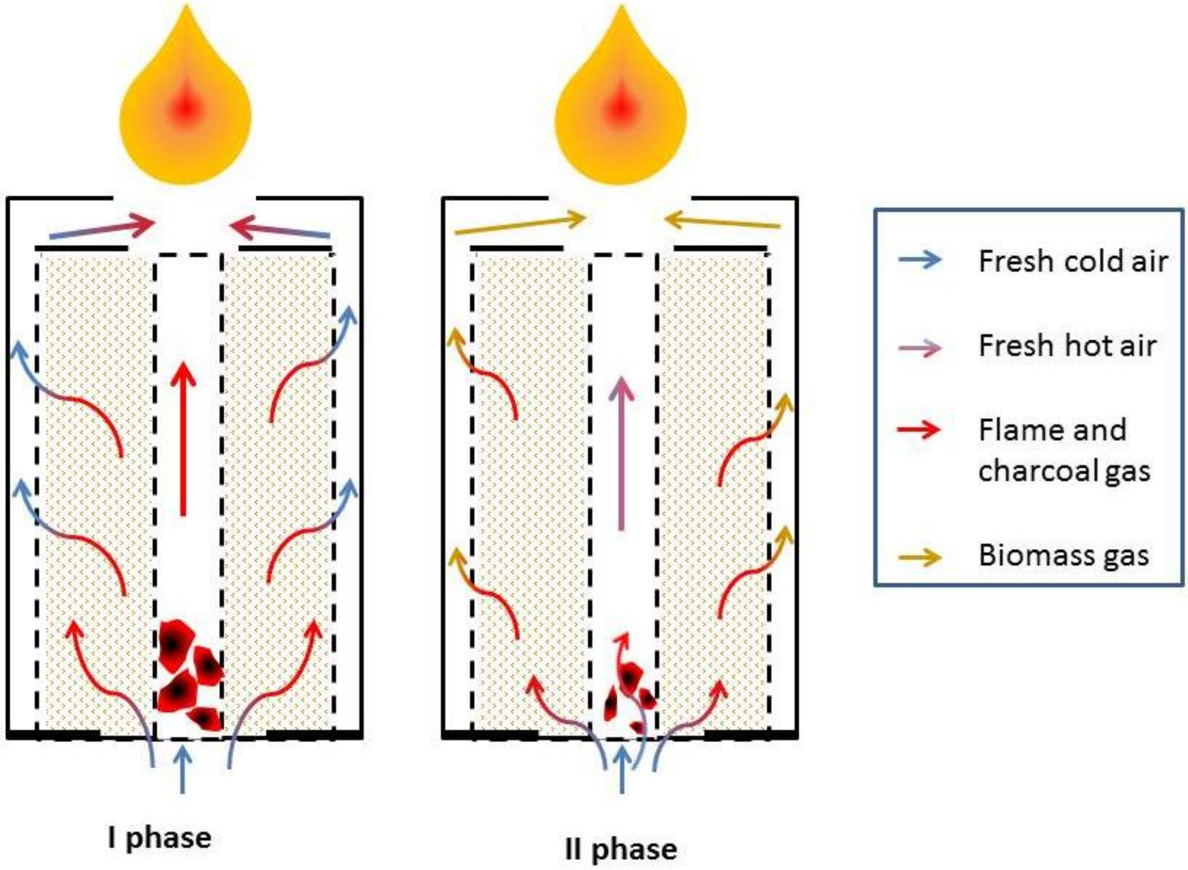



**Figure 75: assumed conceptual dual stage operation of the natural draft *mlc* rice husk burner**

### 6.3.2.3. *Testing results*

Finally, WBT results are shown in Table 29 for three representative runs for three different stoves all associated with the same configuration. All tests were performed boiling 3 litres of water in identical pots without lids. Average values obtained show the good performances of the stove. Such values are very consistent and reliable with relative coefficient of variation ranging between 0.0 and 0.2. Total duration of the test, which represents the duration of the fuel batch, varies according to operations done during the run. In particular in the third a special attention was given to the regulation of the draft using a butterfly valve. That resulted in a longer duration (70 minutes) and lower mean firepower, but without influence on other parameters. Average thermal efficiency resulted 18% that is a value lower than the one of improved stoves (see chapter 0), but acceptable considering the evolution stage of the prototype and the difficulties in using rice husk as a fuel. Generally values obtained can be compared to the ones reported in literature for the Mayon Turbo stove (Aprovecho Research Center 2005).

**Table 29: outputs of the WBTs with the final configuration**

| Run ID | | 2 | 3 | 4 | Average |
|---|---|---|---|---|---|
| Water | L | 3.02 | 2.98 | 3.00 | 3.00 |
| ΔT | °C | 73 | 78 | 74 | 75 |
| Water evaporated | kg | 0.70 | 0.64 | 0.70 | 0.68 |
| Rice husk | kg | 1.00 | 0.94 | 1.04 | 0.99 |
| Coal | kg | 0.05 | 0.05 | 0.05 | |
| Efficiency* | % | 18 | 19 | 18 | 18 |
| Boiling time | min | 27 | 27 | 28 | 27 |
| Specific consumption | g/L<br>kJ/L | 331<br>4,152 | 315<br>3,956 | 347<br>4,347 | 331<br>4,152 |
| Burning rate | g/min | 21 | 18 | 15 | 18 |
| Total duration | min | 48 | 53 | 70 | 57 |
| Mean power | kW | 4.8 | 4.1 | 3.4 | 4.1 |
| * calculated considering an LHV of 12540 kJ/kg and for rice husk and 25000 kJ/kg for charcoal | | | | | |

To reconstruct the R&D process and the different configurations tested, the full list of tests done is reported in the Annexes 3.

#### *6.3.2.4. Indoor air pollution measurement*

CO concentrations were measured during the test in order to evaluate the indoor air quality related to the use of the stove. As already verified in the *mcc* model, during a good operation of the stove, a low emission rate in the cooking space is likely to be observed, even if in case of malfunctioning due to a not proper configuration of the stove, the CO levels result very high, despite the use of the chimney.

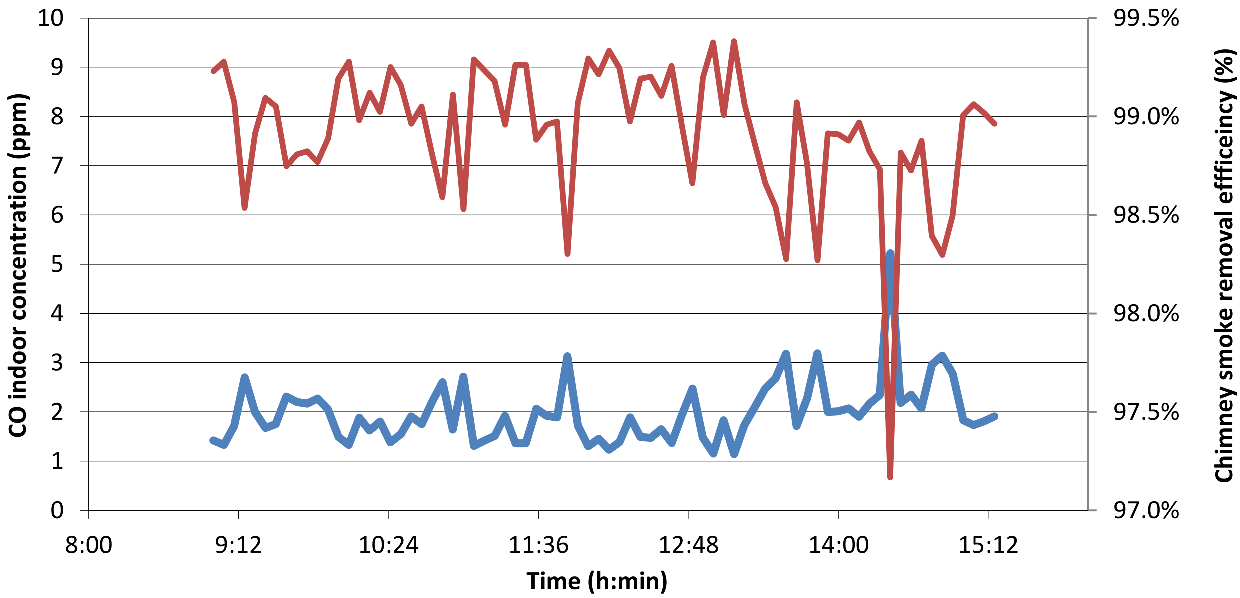



**Figure 76: CO indoor concentration run during a test session (4 WBTs completed)**

The measurements reported in Figure 76 demonstrate that the stove, in its final configuration, produces very little emissions in the area where testers operated (monitor placed according to indications given in paragraph 5.1.3). Average CO concentration during the test time resulted equal to 2 ppm, a value significantly lower to the one of effective ICS tested during the activities on site (see paragraph 5.2.2). A higher run can be observed in the last tests (after 1:00 PM); that is imputable to cumulative saturation of the space where four tests were done 6 hours consecutively. Even in this case (that may be assimilated to a prolonged use of the stove in the day period for the preparation of meals) CO levels remain very low.

A Monte Carlo single-box model (Johnson et al 2011), using a standard room with instantaneous mixing and a test space size ($V$ = 65 $m^3$) and a standard air exchange rate ($\alpha$ = 25 $hr^{-1}$), was adopted to evaluate the smoke withdrawal efficiency of the chimney, according to the model described mathematically as:

$$C_t = \frac{G * f}{\alpha * V}(1 - e^{-\alpha t}) + C_0(e^{-\alpha t})$$

The emission rate $G$ was calculated considering the average CO levels registered in the chimney during that test session (3,300 ppm), and the associated natural draft $Q$. As a first approximation, the following equation was used to estimate the natural draught/draft flow by assuming that the molecular mass of the flue gas and the external air are equal and that the frictional pressure and heat losses are negligible (Walker 2010):

$$Q = C * A * \sqrt{2gH\frac{T_i - T_e}{T_e}}$$

where:

Q = chimney draught/draft flow rate, $m^3/s$

A = cross-sectional area of chimney, $m^2$ (assuming a constant $\Phi$80mm circular cross-section)

C = discharge coefficient (usually taken to be from 0.65 to 0.70)

g = gravitational acceleration, 9.807 $m/s^2$

H = height of chimney, 1.75 m

$T_i$ = average temperature inside the chimney, 473 °K (200 °C)

$T_e$ = external air temperature, 293 °K (20 °C)

The fraction of emissions that enters the kitchen environment $f$ was calculated for each measurement according to the model (Figure 76). The complementary share $(1 - f)$ was taken as indicator of the efficiency of smoke removal by the chimney that on average resulted equal to 98.9%.

#### 6.3.2.5. *Safety evaluation*

The stove safety evaluation was done according the guidelines proposed by Johnson et al (2005). Safety evaluation procedures provide a well-defined and tested method for reducing risk of injury from household stoves in developing nations. The protocol consists in 10 simple tests to be performed on the stove model according to detailed procedures. A rating is given for each test from poor (=1) to best (=4). Overall rating (Safety Rate, SR) is calculated according to a weight system properly defined. It resulted 89

(=”good”) for *mlc* rice husk stove, which is significantly higher in comparison with a number of other traditional stove models, such as the three stone fire (SR= 44), and similar to other chimney equipped improved stoves, such as the Ecofogon (SR=84), or the Patsari (SR=83). In order to investigate in a deeper way the distribution of temperatures on the surfaces of the stove, in the surroundings and in particular on the chimney exterior walls, some thermographies were taken during the testing phase (Figure 77). Indeed those were the weakest points in the safety evaluation. Actually in comparison with metal stove, the *mlc* stove materials are slower in heating. Furthermore the batch system avoids any eventual contact of the user with flames.

**Table 30: safety evaluation overall rating for *mlc* stove**

| **Test** | **Rating** | **Weights** |
|---|---|---|
| Sharp edges and points | Best | 1.5 |
| Cookstove tipping | Best | 3 |
| Containment of fuel | Best | 2.5 |
| Obstructions near cooking surface | Good | 2 |
| Surface temperature | Fair | 2 |
| Heat transmission to surroundings | Best | 2.5 |
| Temperature of operational construction | Best | 2 |
| Chimney shielding | Fair | 2.5 |
| Flames surrounding cookpot | Best | 3 |
| Flames/fuel exiting fuel chamber, canister, or pipes | Best | 4 |
| **Overall** | | 89 |

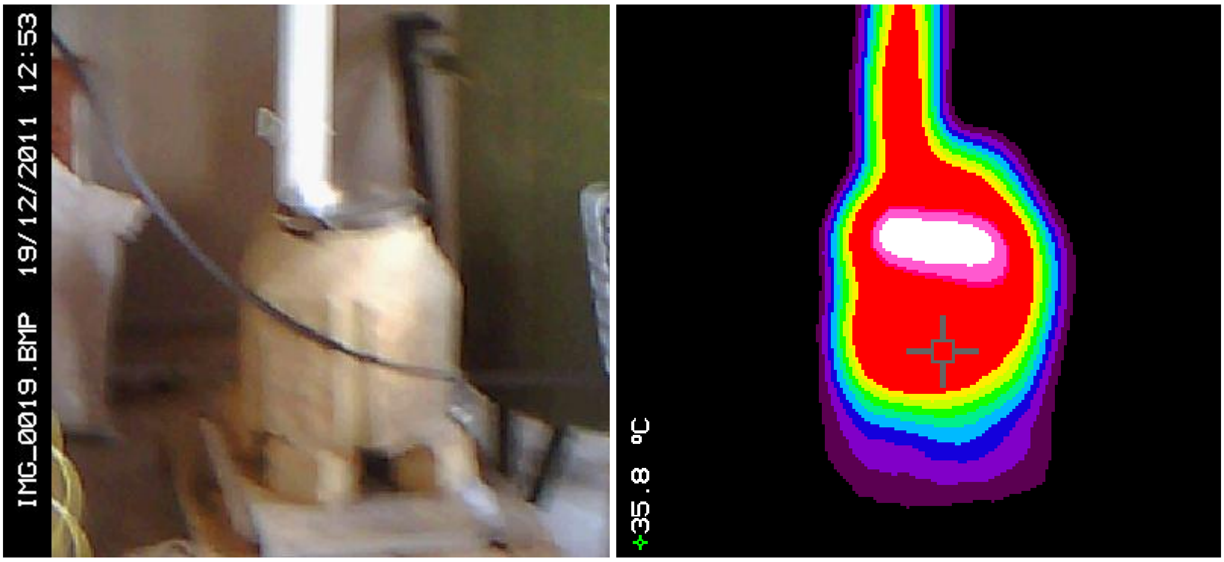



**Figure 77: thermography of the stove during a WBT**

## 6.4. Constraints to the dissemination of the designed technology

The *mlc* stove was not disseminated on site, as the Research & Development phase was implemented mostly in the last year. Nevertheless the design of the prototype was always driven by local inputs. Not only technical aspects such as the material availability or the local artisan skills were considered, but aspects such as the adaptability to local practices, the sustainability and the acceptance by users were addressed.

Table 31 reports a SWOT[12] analysis elaborated in order to assess the internal and external factors that could affect the introduction of the proposed *mlc* stove in the local context considered. Only the small model was considered for this analysis due the more promising features and performances of such a model in comparison with the large model.

**Table 31: SWOT analysis of the *mlc* rice husk stove designed**

| | **Helpful**<br>*to achieve a successful and appropriate dissemination on site* | **Harmful**<br>*to achieve a successful and appropriate dissemination on site* | **To be investigated** |
|---|---|---|---|
| **Internal origin** | Strengths<br><br>• reliable and user-independent operation<br>• thermal efficiency comparable to other effective ICS<br>• use of non-traditionally exploitable alternative resource as fuel<br>• smoke withdrawal by the chimney<br>• affordability<br>• easy and cheap maintenance | Weaknesses<br><br>• not continuous feeding; batch loading limits duration<br>• chimney maintenance required<br>• heat exposed metal parts may incur in early deterioration, because of availability of low quality materials | • adaptability to different kind of local cooking preparations<br>• material resistance to daily use<br>• firepower regulation<br>• optimization of draft and air intakes<br>• manufacturing process (crude-earth mixture compositions, casting for standard replication)<br>• flexibility to other fuels |
| **External origin** | Opportunities<br><br>• *mlc* may increase the access of local population to a wider energy technology portfolio<br>• contrasts high increasing costs of wood and other fuels<br>• wood is becoming everyday less accessible<br>• recovers waste biomass<br>• currently rice husk has no cost | Threatens<br><br>• rice husk is difficult to transport and to store due to its low bulk density<br>• rice husk has low Net Calorific Value<br>• wood is still affordable (up to now)<br>• use of solid fuels is strongly rooted in the daily cooking habits | • rice husk local availability has to be investigated before dissemination<br>• support from governmental household energy strategy |

The stove uses rice husk, a locally available biomass that currently is seen as a waste. Local farmers commonly burnt it just to dispose it off. Thus the recovery of such a resource as fuel can be welcomed

[12] Strengths Weaknesses Opportunities Threatens analysis, a common analysis tool to evaluate the influence of internal and external factors in the achievement of an objective

positively. The production of the fuel does not compete with resources necessary for food production being a wasted by-product of rice production and currently has not a higher value use, such as a building material[13]. Negative impact on the local biodiversity and sustainable management are assured being rice husk a crop already widespread in the Logone Valley. Currently such a biomass has no cost; some elaborations about the economic viability in the long run of the use of priced rice husk have been done and are presented in the next chapter. It needs to be highlighted that where ever there is sufficient firewood or charcoal accessible (available and affordable), people will not be interested to use solid biomass waste as a fuel. As long as there are alternatives which are more convenient to use and are cheaper and easier to access, this option is hardly viable. Moreover the use of solid fuels is strongly rooted in the daily cooking habits: charcoal before and wood currently are more practice and energy-dense than rice husk. However, access to firewood is becoming expensive, unreliable or difficult, thus the provision of the population with a wider energy technology portfolio may protect them from price shocks or fuel shortage. The eventual possibility to use other fuels (such as other biomass residues or firewood itself) in an efficient way with the stove model proposed is a feature that is under investigation.

Rice husk is not a valuable fuel due to the low NCV, and its low bulk density makes it difficult to transport and to store. Nevertheless the good energy performances achieved by the last model configuration allow using effectively such a poor fuel. The batch feed solution avoids a frequent refuelling likely to happen in continuous feed stove. This results in less drudgery and inconveniences for the user, due also to the reliable and user-independent operation of the stove. Firepower regulation has to be studied in order to allow a longer duration of the fuel batch and to better meet the user's need during different cooking tasks. According to observations done in the local markets, the stove can be produced locally, without importing materials from abroad, resulting in a low production cost. Spare parts for the components that are likely to incur in early deterioration (such as the internal duct that is exposed to high temperature in each run) are locally available and cheap. The stove is equipped with a chimney that withdraws the smoke from the cooking position. This is a benefit for the user's health, but the chimney must be installed properly, to prevent accidents, and users must be trained for a proper cleaning and maintenance, which often is not already embedded in local knowledge and habits.

## 6.5. Conclusions

The study presented the research of an alternative fuel stove for household energy purposes. The stove design was addressed to a particular local context, the Logone valley at the border between Chad and Cameroon, where an international development cooperation project is working to improve the poor energy access of local population. The good availability of rice husk, a local agricultural by-product currently without any use neither value on the local market, suggested recovering this biomass for cooking purposes. According to local socio-technical constraints a prototype of rice husk stove was designed. Different system lay-outs were tested, in order to assess the best technical performances and to identify the most proper materials.

[13] Some researches by the University of Brescia are on-going on the possibility to use it as additive in the production of crude-earth bricks, but currently the two activities do not seem to be competitive.

After testing various configurations for the larger and the smaller stoves, the *mlc* stove, with a metal-net fuel reactor placed inside the combustion chamber, resulted to be the most promising one for both sizes. A rigorous Research & Development pathway was implemented in order to investigate in detail the operation of the stove, resulting in a final configuration with very good and reliable performances.

# 7. Economic assessment of the use of alternative fuels

In order to assess the economic sustainability of the use of rice husk as an alternative fuel at household level, a basic model was elaborated considering the main factors impacting the cooking energy expenditure per household, assuming different fuel mixes. The objective of this evaluation was to point out the trade-off threshold that makes feasible the purchase and adoption of the *mlc* rice husk stove in the context studied. Some input data were collected on site regarding the availability of rice husk and the costs of materials for the manufacturing of the stove.

## 7.1. Introduction

### 7.1.1. Rice husk availability in the Logone Valley

In the study area rice production is the main agricultural activity. During the harvesting time, husk (mechanically separated from the seed) is greatly available and without any utilization. Usually it is simply heaped at the corner of the roads, in the fields or near the community mill and burnt to dispose it, as illustrated in Figure 78. Around 20% of the paddy weight is husk (Chungsangunsit et al 2009).

**Figure 78: heaps of rice husk and of husk ashes after burning in the rural area of Bongor (Chad)**

Table 32 reports the data provided by the Chadian Ministry for Agricultural Activities about rice production. In 2010 in the intervention area, 9,553 tons were produced (79% in the dry season and 21% in the rainy season). This results in a by-production of husk of 1,911 tons. 3,613 people were identified as farmer, resulting in an average production per producer per year of 2.64 tons of rice and 0.53 tons of husk (1.45 kg/d).

**Table 32: rice production in the Chadian side of the Logone Valley in 2010**

| | Dry season (February - June) | Rainy season (June – November) | Total |
|---|---|---|---|
| Cultivated area | 2,500 ha | 2,292 ha | 4,792 ha |
| Destroyed area | - | 1,068 ha | - |
| Harvested area | - | 1,224 ha | - |
| Productivity | 3,000 kg/ha | 1,677 kg/ha | - |
| Production (est.) | 7,500 t | 2,053 t | 9,553 t |
| Rice husk production (est.) | 1,500 t | 411 t | 1,911 t |

According to KPT performed on site (see paragraph 5.2.1), the total net energy required for cooking purposes by an average household (9 people) may be assumed equal to 18,000 kJ/d. Similar values have been found in other literature works (Panwar & Rathore 2008). Assuming net calorific values for rice husk equal to 12,500-14,000 kJ/kg as common in literature (Paré 2011, Permchart, and Tanatvanit 2009, Bharadwaj et al 2004, Armesto, et al. 2002), a technology with a 20% overall efficiency may cover 20-25% of the energy need of a family.

### 7.1.2. Local feasibility of the stove

The aim of this step was not to disseminate the model among local population, but to investigate the feasibility, availability and adaptability of materials to realize the stove and their costs. Some issues were faced during the research of the proper materials. The upper cover was realized using the bottom of a drum, cut with basic tools by a local artisan (Figure 79) and filled with the same material used to manufacture the crude-earth bricks. The local smith helped also realizing properly the chimney as no metal pipes with diameter 10 cm were available on the local market. Moreover it was hard to find a suitable net for the internal structure: market restrictions forced to use a low cost material that is likely to occur in fast deterioration. The final cost of the stove was around 31,000 CFA francs (i.e. 49€): such a high cost is due to the specific materials and works required in this prototype study phase and it is hardly affordable by local population. In fact several of these issues are likely to be overcome in the scaling up phase of the technology, simply by importing proper materials from a bigger marketplace (e.g. N'Djamena) where these materials are more easily available and at a lower price.

**Figure 79: Different phases of the construction of the stove on site**

Table 33 reports the production costs of the two prototypes according to the item prices observed on site. For the *mlc* small size model total cost was estimated according to the last evolution, which reduces the quantity of materials required and cuts some specific item, such as the secondary air duct and the upper cover. The estimated cost for the mlc model, according to these considerations, was calculated around 6,700 CFA francs (10.5€). The most expensive item was the metal chimney, which had to be realized manually during the observation on site. The cost of that single item is likely to be significantly lower in case of production on a real small scale, rather than the cost paid for the prototype realization. Actually, in the calculations a conservative production cost of 10,000 for the *mlc* stove was assumed.

**Table 33: production costs of the two prototypes according to prices of materials observed on site**

| Prototype model | | | *mcc* (big size) | | *mlc* (small size) | |
|---|---|---|---|---|---|---|
| | **U.M.** | **Unit cost** | **Quantity** | **Total cost** | **Quantity** | **Total cost** |
| **Item** | | *CFA f/u* | *u* | *CFA f* | *u* | *CFA f* |
| Crude-earth bricks | unit | 25 | 30 | 750 | 8 | 200 |
| Secondary air duct | m | 5,000 | 0.3 | 1,500 | - | - |
| Metal net | $m^2$ | 2,000 | 1 | 2,000 | 0.5 | 1,000 |
| Upper cover | unit | 7,000 | 1 | 7,000 | - | - |
| Chimney | m | 7,500 | 2 | 15,000 | 1.75 | 5,000* |
| Clay and sand | bag | 500 | 1 | 1,000 | 1 | 500 |
| Labour | h | - | forfait | 2,850 | - | - |
| Total | | | | **31,150** | | **6,700** |

* see the text for justification

## 7.2. Material and methods

The model developed in this work for estimating the cooking energy expenditure cost is inspired from other published methods (Habib et al. 2004). The model allows estimating the cooking energy expenditure for a household using a mix of fuels in different shares. This tool has been used to evaluate preliminary the financial sustainability of the usage of different fuels, and the relative cookstove technology, to cover the daily cooking energy needs. That was calculated considering for each fuel *i* used the cost of the proper stove, spread on its lifespan, and the fuel cost, according to the share of required energy covered by that fuel. The fuel cost was estimated multiplying the unit cost of the fuel *i* for the total quantity of fuel needed. Fuel quantity was calculated considering the net calorific value of that specific fuel and the share of the energy need covered by that fuel. The specific thermal efficiency given by that combination of fuel and cookstove allow calculating the total gross energy need.  Total net energy required for cooking purposes was estimated for a typical family (7 people) according to outputs of KPT performed on site (see paragraph 5.2.1). The model proposed can be summed up in the following equation. Parameters used for the calculations are listed in Table 34.

**Table 34: parameters used in the economic model**

| Parameter | Unit | Type | Description |
|---|---|---|---|
| ET | kJ/y HH | Observed | Total net energy required for cooking purposes by an average household (7 people). An average value of 18,000 kJ/d was assumed according to KPT performed on site |
| $NCV_i$ | kJ/kg | Fixed | Net calorific value for the fuel *i* |
| $f_i$ | % | Variable | Share of cooking energy needs covered by fuel *i* |
| $\eta_{ij}$ | % | Variable | Transfer efficiency of the stove *j* using the fuel *i* |
| $C_{fi}$ | CFA francs/kg | Variable | Cost of the fuel *i* |
| $C_{Sj}$ | CFA francs/unit | Variable | Capital cost of the stove *j*. Stove capital cost is included in the calculation of the cooking energy expenditure only when relative $f_i > 0$ |
| $L_{Sj}$ | years | Variable | Lifespan of the stove *j* |

The yearly cooking energy expenditure was calculated according to the following equation:

$$\sum_{i,j} \frac{C_{Sj}}{L_{Sj}} + \left(\frac{ET * f_i}{\eta_{ij} * NCV_i}\right) * C_{fi}$$

In the elaborations done the use of the proposed model of rice husk stove was investigated. Thus, the graphs discussed in the result section take for comparison a baseline scenario calculated assuming the use of wood as the only energy source. In the scenarios calculated with different fuel mixes, the share of cooking energy covered by rice husk is complementary to the total with woodfuel.

## 7.3. Results

A number of considerations were done applying the model proposed modifying the value of variable parameters. As a baseline, the current cooking practice was considered, which is the use of three stone fire as only cooking system (f = 100%). Net calorific values were taken by Harker et al (1982) as suggested in the protocol of WBT. The baseline thermal efficiency, as the ratio between energy used and energy consumed, was assumed 15%, according to KPT performed on site by the author (see paragraph 5.2.1). Wood cost was assumed 35 CFA francs/kg, according to the considerations done at paragraph 3.3. Figure 80 shows the current scenario according to baseline assumptions. For the calculation of the costs related to the use of the *mlc* rice husk stove a capital cost of 10,000 CFA francs and a thermal efficiency of 15% were assumed. Rice husk cost was considered null according to current status in the local context. According to the model proposed, the threshold for the trade-off of the *mlc* stove is the use of rice husk to cover 15-20% of the household energy needs.

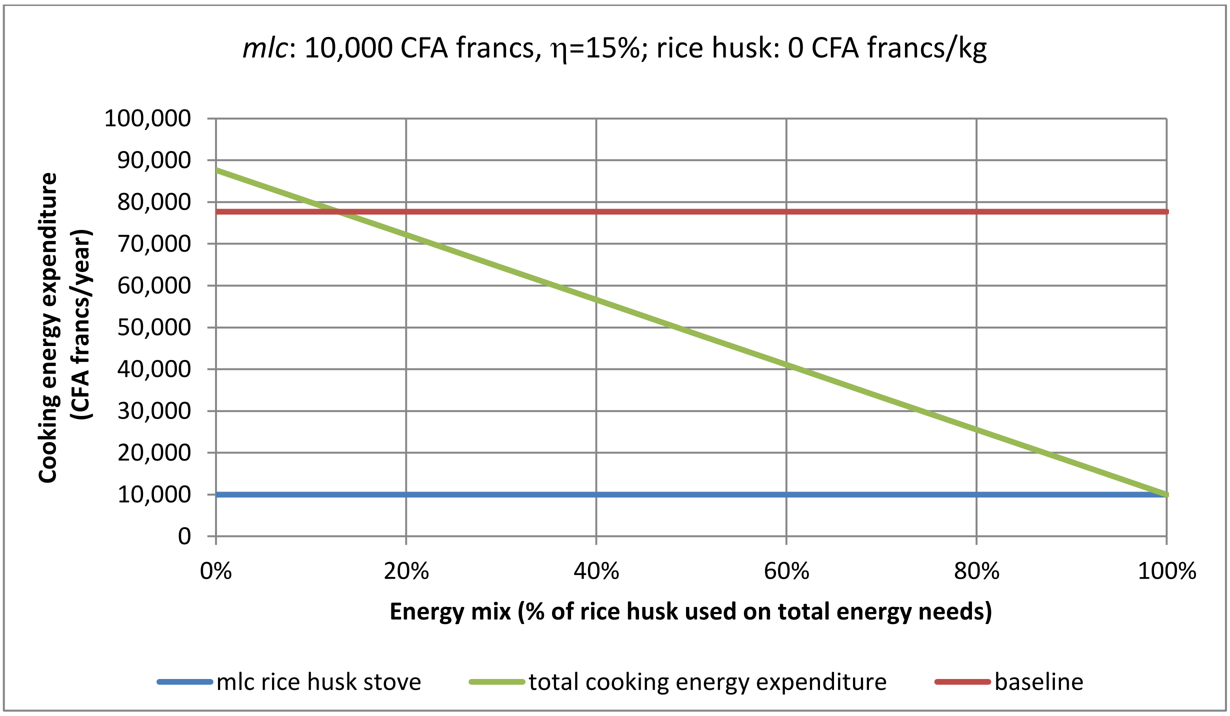



**Figure 80: current scenario for the economic sustainability of the *mlc* rice husk stove**

The model was used in order to investigate possible evolutions of the local energy context. A first focus was given to the cost of the rice husk. Currently such a biomass is an agricultural residue and has any value. Farmers are used to burn it just to dispose it. Thus, it is easy to have it for free. In fact, if a technology such as the stove proposed is introduced in the local context, the rice husk is likely to assume a certain value on the local market. Figure 81 shows how the convenience in the use of rice husk as alternative domestic fuel with the technology proposed is economically sustainable until rice husk price sets at 10-15 CFA francs/kg. The trade-off threshold is at about 20 CFA francs/kg. A price of 30 CFA francs/kg, that is similar to wood, would be absolutely not convenient, as it would increase the household total energy expenditure.

