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FEASIBILITY STUDY TO REDUCE HOSPITAL'S LOAD OF WOOD COOKING BIOMASS IN BURUNDI

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KUMVIKANA N'UWUNDI N'INTANGO Y'ITERA MBERE

Relating to others is the basis of all development.

- African proverb -

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Abbreviation Index

ABER	Burundian Agency for Rural Electrification
AGEEC	Advisory Group on Energy and Climate Change
ASAE	American Society of Agricultural Engineers
COP	Coefficient Of Performance
DC	Developing County
DGEE	General Directorate of Water and Energy
DGHER	General Directorate of Water and Rural Energies
DNI	Direct Normal Irradiation
DRC	Democratic Republic of Congo
EAPP	Eastern Africa Power Pool
EDI	Energy Development Index
EMC	Equilibrium Moisture Content
EUEI PDF	European Union Energy Initiative Partnership Dialogue Facility
FBU	Burundian Franc
GACC	The Global Alliance for Clean Cookstoves
GDP	Gross Domestic Product
GNI	Gross National Income
HDI	Human Development Index
HP	Heat Pump
ICS	Improved Cook Stove
IEA	International Energy Agency
LHV	Low Heating Value
LPG	Liquefied petroleum gas
MWEM	Ministry of Water, Energy and Mines

NGO	Non-Governmental Organization
PDC	Pompa di Calore
REGIDESO	Régie de Production et de Distribution d'Eau et d'Electricité
RES	Renewable Energy System
SDG	Sustainable Development Goal
SE4All	Sustainable Energy for All
SINELAC	Société Internationale d’Electricité des Pays des Grands Lacs
SNEL	Société Nationale d'Electricité de la République Democratique du Congo
WBT	Water Boiling Test
WHO	World Health Organization

Nomenclature

A	Area
C_p	Specific Heat
E	Energy
E_I	Primary energy
E_{II}	Secondary Energy
h_{eq}	Equivalent Hours
I	Insolation
m	Mass
p	Standard barometric pressure
P	Cooking power
Q	Thermal Power
RH	Relative Humidity
S	Percentage of savings
T	Temperature
V	Volume
W	Power
x	Mass ratio
y	Mass content
Z	Altitude
α_S	Solar altitude
ΔT	Temperature difference
Δt	Time difference
η	Efficiency

Abstract

Access to energy is a major topic in developing countries and one of the most discussed issues of the new millennium. One of the branches is the theme of access to clean cooking facilities. This is globally discussed because of the relation to the problem of deaths from pneumonia, chronic lung disease, and lung cancer caused by the smokes of improper cooking appliances. On the other hand, the increasing need of wood used for cooking by people in low efficient devices is contributing to increase the process of deforestation in many developing countries. In particularly, the heavy reliance on wood for cooking makes Burundi the country with the highest rate of deforestation in Africa. Wood represents the unique type of fuel used by 99% of Burundian people with the consequents of a more pressing need to cut trees.

This work represents the research and test of energy alternatives to wood biomass and limit its pressure on the actual uncontrolled phenomenon of deforestation in Burundi. After a historical socio-economic overview of the country, the feasibility study and the forecast of the benefits have been carried out in a hospital of a small village on the Burundian hill of Mutoyi and where a local Italian NGO called Vispe works. This is where the highest consumption of wood cooking biomass takes place in traditional stoves. The research done confirms the availability of a high but not fully exploited potential of local renewable resources such as hydroelectric and sun power. The analysis of their technological application suggests the possibility to reach a satisfying 30% of wood savings compared with the consumption of the actual stoves. Moreover, the use of technologies such as heat pumps, solar collectors or homemade solar cookers has been found to be even more affordable than wood biomass.

In conclusion, the results forecasted in the examined location give this work the prospect of being replicated in numerous similar structures throughout Burundi for a more active stand against deforestation.

keywords: access to modern energy sources, deforestation, Burundi, wood biomass, renewable energies, hydroelectricity, solar cooker, hospital

Sommario

Il tema dell'accesso all’energia nei paesi in via di sviluppo è uno dei temi più discussi del nuovo millennio, e, in particolare, vi è un crescente interesse riguardo il tema dell’accesso a fonti di energia pulite per scopi domestici. Parallelamente al relativo problema delle morti per polmonite, malattia polmonare cronica, e cancro ai polmoni causato dai fumi di impropri apparecchi di cottura, il crescente e sempre più pressante bisogno di legna per la cottura contribuisce ad accelerare il processo di deforestazione in molti paesi in via di sviluppo. In particolare, l’elevato consumo di legna rende il Burundi la nazione con il più alto tasso di deforestazione in Africa. Attualmente, la legna rappresenta l'unico tipo di combustibile utilizzato per il 99% degli abitanti burundesi con una conseguente sempre più pressante necessità di tagliare alberi.