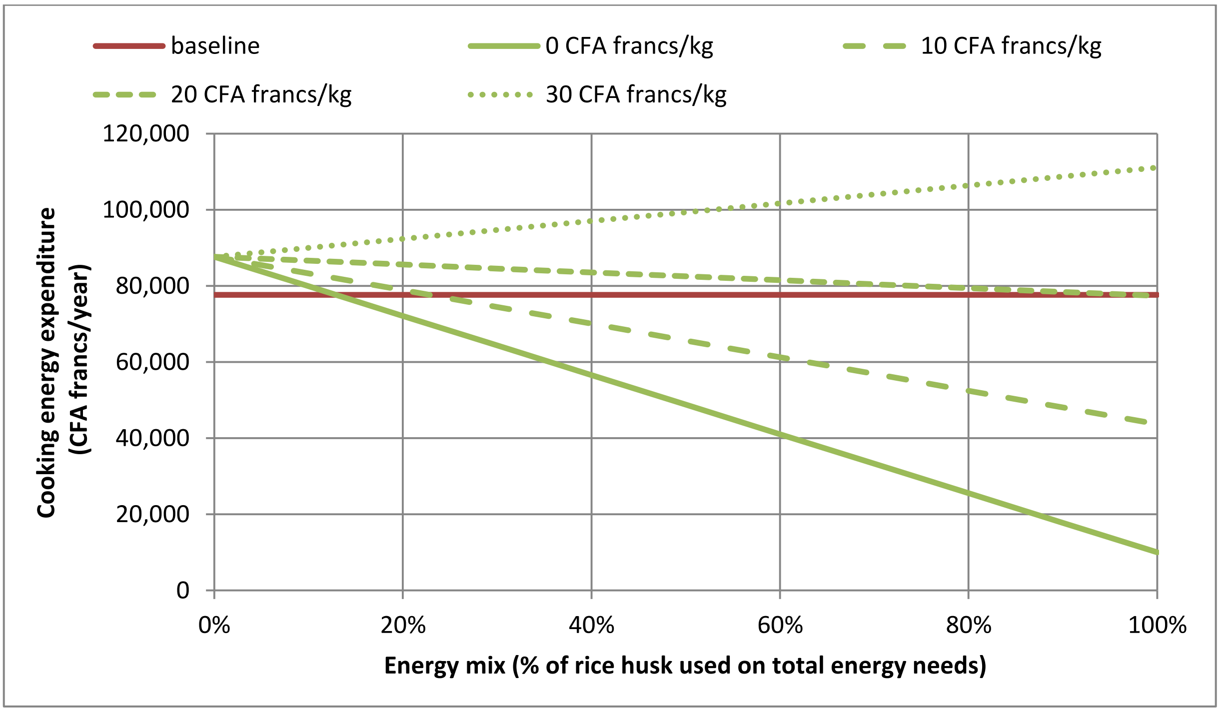



**Figure 81: convenience of use of rice husk according to different hypothetic costs of such a biomass**

Given the structure of the model proposed, a rice husk price was fixed in order to make possible some further considerations. The following graph (Figure 82) shows the minimum technical requirements of the stove to be convenient. With the efficiency level achieved in the WBTs the *mlc* stove would result sustainable up to a threshold of 7.5%, significantly lower than the resulted obtained.

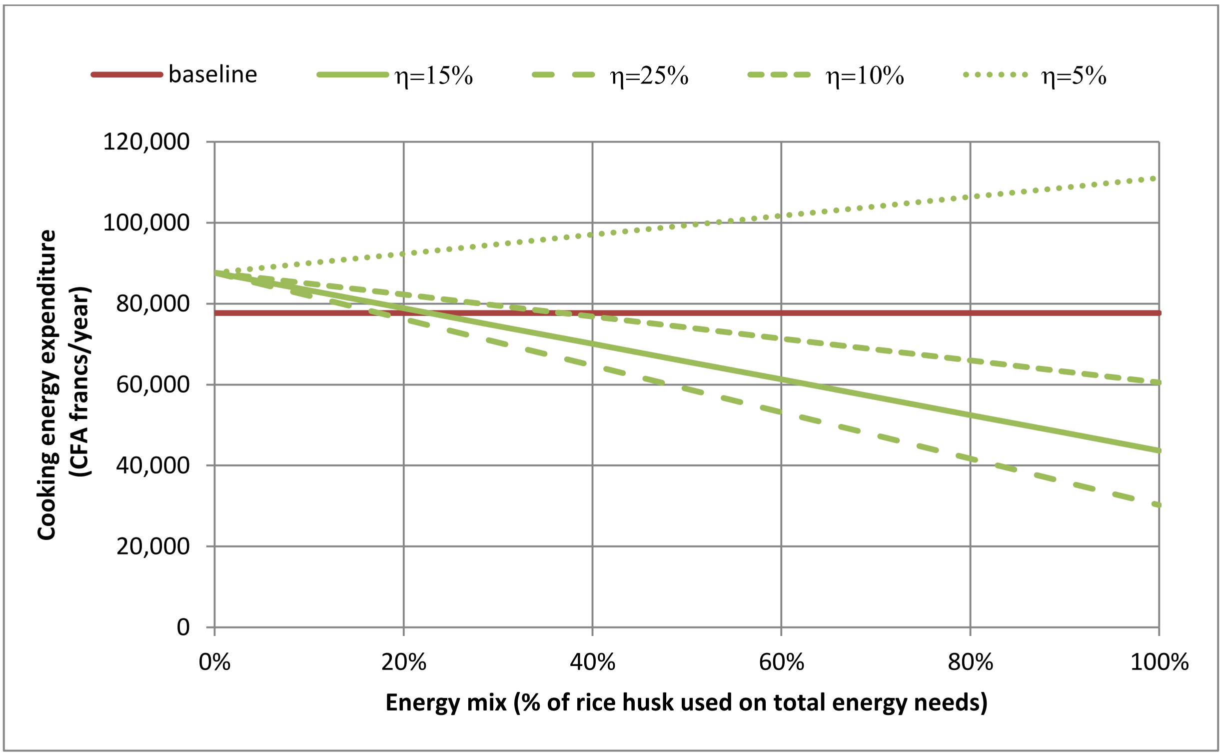



**Figure 82: convenience of use of rice husk according to different hypothetic efficiency of the rice husk stove (according to a fixed assumed price of 10 CFA francs/kg)**

The model was also used to compare the convenience of the adoption of the rice husk stove, rather than other improved cookstoves, such as the ones studied within this research. The current scenario present in Figure 80 was integrated with the outputs of the model considering the use of improved wood stove, as shown in Figure 83. The use of wood only and the mixed use of wood and rice husk were compared for each alternative system. A capital cost of 6,000 CFA francs and an efficiency of 30% was considered for the Centrafricain stove, while 1,500x2=3,000[14] CFA francs and 20% are the inputs of the model for the ceramic stove. According to the availability of rice husk observed on site (see paragraph 7.1.1), a likely mix of household energy sources is shared in a 35% by rice husk (with a cut-off of 50% for the rice producers) and the other 65% by wood fuel. The outputs of the model show trade-offs at almost 20% and 25% for the Ceramic and Centrafricain ICS respectively, which fall both in the field of the economic sustainability for the technology proposed. Moreover, the adoption of the only *mlc* stove maintaining the use of the traditional three stone fire results to be a less convenient alternative in comparison with the adoption of the improved cookstoves. Indeed such a combination would have high trade-offs, at 35% for the Ceramic ICS (efficiency 20%) and 55% for the Centrafricain ICS (efficiency 30%).

[14] Capital cost of the ceramic ICS is 1,500 CFA francs and the lifespan 6 months. Referring these elaborations to a 1-year period, the initial cost of the purchase of the stove and its replacement after six months was considered in the calculations.

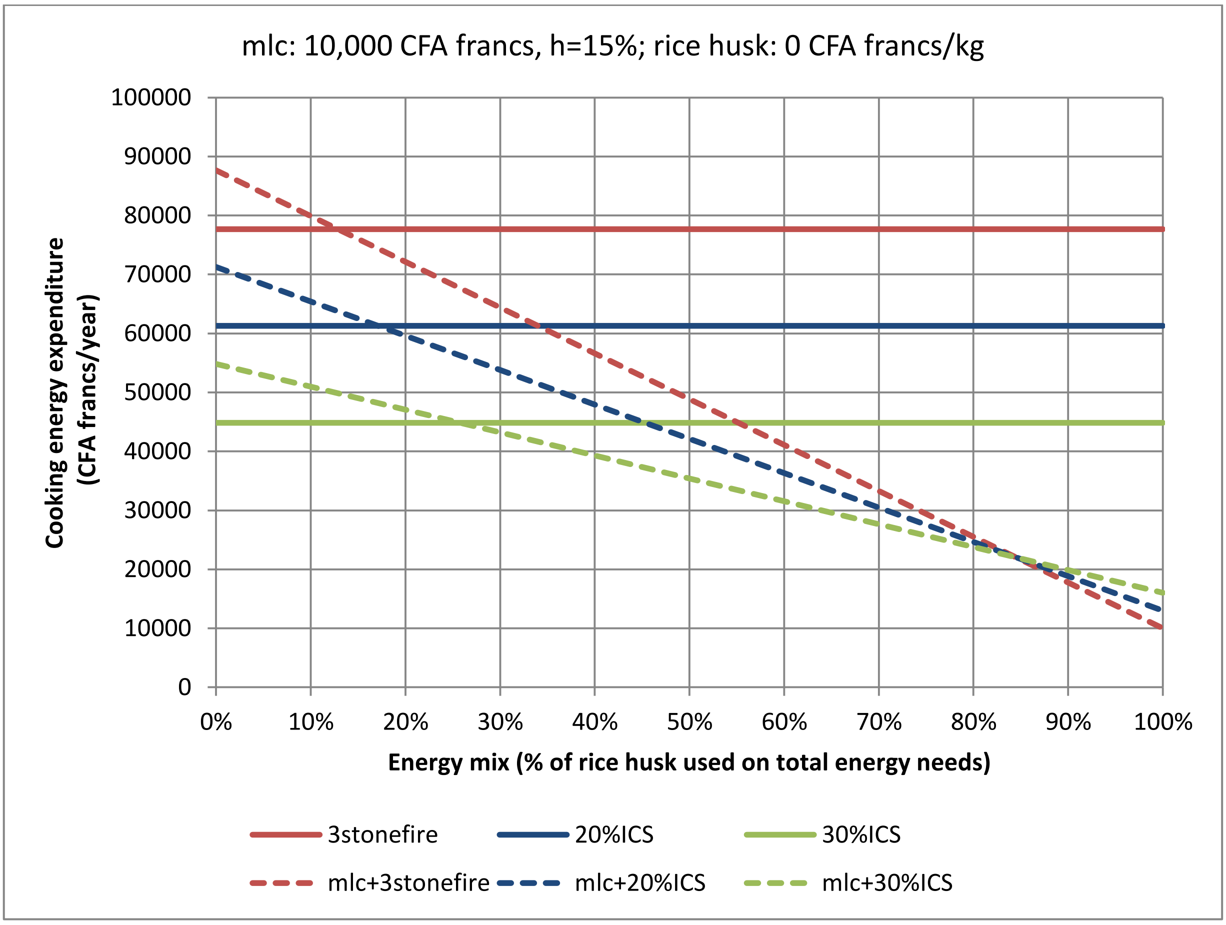



**Figure 83: convenience of use of rice husk compared to other improved wood cookstoves (ICS)**

## 7.4. Conclusions

The introduction of the *mlc* rice husk stove in the cooking energy pool of households results economically sustainable according to the outputs of the model proposed. All the scenarios elaborated show how the rice husk stove adoption would reduce significantly the household fuel expenditure, within the local availability of such a biomass. The use of the technology proposed in combination with improved woodstove would provide householders with an appropriate and convenient cooking technology pool, increasing the opportunities of choice of the preferred energy system for the user. This results even more important considering the increasing wood fuel price observed on site, which may affect negatively the advantages related to the use of the improved wood stoves alone.

# 8. Multi-criteria assessment of the appropriateness of a cooking technology

## 8.1. Introduction

The work presented in the previous chapters gives a wide overview of the activities implemented both on site and in laboratory aimed at the research of appropriate cooking technologies for the context of this case study: the Logone Valley at the border between Chad and Cameroun. Different aspects of the technologies proposed have been assessed according to recognized literature methodologies. In this final chapter an assessment of the appropriateness of the technologies studied is given providing a global analysis of the results obtained in different activities.

Many past studies and models linked the household energy choice mainly to a kind of neoclassical consumer behaviour basing their preference on economic convenience (Arnold et al 2006, Brouwer and Falcao 2004). However, trends observed in the urban areas and cities have often not followed such patterns and fuelwood continues to be important in most areas. Thus, the energy transition is seen to be driven ‘‘not by an emerging desire for modern fuels so much as by socio-economic changes, which help to break the constraints on their wider use’’ (Leach 1992). This is chiefly because its model of household fuel switching largely dismisses the importance of active (and strategic) decision making by consumers and their responsiveness to structural factors such as relative fuel prices (Hiemstra-van der Horst and Hovorka 2008). Similarly in rural contexts an integrated approach to understanding household energy choice is required, given the number of endogenous and exogenous factors affecting such a choice (Kowsari and Zerriffi 2011).

These concerns and limitations have motivated the design of a multi-criteria decision support approach that combines technical and non-technical criteria for the development of rural infrastructure, to promote effective and sustainable energy solutions by improving decision-making processes (Henao et al 2011). Recently, some studies were focused on selecting the best energy policy and determining the best energy alternatives. In most of these studies, multi-criteria and fuzzy approaches to energy policy making are frequently used. The decision-making process, regarding the determination of the best energy policy, is multidimensional and made up of a number of aspects at different levels such as economic, technical, environmental, political and social. The proposed multi-criteria approach tries to give a reply to a recent viewpoint emerged in the energy policy maker scientific community: “How many times again will we examine the energy-income nexus using a limited range of traditional econometric tools?” (Karanfil 2009). Indeed financial and technical criteria have generally prevailed, while the possibility of using a conceptual framework that encompasses sustainable energy development, such as this work proposes (see Roseland 2000, Huang et al 1995, Srivastava and Rehman 2006), has often been neglected. In fact if provision of energy is addressed from technical and financial views alone, solutions are likely to remain unsustainable and hence give little support to poverty reduction (Cherni et al 2007). In this perspective a multi-criteria approach to decision making appears to be the most appropriate tool to understand all the different perspectives involved (Kahraman and Kaya 2010).

The methodology was built in order to point out the best cooking technology for the local context according to the different impacts that such a system could have on the user. Thus, four main clusters have been investigated, structuring quantifiable indicators for financial, environmental, social and health related impacts of the use of a certain energy technology. The weight systems adopted were chosen in order to consider the features of each technology according primarily to their relevance to the local needs.

## 8.2. Materials and methods

The technological alternatives have been selected among options available on the local market or according to the household energy strategy. The ranking criteria considered were adopted in order to use quantifiable variables and representative clusters of the sector impacted at household level by the cooking energy system.

### 8.2.1. Alternatives evaluated

A number of different cooking systems were evaluated with the methodology proposed. Data collected on the field on technological options available were crossed with literature data. The next section gives a brief description of alternative chosen.

**Table 35: technological alternatives evaluated**

| | **Technological alternatives** | **Notes** |
|---|---|---|
| Traditional system | 3 stone fire | Traditional open fire, common in the study area; overall thermal efficiency assumed equal to 15% |
| Improved wood cooking stoves | Centrafricain ICS | ICS introduced by the project, composed by a metal structure with an insulating clay belt; overall thermal efficiency assumed equal to 30% |
| | Ceramic ICS | ICS introduced by the project, composed by a ceramic structure to hold the fire; overall thermal efficiency assumed equal to 20% |
| Gas stoves | LPG stove | Combination of LPG gas bottle and proper burner |
| | Biogas stove | Combination of gas burner and anaerobic digester promoted in the region by a local NGO |
| Alternative stove | *mlc* rice husk stove | Prototype proposed by the authors for the energy recovery for cooking purposes of a local available waste biomass, rice husk |
| | Solar cooker | Parabolic concentrator promoted on site by different NGOs |

#### *8.2.1.1. Traditional three stone fire*

The three stones open fire persists as the most prevalent fuel-using technology to cook the meals in the developing world. Indeed, firewood can be used for cooking even in the absence of a “stove”. Some disadvantages related to the use of the open fire are smoke, health risks, low efficiency and high fuel consumption. On the other hand, some positive effects may be welcomed by users, for example the emission of warm and light, the easiness of use, the production of smoke useful to preserve food or to chase away mosquitoes in malaria-infested areas.

#### *8.2.1.2. Improved wood cooking stoves*

As detailed in previous chapters, the use of improved cookstove (ICS) may have several positive implications. Fuel consumption reduction, better combustion process and therefore cleaner smoke emissions are the more self-evident advantages. Not all of them are perceived with the same importance by the user. Different ICS models have been promoted in several cooperation projects in developing Countries with different dissemination strategies. Local technical know-how for reproduction or sparing and user acceptance may represent risky factors or even barriers in the effective adoption by the local users. In this work two ICS stove models have been considered (see paragraph 7.2.1.1 and 7.2.1.2).

#### *8.2.1.3. Gas stoves*

The use of liquid/gaseous fuel implies a more modern, convenient and cleaner access to household energy. Actually, a number of factors affect the sustainability and acceptance of such a system as the reliability of the supply, the cost of the cooking equipment and of the fuel, the switch to new cooking practices. According to Chadian national strategy for household energy supply (AEDE 2002), LPG gas should replace traditional fuels such as wood and charcoal. In the study area some concerns in the dissemination of such a cooking system have emerged, as detailed at paragraph 7.2.1.4. In this work also the use of biogas produced by anaerobic digestion of organic waste and cow manure has been considered, being promoted by a local NGO[15]. The system, proposed by a Nigerian university, is very simple (see Figure 84).

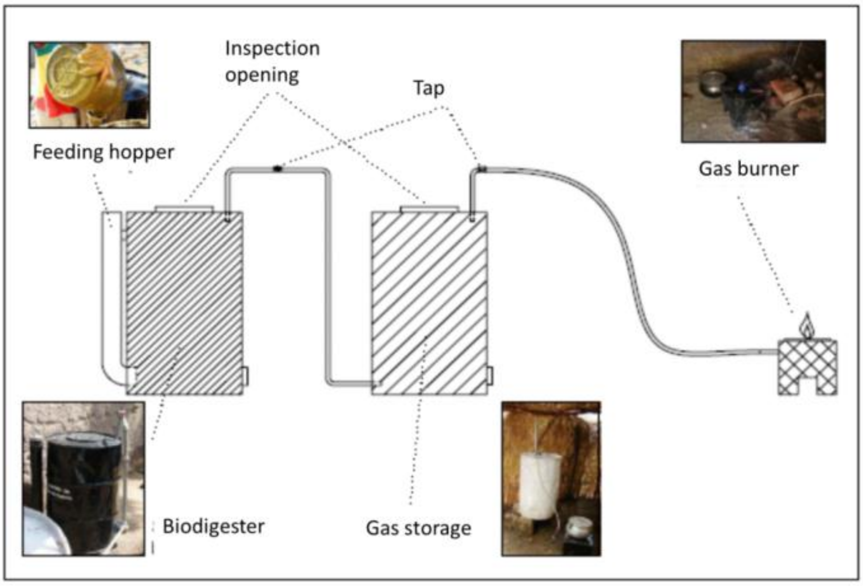



**Figure 84: conceptual scheme of the biogas system proposed by a local NGO**

The cattle manure, mixed in equal volume with water, is loaded into the first 200 L barrel, where the fermentation takes place due to the increase in temperature due to exposure to sunlight. The produced gas is then fed into the second 200 L barrel, placed inside the kitchen, where it is stored and used by means of

[15] Visit http://copres-sa.e-monsite.com

a proper burner. No technical reports on the actual performance of this system were available nor were experimental tests possible to be performed. The system is particularly suited to the local context, as it does not require extensive construction work, unlike the underground digesters, since the average temperature during the day is still mild enough to allow the biodigestion process of organic matter by anaerobic bacteria. The first barrel is painted black in order to allow rapid absorption of heat by solar radiation during the day. The bins are equipped with an opening on the top to permit inspection and within a system of drainage fund for the evacuation of the digestate.

#### 8.2.1.4. Alternative systems

Two alternative stoves have been assessed in the technology pool of this work: a rice husk stove and a parabolic solar cooker.

The *mlc* rice husk stove was designed according to a research and development pathway described in the chapter 6. The energy recovery of rice husk, a locally available waste biomass, finds a justification in the use of a renewable natural resource that has no cost, and therefore could provide especially low income classes in peri-urban areas with a cheap substation fuel for wood. In particular, the use of rice husk as the unique household fuel is an unreliable option. That is due both to the uncertain availability of sufficient quantities of such a biomass and to unverified adaptability to all local cooking practices. Some further considerations about the financial feasibility of the adoption of such a technology have been done in chapter 7. According to the model proposed in that chapter, rice husk could be used as complementary fuel together with wood.

The parabolic solar cooker is a technology whose diffusion was initially enhanced by the project, on the basis of positive experiences of other organizations operating in other parts of the country. The reflecting materials come from abroad, while the assembly is performed by specially trained local artisans. Given the obvious limitations caused by dependence on weather conditions, it can be proposed as an alternative energy source only partially substitutive for traditional fuels.

Representing both the alternative stove models a complementary cooking energy system, in the analysis they are studied together with the use of the traditional 3 stone fire or the Centrafricain improved cookstove.


**Figure 85: *mlc* rice husk stove and parabolic solar cooker**

### 8.2.2. Criteria of choice

**A number of criteria may be chosen for the assessment of different cluster contribution to the overall impact and, thus, the relative appropriateness of the household energy technology.**

Table 36 gives a not-exhaustive list of possible indicators for each feature that has to be considered in the evaluation of the appropriateness of a technology.

**Table 36: main criteria and relative impact indicators in household cooking energy technologies**

| Criteria | Indicators |
|---|---|
| Technical | • Feasibility and local technical know-how |
| | • Reliability of performances |
| | • Efficiency |
| | • Durability/Useful life of the technology |
| Environmental | • Need of waste disposal |
| | • GHG and pollutant emissions |
| | • Natural resources requirements |
| | • Renewability of the fuel used |
| | • Prevention in declines of soil fertility |
| Social-behavioural | • Social acceptance and adaptability to local cooking practices |
| | • Labour and drudgery impact |
| | • Participation of individual household members in cooking and other energy related tasks |
| | • Dis-adoption and sustained adoption rates |
| Economic | • Implementation costs |
| | • Operation & maintenance costs |
| | • Income generation opportunities (artisans) |
| | • Affordability of fuel and technology |
| | • Incidence of cooking energy expenditure on household budget |
| | • Time value |
| Political-Institutional | • Compatibility with the national energy policy objectives |
| | • Compatibility with local environmental regulation (e.g. emission limits; ban of fuel) |
| | • Presence of incentives and subsidies |
| Health | • Impact on indoor air pollution quality |
| | • Exposure to indoor air pollution |
| | • Pollutant specific biomarkers |
| | • Local incidence of IAP related diseases |
| | • DALYs due to IAP exposure |

The indicators listed have a different level of significance in describing in a comprehensive way the related aspect; at the same time different aspects influence each other with respective effects not easy to be reported in a quantitative way. Moreover, the easiness of gathering the data strongly depends to the level of the evaluation to be done (from global and national, to local, down to household level), the material barriers given by the project/action assessed (time and financial resources available, availability

and reliability of historical local data, support and collaboration of local authorities and institutions, local population active participation).
As regards the health area the estimation of DALYs due to IAP exposure is probably the most recognized and reliable indicator. Similarly local incidence of IAP related diseases and pollutant specific biomarkers are indicators that well describe the effect of a cooking technology on the users. Actually such indicators are likely to be meaningful and reliable when a proper study, based on epidemiological evidences or national or regional clinical data are available and accessible. Exposure to and quality of indoor air pollution may be used, with proper assumptions and limitations, as indirect indicators of the heath impact that a certain cooking technology may have on the user. Indeed, a safer and healthy household environment is likely to be a significant factor reducing the burden of diseases linked to an inappropriate access to cooking energy. Moreover being exposure given by the product of dose (for instance indoor air pollutant concentrations) and exposition time (i.e. the time spent in the kitchen or close to the fire), users' behaviours and the role of individual household members in cooking and other energy related tasks assume a considerable importance. Furthermore, an undesired effect registered in some cases is that the increased livelihood of indoor spaces (due to reduction of smoke thanks to the adoption of improved systems) allows people spending more time inside the house, resulting in an increased exposition time, and therefore in a neutral, if not even higher, change in total exposure to IAP. A social influence is given also by the users' acceptance and the adaptability to local cooking practices that often is difficult primarily to really understand, and even more to evaluate, due to cultural barriers. Dis-adoption and sustained adoption rates can be reliable indicators of the effective success of the dissemination of a cooking energy technology and recent technological devices allow obtaining a continuous and reliable quantification of them (Ruiz-Mercado et al 2011). Labour and drudgery impact may vary according to very local factors and social or individual perceptions: wood collection may occur not in a great burden of work in forest areas, or may be an activity not impacting the time budget of householders. Moreover even time could assume a different value according to a number of external factors such as user attitudes and priorities or local social, environmental or economic constraints. Fuel and capital costs can be seen as local fixed indicators, but once more, the actual affordability and the perceived impact of cooking energy expenditure on income budget may vary according to several peculiar conditions. The specific political strategies and policies, subsidizing (the case of national LPG or biogas programme) or banning (the case of charcoal in Chad) certain fuels or technologies, may play a key role in the feasibility of the dissemination of a cooking technology, but as demonstrate by several cases, a sustained and sustainable adoption of such systems is necessarily tied to reliability of the supply, affordability also once the subside will be removed, and user acceptance, preferences and convenience. Technical performances and their reliability during the useful lifespan of the system are aspects that influence significantly the economic feasibility and sustainability of a technology. In particular the efficiency may permit the recovery of fuels whose use would be otherwise not convenient or impossible (the case of rice husk described in the previous chapters), or the use in a more appropriate way of a traditional resource (the case of improved woodstoves in comparison to traditional open fires). A more efficient use of a resource results also in a positive environmental impact, that could be expressed by the renewability of the fuel used , or a reduced requirement of land for its production or limited emissions of GHGs due thanks to improved energy conversion and transfer processes. Also in this case, the environmental impact can be evaluated at a different scale. At global level the contribution to climate change of the emissions of PICs, including black carbon, from the household sector is considerable but may

be far from user priorities in choice of an energy system; at the same time the direct effect on local natural resources, such as community forests and fertility of agricultural soils, may convey the an awareness among users also towards the importance of environmental protection and conservation.

In this work it was not possible to evaluate and address all the listed indicators, therefore a pool of indicators was chosen according to the reliability of data available and taking into account the different influences and interconnections discussed above. Four main clusters have been considered in the building of the evaluation matrix, according to impacts assessed on the field (see chapters 4, 5 and 6). In Table 37 the quantitative indicators considered representative of the relative cluster are listed. All the criteria indicators were structured so that the lower the value obtained, the lower the negative impact. All values obtained in the evaluation matrix were normalized to the maximum of each row in order to make data homogenous and comparable.

**Table 37: criteria taken into account to select the best cooking energy system**

| Main criteria | Quantitative variable calculated |
|---|---|
| $C_1$: financial | Cooking energy expenditure |
| $C_2$: health related | Exposure to CO concentration |
| $C_3$: environmental | $CO_{2eq}$ emissions |
| $C_4$: social | Concordance with users' preferences |

#### *8.2.2.1. $C_1$ financial impact: cooking energy expenditure*

The financial impact of the use of a certain cooking technology was assessed according to economic considerations described in the previous paragraphs. Generally, this indicator is given by the sum of the capital cost for the purchase of the cooking system/s and the fuel expenditure. The indicator takes into account the useful life of the system, the overall efficiency of the combination "fuel/stove" in the provision of the net energy needed for cooking purposes and the total amount of fuel purchased. In this simple analysis no changes for the increase of fuel price or other possible evolutions of the local energy market have been taken into account.

#### *8.2.2.2. $C_2$ health impact: exposure to CO concentration*

The impact of the use of a stove on the indoor air quality was taken as indicator of the possible health consequences, even if the reduced quantity of measurement on the field and the lack of data regarding the local burden of diseases linked to the exposure to this pollution limit the completeness of this criterion. WHO (2010) suggests that the reference guideline for longer-term average concentration of carbon monoxide is the 8-hour. Thus, average 8-hour CO concentrations $\overline{CO}_{8h\,i}$ were calculated when available from field-monitoring or using a time factor calculated on the basis of the WBT outputs (see paragraph 4.3.1) for each cooking system considered. The total exposure of users $Exp_{CO}$ was calculated according to average daily cooking time $t_i$ assumed for each device on the basis of tests performed on site (see paragraph 4.3.1).

$$c_2 = exposure_{CO} = \sum_i \overline{CO}_{8h\,i} * t_i$$

### 8.2.2.3. $C_3$ environmental impact: $CO_{2\,eq}$ emissions

GHG emissions and other aspects linked to a global environmental education and sensitiveness are usually neglected. Nevertheless there is a growing debate in the scientific community about this topic and in particular about the contribution of household combustion devices to GHG emissions. Thus also these aspects have been taken into account in the evaluation. The impact on GHG emissions of switching to advanced biomass technologies and LPG is very difficult to quantify, because of the diversity of factors involved, including the particular fuels, the types of stove and whether the biomass used in replaced by new planting and that a sustainable forestry management is in place. But it is widely accepted that improved stoves and greater conversion efficiency would result in emission reductions (IEA 2010).

$CO_2$ emissions were calculated summing the emission contribution of each fuel $i$, given by the specific fuel use $F_i$ multiplying the relative emission factor $EF_i$ as show in the equation below.

$$c_3 = E_{CO_2} = \sum_i F_i * EF_i$$

### 8.2.2.4. $C_4$ social impact: concordance with users' preferences

Social impact was evaluated ranking the different stove models according to the concordance with the preferences pointed out by users (see paragraph 5.2.4.3). A qualitative score ($s_i$ ranging from 0 to 4) was assigned by the author to the following characteristics: fuel savings, charcoal production, heat conservation, good food taste, cooking speed, transportability, easiness of use, adaptability to traditional cooking practices, durability, hygiene, cleanliness and safety. The final score was given by the sum of sub-score for each characteristic, and it may be interpreted as an evaluation of the capacity of the technology to meet the users' preferences.

$$c_4 = \sum_{i=1}^{12} s_i$$

## 8.2.3. Structure of the evaluation matrix

In the analysis a normalized indicator $a_{i,j}$ was used for each technological alternative $A_j$ for each criterion $C_i$. Such indicator was found according to an interval standardization method, with the following equation:

$$a_{i,j} = {c_{i,j} - \min\{c_{i,1}, \dots, c_{i,j}\}} \Big/ {max\{c_{i,1}, \dots, c_{i,j}\} - \min\{c_{i,1}, \dots, c_{i,j}\}}$$

Scores are standardized to values between zero and one with a linear function between the absolute lowest score and the highest score, as common in this method (Bennagen et al 2005, Vogdt 1983).

Final score $S_j$ of each cooking technology analysed $A_j$ was calculated multiplying each indicator $a_{i,j}$ for the weight $w_{1,..,4}$ of the correspondent criterion $C_{1,..,4}$ as expressed by the equation below.

$$S_j = \sum_{i=1}^{4} w_i * a_{i,j}$$

The evaluation matrix was therefore structured as shown in Table 38. Weight systems considered are presented in the following paragraph.

**Table 38: evaluation matrix considered for the multi-criteria analysis**

| **Criteria** | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | **Total score** |
|---|---|---|---|---|---|---|
| **Weights** | | $w_1$ | $w_2$ | $w_3$ | $w_{i4}$ | |
| **Technological alternatives** | $A_1$ | $a_{1,1}$ | $a_{1,2}$ | $a_{1,3}$ | $a_{1,4}$ | $S_1$ |
| | $A_2$ | $a_{2,1}$ | $a_{2,2}$ | $a_{2,3}$ | $a_{2,4}$ | $S_2$ |
| | … | … | … | … | … | … |
| | $A_j$ | $a_{j,1}$ | $a_{j,2}$ | $a_{j,3}$ | $a_{j,4}$ | $S_j$ |

#### 8.2.3.1. *Weight systems and sensitiveness analysis*

The weight system is the core of this analysis. It was set in order to rank different criteria considered according to their relative importance. Being the evaluation of the appropriateness the main objective of this analysis, the weights were directly assigned to the criteria in order to address optimally the users' priorities. The weighting system was built considering the advantages of an improved cooking stove indicated by users (see paragraph 5.2.4.3), grouped according to the four clusters identified as evaluation criteria. The total score of each cluster, expressed as share of the total number of points assigned, was taken as indicator of the users' priorities, and, thus, as value of the relative weight in the analysis. Analysis outputs were compared to those obtained varying the weights according to three different perspectives.