Questo lavoro rappresenta il primo tentativo di ricerca e test di fonti energetiche alternative alla biomassa legnosa e limitarne gli effetti sul dilagante fenomeno della deforestazione Burundi. A seguito di una panoramica socio-culturale del Paese, sono stati effettuati uno studio e previsione dei benefici raggiungibili in un ospedale di un piccolo villaggio sulla collina burundese di Mutoyi gestito dall’ONG italiana Vispe dove hanno luogo i più alti consumi di combustibile legnoso. La ricerca conferma la disponibilità di un elevato potenziale non sfruttato di risorse rinnovabili locali quali l’idroelettrico e sole. L’analisi delle diverse applicazioni tecnologiche di quest’ultime ha permesso di stimare soddisfacenti risparmi del 30% di legna rispetto al consumo nelle comuni stufe utilizzate in Missione. Inoltre l’utilizzo di tecnologie quali pompe di calore, collettori solari o cucine solari auto costruite si rivelato più conveniente della biomassa legnosa.

Infine, i confortanti risultati previsti nel luogo preso in esame conferiscono a questo lavoro l’auspicabile prospettiva di essere replicato nelle numerose strutture analoghe diffuse in Burundi per una lotta più attiva e partecipata contro la deforestazione.

parole chiave: accesso a risorse energetiche moderne, deforestazione, Burundi, biomassa, energie rinnovabili, idroelettrico, stufe solari, ospedale

Estratto in lingua italiana

L'interesse verso il tema dell'accesso all'energia nei Paesi in via di sviluppo è in continua crescita, come viene testimoniato dai molti documenti internazionali che ne trattano, come ad esempio il World Energy Outlook 2013, pubblicato dall'International Energy Agency. In particolar modo, uno degli argomenti più dibattuti è quello dell'accesso ai combustibili moderni e a strumenti appropriati per il loro utilizzo a scopi domestici. E' bene ricordare che se circa 1.3 miliardi di persone al mondo non hanno accesso all'elettricità, ben 2.6 miliardi di persone non hanno accesso ai combustibili moderni. La Figura 1 mostra la percentuale di popolazione che non ha accesso ai combustibili moderni nel mondo ed evidenzia bene come questo problema sia particolarmente significativo nei Paesi a basso reddito e dell'Africa sub-sahariana.

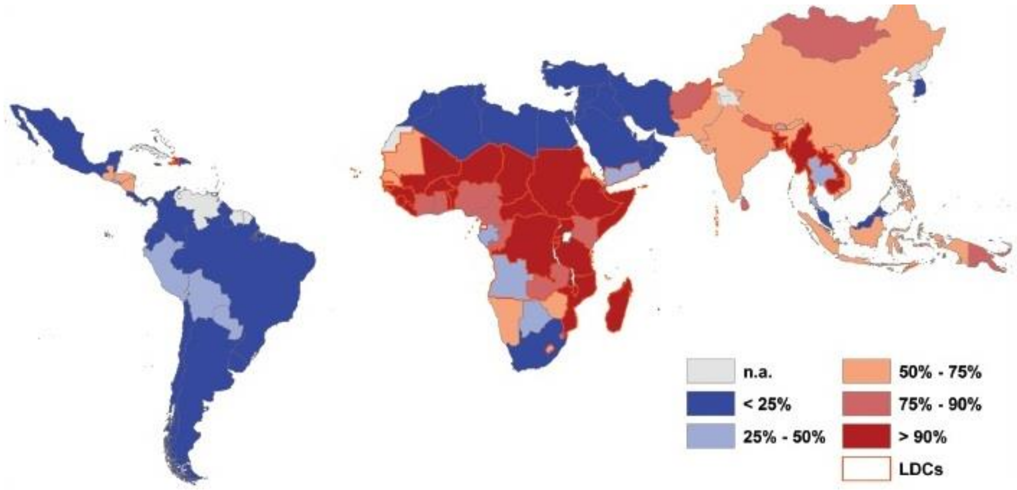


Figura 1 -Percentuale di popolazione che non ha accesso ai combustibili moderni nei Paesi in via di sviluppo.

La prima dannosa conseguenza dell'eccessiva dipendenza dal combustibile legnoso sono le morti per intossicazione, malattie quali la polmonite, il cancro ai polmoni e, in generale, malattie delle via aeree attribuite all'utilizzo di dispositivi inappropriati per la cottura in ambiente domestico che nel 2012 hanno causato 4,3 milioni di morti.

Anche se meno discussa, un'altra grave conseguenza di ciò è il dannoso impatto sull'ambiente. In molti Paesi, infatti, l'approvvigionamento di legno da parte delle comunità rurali più povere contribuisce ad accelerare il processo di deforestazione. Nonostante la raccolta di legna utilizzata per cucinare non sia la sola causa del fenomeno della deforestazione, in molti paesi come l'Africa sub-Sahariana tale collegamento risulta assai evidente.

Infine, la dipendenza dall'utilizzo di legna ha un notevole impatto sociale sulle famiglie, in particolare su donne e bambini, costretti a spendere gran parte del loro tempo per la raccolta della legna.

Uno dei Paesi con il minor accesso all'energia sia in termini di elettrificazione che accesso ai combustibili moderni è il Burundi. Infatti, il Paese versa in una situazione di estrema criticità, e questo si può evincere anche confrontando il Burundi con altri Paesi africani (Figura 2). Solo il 5% della popolazione ha accesso all'elettricità, concentrata soprattutto in capitale e nelle province.

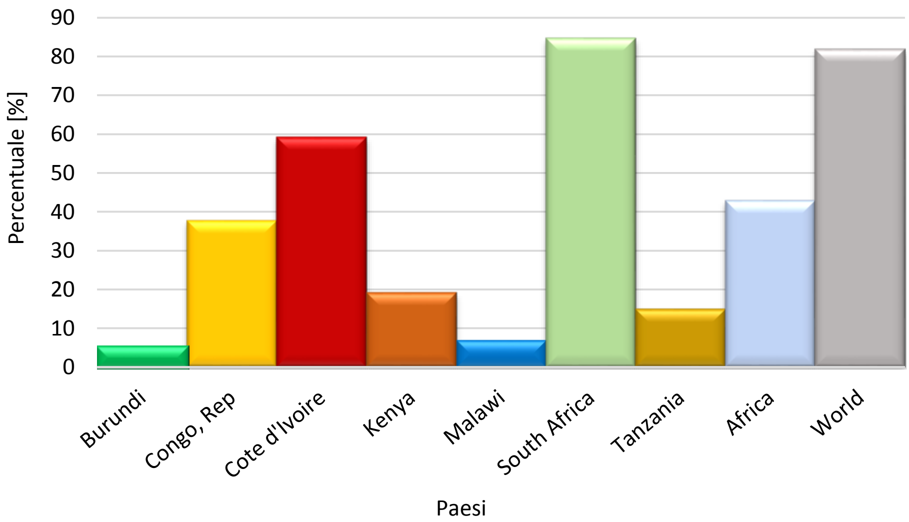


Figura 2 - Accesso all'elettricità in Burundi e diverse altre regioni.

Se si considera invece l'accesso ai combustibili moderni[1], si vede come la condizione del Paese sia ancora più critica: meno dell'1% della popolazione utilizza i combustibili moderni, invece di quelli tradizionali (Figura 3).

[1] Elettricità, combustibili liquidi come kerosene, combustibili gassosi come gas di petrolio liquefatto e gas naturale, biogas, biocombustibili, sole.

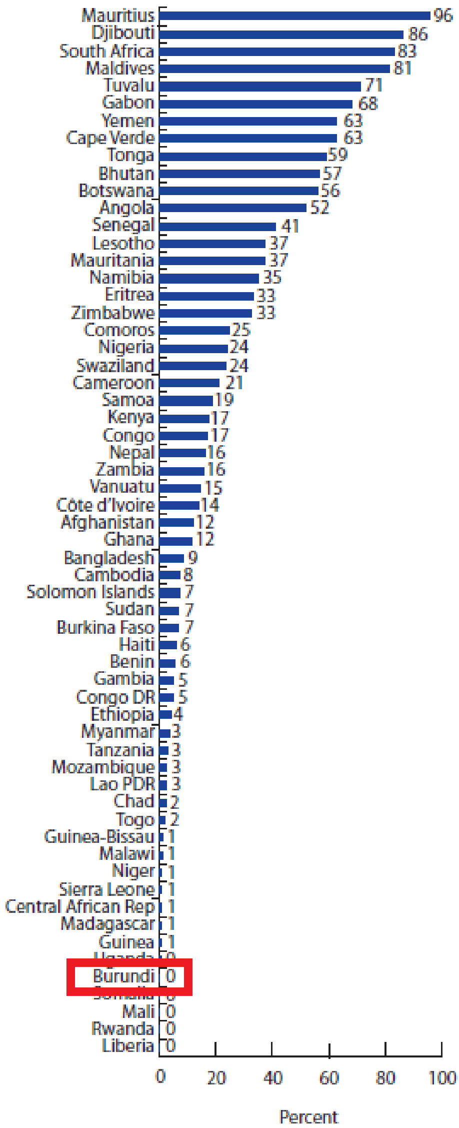


Figura 3 -Percentuale di popolazione con accesso ai combustibili moderni nei Paesi a basso reddito e dell'Africa sub-Sahariana.

Tale situazione contribuisce a rendere il Burundi il Paese con il più alto tasso di deforestazione di tutto il continente africano. Dal 1990, l'area totale ricoperta da foreste decresce con un tasso medio del 2% annuo (si sostiene che durante la guerra civile degli anni '90 si sia osservato nel Paese uno dei tassi più alti mai registrati al mondo superiore al 9%). Le dannose conseguenze e le complicazioni provocate sono elevate. Prima tra tutte il fenomeno dell'erosione del suolo che causa la perdita di suolo fertile e coltivabile. A livello sociale, dal momento che la deforestazione provoca un aumento della distanza per raggiungere i boschi, le donne e bambini burundesi che all'interno delle famiglie hanno il compito di raccogliere la legna sono costretti a spendere più tempo per la raccolta. Inoltre, l'erosione dei pendii delle colline e dei terreni adiacenti i fiumi contribuiscono alla sedimentazione nei ruscelli, laghi e paludi con conseguenze dannose per la riproduzione ed ecosistema acquatici. L'insabbiamento e inquinamento delle acqua del lago Tanganika e la perdita di biodiversità marina con ripercussioni sulla pesca ne è un esempio. La perdita di paludi e zone umide ha un grosso impatto negativo sulla fauna selvaggia, uccelli e flora e ha caratterizzato a suo tempo l'estirpamento di animali quali i gorilla ed elefanti.