- A "flat" system (the same weight assigned to all the criteria).
- A system structured according to the priorities set by a pool of experts in the sector. In order to structure this second weight system a number of structured interviews were proposed to researchers and people involved in the household energy sector. The people interviewed were asked to assign a total amount of 100 points to the positive features of an improved cooking system. Annex 5 reports the form used for the e-survey.
- A system structured in order to take into account the point of view of the international scientific community. A review of the literature works, matching the word "cookstove" in their title or key-words, published between 2009 and 2011 was done on the ISI Web of Knowledge[16] database. If the topic or the aspects discussed in the paper matched, a point was assigned to clusters considered in this analysis. The final weight system was given to each cluster as a share of the total sum of points assigned. Annex 5 reports the full list of papers considered and the relative score assigned to each cluster.

## 8.3. Results

In this section all the steps for the calculation of the indicators $a_{i,j}$ used as inputs for the analysis are presented. The use of alternative stoves (*mlc* rice husk and solar cooker) is assumed not to fully cover the total energy needs; thus, in the calculations it covers only 33% of the total. The other 66% is covered by

[16] http://apps.webofknowledge.com

traditional device (three stone fire) or by the Centrafricain ICS. The Centrafricain ICS was taken as reference improved technology, given its successful dissemination on site already stated (as detailed in the chapter 5). Table 39 sums up the main characteristics of alternatives analysed.

**Table 39: technological alternatives analysed and relative assumptions for the calculations**

| Technological alternative $A_j$ | Description | Overall efficiency | Energy source |
|---|---|---|---|
| 3sf | Traditional 3 stone fire | 15% | Wood |
| Centrafricain ICS | Improved cooking stove | 30% | Wood |
| *mlc* (+3sf*) | Alternative fuel cooking stove with traditional three stone fire | 20% | Rice husk (33%) + wood (66%) |
| *mlc* (+Centr. ICS*) | Alternative fuel cooking stove with Centrafricain ICS | 20% | Rice husk (33%) + wood (66%) |
| LPG | Gas stove | 50-60% | LPG |
| Biodigester | Biogas stove | na | Biogas |
| Solar (+3sf*) | Solar cooker with traditional three stone fire | na | Sun (33%) + wood (66%) |
| Solar (+Centr. ICS*) | Solar cooker with Centrafricain ICS | na | Sun (33%) + wood (66%) |
| Ceramic ICS | Improved cooking stove | 20% | Wood |

* Alternative stoves covers 33% the total energy needs; the other 66% is covered by the woodstove indicated in brackets

## 8.3.1. Criteria indicators

### 8.3.1.1. $C_1$ financial impact: cooking energy expenditure

Cooking energy expenditure for a 1 year period was calculated for all the technological options, as reported in Table 40. Capital costs reported were observed on site. The solar cooker and the biodigester occur in very high capital costs: that is caused by the costs of the materials needed for the construction that are difficult to find in the local market or are imported. In particular despite the simplicity of the biodigester system, the cost of the plant is about 300,000 CFA francs: materials for construction are imported from Nigeria and this inevitably affects the final price. 80,000 CFA francs was the price subsidized by some local NGOs in the country for the promotion of the parabolic solar cooker; actually a higher capital cost is likely to occur. The capital cost of *mlc* rice husk stove was assumed to be 7,000 CFA francs, according to price observed on site for the materials required for the construction. Straight line depreciation method was used to calculate the depreciation expenses for the reference year, taking into account the useful life of each technology.

Fuel expenditure was calculated for a typical household (family size = 9 members). Daily fuel consumption was considered for the technologies considered according to tests performed on site (see chapter 5). For alternative systems, the fuel purchased quantity was reduced by the share covered by the use of other energy sources (rice husk as a waste biomass and solar energy), which have been considered for free. Also for the biodigester the fuel cost was assumed null, considering the system fed with organic waste and cow manure available free of cost for the household adopting such a system. Missing the experimental data about LPG consumption, the minimum standard suggested by Practical action (2011, see Table 1) for such a fuel was considered. According to analysis done, the three stone fire and the LPG stove with a very close value, occur in the highest cooking energy expenditure per year. The use of improved cooking stove, in particular the Centrafricain model, allows a significant reduction of cooking energy expenditure, as already discussed in previous chapters. It is less convenient the adoption of ICS with a lower overall efficiency, such as the Ceramic model. The adoption of alternative systems results more financially convenient only if partnered with the use of ICS. The best indicator is observed for the biodigester, even if some concerns remain about the effective possibility of implementation on a large scale.

**Table 40: calculation of the financial indicators**

| **Technological alternative $\mathbf{A_j}$** | **Investment cost** | | | **Fuel cost** | | | **Cooking energy cost** | $a_{j,1}$ |
|---|---|---|---|---|---|---|---|---|
| | Capital costs | Useful life | Depreciation expenses | Fuel use | Fuel cost | Fuel expenditure | | |
| | *CFA f* | *years* | *CFA f /y* | *kg/d pp* | *CFA f / kg* | *CFA f/ y HH* | *CFA f/ y HH* | - |
| 3sf | 0 | - | 0 | 1.15 | 35 | 102,839 | 102,839 | 1.00 |
| Centrafricain ICS | 6,000 | 2 | 3,000 | 0.55 | 35 | 49,184 | 52,184 | 0.22 |
| mlc (+3sf*) | 7,000 (+0) | 2 | 3,500 | 0.76 | 35 | 67,874 | 71,374 | 0.52 |
| mlc (+Centr. ICS*) | 7,000 (+6000) | 2 (+2) | 6,500 | 0.36 | 35 | 32,461 | 38,961 | 0.02 |
| LPG | 8,000 | 5 | 1,600 | 0.04 | 980 | 100,156 | 101,756 | 0.98 |
| Biodigester | 300,000 | 8 | 37,500 | 0 | 0 | 0 | 37,500 | 0.00 |
| Solar (+3sf*) | 80,000 (+0) | 10 | 8,000 | 0.76 | 35 | 67,874 | 75,874 | 0.59 |
| Solar (+Centr. ICS*) | 80,000 (+6000) | 10 (+2) | 9,980 | 0.36 | 35 | 32,461 | 42,441 | 0.08 |
| Ceramic ICS | 1,500 | 0,5 | 3,000 | 0.82 | 35 | 73,776 | 76,776 | 0.60 |

*the alternative system is assumed to cover 33% of the total energy need. The other 66% is covered by wood technologies.

#### 8.3.1.2. $C_2$ health impact: exposure to CO indoor concentration

Exposure to carbon monoxide indoor concentration was taken as indirect health impact indicator. CO indoor concentrations for the three stone fire and the Centrafricain ICS were measured on site (see paragraph 5.2.2). Gas stoves and alternatives systems are supposed to have very low pollutant emissions. In particular the effectiveness of the withdrawal of smokes through the chimney of the *mlc* rice husk burner was confirmed by apposite measurement taken during the laboratory tests; according to results reported in paragraph 6.3.2.4 the average CO concentration associated to the use of *mlc* rice husk stove was taken equal to 4 ppm. Concentrations associated to the alternatives including more than one technology were calculated as a weighted sum of the specific concentration values according to the share of energy need covered by the relative source.

An average daily cooking time of 4 hours was observed on site in household using the Centrafricain ICS. Other cooking time were calculated proportionally using a time factor calculated on the basis of WBT results (see paragraph 4.3.1).

As shown in Table 41 gas stoves are the best performing options according to this criterion, with an estimated exposure to CO significantly lower than other wood based energy technologies.

**Table 41: calculation of the health impact related indicator**

| Technological alternative $A_j$ | CO average concentration | Time factor | Daily cooking time | Exposure | $a_{j,2}$ |
|---|---|---|---|---|---|
| | ppm | - | h/d | | - |
| 3sf | 16 | 1.00 | 4.0 | 62.4 | 1.00 |
| Centrafricain ICS | 12 | 0.95 | 3.8 | 45.6 | 0.69 |
| mlc (+3sf*) | (4)+ 11 | 1.17 | 4.7 | 51.1 | 0.79 |
| mlc (+Centr. ICS*) | (4)+ 9 | 1.13 | 4.5 | 39.9 | 0.59 |
| LPG | 2 | 1.00 | 4.0 | 8.0 | 0.00 |
| Biodigester | 2 | 1.00 | 4.0 | 8.0 | 0.00 |
| Solar (+3sf*) | (0)+ 9 | 1.17 | 4.7 | 43.7 | 0.66 |
| Solar (+Centr. ICS*) | (0)+ 7 | 1.13 | 4.5 | 32.6 | 0.45 |
| Ceramic ICS | 14 | 0.90 | 3.6 | 51.8 | 0.81 |

*the alternative system is assumed to cover 33% of the total energy need. The other 66% is covered by wood technologies; + in brackets the values of CO concentration assumed for the alternative system

### 8.3.1.3. $C_3$ environmental impact: $CO_{2\,eq}$ emissions

$CO_2$ emissions were calculated summing the emission contribution of each fuel used multiplied for the relative emission factor. Emission factors considered where taken from Johnson et al (2009) both for wood open fire and LPG. No field measurements were possible for the ICS and the *mlc* rice husk stove, thus the same emission factor than wood open fire was taken. Such a choice is acceptable as similar $CO_2$ emission values have been reported by the same work by Johnson et al (2009) and other literature studies (Bailis et al 2003, Bhattacharya et al 2002) for open fire and improved wood stove with or without chimney. While wood was not considered a renewable resource for the purposes of this analysis, due to the current unsustainable management as explained in paragraph 5.2.3.1, rice husk was considered carbon neutral. Furthermore open burning of rice husk is currently a common practice in the rural areas, thus the energy recovery of such a biomass as alternative fuel does not add further emissions. Biogas emission factor was considered the same of LPG.

Table 42 shows the calculations for indicator $a_{j,3}$. The three stone fire results the most environmental impacting energy technology. Alternative systems, even if based on totally renewable resources, are not the best performing under this point of view, being complementary in the household energy mix to wood based technologies. Gas based systems have the best indicators, resulting in a magnitude lower amount of emissions than other energy technologies.

**Table 42: calculation of the environmental indicator**

| Technological alternative $A_j$ | Wood fuel used | Emission factor | Other fuel use | Emission factor | Total emission | $a_{j,3}$ |
|---|---|---|---|---|---|---|
| | kg/d | $gCO_{2eq}$/kg | kg/d | $gCO_{2eq}$/kg | $tonCO_2$/ y HH | - |
| 3sf | 1.15 | 1.85 | 0 | - | 5.4 | 1.00 |
| Centrafricain ICS | 0.55 | 1.85 | 0 | - | 2.6 | 0.44 |
| *mlc* (+3sf*) | 0.76 | 1.85 | 0 (1.4) | 0 | 3.6 | 0.64 |
| *mlc* (+Centr. ICS*) | 0.36 | 1.85 | 0 (1.4) | 0 | 1.7 | 0.27 |
| LPG | 0 | - | 0.04 | 3.34 | 0.3 | 0.00 |
| Biodigester | 0 | - | 0.04 | 3.34[+] | 0.3 | 0.00 |
| Solar (+3sf*) | 0.76 | 1.85 | 0 | - | 3.6 | 0.64 |
| Solar (+Centr. ICS*) | 0.36 | 1.85 | 0 | - | 1.7 | 0.27 |
| Ceramic ICS | 0.82 | 1.85 | 0 | - | 3.9 | 0.70 |

*the alternative system is assumed to cover 33% of the total energy need. The other 66% is covered by wood technologies; [+] data not available, thus the same of LPG was adopted

### *8.3.1.4. $C_4$ social impact: concordance with users' preferences*

Social impact was evaluated ranking the different stove models according to the concordance with the preferences pointed out by users. A qualitative score was assigned to the characteristics indicated in Table 43. Alternative systems, including biodigester, results the farthest options from the users' preferences. In particular it was observed that women did not appreciated the use of solar cookers as this technology requires to be used in an open space, depriving them of their own private space in the kitchen. The *mlc* rice husk burner, even if not practically disseminated on site, is supposed not to be so easily used due to the specific operation mode (batch system). LPG, although not being widely disseminated on site, well matches some users' preferences. On the contrary, local householders recognize several disadvantages and negative constraints in the usage of the traditional three stone fire. These features of such technologies are well caught by the score structured for the analysis purposes.

**Table 43: calculation of the social indicator**

| | Fuel savings | Charcoal production | Heat conservation | Good food taste | Cooking speed | Transportability | Easiness of use | Adaptability to cooking practice | Durability | Hygiene | Cleanliness | Safety | Users' preferences matching score* | $a_{j,4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3sf | 4 | 2 | 3 | 0 | 2 | 0 | 1 | 0 | 0 | 4 | 4 | 3 | 23/48 | 0.25 |
| Centrafricain ICS | 1 | 1 | 0 | 1 | 2 | 2 | 1 | 0 | 1 | 3 | 4 | 3 | 19/48 | 0.00 |
| *mlc* (+3sf*) | 2 | 3 | 1 | 2 | 3 | 4 | 3 | 2 | 2 | 2 | 4 | 1 | 29/48 | 0.63 |
| *mlc* (+Centr. ICS*) | 0 | 2 | 0 | 2 | 2 | 4 | 3 | 3 | 2 | 1 | 4 | 1 | 24/48 | 0.31 |
| LPG | 4 | 4 | 4 | 4 | 0 | 2 | 2 | 3 | 1 | 0 | 0 | 2 | 26/48 | 0.44 |
| Biodigester | 0 | 4 | 4 | 4 | 0 | 4 | 3 | 3 | 1 | 3 | 3 | 2 | 31/48 | 0.75 |
| Solar (+3sf*) | 2 | 3 | 3 | 4 | 4 | 4 | 3 | 4 | 2 | 2 | 1 | 3 | 35/48 | 1.00 |
| Solar (+Centr. ICS*) | 1 | 2 | 3 | 4 | 4 | 4 | 2 | 4 | 2 | 2 | 1 | 2 | 31/48 | 0.75 |
| Ceramic ICS | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 3 | 3 | 3 | 2 | 22/48 | 0.19 |

* the lower the value the better the users' preferences are meet

#### 8.3.1.5. Evaluation matrix

Table 44 sums up the values of indicators calculated for the technological alternatives analysed according to different criteria taken into account.

**Table 44: evaluation matrix for technological alternatives $A_j$ and criteria $C_i$**

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|
| | **Financial impact** | **Health impact** | **Environmental impact** | **Social impact** |
| 3sf | 1.00 | 1.00 | 1.00 | 0.25 |
| Centrafricain ICS | 0.22 | 0.69 | 0.44 | 0.00 |
| *mlc* (+3sf) | 0.52 | 0.79 | 0.64 | 0.63 |
| *mlc* (+Centr. ICS) | 0.02 | 0.59 | 0.27 | 0.31 |
| LPG | 0.98 | 0.00 | 0.00 | 0.44 |
| Biodigester | 0.00 | 0.00 | 0.00 | 0.75 |
| Solar (+3sf) | 0.59 | 0.66 | 0.64 | 1.00 |
| Solar (+Centr. ICS) | 0.08 | 0.45 | 0.27 | 0.75 |
| Ceramic ICS | 0.60 | 0.81 | 0.70 | 0.19 |

### 8.3.2. Weight systems adopted

The aim of this analysis was to assess the appropriateness of an energy technology to the local context studied. Thus, the weight system was structured in order to address in the best way the priorities perceived by householders. Indeed householders are the stakeholders in charge of the choice and of the sustained adoption of an energy technology. Besides the technical and financial factors, the behaviours and the perceptions of the users play a key role in the success of the dissemination of a certain cooking system.

Advantages of an improved cooking stove pointed out by users (see paragraph 5.2.4.3) were grouped in the four main clusters identified as evaluation criteria. This choice reflects the strict point of view of the users, thus, a sensitiveness analysis was implemented, according to other weight systems, whose values are reported in Table 45.

**Table 45: different weight system considered**

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|
| | financial | health related | environmental | social |
| Flat system | 0.25 | 0.25 | 0.25 | 0.25 |
| Users' priorities | 0.49 | 0.10 | 0.00 | 0.41 |
| Experts' priorities | 0.21 | 0.24 | 0.30 | 0.25 |
| International literature 2009-2011 | 0.23 | 0.37 | 0.19 | 0.21 |

The different weight systems are illustrated also in Figure 86, which well describes the different perceptions of the local users in comparison with the ones of the group of ten Italian experts involved in the survey. The recent community research interest is focusing on environmental and health related aspects of the use of improved stoves, while users' priorities shift towards aspects related to the adaptability to local traditional practices and financial savings.

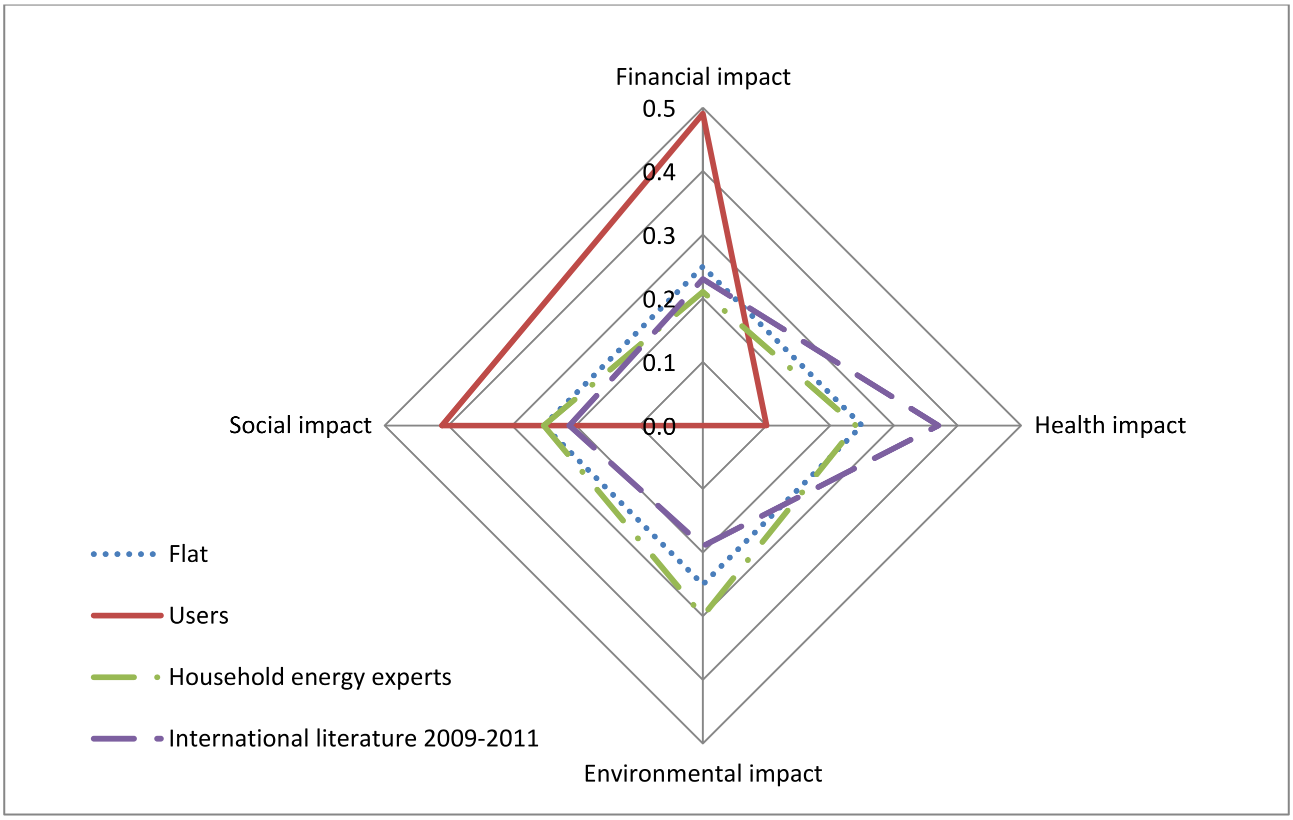



**Figure 86: different weight systems considered**

### 8.3.3. Assessment of appropriateness

Evaluation matrix (reported in Table 44) was crossed with different weight systems adopted in order to assess the overall impact in the local context of different technologies analysed. Multi-criteria analysis outputs are reported in Figure 87.

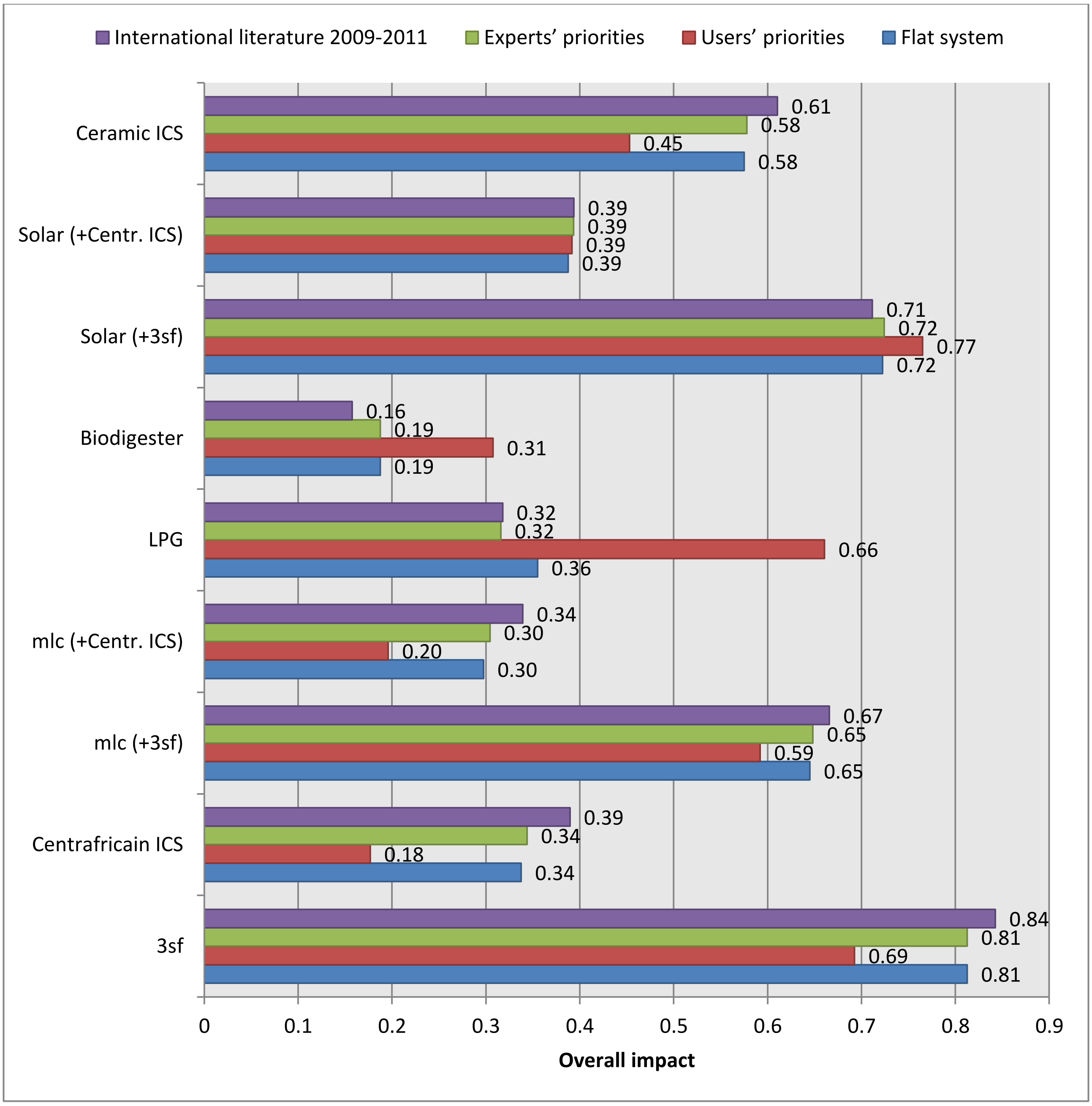



**Figure 87: appropriateness assessment according to different weight system considered in the multi-criteria analysis**

The alternatives obtaining the lowest values, and thus resulting preferable according to the criteria set, are the biodigester, the Centrafricain ICS and the combination of this last option with alternative systems. While uncertainty may affect these results for the biodigester option due to assumptions done in the calculations, the outputs of the analysis underline the appropriateness of the Centrafricain ICS for the local context, in particular according to users' priorities. Also the introduction of *mlc* rice husk stove is likely to meet in an appropriate way the users' preferences. The use of the three stone fire results the worst options according all the weight systems, and it influence negatively also the adoption of the alternative systems. LPG results to be a good option according to the experts' weight system, mainly due to the reduced impact on environment and health. On the contrary in the users' preference set, it results very far from the most appropriate technologies, as proven by the scarce dissemination of this cooking system in the local context.

A further sensitiveness analysis was performed excluding each time a single criterion. Thus, the total score of each cooking technology considered was re-calculated subtracting each time one out of the four criteria considered. The outputs of the analysis are reported in Figure 88.

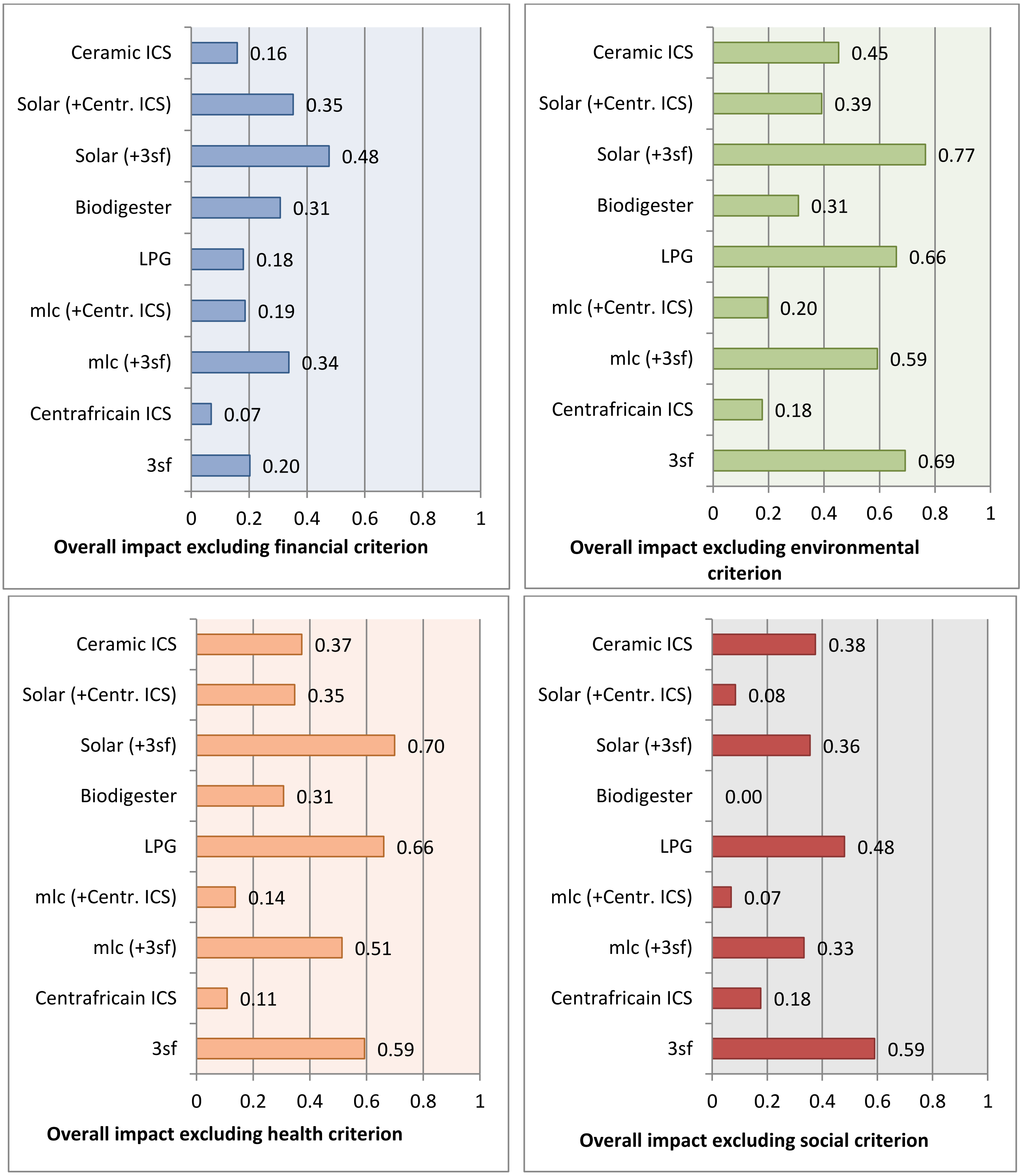



**Figure 88: appropriateness assessment excluding different criteria considered**

Excluding the financial criterion, it is clearer that the Centrafricain ICS matches in a better way the users' priorities, and it results the best option according to that weight system. In this case the biodigester option loses rank among the most appropriate technologies, resulting in a higher negative impact. LPG stove, *mlc* stove and Ceramic ICS occur in a score closer to the one of three stone fire. That may justify the scarce success verified in the dissemination of such energy options in the local context, in particular in the rural context. LPG is more affordable and appropriate in urban areas, where wood fuel is currently purchased. However, for many rural consumers who do not participate in the monetized economy, it will be premature to promote technologies that do not improve significantly the energy access and have not perceived advantages for them in comparison with traditional systems.

The use of the Centrafricain ICS alone or in combination with the *mlc* stove is the most appropriate option excluding the environmental aspect. LPG or alternative energy sources (solar and waste biomass) result in a similar final score to 3 stone fire, while other solutions, such as the biodigester or the Ceramic ICS are slightly more convenient. Similar considerations can be done also excluding the heath aspect.

The exclusion of the social criterion (and therefore the preferences expressed by the users) highlights that promising technologies, which are often promoted by cooperation intervention (such as biodigesters, solar devices and alternative fuel systems), obtain the best scores.

Some overall considerations can be drawn from Figure 89 that reports the sensitiveness range of the appropriateness score for each technology considered excluding the different criteria.

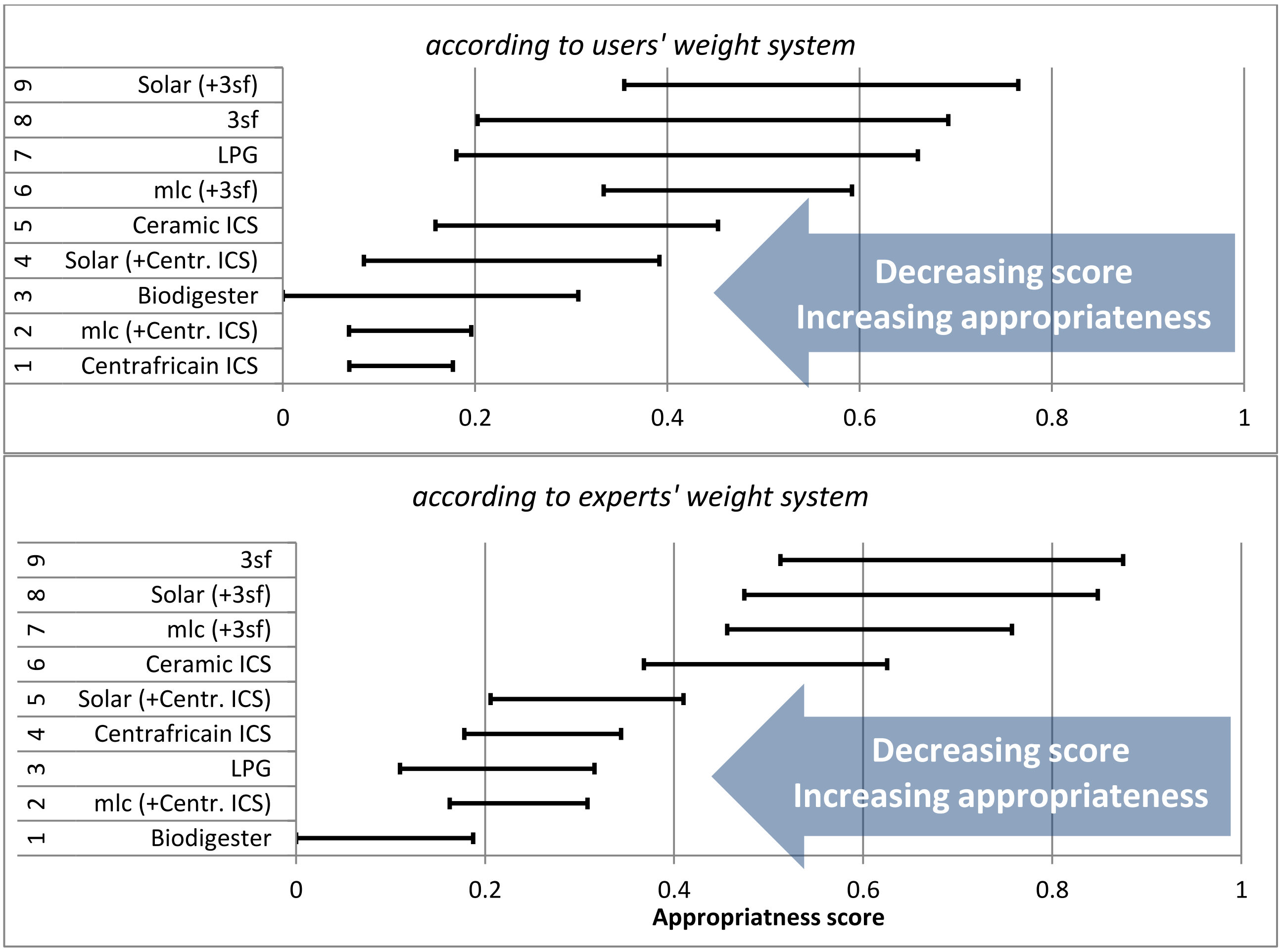



**Figure 89: appropriateness score ranking of cooking technologies considered according to users' and experts' weight systems**

The main observation is that the Centrafricain stove (and its eventual combined use with the *mlc* stove) is the only cooking technology whose range does not overlap the one of three stone fire. That may indicate that these technologies are generally more appropriate than the current traditional cooking system, and therefore are the more promising for a successful dissemination on site. Other technologies may incur in failure or not full acceptance by the users for a number of factors that affect their appropriateness in comparison to the traditional three stone fire. That is confirmed by observations on the field, in particular for the Centrafricain ICS, which is often adopted in a sustained way by users whose basic needs were met by such a simple, but effective, improved stove. On the other side the use of the solar cooker was often given up, due to the barriers given by the conflicts with the social requirements of cooking women and by the intrinsic limited use, in particular if not associated to another improved system. Systems such as the LPG stoves or the Ceramic ICS have been promoted on site with variable outcomes. That is due to specific local (for instance, an easy access to wood for free in the rural areas) or user-dependent factors (such as individual preferences, financial capacities) and it is well expressed by their ranges of appropriateness score overlapping with the one of the tree stone fire. The adoption of anaerobic digestion results to be a promising option, even if its appropriateness to the local context may incur in different issues that have to be further assessed. LPG is the technological option with the more evident change in rank according to the two different weight systems. The high local costs and the reduced perception of its advantages (mainly related to low air quality impacts, both in terms of environmental and users' health aspects) by local population make this option among the less preferred. On the other hand it is ranked as one of the most valuable options according the analysis taking into account the experts' weight system. This is an indication to be taken in serious account, in particular by decision makers developing household energy strategies at national or regional level. Modern fuels, which have a number of convenient and note advantages, are not always supposed to be the most appropriate solution, as they have to face issues of affordability and acceptability by the local specific users, which are the key stakeholders in the adoption process. Even if their adoption is desirable at a larger scale in the developing world, as already discussed in the first chapter of this thesis, the vast majority of people will go on relying on traditional solid fuels in the next future. Therefore, according to specific local conditions to be considered from case to case, the dissemination of more effective and improved biomass cooking system is likely to be a more appropriate solution for household energy access in these contexts.

## 8.4. Conclusions

The choice of an appropriate technology for cooking energy is extremely influenced by a number of factors of different nature. The methodology adopted in this work was built in order to point out the best cooking technology for the local context according to the different impacts that such a system could have on the user. Thus, four main clusters have been investigated, structuring quantifiable indicators for financial, environmental, social and health related impacts of the use of a certain energy technology. The range of alternatives and criteria adopted is not exhaustive of the complexity of the energy access at household level but tries to give a wide and comprehensive view of the issue. The weight systems adopted were chosen in order to consider the features of each technology according primarily to their relevance to the local needs and the users' perceptions, which inevitably address their choices. A sensitiveness analysis taking into account a weight system based on priorities listed by a group of energy experts marked some relevant differences between the point of view on people working in the sector and that of people supposed to adopt and use daily the technology. In particular the recent community research interest is focusing on environmental and health related aspects of the use of improved stoves. These are certainly important, but do not seem likely to be the more appropriate drivers to promote a cooking technology. Transferring appropriate environmentally sound technologies and ensuring their effective implementation can help arrest the growth in the greenhouse gas emissions from developing countries. However, past experiences indicate that, to be successful, the technologies being transferred have to match certain requirements of the DC (Ramanathan 2002). A shared and appropriate set of priorities should be achieved by one side through awareness and education of local population on environmental and health protection, so that also negative impacts related to this clusters could by effectively perceived by the direct users. By the other side friendly usage, adaptability to local cooking practices and reliability of fuel and technologies are aspects that should not be neglected but drive the design of a new cooking system. Also policies and national energy strategies that play a fundamental role in the dissemination should address these aspects. A tool like the one proposed in this work, opportunely adapted with local inputs, could be useful for decision makers, supporting the choice of an appropriate cooking technology for a certain context.

# Summary of results and conclusions

Energy is one of the basic requirements of human societies. It is vital for human life and for technological advancement. In general energy can contribute to widening opportunities and empower people to exercise choices. Energy poverty is related to the absence of sufficient choice in accessing adequate, affordable, high-quality, safe and environmentally benign energy services to support economic and human development (UNDP & WEC 2004). Without access to efficient and affordable energy sources, people living in poor conditions have very limited opportunities for economic and social advancement. International Energy Agency (2011) estimates that 1.3 billion people – over 19% of the global population – lack access to electricity and about 2.7 billion people – some 40% of the global population – rely on the traditional use of solid biomass for cooking. This number is higher than previously estimated by IEA (2008) due to population growth, rising liquid fuel costs and the global economic recession, which have driven a number of people back to using traditional solid biomass.

The use of traditional solid fuels leads to a number of dramatic impacts not only on the users but also for the environment. In order to gather the fuel required for their daily energy needs, householders have to cover every day longer distances (carrying heavy loads) or invest a significant share of their budget to purchase it in the local market. Besides wasting a resource (for which a lot of drudgery or money were spent), the use of solid fuels on open fires or inefficient stoves results in a range of health-damaging pollutant emission, often under conditions of poor household ventilation (Refhuess et al 2011). Women and young children, who usually spend many hours close to the smoky source, are the most exposed. Such emissions have also significant global warming effects, due to incomplete combustion of fuel carbon. Moreover, the unsustainable overexploitation of natural resources leads to their faster depletion. Often (where existing) national household energy policies and strategies do not have the capacity to effectively target an adequate diffused energy access, chasing the hope to switch to more modern and clean fuels, like LPG, and missing meeting the financial capacities and the needs of the population. Thus, especially for the weakest income classes, energy poverty seems to be a no-way-out situation: by the one side they have no financial means to step up their own energy condition, accessing the use of more convenient, cleaner and modern fuels. By the other side, the limited energy level provides them with no emancipation means, both to improve their quality of life and to eventually start a small income generating activity.

Appropriate technologies play a key role in breaking this vicious circle, providing with the intermediate solutions to escape from this limiting condition. Actually there are many technology options to use traditional fuels more efficiently. The suitability of the existing improved technologies depends on factors such as availability, applicability, acceptability and affordability, including access to finance to cover initial investments. The decreasing availability of existing sources of fuel makes switching to modern alternatives a necessity in some places. In some others, the inconsistence of a market not supported by realistic political energy strategies makes unaffordable for most of the people gaining access to more appropriate fuels, getting back to traditional cheaper fuels. According to these aspects, and to the estimated increasing number of people relying on biomass for cooking purposes in the next future, the adoption of improved technologies, which allow to use even poor fuels, but in a convenient, cleaner and more efficient manner, appears to be a viable way to walk to reach the goal of minimum energy access for the poor.

The approach adopted in this work is strongly influenced by the considerations done here above. A specific context, the Logone Valley at the border between Chad and Cameroun, was the one where field observations and activities were implemented. The research leans on the activities of an international development cooperation project (ENV/2006/114-747) implemented by the Italian NGO ACRA and funded by the EU. At the beginning of the project (2008), in the intervention region charcoal and wood were the traditional fuels for household energy supply. Only in urban areas some high income families used to cook with LPG gas. Charcoal production and sale have been forbidden by the Chadian national government since 2009. This had a shocking effect on local wood prices that more than doubled, from 15 CFA francs /kg in 2008 to 35 CFA francs /kg in 2010. The project aimed at the reduction of wood consumption at household level. The dissemination of low-technology but high-efficiency models was implemented according to the socio-economic conditions of the local people (minimal investment capacity due to the very low level of income) and of the skills and the tools available for small local workshops (in particular the lack of electricity impacting in basic manufacturing capabilities).

A number of tests were conducted on site to evaluate which stove model, in combination with proper fuel, would be suitable for the dissemination among the local population. Stove models were chosen among traditional and improved stoves already available in the region and tested following international recognized standard protocols (Water Boiling Test and Controlled Cooking Tests). The two models chosen for the dissemination (through the training of local artisan) were the Ceramic and the Centrafricain effective improved cookstoves. Both of them were selected not only for their good (but not “best” compared to advanced improved cookstove) performances, but mainly for the appropriateness to the local contest in terms of acceptability by the users and suitability to the local technical manufacturing skills. Result based impact assessment was done by means of a number of surveys both quantitative (Kitchen Performance Test, Indoor Air Pollution monitoring, $CO_2$ avoided emissions estimations) and qualitative (interviews, observations). Increasing adoption rates (more than 3,500 units sold at March 2011) and appreciation by the users indicate the appropriateness of the stove model proposed by the project to the local context. Fuel consumption reduction (-55% for the Centrafricain ICS in comparison with the traditional three stone fire) and adaptability to the local cooking practices are the main features that the users indicates as strengthens of the technology. These aspects have been fundamental for the successful scaling-up of the Centrafricain stove.

A parallel activity done was the experimentation of a new stove design. The input was given by the local availability of a waste biomass, rice husk, which was thought to be recoverable as an alternative fuel to wood for household energy supply. In full collaboration with DIMI a proper stove was designed and tested to recover such a biomass. The crude-earth brick stove is equipped with a chimney and an internal bi-cylindrical metal-net reactor to contain the fuel. Such a lay-out allows a mix of combustion/gasification of the biomass occurring in a completely burning fire, appropriate for cooking tasks. A rigorous Research & Development pathway was implemented in order to investigate in detail the operation of the stove, resulting in a final configuration with very good and reliable performances (average efficiency 18%, low indoor and environmental emission of pollutants). The stove has not been disseminated on site yet. Nevertheless, the design of the prototype was always driven by local inputs. Not only technical aspects such as the material availability or the local artisan skills were considered, but aspects such as the adaptability to local cooking practices, the sustainability and the acceptance by users were addressed. According to the outputs of a simple economic model elaborated *ad hoc*, the introduction of the *mlc* rice husk stove in the cooking energy system of a household resulted economically sustainable. All the scenarios elaborated show how the rice husk stove adoption would reduce significantly the household fuel expenditure, within the limits of the local availability of such a biomass. The use of the technology proposed in combination with improved woodstove would provide householders with an appropriate and convenient cooking technology pool, increasing the opportunities of choice of the preferred energy system for the user. That results even more important considering the increasing wood fuel price observed on site that may affect negatively the advantages related to the use of the only improved wood stoves.

A final multi-criteria analysis assesses the appropriateness of the technologies studied providing with a global overview of the results obtained in different activities. The analysis structure was built in order to point out the best cooking technology for the local context according to the different impacts that such a system is supposed to have on the user. Thus, four main clusters have been investigated, structuring quantifiable indicators for financial, environmental, social and health related impacts of the use of a certain energy technology. The weight systems adopted were chosen in order to consider the features of each technology according primarily to their relevance to the local needs. A sensitiveness analysis taking into account a weight system based on priorities listed by a group of energy experts marked some differences between the point of view on people working in the sector and that one of people supposed to adopt and use daily the technology. A shared and appropriate set of priorities should be achieved by one side through awareness and education of local population on environmental and health protection, so that also negative impacts related to these clusters could be effectively perceived by the direct users. By the other side friendly usage, adaptability to local cooking practices and reliability of fuel and technologies are aspects that should not be neglected but they should drive the design of a new cooking system.

The analysis done in this work allows drafting some general final considerations. The traditional "energy ladder", like any such general model, is likely to provide only a limited view of reality in actual households (Masera et al 2000). Due to the failures of the linear energy ladder to describe adequately the fuel use dynamics in several cases, a "multiple fuel" model appears more appropriate. The wide range of new cooking technologies available has a great potential to make use of a variety of biomass residues that are difficult to burn cleanly in conventional stoves. In many places in the developing world wood is still the most preferred fuel, due to traditional habits and social rooted practices, even if the physical drudgery and time losses related to the collection activity or the financial impact on household budget is very high, and often increasing day by day. At the same time in the same areas where charcoal and firewood are becoming a scarce and/or an expensive resource, innovative systems, like micro-gasifiers or alternative fuel stoves will be of growing relevance as an option to cleanly burn biomass fuels. Making available these new technologies, promoting the research and finding the more appropriate and local tailored scaling-up strategies could help practically people living in energy poverty to escape from their miserable condition, gaining access to a wider energy technology portfolio. The adoption of a variety of combinations of affordable, reliable, convenient and clean cooking systems based on a multiple-fuel supply, could further protect low income population who are the most exposed to fuel price shocks. That would define a new comprehensive and "higher" first step in the classical view of the energy ladder, defining a new "flatter" energy ladder (Figure 90). Indeed new technologies available may reduce significantly the gap in adequate access to cooking energy between low- and high-income classes and achieve an efficient (not only effective) use of biomass at the level of the more modern fuels.

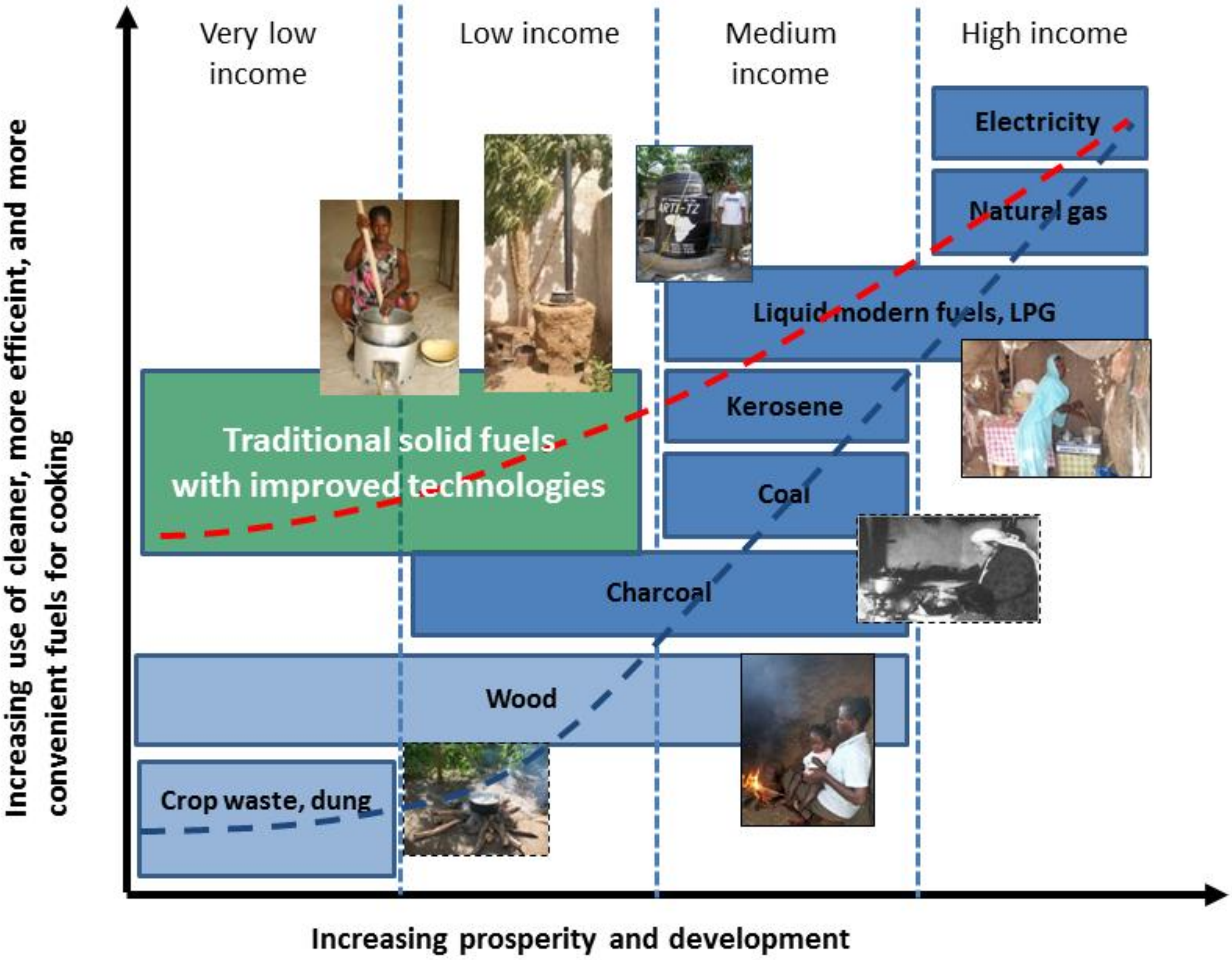



**Figure 90: definition of a "new" energy ladder. Comparison between the conventional one and the one proposed by this work.**

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# Website visited

| | |
|---|---|
| Bioenergy list | http://www.bioenergylists.org/ |
| Fuoco Perfetto (Perfet fire) | http://fuocoperfetto.altervista.org/ |
| Global Alliance for Clean Cookstoves | http://cleancookstoves.org/ |
| Household energy network | http://www.hedon.info/ |
| International Energy Agency | http://www.iea.org/ |
| International Rice Research Institute | http://www.knowledgebank.irri.org |
| Partnership for Clean Indoor Air | http://www.pciaonline.org/ |
| Practical Action | http://practicalaction.org/ |
| World Health Organization | http://www.who.int/ |

# Annexes

## Annexes 1: household energy survey form

| | | | | |
|---|---|---|---|---|
| **Enquête sur l'accès à l'énergie domestique**<br>Vallée du Logone (Tchad – Cameroun) | | | | |
| ***0*** | ***Identification*** | | | |
| | Localité | | Questionnaire n° | Date |

| | | | | |
|---|---|---|---|---|
| ***1*** | ***Caractérisation du ménage*** | | | |
| 1.a | Personne responsable préparation repas | ---------------------------------- | Chef du ménage | ------------------------------------- |
| | Occupation | | Occupation | |
| | Scolarisation | □ Aucune □ Primaire □Secondaire □Supérieur | Scolarisation | □ Aucune □ Primaire □Secondaire □ Supérieur |

| | | |
|---|---|---|
| 1.b | Nombre des personnes dans le ménage | Nombre total : |
| | Enfants qui ne travaillant pas (<14 ans) | |
| | Femmes adultes (>14ans) | |
| | Hommes adultes (>14ans) | |

| | | | | |
|---|---|---|---|---|
| 1.c | Revenu moyen (disponibilité d'argent) | (francs/mois) | | |
| | Niveau du revenu | *En alternative* | □ Subsistance □ Bas □ Moyen □ Haut | |
| | Principal activité génératrice de revenue | | | |
| | Production agricole (sacs/année) | | Mil | (prix par sac ____________________) |
| | | | Arachide | (prix par sac ____________________) |
| | | | | (prix par sac ____________________) |
| | | | | (prix par sac ____________________) |
| | Elevage | | Nr poulets_________ Nr chèvres __________ Nr bœufs ____________ | |

| | | | | | |
|---|---|---|---|---|---|
| ***2*** | ***Habitudes culinaires*** | | | | |
| 2.a | Habitudes culinaires dans l'année | | | | |
| | Lieu du cuisine | Saison sèche | [O] a l'aire libre | [V] chambre ventilé (hangar) | [NV] chambre fermé |
| | | Saison humide | [O] a l'aire libre | [V] chambre ventilé (hangar) | [NV] chambre fermé |
| | | | | | |
| Combien de fois vous faitez la cuisine par jour ? | | | | | |
| 2.b | Habitudes culinaires dans la journée | | | | |
| | Petite déjeuneur : (temps qui il faut pour la préparation) : | | | | |
| | Repas de midi : (temps qui il faut pour la préparation) : | | | | |
| | Repas de la soir (temps qui il faut pour la préparation) : | | | | |
| | Autres activités : (temps qui il faut pour la préparation) : | | | | |
| | : (temps qui il faut pour la préparation) | | | | |
| | : (temps qui il faut pour la préparation) | | | | |
| | | | | | |
| 2.c | Nombre de personnes par repas (signer les personnes en plus, invités, étrangers) | | | | |
| | | | | | |
| 2.d | Type de foyer utilisée | [ ] Traditionnel | [ ] Amélioré | [ ] Autres (décrive) | |
| | | | | | |

| | | | | |
|---|---|---|---|---|
| ***3*** | ***Besoins de combustible*** | | | |
| 3.a | Principal combustible utilisée pour la cuisine<br>(Cocher les cases concernées) | □ Bois | □ Charbon | □ Gaz |
| | | □ Kérosène | □ Pétrole | □ Autres (spécifier) |
| | | Notes | | |

| | | | | |
|---|---|---|---|---|
| 3.b | Approvisionnement en combustible | □ toujours collecté | □ principalement collecté | □ collecté/acheté |
| | | □ principalement acheté | □ toujours acheté | |

| | | | |
|---|---|---|---|
| 3.c | Dépense pour le principal combustible (si acheté)* | (francs/semaine) | |
| | *Vous achetez le combustible pour combien ?* | | |
| | *Combien de jours il peut durer ?* | | |

| | | | |
|---|---|---|---|
| 3.d | Dépense pour autres combustibles(si acheté)* | (francs/semaine) | |
| | *Vous achetez le combustible pour combien ?* | | |
| | *Combien de jours il peut durer ?* | | |

| | | | |
|---|---|---|---|
| 3.e | Distance entre le ménage et le lieu d'approvisionnement en combustibles | (km) | |
| | | (fois/semaine) | |

| | | | |
|---|---|---|---|
| 3.f | Temps pour la collecte du bois | (heures/fois) | |
| | | (fois/semaine) | |

| | | |
|---|---|---|
| 3.g | Personne responsable de l'achat ou de la collecte du combustible | □ Chef du ménage □ Femme du ménage □ Enfants |
| 3.h | Quelle espèces de bois vous préférez pour la cuisine ? | □ foula ful □ margasta □ glara □ hoina □ tchoutna □ autres ______________ |

| | | | | |
|---|---|---|---|---|
| ***4*** | ***Eclairage du ménage*** | | | |
| 4.a | Facon d'éclairer le ménage | □feu de bois | □ lampe à pétrole | □Batteries |
| | | □électricité | □lampe gaz | □bougie |

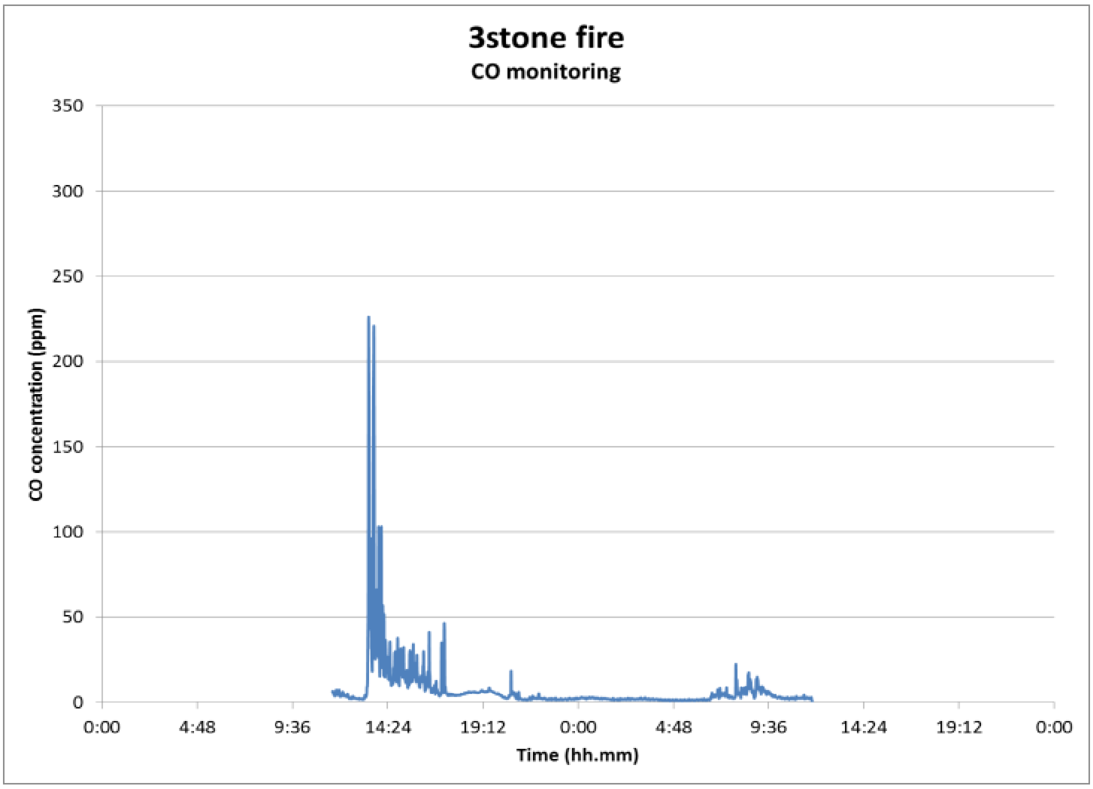
| | | | |
|---|---|---|---|
| 4.b | Cout (si autres que bois) | (francs/semaines)* | |
| | | Si électricité (francs/mois) | |
| | *Vous achetez le ________ pour combien ?* | | |
| | *Combien de jours il peut durer ?* | | |

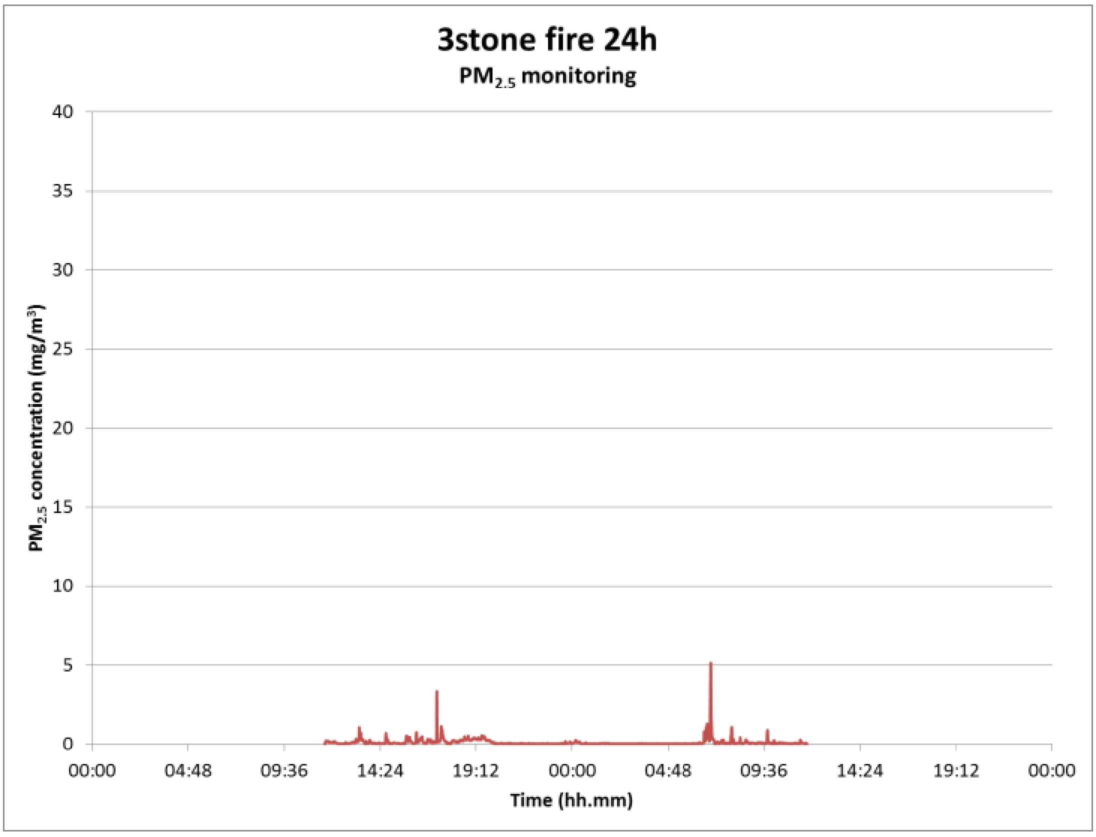
* si l'interviewe ne peut pas répondre sur une base hebdomadaire, tournez-vous la question : signer le prix unitaire du combustible et la durée en jours de durée

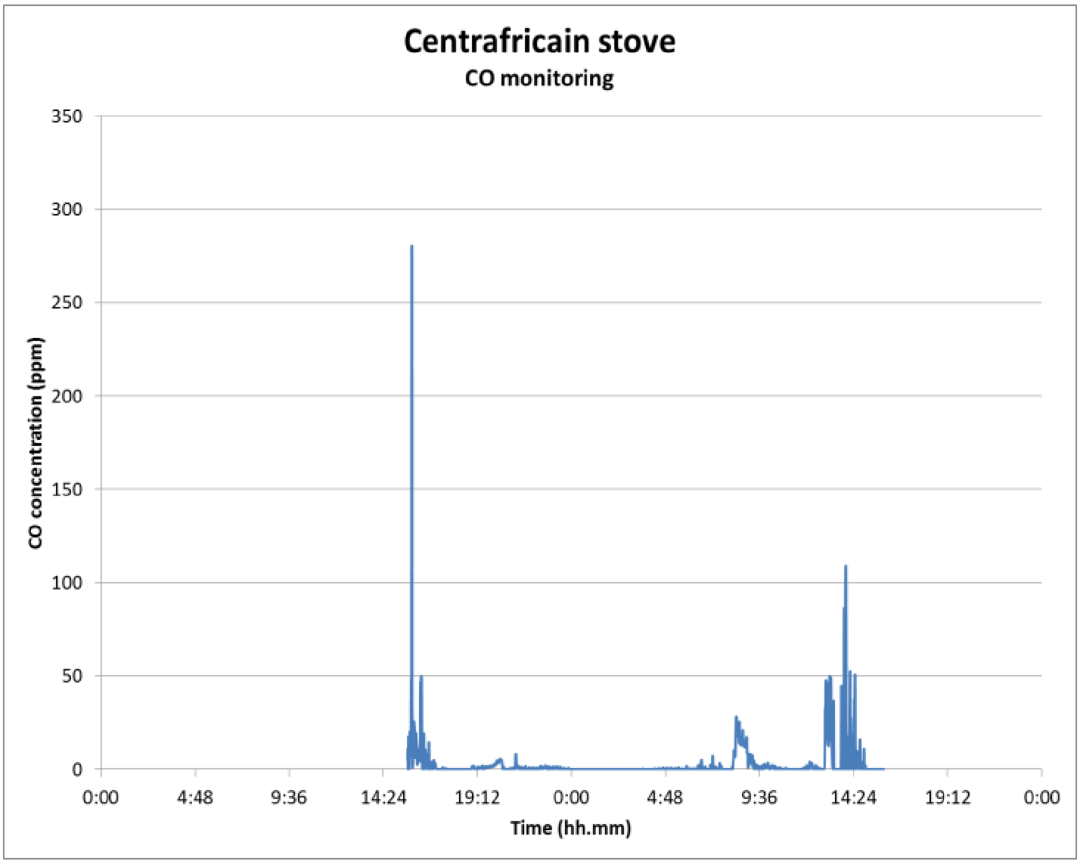
| | | | |
|---|---|---|---|
| **5** | **Energy access index evaluation (according to PPEO 2010)**<br>**(l'interviewer circules en niveau selon son observation)** | | |
| | Besoin d'énergie | Niveau | Qualité |
| 5.1 | Combustible domestiques | **1** | Collection de bois et utilisation de foyer 3pierres |
| | | **2** | Collection de bois et utilisation de foyer améliorée |
| | | **3** | Achat de bois et utilisation de foyer améliorée |
| | | **4** | Achat de charbon et utilisation de foyer améliorée |
| | | **5** | Usage de combustible liquide moderne (Gaz) |
| 5.2 | Electricité | **1** | Pas d'électricité |
| | | **2** | Accès pour recharger les batteries chez quelqu'un |
| | | **3** | Propre DC connexion domestique a bas voltage |
| | | **4** | 240 V AC connexion (pauvre qualité et intermittent disponibilité) |
| | | **5** | fiable 240 V AC connexion disponible toujours |
| 5.3 | Mécanisation | **1** | Pas d'accès: travail manuel avec basic outils |
| | | **2** | Outils mécanisés disponibles pour renforcer l'effort humain/animal |
| | | **3** | Moyens motorisés disponibles pour certaines activités |
| | | **4** | Moyens motorisés disponibles pour toutes les activités |
| | | **5** | Principalement achat de services mécanisés. |