Questo lavoro di tesi, pertanto, vuol essere un primo tentativo di ricerca e analisi di molteplici soluzioni che possano diminuire il consumo di legna per la cottura dei cibi e contribuire a limitarne la pressione sul dilagante fenomeno della deforestazione. In particolar modo, tale indagine è stata effettuata in collaborazione con l'ONG Vispe che dagli anni '70 è presente in Burundi con una Missione situata nell'area rurale di Mutoyi. In collaborazione con essa e il partner FLAEI (Federazione Lavoratori Aziende Elettriche Italiane), nell'estate 2013 è stato possibile effettuare un sopralluogo di due settimane a Mutoyi per valutare l'entità del problema (Figura 4) ed effettuare una prima raccolta dati.

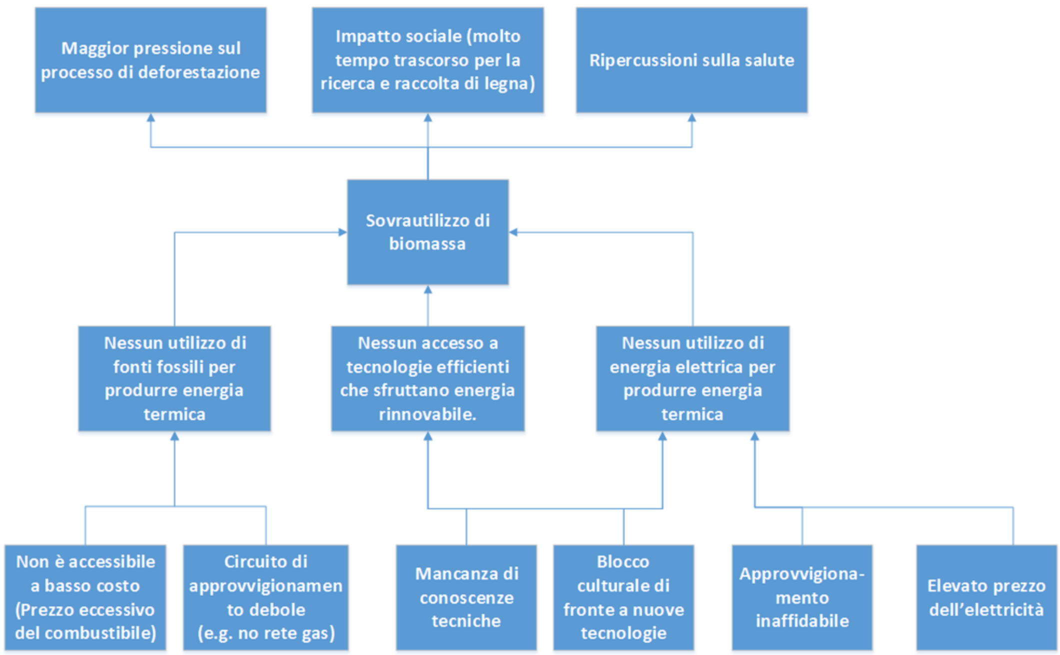


Figura 4 – Analisi dei problemi.

L’analisi dei problemi ha permesso di individuare nel mancato utilizzo di fonte energetiche alternative alla biomassa e nell’utilizzo di tecnologie non efficienti le cause principali del sovra utilizzo di legna per cucinare. Alla luce di queste informazioni, il primo fondamentale obiettivo della tesi è stata la ricerca delle risorse energetiche alternative alla biomassa che il Paese offre e che sono localmente accessibili. Escludendo i combustibili fossili come il diesel e carbone per il loro costo eccessivo e il gas per l’effettiva mancanza di una rete di distribuzione, si sono analizzate le seguenti fonti rinnovabili disponibili:

1. L’energia idroelettrica si è rivelata la fonte rinnovabile con il potenziale più elevato. Si stima che il Burundi disponga di un altissimo potenziale idroelettrico di circa 1700 MW, di cui solo 32 MW vengono sfruttati in centrali ad acqua fluente dislocate lungo i numerosi fiumi che attraversano il Paese. Tale potenza installata rappresenta l’85% di tutto il parco di generazione del Paese; il resto è garantito da una piccola centrale termoelettrica di circa 5MW situata a Bujumbura. Confrontando la curva dei carichi elettrici diurni resa disponibile dal Ministro dell’Energia e Miniere burundese relativa ad un normale giorno infrasettimanale (Figura 5), si è osservato che durante le ore notturne la potenza installata è superiore di alcuni Megawatt rispetto alla richiesta.