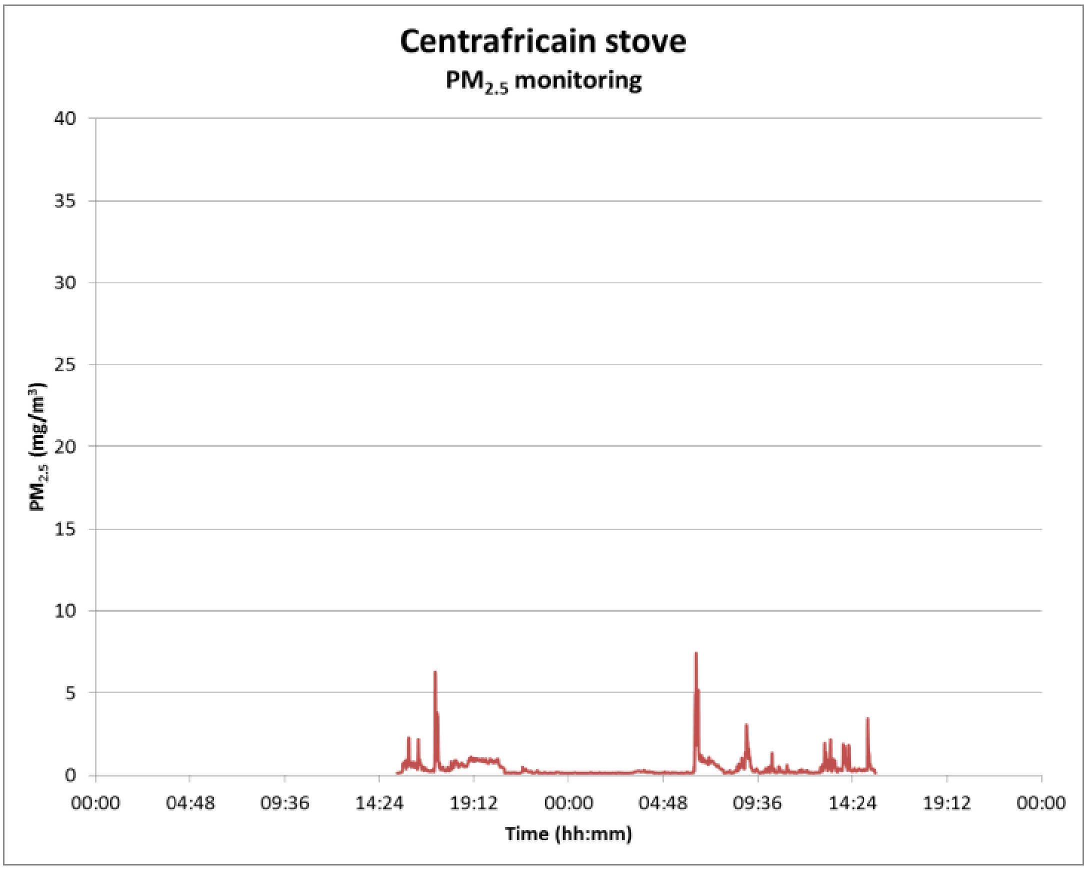
## Annexes 2: graphs of 24h IAP monitoring

### Household 1: CO and $PM_{2.5}$ monitoring

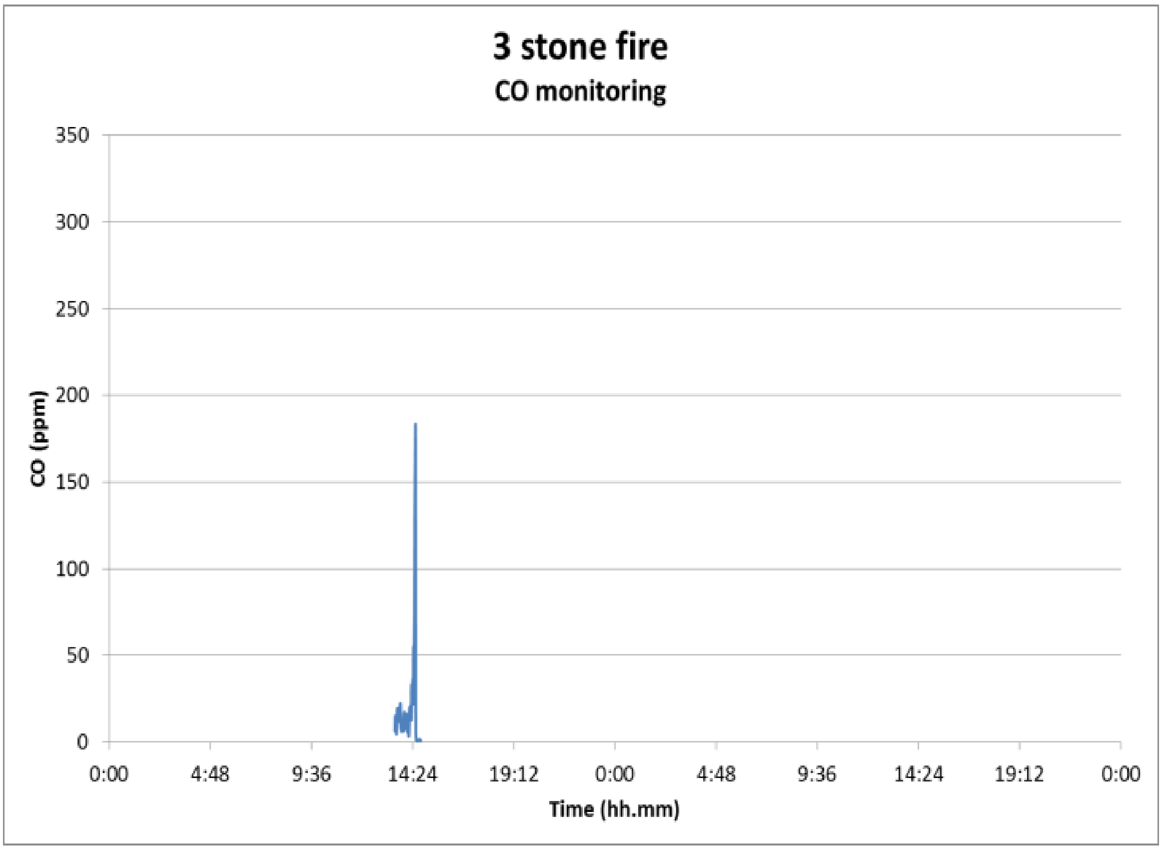


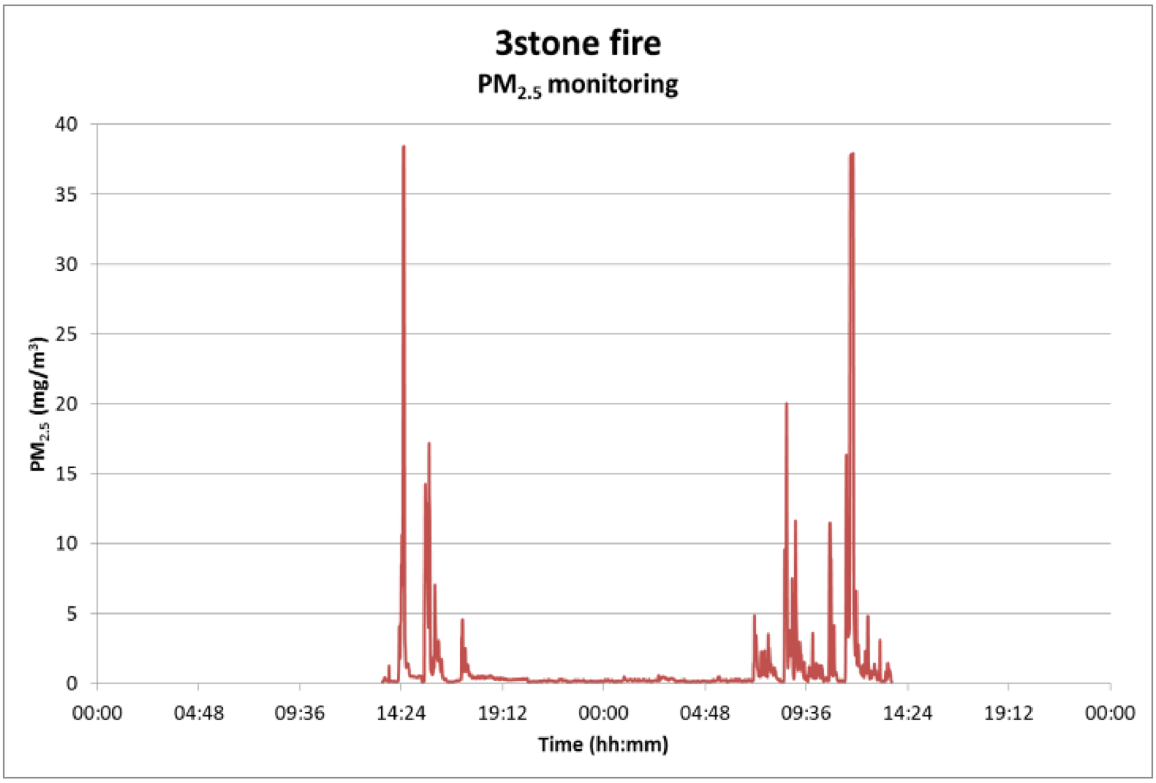



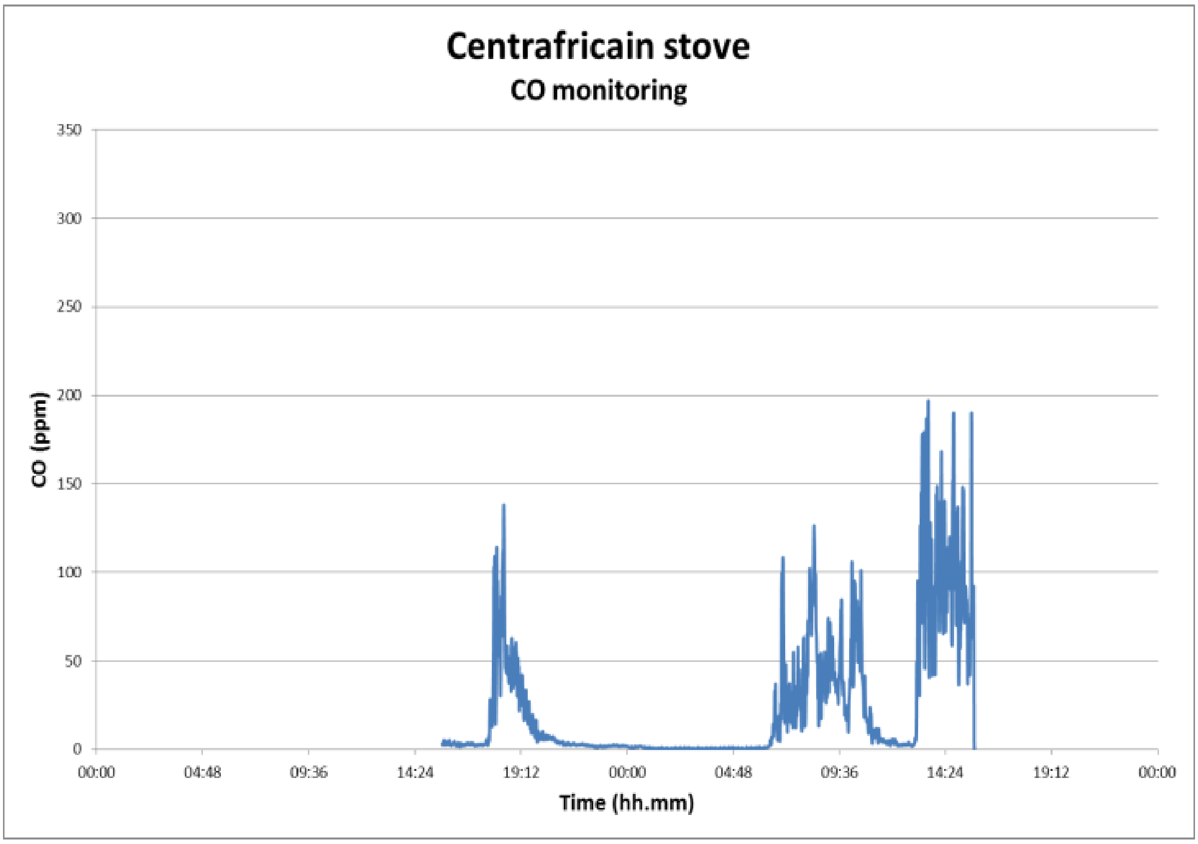

Centrafricain stove
CO monitoring
CO concentration (ppm)
350
300
250
200
150
100
50
0
0:00
4:48
9:36
14:24
19:12
0:00
4:48
9:36
14:24
19:12
0:00
Time (hh.mm)

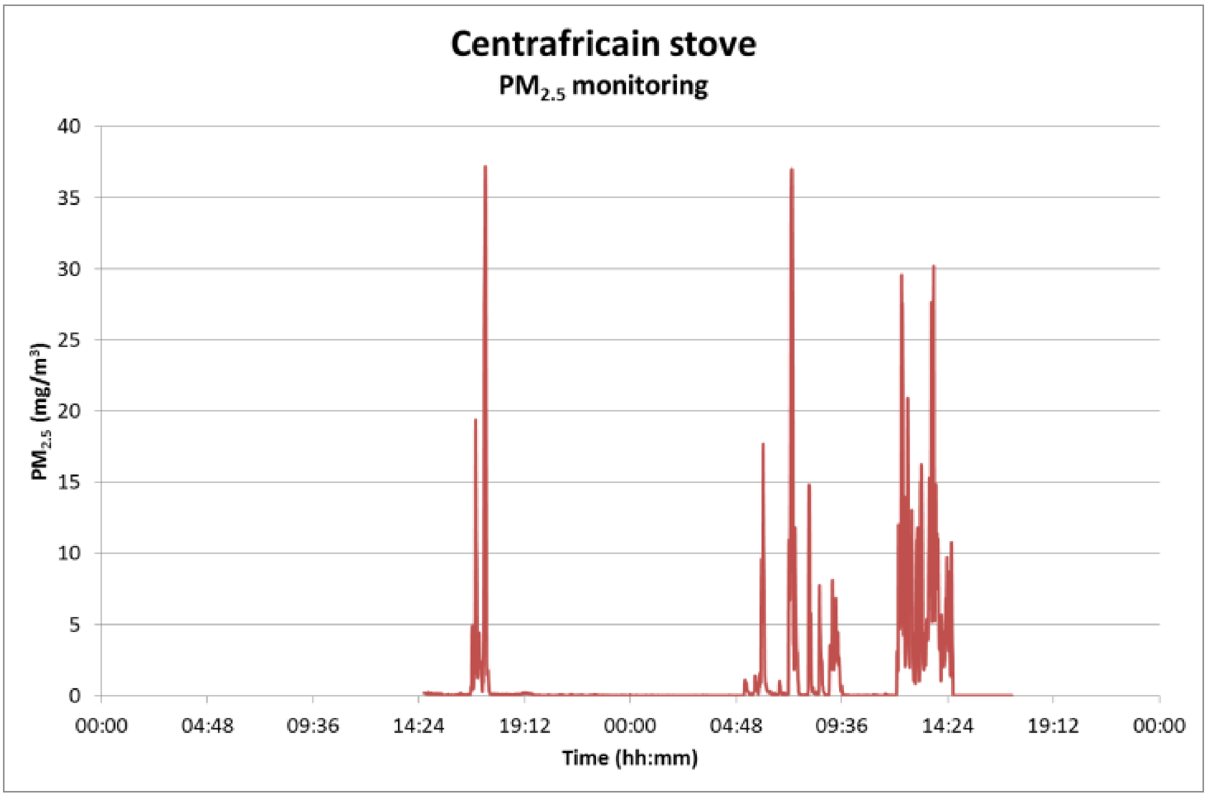

Centrafricain stove
PM2.5 monitoring
PM2.5 (mg/m3)
40
35
30
25
20
15
10
5
0
00:00
04:48
09:36
14:24
19:12
00:00
04:48
09:36
14:24
19:12
00:00
Time (hh:mm)

## Household 2: CO and $PM_{2.5}$ monitoring

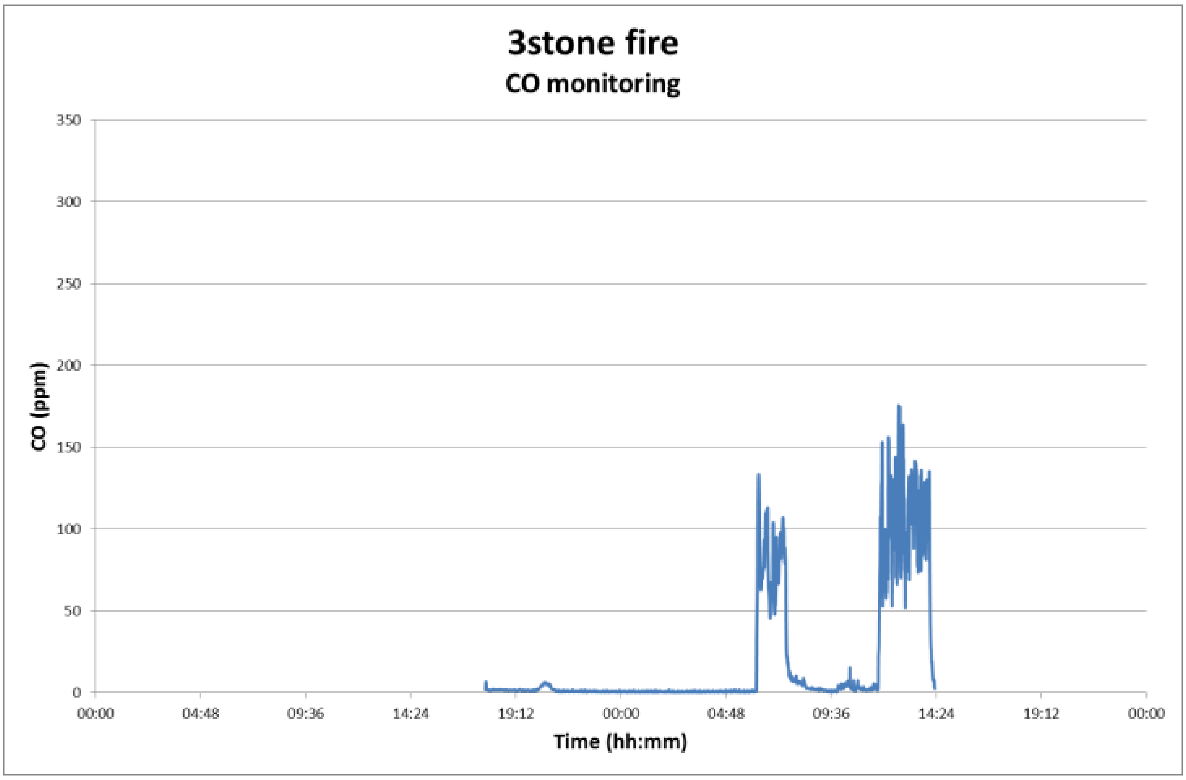


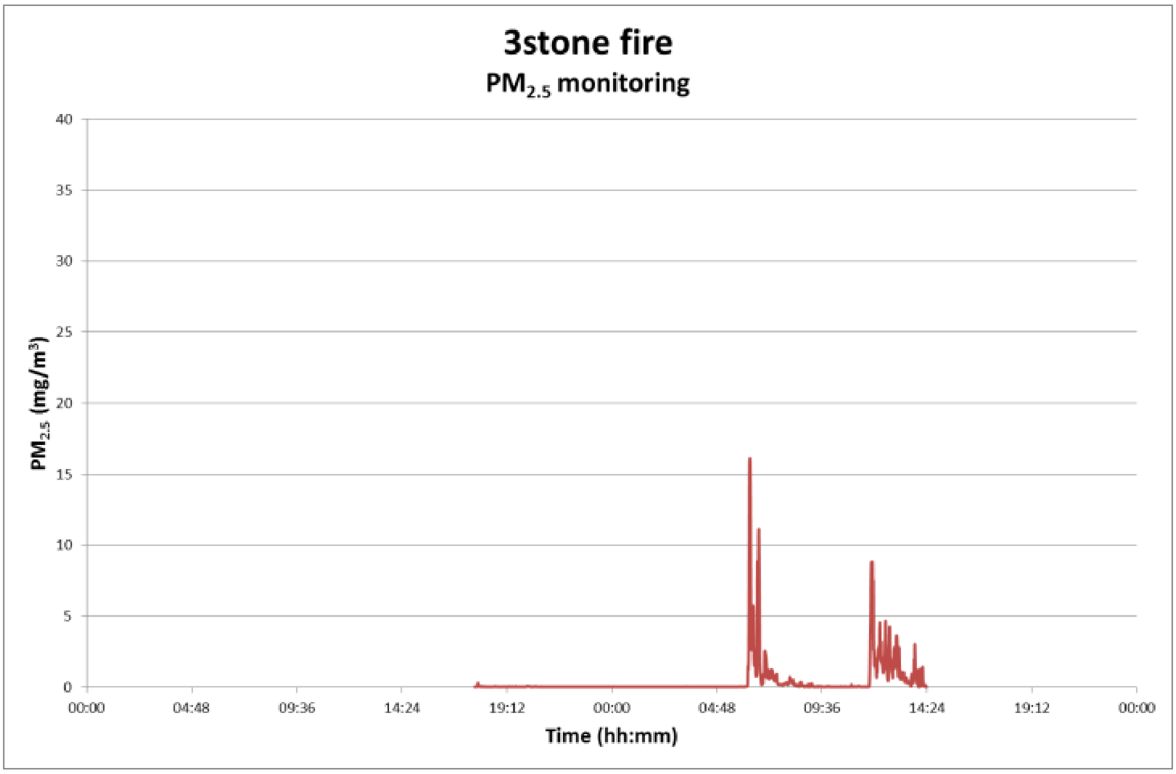



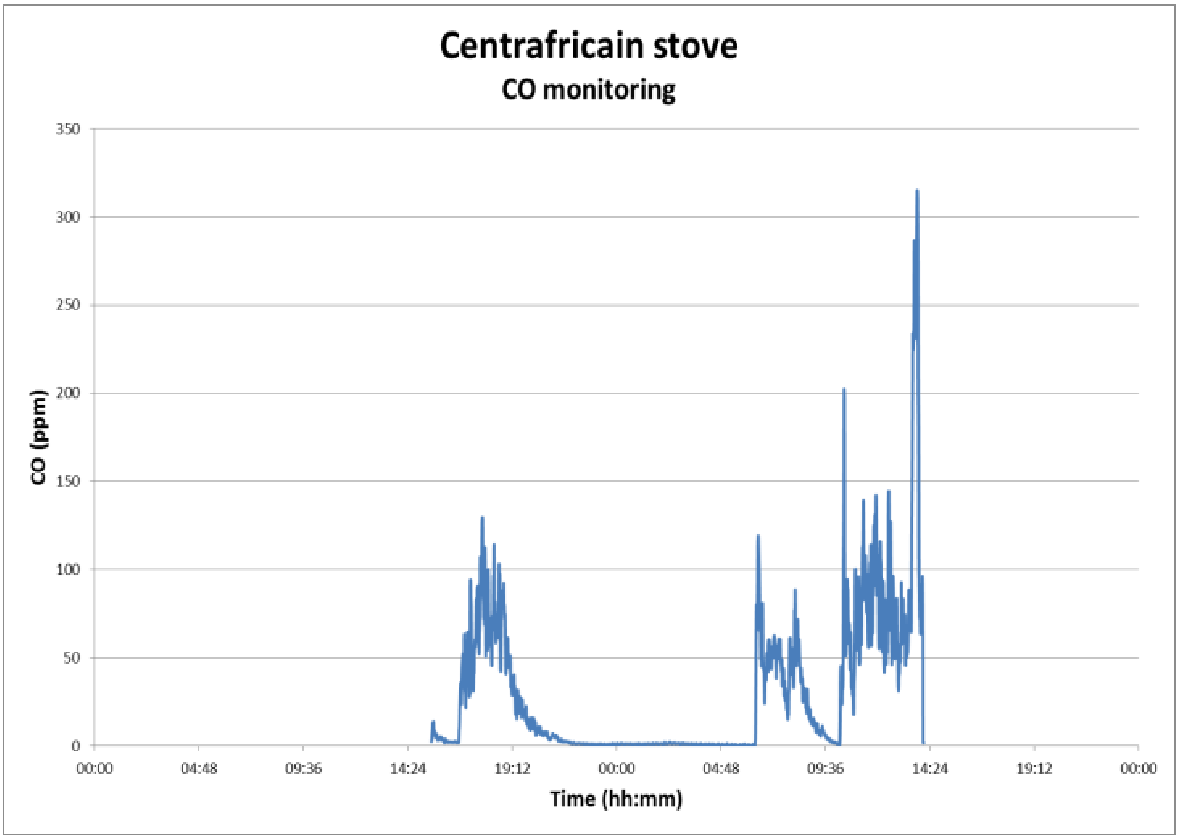

Centrafricain stove
CO monitoring
CO (ppm)
350
300
250
200
150
100
50
0
00:00
04:48
09:36
14:24
19:12
00:00
04:48
09:36
14:24
19:12
00:00
Time (hh.mm)


Centrafricain stove
$PM_{2.5}$ monitoring
$PM_{2.5}$ (mg/m³)
40
35
30
25
20
15
10
5
0
00:00
04:48
09:36
14:24
19:12
00:00
04:48
09:36
14:24
19:12
00:00
Time (hh:mm)

## Household 3: CO and $PM_{2.5}$ monitoring




Centrafricain stove
CO monitoring
CO (ppm)
350
300
250
200
150
100
50
0
00:00
04:48
09:36
14:24
19:12
00:00
04:48
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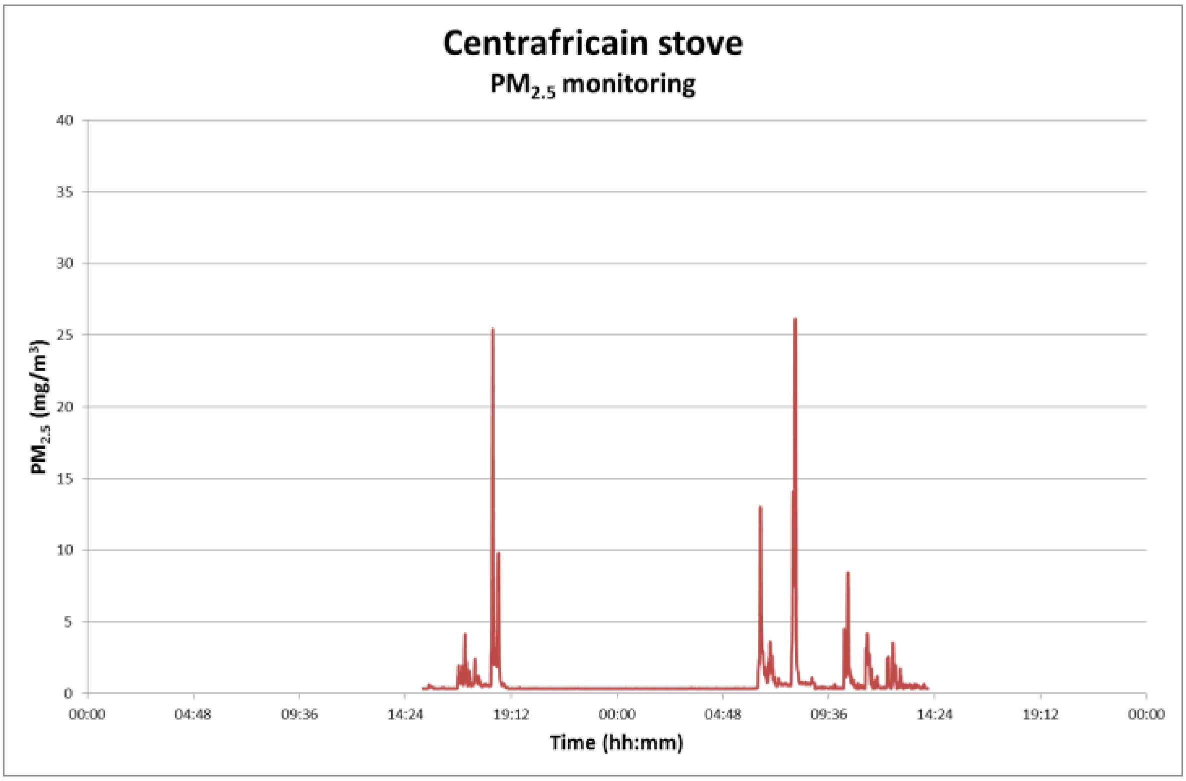
14:24
19:12
00:00
Time (hh:mm)

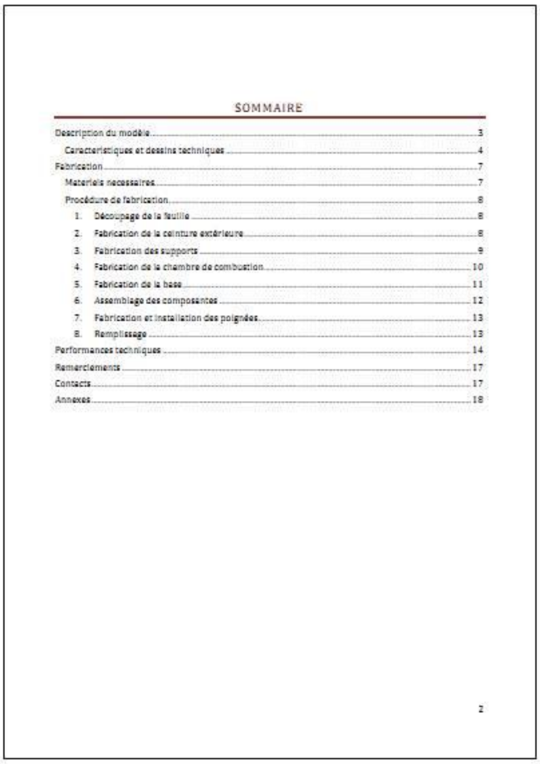

Centrafricain stove
PM2.5 monitoring
PM2.5 (mg/m3)
40
35
30
25
20
15
10
5
0
00:00
04:48
09:36
14:24
19:12
00:00
04:48
09:36
14:24
19:12
00:00
Time (hh:mm)

Foyer modèle Centrafricain

Fiche technique de réalisation

mai 2010

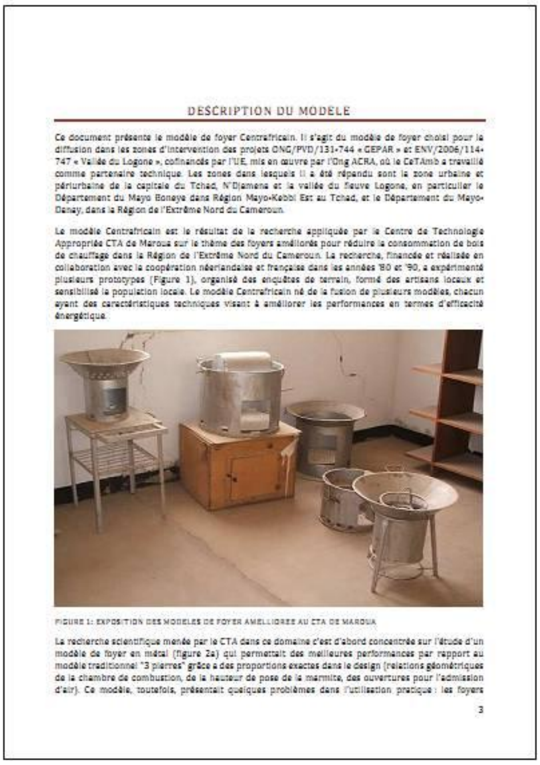
CeTAmb



SOMMAIRE



2



DESCRIPTION DU MODELE

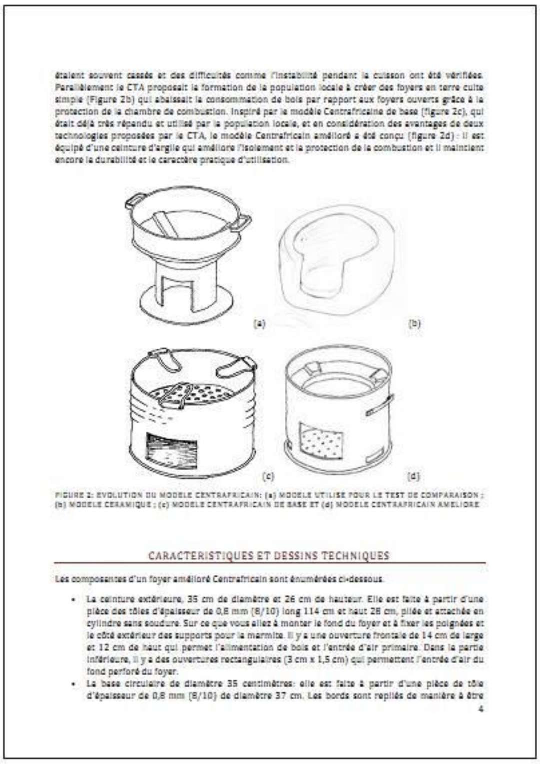
Ce document présente le modèle de foyer Centrafricain. Il s'agit du modèle de foyer choisi pour la diffusion dans les zones d'intervention des projets ONG/PVD/131-744 « GEPAR » et ENV/2006/114-747 « Vallée du Logone », cofinancés par l'UE, mis en œuvre par l'Ong ACRA, où le CeTAmb a travaillé comme partenaire technique. Les zones dans lesquels il a été répandu sont la zone urbaine et périurbaine de la capitale du Tchad, N'Djamena et la vallée du fleuve Logone, en particulier le Département du Mayo Boneye dans Région Mayo-Kebbi Est au Tchad, et le Département du Mayo-Danay, dans la Région de l'Extrême Nord du Cameroun.