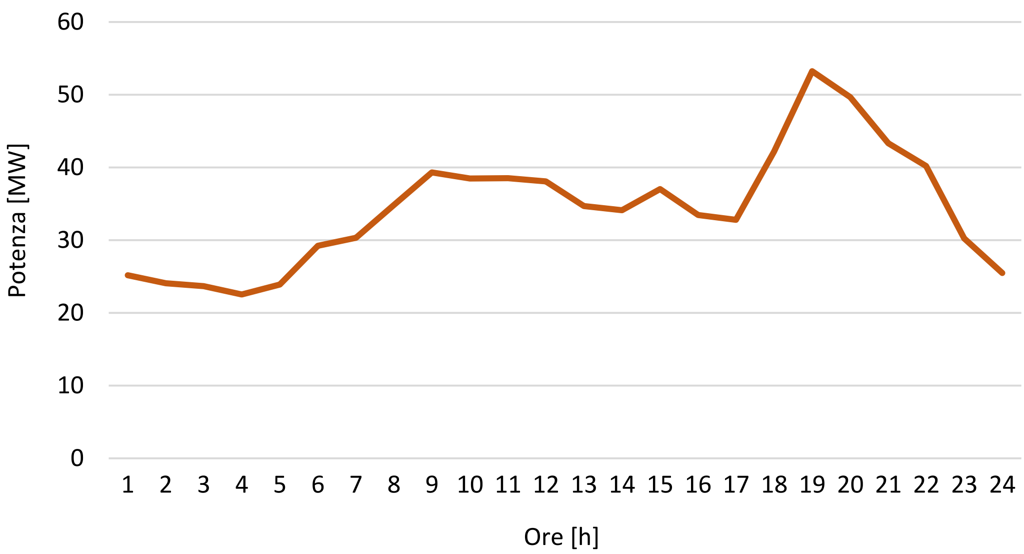


Figura 5 - Carico elettrico burundese interconnesso alla rete il 10/10/2013.

Attraverso il calcolo delle ore equivalenti di funzionamento degli impianti e della loro effettiva disponibilità, si è stimato che durante l'anno, per circa la metà delle notti burundesi, il parco di generazione idroelettrica del Paese disponga di un potenziale non sfruttato tra 1 e 10 MW. Poiché la rete elettrica burundese, essendo sottodimensionata rispetto alle esigenze diurne, soffre di black-out frequenti, tale disponibilità dovuta ai minor carichi connessi la rende meno sovraccaricata nelle ore notturne e garantisce maggior sicurezza e affidabilità nell'approvvigionamento. A livello locale, inoltre, Vispe sta collaborando con FLAEI per la realizzazione di una centrale idroelettrica da 700 kW a servizio della Missione che risolverebbe il problema dell'approvvigionamento costoso e inaffidabile di energia elettrica. In conclusione, il futuro approvvigionamento gratuito di energia idroelettrica alla Missione e una maggior affidabilità e sicurezza nelle ore notturne rendono tale fonte interessante in vista di un impiego come alternativa alla biomassa.

2. La seconda fonte di energia studiata per il suo alto potenziale è quella solare. Ogni anno, l'energia direttamente irradiata sul suolo burundese si aggira intorno i 2000 kWh/m^2, con una potenza media mensile superiore ai 700 W/m^2 nelle ore centrali dei giorni non nuvolosi e sfruttata in numerose applicazioni sia termiche che fotovoltaiche.
3. Per ultima è stata analizzata la filiera della biomassa che rappresenta la fonte energetica più utilizzata nel Paese; soddisfa il 96% di tutto il bisogno di energia primaria nel Paese e viene utilizzata totalmente per applicazioni termiche (senza considerare un piccolo impianto pilota per applicazioni elettriche nella capitale Bujumbura). Poiché il presente lavoro di tesi ha il principale obiettivo di ridurre il consumo della biomassa, è stata presa in considerazione la possibilità di introdurre tecnologie più efficienti che diminuissero il fabbisogno di legna. L'utilizzo di carbonella prodotta localmente non è stata approfondita; infatti, poiché il processo di conversione della legna in carbonella dipende fortemente dal processo e dagli usi finali, il bilancio energetico che ne considera l'intera filiera di produzione e utilizzo finale è spesso a sfavore di quest'ultima e andrebbe di conseguenza meglio approfondito.

Secondo obiettivo di questo lavoro è stata l'analisi del contesto locale necessario per effettuare il successivo studio di fattibilità. A Mutoyi, il più elevato utilizzo di biomassa ruota attorno all'ospedale *Centre de Santé* gestito da Vispe e dalla parrocchia locale. Ogni giorno, una media di 300 persone ricevono il pranzo. La preparazione dei pasti è a carico di una cooperativa locale chiamata PaMu (*Pâtisserie de* Mutoyi), l'unico servizio di ristorazione della zona. In una cucina appositamente dedicata, la struttura prepara giornalmente le pietanze per

l'ospedale in due grosse stufe a legna. All'interno dell'ospedale, invece, per tutti i degenti viene servito al mattino e il pomeriggio il tè o latte che viene preparato in due stufe a legna identiche a quelle presenti al PaMu. Come tipicamente accade negli ospedali africani, la preparazione della cena non è a carico dell'ospedale, ma dei parenti degli ospedalizzati che, in una struttura appositamente dedicata, hanno la possibilità di cucinare per sé e i propri famigliari ricoverati. Tale cucina è costituita da una semplice pensilina con una lunga struttura in pietra sottostante dove poggiare la legna e ricoperta da una griglia.
Poiché tutte queste attività che ruotano attorno l'andamento e gestione dell'ospedale avvengono sotto il controllo e monitoraggio dell'ONG, è stata valutata come la location più adeguata per introdurre un primo cambiamento e tentativo di miglioramento. Uno dei più ricorrenti fallimenti all'interno dei progetti di cooperazione è infatti dovuto alla non accettazione di interventi tecnologici che spesso cambiano le consuetudini delle persone. Per non incorrere in questo rischio, la collaborazione e il supporto di Vispe nelle tre strutture di cui sopra risulta quindi necessaria per la lenta e monitorata accettazione di ogni tipo di intervento tecnico che può in futuro essere diffuso.
Per l'ospedale e il ristorante, l'analisi del contesto ha previsto la raccolta tutti i dati relativi al consumo giornaliero di legna e di acqua e le informazioni circa l'approvvigionamento di biomassa. Poiché prima d'ora non sono mai stati raccolti dati circa la quantità di legna consumata, uno degli obiettivi intermedi di questo lavoro di tesi è stato estendere lungo tutti i mesi dell'anno i dati di consumo di legna osservati durante il soggiorno a Mutoyi attraverso considerazioni energetiche.
Infine, per completare l'analisi, per ogni struttura si è studiato e analizzato l'attuale set-up tecnologico presente in Missione con il fine di valutarne le performance energetiche. Esso è attualmente composto da una *Rocket Institutional* e *Plancha* per il PaMu e l'ospedale, mentre una *Open Fire* per la cucina utilizzata dai parenti.

Figura 6 – Rispettivamente *Plancha*, *Rocket* e *Open Fire Stove* utilizzate a Mutoyi.

Alla luce dei risultati ottenuti tramite la prima analisi delle risorse energetiche disponibili e del contesto locale, la strategia suggerita dall'iniziale albero dei problemi permette di individuare le seguenti tecnologie:

– *scaldacqua elettrico;*
– *pompa di calore (pdc) con resistenze elettriche integrate;*
– *integrazione delle precedenti tecnologie con pannelli solari termici;*
– *esclusivo utilizzo di pannelli solari termici e accumulo termico;*
– *stufe migliorate;*
– *stufe solari.*

Al PaMu e all'ospedale si è ricercato un possibile set-up tecnologico che non andasse a sostituire le stufe attuali. Infatti, oltre ad essere state recentemente acquistate, l'analisi della stufa *Rocket* ne ha confermato le alte performance termiche. Inoltre, il loro utilizzo è già ben radicato nelle abitudini dei cuochi e indispensabile per cucinare alcuni piatti locali. Di conseguenza, le prime quattro tecnologie elencate permetterebbero di sostituire l'utilizzo di legna nella fase di preriscaldo dell'acqua consumando energia elettrica durante le ore notturne.
Le ultime due tecnologie elencate sono state considerate come alternative nella cucina utilizzata dai parenti dei degenti. Infatti, viste le molteplici abitudini delle persone ogni giorno diverse (ad esempio la consuetudine di alcuni di iniziare a cucinare il cibo in acqua fredda), l'assenza di un posto specifico sorvegliato dove cucinare e il maggior rischio di incidenti, si è preferito introdurre inizialmente

una tecnologia simile a quella già presente. Alla luce di queste considerazioni, le stufe migliorate si rivelano la tecnologia più appropriata perché molto simili alle attuale stufe ma con il grande vantaggio di avere la camera di combustione chiusa riducendo le perdite termiche verso l'ambiente. Inoltre, a differenze delle precedenti tecnologie che andrebbero importate dall'estero, vicino a Mutoyi vi sono cooperative che costruiscono e vendono stufette migliorate.
Per quanto riguarda le stufe solari, dall'iniziale albero dei problemi emerge che una delle cause che concorre al problema del sovra utilizzo di legna è la non accettazione di tecnologie alternative da parte delle persone. Tale considerazione è in particolar modo di grande ostacolo alla diffusione dei forni solari. Di conseguenza, la tesi si limita a dare un giudizio sulla fattibilità tecnica e compatibilità di utilizzo con il potenziale solare Burundese. Tale tecnologia è stata considerata in quanto potrebbe adattarsi bene ad un contesto ospedaliero dove il tempo superiore necessario a cuocere il cibo può essere impiegato per la visita dei propri famigliari ammalati. L'analisi ha previsto inizialmente la costruzione di due modelli "a pannello" e "a scatola". La scelta è ricaduta su questi due modelli perché facilmente realizzabili con materiale facilmente reperibile a Mutoyi, richiedono un investimento molto basso e soprattutto non sono pericolose e di immediato utilizzo. Questi aspetti hanno escluso dall'analisi la più comune stufa solare "a parabola" che presenta alcuni svantaggi determinati:

- richiede materiali non facilmente reperibili come parabole satellitari usate o strutture che devono essere realizzate in maniera precisa per concentrare correttamente i raggi solari nel fuoco;
- necessita di molto tempo per la realizzazione e un costo elevato nel caso venisse acquistata (superiore ai 300$);
- non è di immediato utilizzo perché può provocare gravi danni agli occhi delle persone se non correttamente utilizzata. Quest'ultimo aspetto è particolarmente rilevante poiché l'area destinata ai famigliari è frequentata da bambini, malati e da persone diverse ogni giorno che non ne conoscono il funzionamento.