Le modèle Centrafricain est le résultat de la recherche appliquée par le Centre de Technologie Appropriée CTA de Maroua sur le thème des foyers améliorés pour réduire la consommation de bois de chauffage dans la Région de l'Extrême Nord du Cameroun. La recherche, financée et réalisée en collaboration avec la coopération néerlandaise et française dans les années '80 et '90, a expérimenté plusieurs prototypes (Figure 1), organisé des enquêtes de terrain, formé des artisans locaux et sensibilisé la population locale. Le modèle Centrafricain né de la fusion de plusieurs modèles, chacun ayant des caractéristiques techniques visant à améliorer les performances en termes d'efficacité énergétique.

FIGURE 1: EXPOSITION DES MODELES DE FOYER AMELLIOREE AU CTA DE MAROUA

La recherche scientifique menée par le CTA dans ce domaine c'est d'abord concentrée sur l'étude d'un modèle de foyer en métal (figure 2a) qui permettait des meilleures performances par rapport au modèle traditionnel "3 pierres" grâce a des proportions exactes dans le design (relations géométriques de la chambre de combustion, de la hauteur de pose de la marmite, des ouvertures pour l'admission d'air). Ce modèle, toutefois, présentait quelques problèmes dans l'utilisation pratique : les foyers

3



étaient souvent cassés et des difficultés comme l'instabilité pendant la cuisson ont été vérifiées. Parallèlement le CTA proposait la formation de la population locale à créer des foyers en terre cuite simple (Figure 2b) qui abaissait la consommation de bois par rapport aux foyers ouverts grâce à la protection de la chambre de combustion. Inspiré par le modèle Centrafricaine de base (figure 2c), qui était déjà très répandu et utilisé par la population locale, et en considération des avantages de deux technologies proposées par le CTA, le modèle Centrafricain amélioré a été conçu (figure 2d) : il est équipé d'une ceinture d'argile qui améliore l'isolement et la protection de la combustion et il maintient encore la durabilité et le caractère pratique d'utilisation.

(a) (b) (c) (d)

FIGURE 2: EVOLUTION DU MODELE CENTRAFRICAIN: (a) MODELE UTILISE POUR LE TEST DE COMPARAISON ; (b) MODELE CERAMIQUE ; (c) MODELE CENTRAFRICAIN DE BASE ET (d) MODELE CENTRAFRICAIN AMELIORE

CARACTERISTIQUES ET DESSINS TECHNIQUES

Les composantes d'un foyer amélioré Centrafricain sont énumérées ci-dessous.

- La ceinture extérieure, 35 cm de diamètre et 26 cm de hauteur. Elle est faite à partir d'une pièce des tôles d'épaisseur de 0,8 mm (8/10) long 114 cm et haut 28 cm, pliée et attachée en cylindre sans soudure. Sur ce que vous allez à monter le fond du foyer et à fixer les poignées et le côté extérieur des supports pour la marmite. Il y a une ouverture frontale de 14 cm de large et 12 cm de haut qui permet l'alimentation de bois et l'entrée d'air primaire. Dans la partie inférieure, il y a des ouvertures rectangulaires (3 cm x 1,5 cm) qui permettent l'entrée d'air du fond perforé du foyer.
- La base circulaire de diamètre 35 centimètres: elle est faite à partir d'une pièce de tôle d'épaisseur de 0,8 mm (8/10) de diamètre 37 cm. Les bords sont repliés de manière à être

4

collée sur le bas de la ceinture. Elle est percée dans la zone correspondante à la chambre de combustion afin de permettre la chute de cendres et l'entrée d'air par dessous.

- La chambre de combustion avec un diamètre de 20 cm et une hauteur de 14 cm: elle est faite d'une pièce des tôle d'épaisseur de 0,8 mm (8 / 10) long de 70 cm et haut de 16 cm, pliée et attachée sans soudure à la base. Elle est reliée à la ceinture extérieure, près de ce front de l'ouverture et elle est fixée avec des poinçons obtenus à partir de têtes de clous.
- L'isolation d'argile occupe l'espace entre la ceinture extérieure et la chambre de combustion, ce qui permet la protection de celui-ci en réduisant les pertes de chaleur.
- Les supports pour la marmite (3) sont fabriqués à partir de bandes de la même matière que les principaux éléments de longueur 16 cm et hauteur 3 cm. Ils sont fixés à la ceinture extérieure et inclinés vers la chambre de combustion pour former un ensemble stable et flexible de soutien pour le fond ronde des marmites répandus localement.
- Les deux poignées sont fixées à la bordure extérieure du foyer et elles permettent son déplacement, même quand le foyer est chaud.

On reporte les dessins du foyer et les modèles (gabarits) nécessaires pour fabriquer les différents éléments. Les dessins complets sont joints avec des sections d'intérêt.

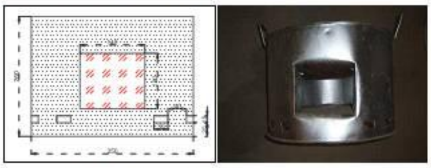


FIGURE 3: VUE FRONTALE DU MODELE CENTRAFRICAIN

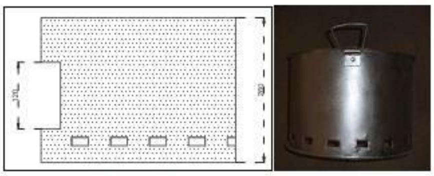


FIGURE 4: VUE LATERALE DU MODELE CENTRAFRICAIN

5

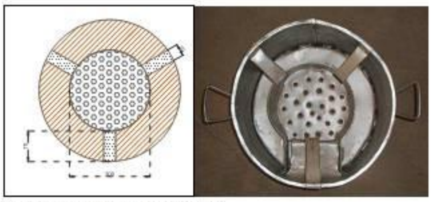


FIGURA 5: VUE D'EN HAUT DU MODELE CENTRAFRICAIN

Les avantages de ce modèle sont les suivants:

- la couche d'argile protège la chambre de combustion, assurant une plus grande isolation et diminuant les pertes de chaleur;
- la stabilité, que la masse d'argile donne au foyer, tout en conservant la mobilité et la facilité de mouvement, ce qui rend pratique l'utilisation à la maison plus que d'un modèle fixe en argile ou en briques;
- la résistance et la durabilité accrues par rapport à un modèle en seul métal ou d'argile;
- la capacité d'adaptation du foyer au fond rond des marmites de différentes tailles grâce à la configuration des supports.

La figure 6 montre une vue isométrique du modèle Centrafricain.

FIGURE 6: VUE ISOMETRIQUE DU MODELE CENTRAFRICAIN

6

## FABRICATION

Pour l'analyse de la fabrication du modèle Centrafricain, on a suivi le travail d'un artisan formé à la production de ce type de foyer dans le cadre des activités du projet d'ACRA. La séance d'observation de la technique de construction a eu lieu le premier avril 2010 au laboratoire de l'artisan à Yagoua (Cameroun).

## MATERIELS NECESSAIRES

Les matériaux nécessaires pour réaliser un foyer Centrafricain sont les suivants:

- Une feuille de métal de 1m x 2m et l'épaisseur de 0,8 mm (8/10) : on peut fabriquer trois foyers avec 1 feuille entière si on coupe les différentes composantes en fonction de l'arrangement suggéré à la figure 7;
- Poinçons (4, obtenu par des têtes de clous), pour fixer les supports pour la marmite à la chambre de combustion et à la ceinture extérieure de la chambre;
- Argile, pour le remplissage de l'isolation entre la chambre de combustion et la ceinture extérieure
- Peinture antirouille;
- Fer Φ6 pour la réalisation des poignées.

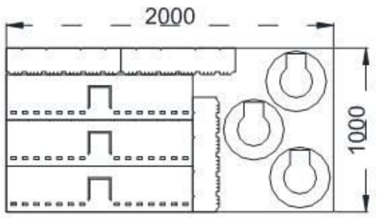



FIGURE 7: ARRANGEMENT OPTIMAL DES GABARITS SUR UNE FEUILLE 1m x 2m

7

Il faut également des équipements techniques pour les différentes étapes de dessin et découpage des formes et du travail des métaux:

- Gabarits, présentés sur la figure 8 et dont le dessin est reporté dans l'appendice
- Marteau
- Ciseaux en métal
- Poinçons
- Traceur

FIGURE 8: GABARITS POUR LE DESSIN DES COMPOSANTES SUR LA FEUILLE DE METAL : LA CEINTURE EXTERIEUR (a), LA CHAMBRE DE COMBUSTION (b), LA BASE (c).

La fabrication d'un foyer Centrafricain est assez économique et rapide, en fonction de la disponibilité des matériaux appropriés et de l'artisan. Les délais nécessaires, alors qu'ils disposent du matériel et des équipements mentionnés ci-dessus, est d'environ 1,5-2 heures. Le principal poste de dépenses est la feuille de métal: le prix d'achat d'une feuille neuve varie, selon les artisans locaux, de 5000 FCFA à N'Djamena à 15000 FCFA à Yagoua. La baisse des prix de 20-40% peut être atteinte en utilisant des matériaux d'occasion, ce qui peut cependant réduire la qualité du foyer. Les prix de vente observés sur les sites au cours des missions varient entre 6000 et 7500 FCFA.

## PROCEDURE DE FABRICATION

### 1. DECOUPAGE DE LA FEUILLE

La première phase est celle de suivre les contours des pièces de tôle, en utilisant les gabarits pré-dimensionnées et un traceur de métal, puis procéder à couper la feuille d'après les dessins ainsi obtenus.

FIGURE 9: TRACEMENT (a), DECOUPAGE (b) ET CONTROL DES PROFILS (c)

### 2. FABRICATION DE LA CEINTURE EXTERIEUR

Après avoir coupé la plaque, nous traçons les détails internes et nous définissons leur contour avec un poinçon (figure 10a). Les bords extérieurs sont repliés sur eux-mêmes en forme de « S » afin qu'ils puissent être joints (Figure 10b et 10c).

8

FIGURE 10: DEFINITION DES DETAILS (a), TRAVAIL DU BORD (b), DETAIL (c)

Après la plaque est pliée (figure 11a) et accrochée (figure 11b). La jonction n'est pas soudée mais simplement fixée sous pression avec un marteau (figure 11c).

FIGURE 11: PLIAGE (a), ACCROCHEMENT (b) ET FIXAGE (c) DE LA CEINTURE EXTERIEUR

Les bords de la feuille sont traités pour éviter les coupures dans les phases de travail et d'utilisation quotidienne.

FIGURE 12: EMOUSSAGE DES BORDS DE LA CEINTURE EXTERIEUR (a), PLIAGE DES OVERTURES A LA BASE (b, c)

Les ouvertures à la base, en fonction du profil obtenu à partir du découpage à l'étape précédente (voir la figure 10a) sont pliées à l'intérieur afin qu'ils puissent fournir un soutien pour la base du modèle.

## 3. FABRICATION DES SUPPORTS

Nous réalisons alors quatre supports: à partir des chutes du découpage de la feuille (de taille 20 x 5 cm) avec des bords pliés pour augmenter la sécurité et la résistance (figure 13 b), nous avons obtenu quatre plaques de taille 16 cm x 3 cm qui seront ensuite installées sur le foyer. Chaque support est percé d'un seul côté avec l'aide d'un clou (figure 13c).



FIGURE 13: PLIAGE (a , b) ET PERCAGE (c) DES SUPPORTS POUR LA MARMITE

Une des quatre bandes obtenues est utilisée comme une fermeture de la chambre de combustion et donc elle est traitée de manière différente. Elle est percée aux deux extrémités et au milieu et pliée comme le montre la figure 14a. Après elle est installée sur un des trois supports pour la marmite grâce à un poinçon fermé à pression (Figure 14b et c).

FIGURE 14: PLIAGE DE LA FERMETURE DE LA CHAMBRE DE COMBUSTION (a), INSTALLATION (b) ET FIXAGE (c) SUR ELLE DE UN SUPPORT POUR LA MARMITE

## 4. FABRICATION DE LA CHAMBRE DE COMBUSTION

La chambre de combustion est obtenue en traçant la forme du profil de la figure 8b.

FIGURA 15: DECOUPAGE DES BRIDES SUR LE BORD INFERIEUR (a) BORDURE SUPERIEURE (b) ET PLIAGE (c) DE LA CHAMBRE DE COMBUSTION.

Les brides sont coupés (figure 15a) selon le schéma de la figure 16 et la feuille est percée par un poinçon aux points indiqués pour le positionnement des charnières. Le bord supérieur est replié sur lui-même afin d'éviter les bords tranchants (figure 15b). Puis la plaque est repliée (figure 15c), selon les lignes pointillées de la figure 16 ; Les parties extérieures servent comme murs de l'ouverture frontale qui relie la chambre de combustion avec la ceinture extérieure, tandis que la partie intérieure, proprement pliée, forme la chambre de combustion réelle.



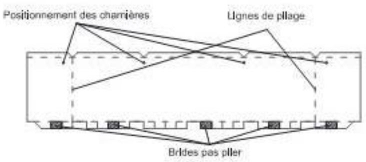



FIGURE 16: SCHEMA DE TRAVAIL DE LA FEUILLE POUR LA CHAMBRE DE COMBUSITION

Les deux supports sont installés en position centrale, comme illustré à la figure 17 (a, b), la feuille est ensuite pliée (Figure 17c).

FIGURE 17: INSTALLATION DES SUPPORTS SUR LA CHAMBRE DE COMBUSTION (a, b) ET PLIAGE (c) DE LA CHAMBRE DE COMBUSTION.

La chambre de combustion est ensuite fermée avec la bande faite à l'étape précédente (voir la figure 14) au moyen de deux poinçons afin de déterminer la forme définitive de la chambre de combustion (figure 18c).

FIGURE 18: APPOINTEMENT DE LA CHAMBRE DE COMBUSTION.

## 5. FABRICATION DE LA BASE

On a ensuite travaillé le fond du foyer: après avoir coupé le profil avec la forme de la figure 8c, la plaque est perforée par un coup de poinçon (figure 19a) à la partie qui forme le fond de la chambre de combustion. Les bords sont ensuite pliés à 90 degrés à l'extérieur (figure 19b), afin que vous puissiez monter avec des brides de la ceinture extérieure, comme cela sera expliqué plus tard. 5 gravures sont effectuées (Figure 19c), dont ils sont inséré et fixé les brides pas pliées comme montre la Figure 16. La Figure 20 indique le schéma de travail de la base.



FIGURE 19: PERCAGE DE LA BASE (a) BORDURAGE (b) ET GRAVURES POUR LE FIXAGE DE LA CHAMBRE DE COMBUSTION (c).

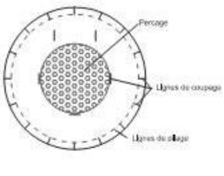



FIGURE 20: SCHEMA DE TRAVAIL DE LA BASE

## 6. ASSEMBLAGE DES COMPOSANTES

Une fois préparés tous les composants, on passe à l'assemblage final. La chambre de combustion est installée (figure 21a) et fixée sur la base en faisant glisser les brides (celles qui ne sont pas pliés) dans les cinq incisions réalisées ad-hoc, comme expliqué dans l'étape précédente.

FIGURE 21: INSTALLATION (a) ET FIXAGE (b) DE LA CHAMBRE DE COMBUSTION SUR LA BASE ET INSERTION DANS LA CEINTURE EXTERIEUR (c).

La structure ainsi obtenue est ensuite glissée à l'intérieur de la ceinture extérieure (Figure 21c). L'ouverture frontale est repliée vers l'intérieur afin de faire la couverture du canal reliant la chambre de combustion et la ceinture extérieure (figure 22a). Les rebords de la base des boutures se reposent sur le brides pliées a la base de la ceinture extérieure et ils sont fixés (figure 22b). Les supports pour la marmite sont pliés et fixés sur le bord supérieur de la ceinture extérieure (Figure 22c).

(a) (b) (c)

FIGURA 22: PLIAGE DE L'OUVERTURE FRONTALE (a), FIXAGE DE LA STRUCTURE (b) ET DES SUPPORTS POUR LA MARMITE (c).

## 7. FABRICATION ET INSTALLATION DES POIGNEES

Enfin, les poignées sont fabriquées avec le fer Φ6. Celles sont ensuite jointes au bord supérieur de la ceinture extérieure.

(a) (b) (c)

FIGURE 23: FABRICATION (a, b) ET INSTALLATION (c) DES POIGNEES.

## 8. REMPLISSAGE

Le remplissage externe peut être effectué par la suite. Le meilleur matériau est l'argile avec des caractéristiques d'isolation thermique spéciales (vermiculite par exemple), mais la disponibilité et les coûts doivent être évalués parallèlement. Des tests comparatifs n'ont pas été effectués avec les modèles de foyer Centrafricain avec différents types de matériel d'isolation.



## REMERCIEMENTS

Nous remercions le Centre de technologie appropriée de Maroua d'avoir partagé des informations sur leurs recherches et la mise à disposition de ses archives et de documentation, en particulier dans la figure de M. Thomas Madine.

Nous remercions le personnel de l'ACRA pour soutenir la recherche sur le site.

Nous remercions l'atelier de M. Bagao de Yagoua pour le soutien à la mise en œuvre du modèle de four Centrafricain.

## CONTACTS

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CeTAmb — Centro di Tecnologie Appropriate per la gestione dell'Ambiente nei Paesi in Via di Sviluppo, Facoltà di Ingegneria, Università degli Studi di Brescia, via Branze 43, 25123 Brescia (Italia). Telefono: +390303711302 Email: cetamb@ing.unibs.it

CTA — Centre de Technologies Appropriés de Maroua (Cameroun EN), www.minproff.gov.cm



# Braciere modello Ceramico

Manuale di costruzione

luglio 2010

CeTAmb

## DESCRIZIONE DEL MODELLO

In questo documento viene presentato il modello di braciere ceramico, conosciuto anche come "3 pietre migliorato": questo modello è stato oggetto di un corso di formazione nel periodo 22-25 marzo e 30-31 marzo 2010 rivolto ad un gruppo di donne vasaie. Tale attività si inserisce nell'ambito del progetto Vallée Logone (implementato in loco da ACRA, in cui il CeTAmb ha collaborato come partner tecnico, finanziato dall'unione Europea) come azione per incentivare la diffusione di tecnologie che consentano una riduzione del consumo di legna a livello domestico.

Il modello ceramico , simile ad altri modelli migliorati già tradizionalmente in uso nella regione, consiste in una struttura realizzata con un impasto di argilla e sabbia secondo proporzioni stabilite, modellata con l'ausilio di strumenti per il dimensionamento standard. Tale tecnica costruttiva è già diffusa localmente secondo differenti varianti locali, ad eccezione della cottura finale che permette di garantire una maggiore resistenza e durabilità del braciere.

FIGURA 1: ESEMPI DI BRACIERE IN TERRA CRUDA O COTTA DIFFUSI NELLA VALLE DEL LOGONE

Il modello è stato sperimentato in numerosi studi dal CTA (Centre de Technologies Appropriées) di Maroua: i vantaggi di questo modello sono infatti numerosi.

- Semplicità di utilizzo e coerenza con i modelli tradizionali che permettono un facile adattamento dell'utenza all'utilizzo quotidiano.
- Migliori prestazioni in termini di tempi di cottura e di consumo di legna rispetto al focolare a 3 pietre, grazie all'isolamento (anche se minimo) della camera di combustione.
- Realizzazione molto semplice che richiede una formazione basilare delle utenze stesse o di persone già con minime competenze nella lavorazione della terracotta; viene quindi fornita una specializzazione in attività artigianali semplici che può rappresentare un'attività generatrice di reddito aggiuntiva.
- Basso costo di produzione e facile reperibilità dei materiali necessari.

Al tempo stesso la povertà dei materiali e del disegno, inevitabilmente, non possono garantire resistenza all'utilizzo e prestazioni pari a quelle di altri modelli migliorati dotati di camera di combustione più isolata o di ciminiera per l'allontanamento dei fumi di combustione dall'utenza.

## CARATTERISTICHE E DISEGNI TECNICI

In Figura 2 si riportano i disegni tecnici recuperati dagli archivi del CTA relativi al modello ceramico: le misure in realtà variano molto, sia per il processo di fabbricazione che è totalmente manuale, sia perle differenti taglie a seconda delle dimensioni della pentola da reggere. In genere il braciere è costituito da una struttura approssimativamente cilindrica di diametro interno tra i 28 e i 34 cm, di spessore 2-3 cm ed altezza 23-25 cm. Nella parte sommitale sono realizzati tre supporti dello stesso impasto, modellati in modo da poter reggere stabilmente le pentole a fondo tondo diffuse nella zona. Frontalmente viene praticata un'apertura per permettere l'alimentazione della legna alla camera di combustione. Dalla parte opposta all'apertura sono presenti 2 o 3 fori per di favorire l'entrata dell'aria necessaria alla combustione.

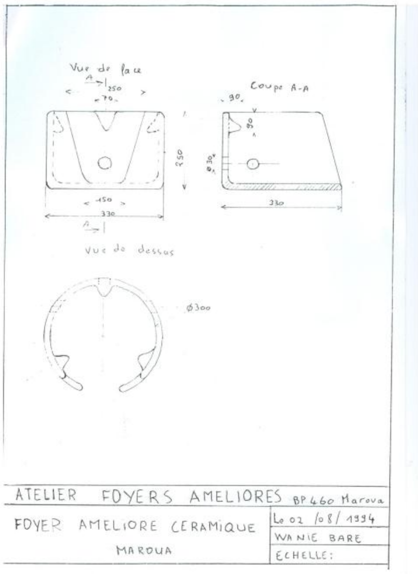



FIGURA 2: DISEGNI TECNICI DEL MODELLO CERAMICO (CTA, 1994)



# REALIZZAZIONE

## MATERIALE NECESSARIO

I materiali necessari per la realizzazione di un braciere ceramico sono:

- Argilla e sabbia reperite localmente in proporzione 3 a 1 in volume

Inoltre è necessaria la strumentazione per le diverse fasi di fabbricazione:

- secchio da 10L: permette di dosare in modo opportuno le diverse quantità di argilla e sabbia
- setaccio a maglia 1mm per la separazione dei materiali grossolani dalla sabbia che nella fase di cottura dell'impasto potrebbero favorire rotture e fessurazioni
- telo impermeabile per la lavorazione e la prima fase di asciugatura
- basamento circolare in legno (Φ 42 cm; spessore 3 cm)
- telai pre-dimensionati (riportati nella figura sottostante)
- spugna per la pulizia degli strumenti di lavoro

## PROCEDURA DI REALIZZAZIONE

### 1. PREPARAZIONE DELL'IMPASTO

La prima attività consiste nella preparazione dell'impasto: l'argilla viene raccolta localmente, frantumata e mescolata con l'acqua, ottenendo un impasto plastico. Questo viene lasciato riposare una notte, di modo che l'acqua abbia tempo sufficiente di infiltrarsi in modo capillare nel materiale argilloso. Il telo impermeabile viene utilizzato come protezione per evitare un'eccessiva evaporazione dell'acqua e mantenere un giusto grado di umidità nell'impasto.


FIGURA 3: ALCUNE FASI DELLA PREPARAZIONE DELL'IMPASTO: DA SINISTRA, LA FRANTUMAZIONE (a), LA BAGNATURA (b), LA LAVORAZIONE (c).

L'impasto viene lavorato e mescolato in proporzioni 3 a 1 con la sabbia precedentemente setacciata in modo da eliminare gli elementi di granulometria maggiore che aumenterebbero la disomogeneità dell'impasto, rappresentando dei possibili punti di fessurazione preferenziali durante la fase di essiccamento e cottura.

### 2. REALIZZAZIONE DEL BRACIERE

La realizzazione del braciere avviene utilizzando come supporto l'asse di legno sulla quale viene depositato un primo stato di circa 40 cm di diametro che sarà il fondo del braciere. Dopo averlo compattato battendolo, si procede, con l'ausilio dei telai pre-dimensionati alla realizzazione delle pareti del braciere. Queste vengono innalzate utilizzando la tecnica Colombine che consiste nel preparare dei cilindri di impasto di diametro circa 3 cm e lunghezza variabile che man mano vengono



uniti a formare la struttura desiderata. L'utilizzo dei telai permette di garantire il rispetto e il controllo delle dimensioni del braciere in fase realizzativa.


FIGURA 4:PREPARAZIONE DEL FONDO (a) E INNALZAMENTO DELLE PARETI (b, c, d) DEL BRACIERE CON L'AUSILIO DEI TELAI PRE-DIMENSIONATI; CONTROLLO FINALE DELLE DIMENSIONI (e) E FINITURA (f); REALIZZAZIONE DEGLI APPOGGI PER LA PENTOLA (g), TAGLIO DELL'APERTURA FRONTALE (h) E REALIZZAZIONE DEI BUCHI D'AERAZIONE POSTERIORI (i)

Vengono quindi realizzati i tre appoggi per la pentola, l'apertura frontale con l'ausilio di un coltello e 3 fori di diametro 3 cm sul retro della camera di combustione per permettere l'aerazione. Successivamente il braciere viene spostato in una camera chiusa per la fase di essiccamento.

### 3. ESSICCAMENTO

La fase di essiccamento dura 5 giorni: una prima fase avviene al chiuso, in modo da evitare che l'eccessiva traspirazione dovuta all'esposizione diretta al sole porti alla creazione di fessure e indebolimenti nella struttura.

I. Il braciere appena realizzato viene posto in una stanza chiusa, all'ombra, coperto con un telo impermeabile.
II. Il braciere viene capovolto e lasciato ancora in una stanza chiusa e coperto.
III. Il braciere viene riportato in posizione normale e lasciato sempre al chiuso, senza telo impermeabile.
IV. Il braciere viene capovolto, al chiuso, senza copertura.
V. Il braciere viene esposto al sole per terminare l'essiccamento, a sera avrà luogo la cottura.




FIGURA 5:FASI DI ESSICCAMENTO: TRASPORTO DEL BRACIERE IN UNA STANZA CHIUSA (a), FASE DI ESSICCAMENTO ALL'OMBRA (b) E ESPOSIZIONE FINALE AL SOLE (c)

### 4. COTTURA

La cottura dei bracieri avviene nel corso della notte, dopo averli esposti in giornata al sole a aver realizzato il forno per la cottura. Nel Box 1 è riportata una configurazione possibile per un forno per la cottura dei bracieri.

**BOX 1: IL FORNO PER LA COTTURA DEGLI OGGETTI CERAMICI**

Nel corso della formazione svoltasi in loco, ai partecipanti è stato proposto anche un modello migliorato di forno per la cottura dei bracieri. Tale modello, nella sua semplicità, permette un migliore isolamento della zona ad elevata temperatura ed il raggiungimento e mantenimento delle temperature adeguate alla vetrificazione del materiale ceramico (866°C). Il forno consiste in una buca circolare di diametro 175 cm e profonda 50cm (dimensioni variabili in funzione della quantità di elementi da portare a cottura). Sul fondo vengono tracciati perpendicolarmente due canali di sezione circa quadrata (lato 20cm) lungo i diametri, per permettere un flusso d'aria dal fondo.