Alla costruzione dei modelli è seguito il test scientifico e internazionalmente riconosciuto dalla American Society of Agricultural Engineers (ASAE) per valutare la potenza trasmessa all'interno della stufa al variare della temperatura interna. La prova prevede di sottoporre le stufe alla radiazione solare e di misurare la temperatura dell'acqua tramite termocoppie al variare del tempo e della temperatura ambiente. I risultati vengono poi espressi in termini di potenza termica trasmessa all'interno della stufa e normalizzati con una radiazione media di 700 W.

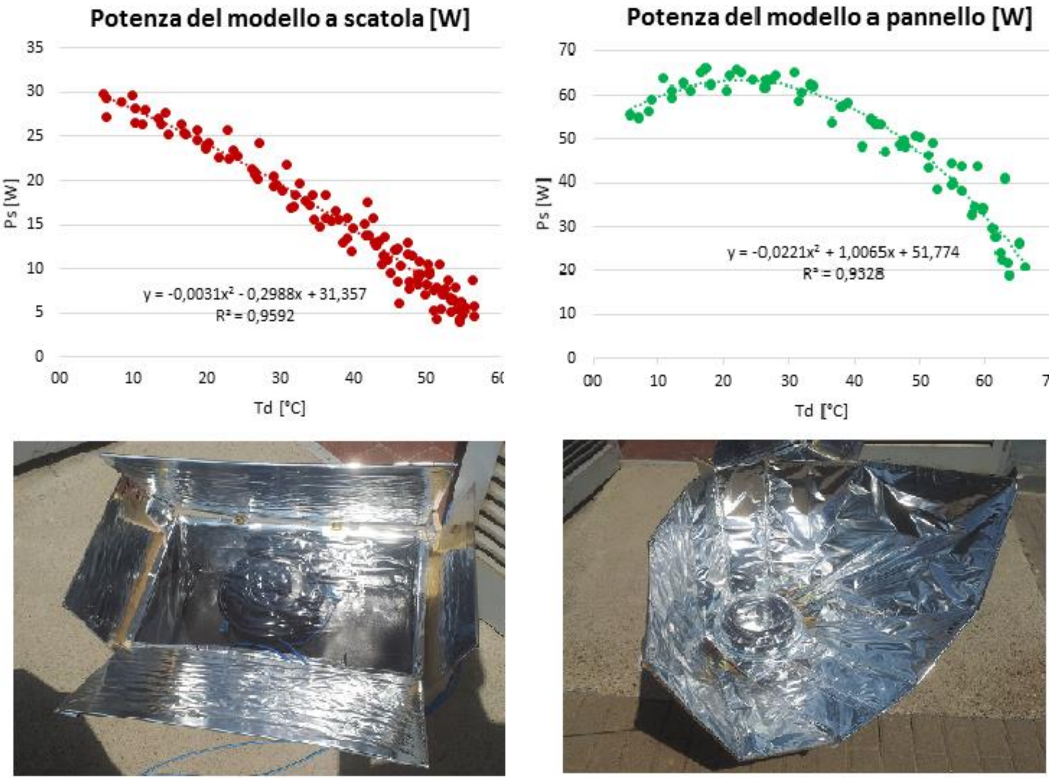


Figura 7 – Stufe costruite e andamento della potenza trasmessa all'interno [W] al variare della differenza tra temperatura interna ed esterna [°C].

Con una efficienza media di poco superiore all'8%, la stufa a pannello si è rivelata più veloce nel raggiungere una temperatura di 90°C. Valutando la temperatura media raggiunta all'interno si è potuto prevedere il tempo necessario per cuocere i fagioli, tipica pietanza cucinata in Burundi. I tempi stimati per cuocere una porzione di 300 grammi di fagioli in circa 400 ml di acqua con la radiazione solare media rilevata in Burundi a mezzogiorno (circa 750 W/m^2) sono di poco superiori ad un'ora disponibili in circa 80 giorni di sole. Per la stufa a scatola non si sono effettuate previsioni poiché solo il tempo per scaldare un litro d'acqua fino a 90°C in Burundi si è stimato essere di circa 8 ore. Concludendo, se da un lato la stufa a pannello sembra essere sicuramente una soluzione per la cottura che vale la pena di implementare in un progetto pilota, la stufa a scatola risulta sicuramente meno appropriata ma utile per altri impieghi come il preriscaldo di cibi già cotti.