# Annexes 4: features of testing campaigns on rice husk stove models

## Tests performed on the *mcc* (large size) rice husk stove model

| Date | Tester | Location | 1air Φ | 2air Φ | Chimney height | Water | ΔT | Evaporated water | Rice husk | Coal | Efficiency | Boiling Time | Specific consumption | Burning Rate | Total Duration | Mean Power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | cm | cm | m | L | °C | kg | kg | kg | % | min | g/L | g /min | min | kW |
| 19/03/10 | FV | Bongor | 10 | 2.8 | 2.0 | 5.0 | 63 | 1.50 | 7.38 | 0.15 | 5 | na | 1476 | 164 | 45 | 35.7 |
| 20/03/10 | FV | Bongor | 7.5 | 2.8 | 2.0 | 5.0 | 69 | 2.11 | 10.39 | 0.15 | 5 | 14 | 2078 | 117 | 89 | 25.1 |
| 01/04/10 | FV | Bongor | 7.5 | 2.8 | 2.0 | 5.0 | 65 | 1.81 | 8.56 | 0.00 | 5 | 15 | 1712 | 113 | 76 | 23.5 |
| 02/04/10 | FV | Bongor | 7.5 | 2.8 | 2.0 | 5.0 | 64 | 2.47 | 7.23 | 0.00 | 8 | 24 | 1446 | 88 | 82 | 18.4 |
| 03/12/10 | FM | Golgi | 10.0 | 4.2 | 2.0 | 5.0 | 83 | 1.22 | 6.00 | 0.10 | 6 | 18 | 1200 | 80 | 75 | 17.3 |
| 03/12/10 | FM | Golgi | 10.0 | 3.3 | 2.0 | 5.0 | 83 | 1.06 | 6.00 | 0.10 | 5 | na | 1200 | 74 | 81 | 16.0 |
| 04/01/11 | FM | Golgi | 13.0 | 4.2 | 2.0 | 5.0 | 86 | 1.28 | 6.00 | 0.20 | 6 | 66 | 1200 | 62 | 96 | 13.9 |
| 04/01/11 | FM | Golgi | 13.0 | 3.3 | 2.0 | 5.0 | 86 | 1.14 | 6.00 | 0.20 | 5 | 72 | 1200 | 58 | 103 | 13.0 |
| 12/01/11 | FM | Golgi | 7.5 | 4.2 | 2.0 | 3.0 | 83 | 1.14 | 6.00 | 0.16 | 5 | 32 | 2000 | 75 | 80 | 16.5 |
| 12/01/11 | FM | Golgi | 13.0 | 3.3 | 2.0 | 3.0 | 83 | 1.32 | 6.00 | 0.20 | 5 | 13 | 2000 | 73 | 82 | 16.3 |
| 13/01/11 | FM | Golgi | 13.0 | 4.2 | 2.0 | 3.0 | 84 | 0.96 | 6.00 | 0.28 | 4 | 9 | 2000 | 86 | 70 | 19.6 |
| 13/01/11 | FM | Golgi | 10.0 | 3.3 | 2.0 | 3.0 | 84 | 1.12 | 6.00 | 0.14 | 5% | 19 | 2000 | 77 | 78 | 16.8 |
| 17/01/11 | FM | Golgi | 10.0 | 4.2 | 2.0 | 3.0 | 85 | 1.88 | 6.00 | 0.10 | 7% | 21 | 2000 | 64 | 94 | 13.8 |
| 17/01/11 | FM | Golgi | 10.0 | 3.3 | 2.0 | 3.0 | 85 | 1.32 | 6.00 | 0.10 | 5% | 69 | 2000 | 61 | 98 | 13.2 |
| 19/01/11 | FM | Golgi | 10.0 | 4.2 | 2.0 | 3.0 | 86 | 1.66 | 6.00 | 0.10 | 6% | 10 | 2000 | 74 | 81 | 16.0 |
| 19/01/11 | FM | Golgi | 10.0 | 3.3 | 2.0 | 3.0 | 86 | 1.12 | 6.00 | 0.10 | 5% | 78 | 2000 | 69 | 87 | 14.9 |
| 25/01/11 | FM | Golgi | 13.0 | 4.2 | 2.0 | 3.0 | 85 | 1.72 | 6.00 | 0.14 | 6% | 8 | 2000 | 67 | 89 | 14.7 |
| 25/01/11 | FM | Golgi | 13.0 | 3.3 | 2.0 | 3.0 | 85 | 0.94 | 6.00 | 0.27 | 4% | na | 2000 | 61 | 98 | 13.9 |
| 26/01/11 | FM | Golgi | 7.5 | 4.2 | 2.0 | 3.0 | 85 | 1.48 | 6.00 | 0.14 | 6% | 54 | 2000 | 62 | 97 | 13.5 |
| 26/01/11 | FM | Golgi | 10.0 | 3.3 | 2.0 | 3.0 | 85 | 1.44 | 6.00 | 0.10 | 6% | 13 | 2000 | 65 | 93 | 13.9 |
| 08/02/11 | FM | Golgi | 7.5 | 4.2 | 2.0 | 3.0 | 83 | 1.24 | 6.00 | 0.11 | 5% | 82 | 2000 | 61 | 99 | 13.1 |
| 08/02/11 | FM | Golgi | 7.5 | 3.3 | 2.0 | 3.0 | 83 | 1.04 | 6.00 | 0.07 | 4% | 20 | 2000 | 69 | 87 | 14.7 |
| 18/05/11 | ML | Golgi | 7.5 | 3.3 | 2.0 | 3.0 | 83 | 1.60 | 6.00 | 0.08 | 6% | | 2000 | 70 | 86 | 15.0 |
| 18/05/11 | ML | Golgi | 10.0 | 4.2 | 2.0 | 3.0 | 78 | 1.34 | 6.00 | 0.08 | 5% | | 2000 | 70 | 86 | 15.0 |
| 19/05/11 | ML | Golgi | 10.0 | 3.3 | 2.0 | 3.0 | 80 | 0.84 | 6.00 | 0.08 | 4% | | 2000 | 61 | 99 | 13.0 |
| 19/05/11 | ML | Golgi | 7.5 | 4.2 | 2.0 | 3.0 | 80 | 1.58 | 6.00 | 0.08 | 6% | | 2000 | 61 | 98 | 13.1 |
| 12/08/11 | ML | Vallio | 10.0 | - | 2.0 | 3.0 | 70 | 0.50 | 3.00 | 0.10 | 5% | | 1000 | 37 | 80 | 8.4 |

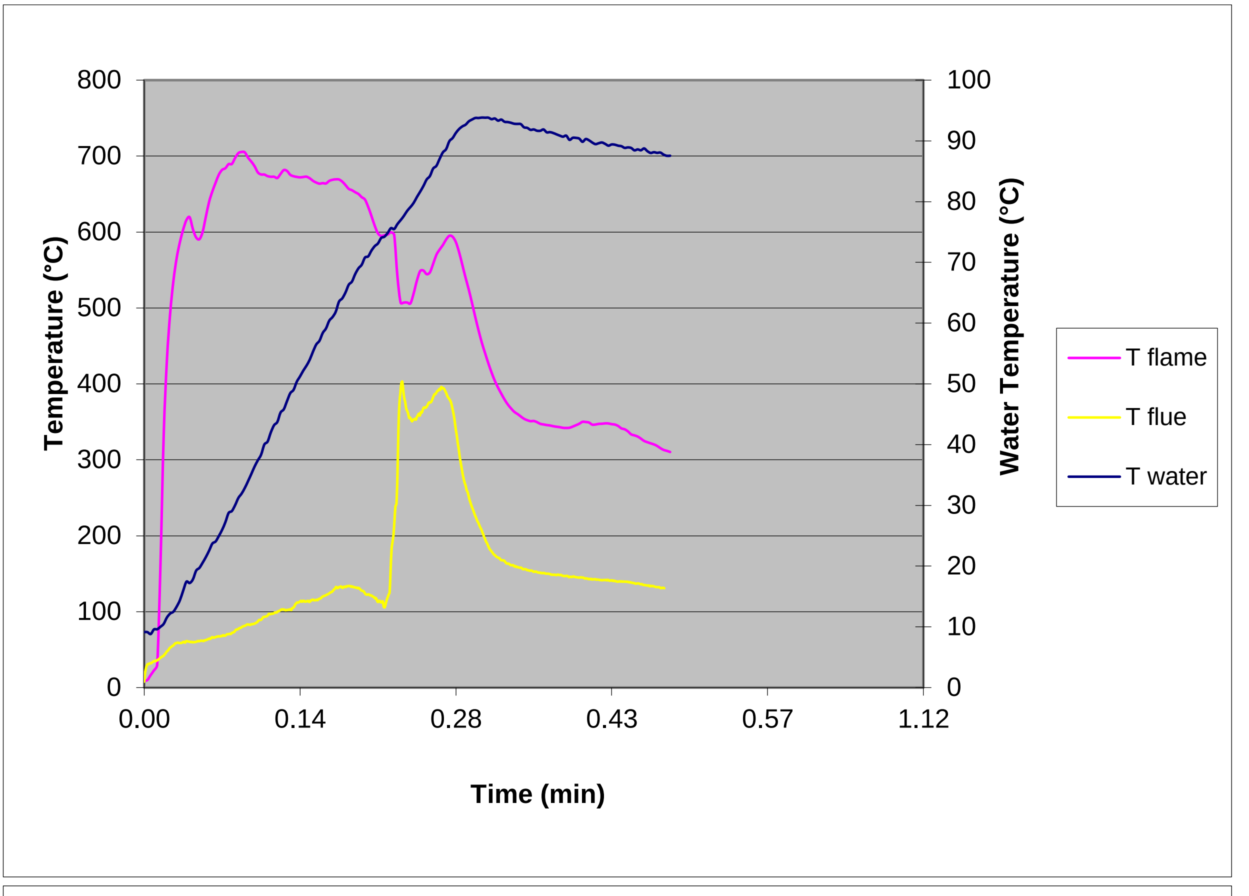
| Date | Tester | Location | 1air Φ | 2air Φ | Chimney height | Water | ΔT | Evaporated water | Rice husk | Coal | Efficiency | Boiling Time | Specific consumption | Burning Rate | Total Duration | Mean Power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | cm | cm | m | L | °C | kg | kg | kg | % | min | g/L | g /min | min | kW |
| 12/08/11 | ML | Vallio | 7.5 | - | 2.0 | 3.0 | 73 | 0.80 | 3.06 | 0.10 | 7% | | 1020 | 32 | 96 | 7.1 |
| 16/08/11 | ML | Vallio | 10.0 | - | 2.0 | 3.0 | 74 | 1.24 | 2.96 | 0.15 | 9% | | 987 | 50 | 59 | 11.5 |
| 16/08/11 | ML | Vallio | 7.5 | - | 2.0 | 3.0 | 71 | 1.28 | 3.06 | 0.15 | 9% | | 1020 | 35 | 87 | 8.1 |
| 24/08/11 | ML | Vallio | 7.5 | - | 2.0 | 3.0 | 73 | 0.76 | 3.32 | 0.10 | 6% | | 1107 | 52 | 64 | 11.5 |
| 25/08/11 | ML | Vallio | 10.0 | - | 2.0 | 3.0 | 72 | 0.80 | 3.10 | 0.15 | 6% | | 1033 | 46 | 68 | 10.5 |
| 02/09/11 | ML | Vallio | 7.5 | - | 1.5 | 3.0 | 75 | 1.00 | 3.46 | 0.12 | 7% | | 1153 | 43 | 81 | 9.5 |
| 23/09/11 | ML | Vallio | 7.5 | - | 3.0 | 3.0 | 75 | 0.84 | 3.24 | 0.10 | 7% | | 1080 | 36 | 90 | 8.0 |
| 27/09/11 | ML | Vallio | 7.5 | - | 3.0 | 3.0 | 75 | 1.46 | 3.40 | 0.15 | 9% | | 1133 | 34 | 99 | 7.8 |
| 11/10/11 | ML | Vallio | 7.5 | - | 3.0 | 3.0 | 73 | 0.90 | 3.16 | 0.10 | 7% | | 1053 | 36 | 88 | 8.0 |
| 25/10/11 | SP FV | ANFUS | 7.5 | - | 10.0 | 5.0 | 54 | 0.42 | 3.38 | 0.10 | 5% | na | 676 | 72 | 47 | 15.9 |
| 31/10/11 | SP FV | ANFUS | 7.5 | - | 10.0 | 3.0 | 55 | 0.14 | 3.30 | 0.12 | 2% | na | 1100 | 87 | 38 | 19.5 |
| 04/11/11 | SP | ANFUS | 7.5 | - | 10.0 | 3.0 | 82 | 0.42 | 3.36 | 0.15 | 4% | 16 | 1120 | 102 | 33 | 23.2 |
| 25/11/11 | SP | ANFUS | 7.5 | - | 10.0 | 3.0 | 56 | 0.42 | 3.38 | 0.15 | 4% | na | 1127 | 73 | 46 | 16.7 |
| 19/12/11 | ML | ANFUS | 10.0 | - | 10.0 | 3.0 | 77 | 0.18 | 3.22 | 0.15 | 3% | na | 1073 | 101 | 32 | 23.0 |

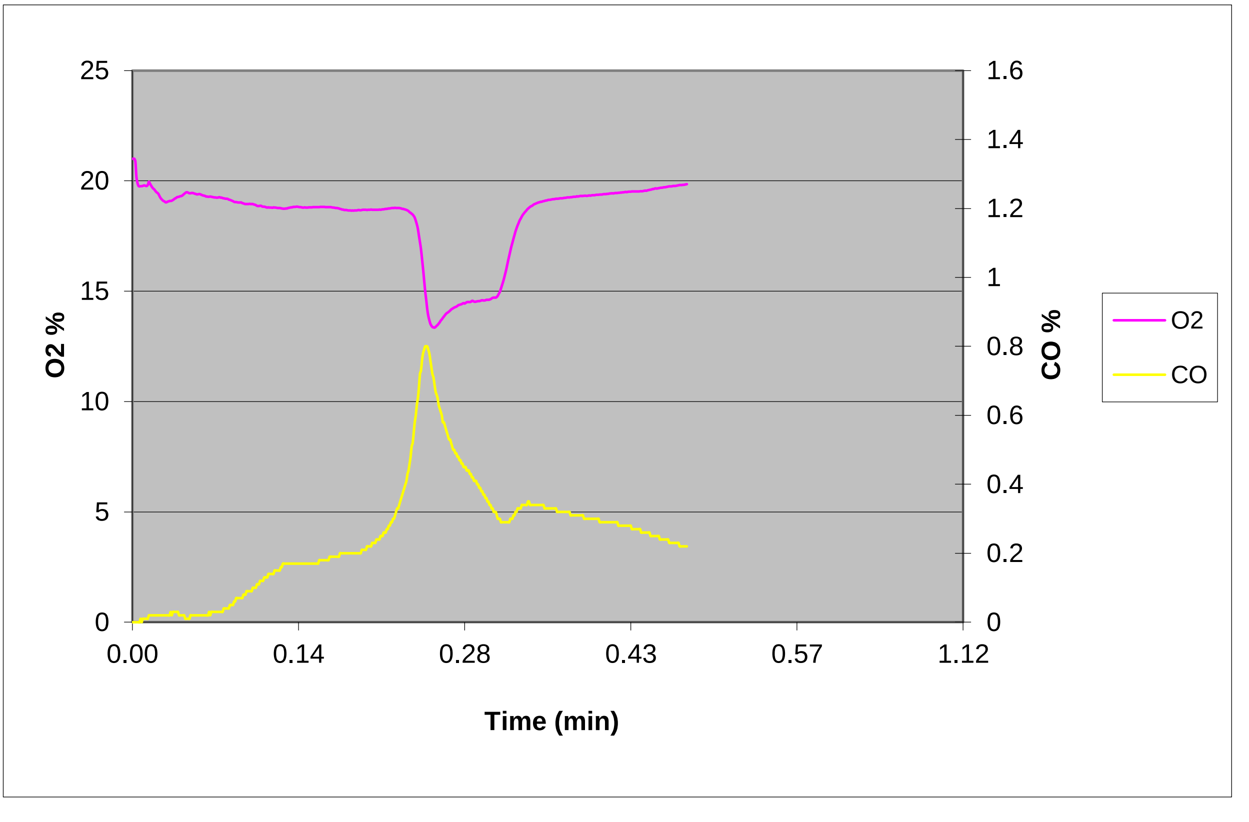
## Tests performed on the *mlc* (small size) rice husk stove model

| Date | Run | Location | Notes | Water | ΔT | Evaporated water | Rice husk | Coal | Efficiency | Boiling Time | Specific consumption | Burning Rate | Total Duration | Mean Power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | L | °C | kg | kg | kg | % | min | g/L | g/ min | min | kW |
| 18/03/11 | 1 | UniBS | 5 auxiliary lateral ducts | 2.0 | 85 | 0.90 | 1.36 | 0.10 | 14% | 15* | 680 | 20 | 67 | 4.9 |
| 30/03/11 | 1 | UniBS | turbulent pre-heated secondary air | 3.0 | 80 | 0.40 | 1.32 | 0.10 | 10% | na | 440 | 19 | 69 | 4.6 |
| 06/04/11 | 1 | UniBS | laminar pre-heated secondary air | 2.0 | 71 | 0.50 | 1.40 | 0.10 | 9% | na | 700 | 24 | 59 | 5.7 |
| 13/04/11 | 1 | UniBS | no secondary air | 2.0 | 81 | 0.48 | 1.20 | 0.10 | 10% | 29 | 600 | 21 | 58 | 5.0 |
| 14/04/11 | 1 | UniBS | very little secondary air | 2.0 | 77 | 0.66 | 1.18 | 0.10 | 12% | na | 590 | 25 | 48 | 6.0 |
| 20/04/11 | 1 | UniBS | little secondary air | 2.0 | 73 | 0.76 | 1.34 | 0.10 | 12% | na | 670 | 20 | 67 | 4.8 |
| 21/04/11 | 1 | UniBS | secondary air closed at start-up | 2.0 | 78 | 0.78 | 1.32 | 0.05 | 14% | 32 | 660 | 19 | 70 | 4.2 |
| 05/05/11 | 1 | UniBS | more coal | 3.0 | 73 | 0.74 | 1.22 | 0.10 | 15% | na | 407 | 18 | 67 | 4.4 |
| 06/05/11 | 1 | UniBS | central duct with raised bottom | 3.0 | 70 | 0.80 | 1.30 | 0.10 | 14% | na | 433 | 15 | 89 | 3.5 |
| 10/05/11 | 1 | UniBS | turbulent pre-heated secondary air | 2.9 | 72 | 0.40 | 1.06 | 0.10 | 11% | na | 363 | 16 | 68 | 3.9 |
| 12/05/11 | 1 | UniBS | | 2.0 | 70 | 0.60 | 1.26 | 0.10 | 11% | na | 630 | 17 | 73 | 4.2 |
| 13/05/11 | 1 | UniBS | | 3.0 | 67 | 0.52 | 1.22 | 0.10 | 11% | na | 407 | 16 | 74 | 4.0 |
| 20/05/11 | 1 | UniBS | restored | 3.0 | 69 | 0.60 | 1.18 | 0.10 | 13% | na | 393 | 14 | 86 | 3.4 |
| 15/06/11 | 1 | UniBS | shortened ducts | 3.0 | 69 | 0.76 | 1.74 | 0.10 | 11% | na | 580 | 24 | 73 | 5.6 |
| 15/07/11 | 1 | SC Friuli | | 3.0 | 70 | 0.62 | 1.54 | 0.10 | 10% | na | 513 | 27 | 57 | 6.4 |
| 15/07/11 | 2 | SC Friuli | small basket | 1.5 | 66 | 0.18 | 0.34 | 0.05 | 15% | na | 227 | 19 | 18 | 5.1 |
| 15/07/11 | 3 | SC Friuli | medum basket | 3.0 | 63 | 0.29 | 0.60 | 0.05 | 16% | na | 200 | 19 | 31 | 4.7 |
| 22/07/11 | 1 | UniBS | large basket | 2.5 | 50 | 0.38 | 0.90 | 0.10 | 10% | na | 360 | 19 | 47 | 4.9 |
| 09/11/11 | 1 | UniBS | upper concentr. no lower annular gap | 3.0 | 82 | 0.6 | 0.82 | 0.10 | 19% | 25 | 273 | 17 | 47 | 4.5 |
| 14/11/11 | 1 | UniBS | upper concentr. no lower annular gap | 3.0 | 85 | 0.46 | 0.86 | 0.10 | 16% | 22 | 287 | 23 | 38 | 5.8 |
| 19/12/11 | 1 | ANFUS | bottom opening 1/1 | 3.0 | 86 | 0.38 | 0.86 | 0.05 | 16% | na | 287 | 18 | 48 | 4.2 |
| 19/12/11 | 2 | ANFUS | bottom opening 1/8 | 3.0 | 77 | 0.26 | 1.08 | 0.05 | 11% | na | 360 | 20 | 54 | 4.6 |
| 19/12/11 | 3 | ANFUS | bottom opening 1/2 | 3.0 | 80 | 0.48 | 0.98 | 0.05 | 15% | na | 327 | 14 | 71 | 3.2 |
| 28/12/11 | 2 | ANFUS | bottom opening 1/2 + flue valve | 3.0 | 73 | 0.70 | 1.00 | 0.05 | 18% | 27 | 331 | 21 | 48 | 4.8 |
| 28/12/11 | 3 | ANFUS | bottom opening 1/2 + flue valve | 3.0 | 78 | 0.64 | 0.94 | 0.05 | 19% | 27 | 315 | 18 | 53 | 4.1 |
| 28/12/11 | 4 | ANFUS | bottom opening 1/2 + flue valve | 3.0 | 74 | 0.70 | 1.04 | 0.05 | 18% | 28 | 347 | 15 | 70 | 3.4 |

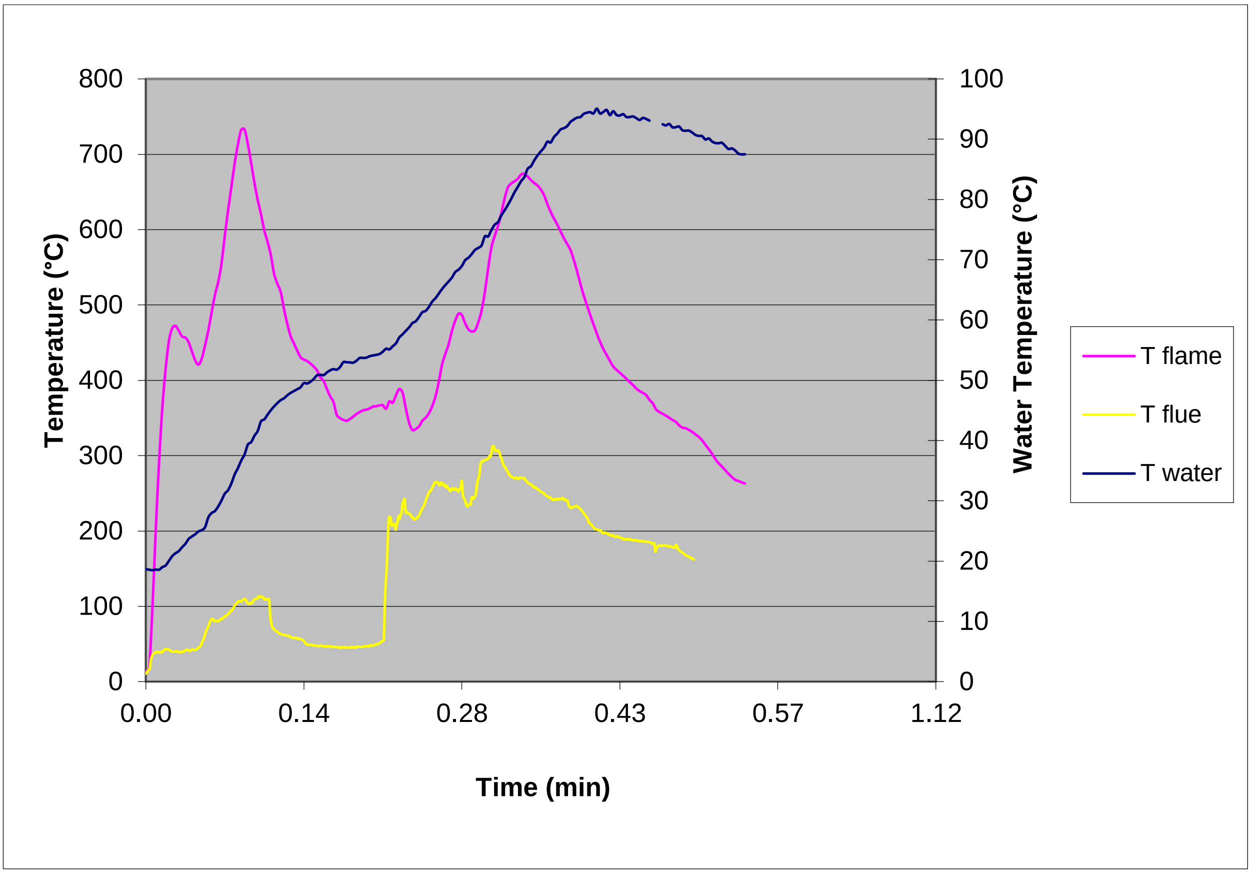
## Temperature and emission runs in tests on the *mlc* (small size) rice husk stove model

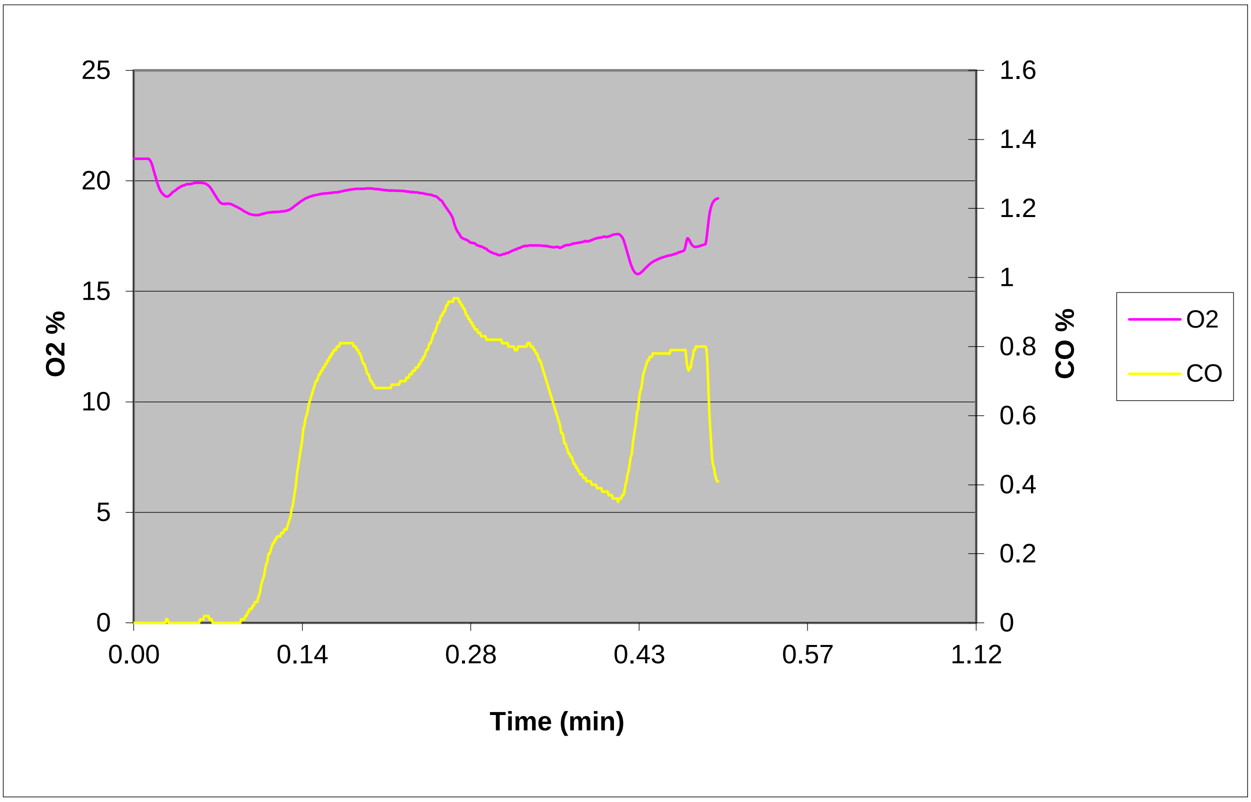
### *19 December 2011 run 1*

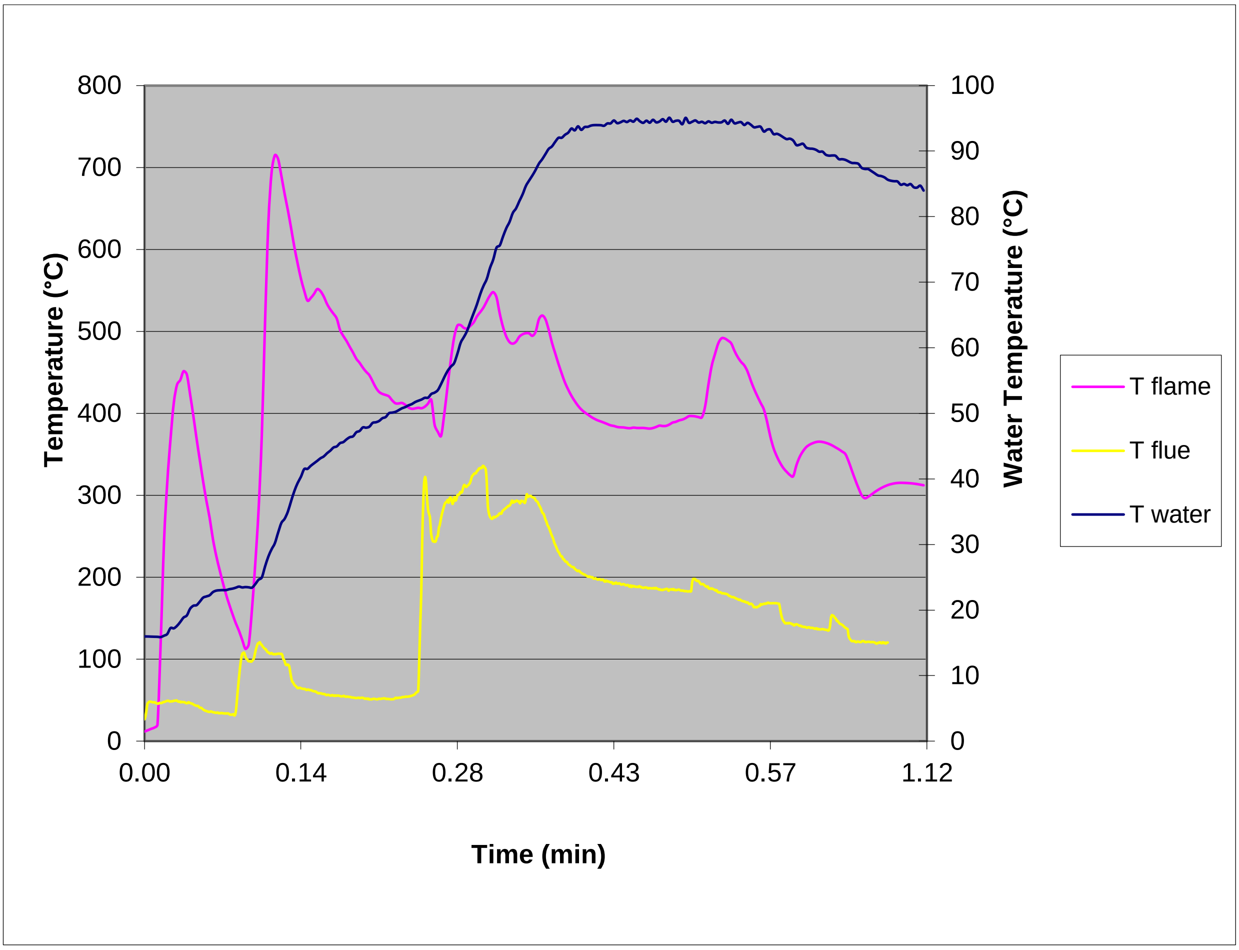


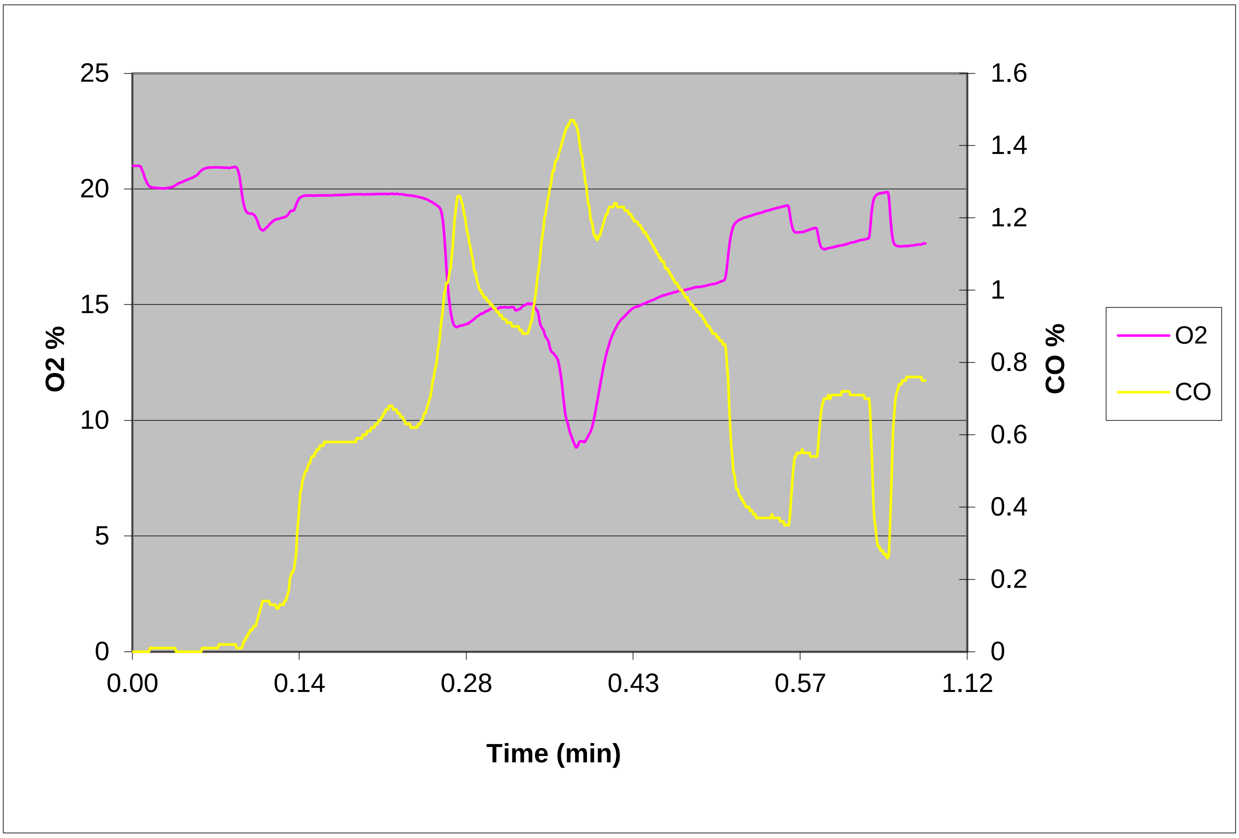



*19 December 2011 run 2*

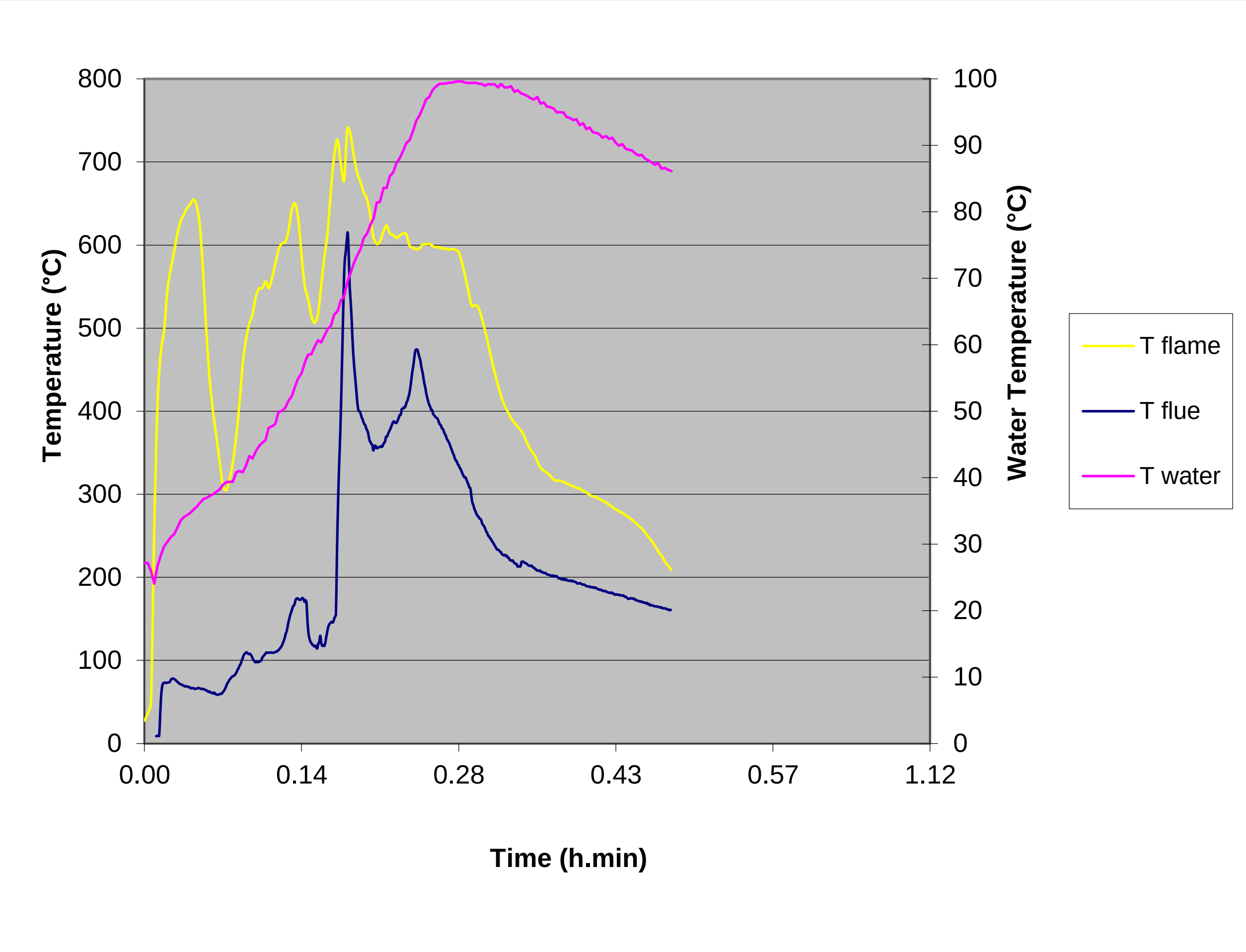


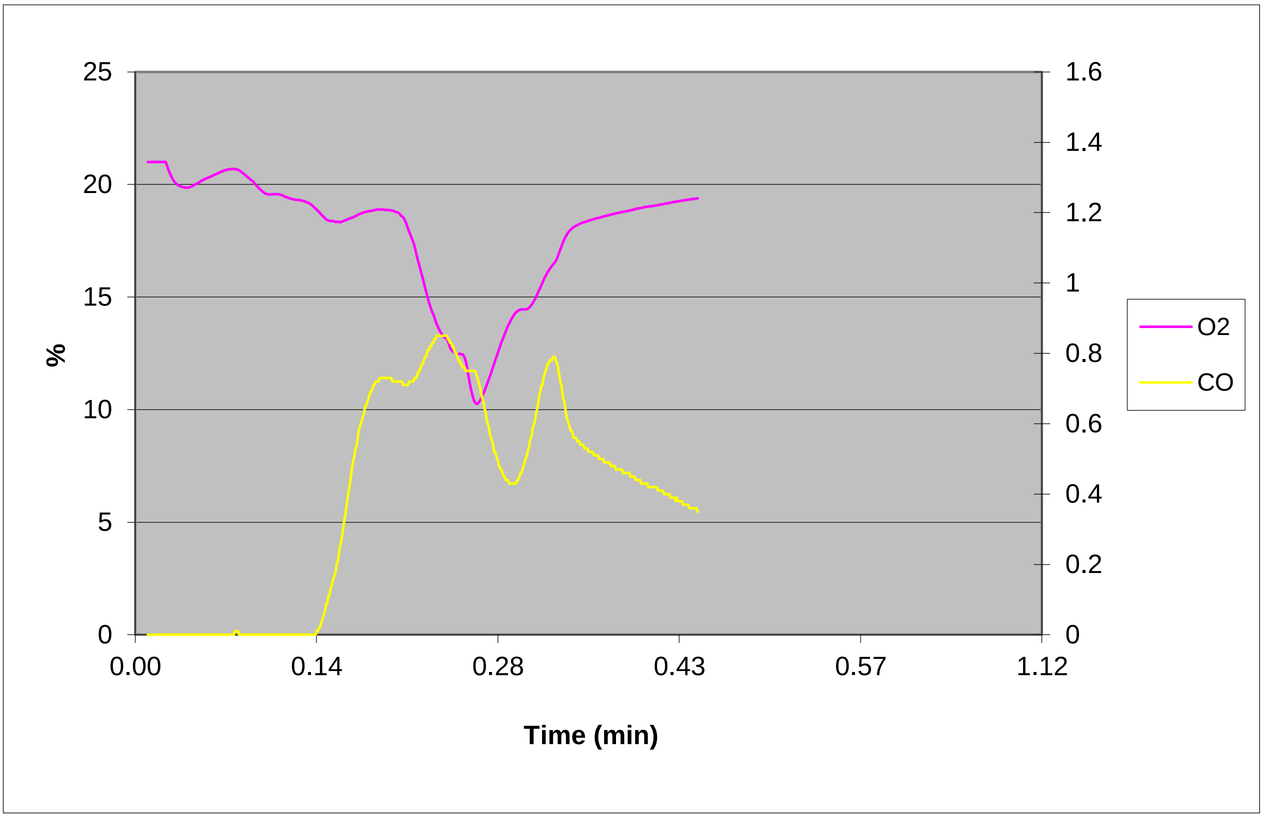



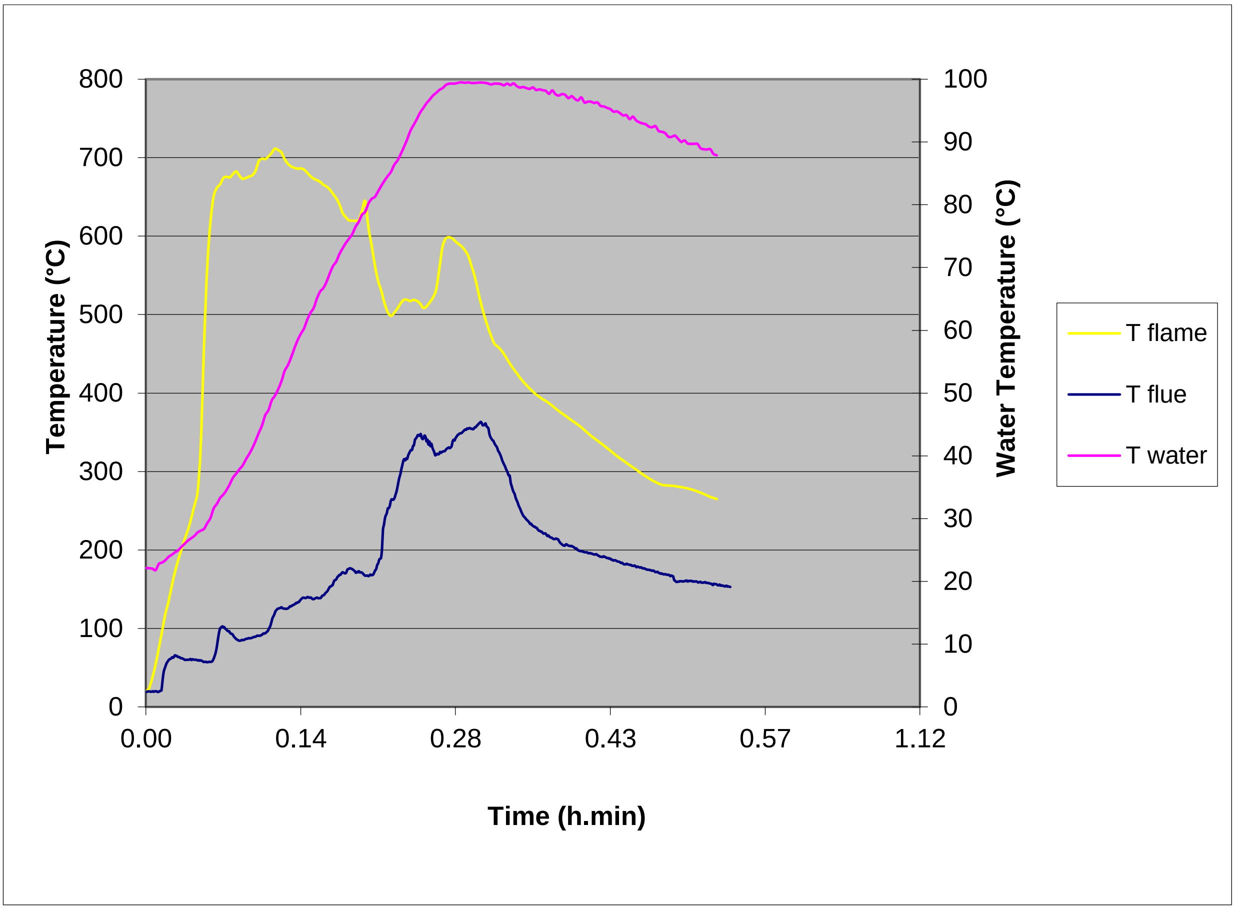

800
700
600
500
400
300
200
100
0
100
90
80
70
60
50
40
30
20
10
0
0.00
0.14
0.28
0.43
0.57
1.12
Temperature (°C)
Water Temperature (°C)
Time (min)
T flame
T flue
T water


25
20
15
10
5
0
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.14
0.28
0.43
0.57
1.12
O2 %
CO %
Time (min)
O2
CO

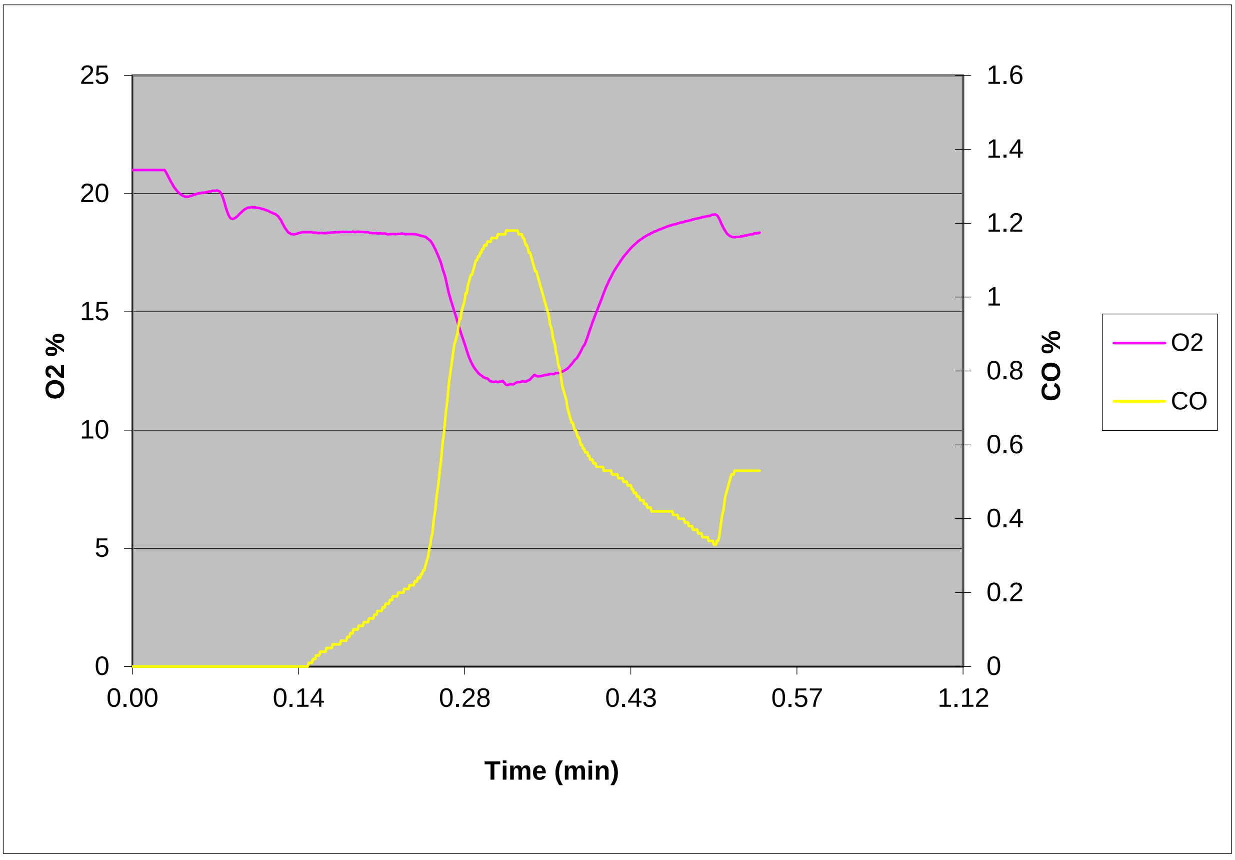
## *28 December 2011 run 1*



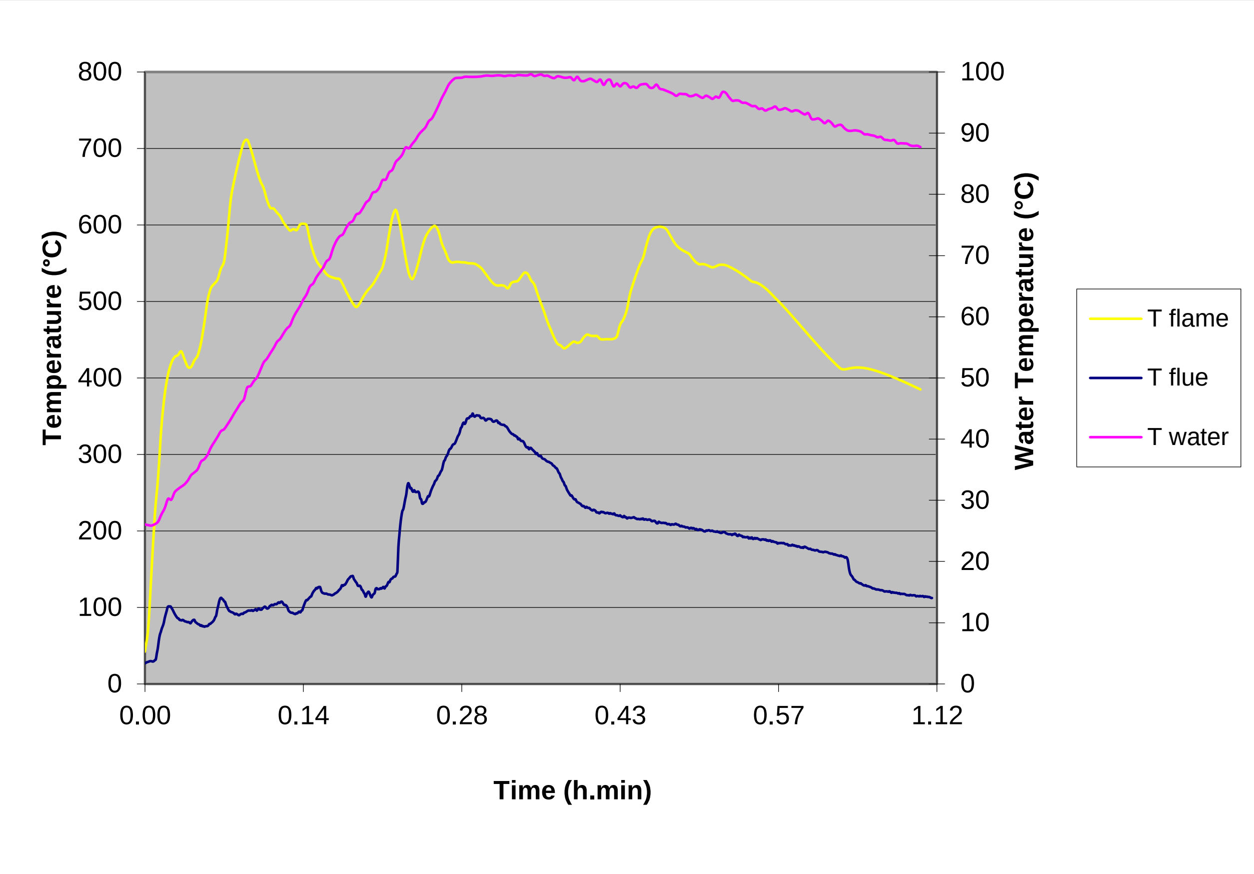


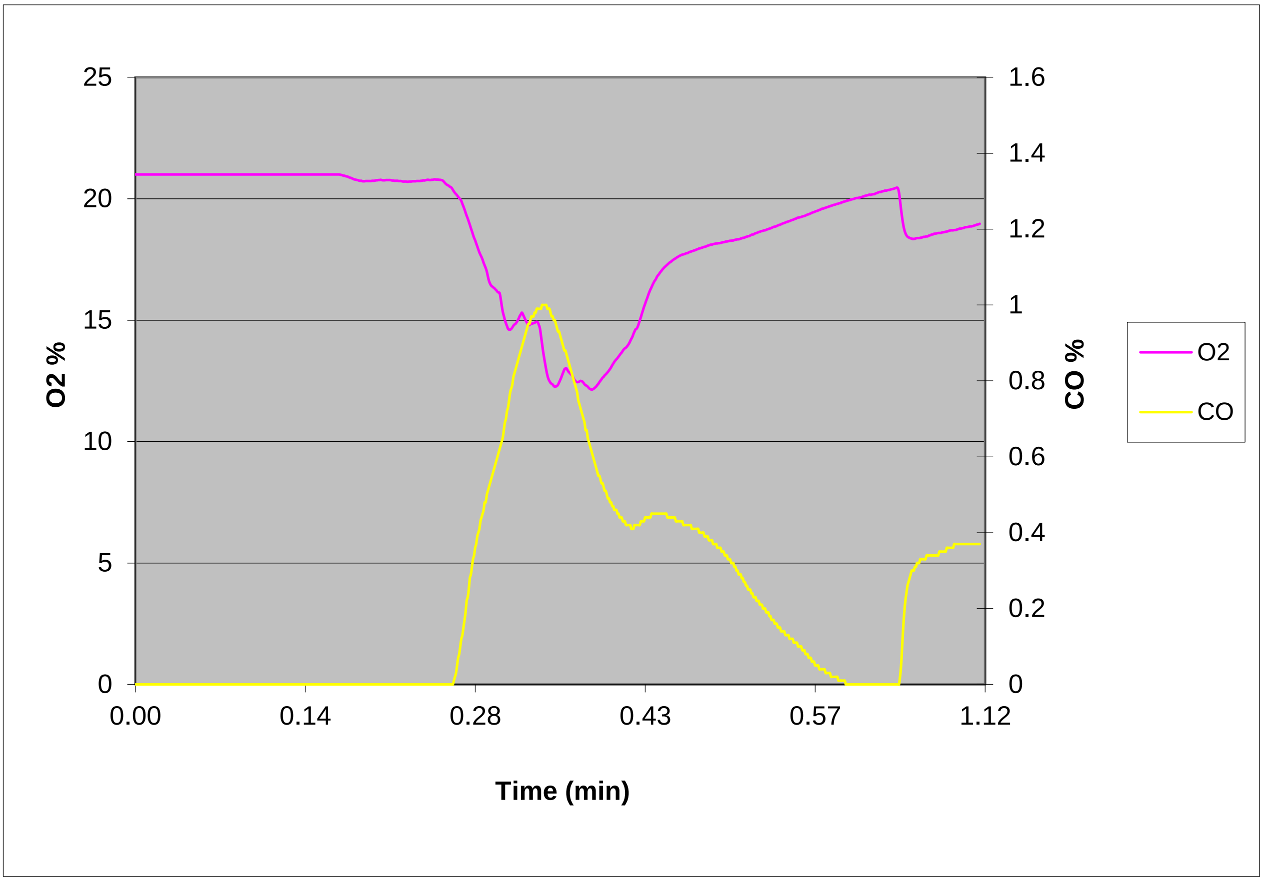
800
700
600
500
400
300
200
100
0
100
90
80
70
60
50
40
30
20
10
0
0.00
0.14
0.28
0.43
0.57
1.12
Temperature (°C)
Water Temperature (°C)
Time (h.min)
T flame
T flue
T water

25
20
15
10
5
0
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.14
0.28
0.43
0.57
1.12
O2 %
CO %
Time (min)
O2
CO

## *28 December 2011 run 3*



## Annexes 5: List of publications reviewed matching the word "cookstove" in their title or key-words, published between 2009 and 2011 on the ISI Web of Knowledge

| Title | Authors | Source Title | Year | Vol | Iss | Pages |
|---|---|---|---|---|---|---|
| Health and Climate Change 1 Public health benefits of strategies to reduce greenhouse-gas emissions: household energy | Wilkinson et al | LANCET | 2009 | 374 | 9705 | 1917 1929 |
| Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves | Roden et al | ATMOSPHERIC ENVIRONMENT | 2009 | 43 | 6 | 1170 1181 |
| Personal child and mother carbon monoxide exposures and kitchen levels: Methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE) | Smith et al | JOURNAL OF EXPOSURE SCIENCE AND ENVIRONMENTAL EPIDEMIOLOGY | 2010 | 20 | 5 | 406 416 |
| Quantification of Carbon Savings from Improved Biomass Cookstove Projects | Johnson et al | ENVIRONMENTAL SCIENCE & TECHNOLOGY | 2009 | 43 | 7 | 2456 2462 |
| Wood fuel use in the traditional cooking stoves in the rural floodplain areas of Bangladesh: A socio-environmental perspective | Miah et al | BIOMASS & BIOENERGY | 2009 | 33 | 1 | 70 78 |
| Solid-fuel household cook stoves: Characterization of performance and emissions | Jetter et al | BIOMASS & BIOENERGY | 2009 | 33 | 2 | 294 305 |
| Thermoelectric power generation from biomass cook stoves | Champier et al | ENERGY | 2010 | 35 | 2 | 935 942 |
| Mind the Gap | Smith et al | ENVIRONMENTAL HEALTH PERSPECTIVES | 2010 | 118 | 12 | 1643 1645 |
| Impact of improved cookstoves on indoor air pollution and adverse health effects among Honduran women | Clark et al | INTERNATIONAL JOURNAL OF ENVIRONMENTAL HEALTH RESEARCH | 2009 | 19 | 5 | 357 368 |
| Fuel use and design analysis of improved woodburning cookstoves in the Guatemalan Highlands | Granderso et al | BIOMASS & BIOENERGY | 2009 | 33 | 2 | 306 315 |
| Arresting the Killer in the Kitchen: The Promises and Pitfalls of Commercializing Improved Cookstoves | Bailis et al | WORLD DEVELOPMENT | 2009 | 37 | 10 | 1694 1705 |
| A GIS-based methodology for highlighting fuelwood supply/demand imbalances at the local level: A case study for Central Mexico | Ghilardi et al | BIOMASS & BIOENERGY | 2009 | 33 | 6-7 | 957 972 |
| Mitigation of greenhouse gases by adoption of improved biomass cookstoves | Panwar et al | MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE | 2009 | 14 | 6 | 569 578 |
| Geographies of mediation: Market development and the rural broker in Maharashtra, India | Simon | POLITICAL GEOGRAPHY | 2009 | 28 | 3 | 197 207 |
| Deployment of Coal Briquettes and Improved Stoves: Possibly an Option for both Environment and Climate | Zhi et al | ENVIRONMENTAL SCIENCE & TECHNOLOGY | 2009 | 43 | 15 | 5586 5591 |
| Indoor air pollution, cookstove quality, and housing characteristics in two Honduran communities | Clark et al | ENVIRONMENTAL RESEARCH | 2010 | 110 | 1 | 12 18 |
| New Approaches to Performance Testing of Improved Cookstoves | Johnson et al | ENVIRONMENTAL SCIENCE & TECHNOLOGY | 2010 | 44 | 1 | 368 374 |
| Estimating personal PM2.5 exposures using CO measurements in Guatemalan households cooking with wood fuel | Northcross et al | JOURNAL OF ENVIRONMENTAL MONITORING | 2010 | 12 | 4 | 873 878 |
| Role of renewable energy sources in environmental protection: A review | Panwar et al | RENEWABLE & SUSTAINABLE ENERGY REVIEWS | 2011 | 15 | 3 | 1513 1524 |
| Characterization of non-methane hydrocarbons emitted from open burning of wheat straw and corn stover in China | Li et al | ENVIRONMENTAL RESEARCH LETTERS | 2009 | 4 | 4 | |
| Biomass smoke exposures: Health outcomes measures and study design | Noonan et al | INHALATION TOXICOLOGY | 2010 | 22 | 2 | 108 112 |
| Improved stove programs need robust methods to estimate carbon offsets | Johnson, et al | CLIMATIC CHANGE | 2010 | 102 | 3-4 | 641 649 |
| Beyond fuelwood savings: Valuing the economic benefits of introducing improved biomass cookstoves in the Purepecha region of Mexico | Garcia - Frapolli et al | ECOLOGICAL ECONOMICS | 2010 | 69 | 12 | 2598 2605 |
| Emission factors and particulate matter size distribution of polycyclic aromatic hydrocarbons from residential coal combustions in rural Northern China | Shen et al | ATMOSPHERIC ENVIRONMENT | 2010 | 44 | 39 | 5237 5243 |
| Emissions of PAHs from Indoor Crop Residue Burning in a Typical Rural Stove: Emission Factors, Size Distributions, and Gas-Particle Partitioning | Shen et al | ENVIRONMENTAL SCIENCE & TECHNOLOGY | 2011 | 45 | 4 | 1206 1212 |
| Effect of chimneys on indoor air concentrations of PM(10) and benzo[a]pyrene in Xuan Wei, China | Tian, et al | ATMOSPHERIC ENVIRONMENT | 2009 | 43 | 21 | 3352 3355 |

| Title | Authors | Source Title | Year | Vol | Iss | Pages |
|---|---|---|---|---|---|---|
| Farmers fighting climate change-from victims to agents in subsistence livelihoods | Olsson, Jerneck | WILEY INTERDISCIPLINARY REVIEWS-CLIMATE CHANGE | 2010 | 1 | 3 | 363 373 |
| Indoor particle size distributions in homes with open fires and improved Patsari cook stoves | Armendariz - Arnez et al | ATMOSPHERIC ENVIRONMENT | 2010 | 44 | 24 | 2881 2886 |
| Health Endpoints Assessed During the Baseline Year of an Improved Cookstove Intervention Among Nicaraguan Women | Clark et al | EPIDEMIOLOGY | 2009 | 20 | 6 | S216 S217 |
| Indoor Air Pollution Concentrations Assessed During the Baseline Year of an Improved Cookstove Intervention in a Rural Nicaraguan Community | Clark et al | EPIDEMIOLOGY | 2009 | 20 | 6 | S218 S218 |
| Mobilizing cookstoves for development: a dual adoption framework analysis of collaborative technology innovations in Western India | Simon | ENVIRONMENT AND PLANNING A | 2010 | 42 | 8 | 2011 2030 |
| QUALITATIVE FINDINGS AND IMPLICATIONS FOR SCALING UP AN IMPROVED COOKSTOVE PROJECT IN RURAL KENYA | Person et al | AMERICAN JOURNAL OF TROPICAL MEDICINE AND HYGIENE | 2010 | 83 | 5 | 355 356 |
| Dirty cookstoves pose enormous health risk | Benac | CANADIAN MEDICAL ASSOCIATION JOURNAL | 2010 | 182 | 16 | 1718 1719 |
| Biomass fuel use, burning technique and reasons for the denial of improved cooking stoves by Forest User Groups of Rema-Kalenga Wildlife Sanctuary, Bangladesh | Chowdhury et al | INTERNATIONAL JOURNAL OF SUSTAINABLE DEVELOPMENT AND WORLD ECOLOGY | 2011 | 18 | 1 | 88 97 |
| Burning for Sustainability: Biomass Energy, International Migration, and the Move to Cleaner Fuels and Cookstoves in Guatemala | Taylor et al | ANNALS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS | 2011 | 101 | 4 | 918 928 |
| Unbelievable but improved cookstoves are not helpful in reducing firewood demand in Nepal | Nepal et al | ENVIRONMENT AND DEVELOPMENT ECONOMICS | 2011 | 16 | | 1 23 |
| Global burden of disease as a result of indoor air pollution in Shaanxi, Hubei and Zhejiang, China | Mestl et al | SCIENCE OF THE TOTAL ENVIRONMENT | 2011 | 409 | 8 | 1391 1398 |
| Evaluation of Mass and Surface Area Concentration of Particle Emissions and Development of Emissions Indices for Cookstoves in Rural India | Sahu et al | ENVIRONMENTAL SCIENCE & TECHNOLOGY | 2011 | 45 | 6 | 2428 2434 |
| Climate Change Impact of Biochar Cook Stoves in Western Kenyan Farm Households: System Dynamics Model Analysis | Whitman et al | ENVIRONMENTAL SCIENCE & TECHNOLOGY | 2011 | 45 | 8 | 3687 3694 |
| Modeling indoor air pollution from cookstove emissions in developing countries using a Monte Carlo single-box model | Johnson et al | ATMOSPHERIC ENVIRONMENT | 2011 | 45 | 19 | 3237 3243 |
| Adoption and use of improved biomass stoves in Rural Mexico | Pine et al | ENERGY FOR SUSTAINABLE DEVELOPMENT | 2011 | 15 | 2 | 176 183 |
| The impact of health behaviour change intervention on indoor air pollution indicators in the rural North West Province, South Africa | Barnes et al | JOURNAL OF ENERGY IN SOUTHERN AFRICA | 2011 | 22 | 3 | 35 44 |
| Greener energy: Issues and challenges for Pakistan-Biomass energy prospective | Bhutto et al | RENEWABLE & SUSTAINABLE ENERGY REVIEWS | 2011 | 15 | 6 | 3207 3219 |
| A mathematical modeling approach to risk assessment for normal and anemic women chronically exposed to carbon monoxide from biomass-fueled cookstoves | Bruce et al | JOURNAL OF APPLIED PHYSIOLOGY | 2011 | 111 | 2 | 473 484 |
| Improving access to energy in sub-Saharan Africa | Prasad | CURRENT OPINION IN ENVIRONMENTAL SUSTAINABILITY | 2011 | 3 | 4 | 248 253 |
| Innovative business models for the scale-up of energy access efforts for the poorest | Zerriffi | CURRENT OPINION IN ENVIRONMENTAL SUSTAINABILITY | 2011 | 3 | 4 | 272 278 |
| Ancillary impacts of energy-related climate change mitigation options in Africa's least developed countries | Rowlands | MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE | 2011 | 16 | 7 | 749 773 |
| Patterns and predictors of personal exposure to indoor air pollution from biomass combustion among women and children in rural China | Baumgartner et al | INDOOR AIR | 2011 | 21 | 6 | 479 488 |
| Cultivating a Demand for Clean Cookstoves Response | Martin et al | SCIENCE | 2011 | 334 | 6063 | 1637 1637 |
| Cultivating a Demand for Clean Cookstoves | Robinson, Baumgartner | SCIENCE | 2011 | 334 | 6063 | 1636 1637 |