Successivamente alla scelta e proposta delle molteplici alternative tecnologiche, l'obiettivo centrale del lavoro di tesi è stato fornire gli strumenti e le conoscenze tecniche necessarie per effettuare un'analisi energetica, economica e di impatto ambientale di quest'ultime. Per le tecnologie elettriche e solari studiate per l'ospedale e il PaMu, a partire dalla potenza termica traferita all'acqua e dalle diverse temperature raggiungibili si sono analizzati i risparmi annuali di legna e di emissioni di CO_2 previsti. L'analisi economica ha valutato la differenza tra i futuri costi dei consumi elettrici (nell'eventuale caso di mancata implementazione dell'impianto idroelettrico di Vispe) e i risparmi nell'acquisto della legna per ogni tecnologia. Per le soluzioni solari si è utilizzato il supporto del software TRNSYS, specifico per la simulazione di sistemi idraulici.

Tabella 1 - Risultati medi per ogni tecnologia al PaMu e al ristorante.

	P.A.M.U.				HOSPITAL			
	Risparmi di legna [%]	*Consumi elettrici [kWh]*	**Risparmi [€]**	**CO_2 [ton]**	*Risparmi di legna [%]*	*Consumi elettrici [kWh]*	**Risparmi [€]**	**CO_2 [ton]**
Scaldacqua elettrico (Max 75°C)	14.20%	10220	-675.90	-22.18	28.10%	7665	-704.8	-8.57
PDC con resistenze elettriche (Max 75°C)	14.20%	5375	-230.20	-22.24	28.10%	4258	-391.5	-8.62
PDC (Max 55°C)	10.05%	1963	7.40	-15.84	18.20%	1712	-157.4	-5.61
Scaldacqua elettrico con integrazione solare (Max 78°C)	14.60%	5332	-218.70	-22.9	29.55%	3407	-313.4	-9.05
PDC con integrazione solare (Max 68°C)	12.50%	784	161.30	-19.70	25.55%	479	-44.1	-7.85
Collettori solari e accumulo (Max 54°C)	9.20%	35	168.75	-14.55	18.10%	36	-3.3	-5.55

Dall'analisi delle stufe migliorate è emerso che il loro utilizzo al posto dell'attuale *Open Fire* garantirebbe numerosi vantaggi come il minor tempo necessario per cucinare e il risparmio di legna stimato tra il 10% e il 60% (fortemente condizionato dai rendimenti delle stufe). Inoltre, a livello di impatto sociale sul territorio, i vantaggi che derivano dall'utilizzo delle stufe verrebbero personalmente sperimentati dalle centinaia di persone diverse che ogni giorno cucinano all'ospedale e ciò favorirebbe future campagne di diffusione di questa tecnologia tra le famiglie.

Infine, per le rimanenti tecnologie ne è stata proposta la scelta attraverso due steps. Il primo è stato condotto sulla base di tre indicatori quantitativi: risparmio di legna consumata, risparmio economico nell'acquisto e costo di investimento. Il costo operativo dovuto ai consumi elettrici non rappresenta un vincolo grazie alla realizzazione dell'impianto elettrico di Vispe che approvvigionerà Mutoyi di energia elettrica gratuita. La tecnologia che permette di raggiungere i risparmi maggiori di legna con il più basso investimento e il maggior guadagno economico è lo scaldacqua elettrico. Infine, il secondo step ha considerato due ultimi indicatori qualitativi, ovvero la diffusione delle tecnologie e il loro impatto sociale in termini di creazione di capacity building. Infatti, poiché nei progetti di cooperazione è importante valutare l'impatto di un'azione sul territorio, è doveroso ragionare anche in ottica di futura estensione del progetto. A questo proposito, il costo dell'elettricità assume un ruolo determinante per tutte le strutture che non hanno accesso gratuitamente all'energia elettrica. Da quest'ultima analisi è emerso che la soluzione che garantirebbe un trade-off tra risparmi di legna e costi è sicuramente la pompa di calore con integrazione solare garantendo anche la diffusione di nuove competenze tecniche. Pertanto, una prima l'installazione a Mutoyi potrebbe avere un impatto positivo su tutto il territorio.

Introduction

In the last few years, the interest on access to energy in developing countries has increased continuously. Hence, this thesis deals with that topic and focuses on access to clean cooking facilities. The first direct result of the exposure to indoor air pollution caused by improper cooking appliances is the increasing number of deaths that accounted in 4.3 million people in 2013. Moreover, the increasing need of wood used for cooking by people is contributing in a second problem that is worrying mainly sub-Saharan African countries which is the rapid process of deforestation and desertification of land. In particular, the combined use of traditional fuels[2] and improper cooking devices applies a great negative pressure on these problems.
This link between the rapid rate of deforestation and the massive use of wood for cooking in improper cooking appliances is particularly evident in Burundi in Southeast Africa. In fact, besides being one of the African countries with the lowest Human Development Index (HDI), it is one of the most backward countries as far access to modern fuels is concerned. 96% of all energy needs are met by traditional biomass, comprised of wood fuel, solid wastes and charcoal and less than 1% of the population have access to modern fuels for cooking and Improved Cook Stoves (ICSs). The increasing need of cutting tree for wood cooking supply and the increasing deforestation are causing a great problem with soil erosion and desertification that are badly impacting the human agricultural activities, social conditions of women and children who have to spend more time on collection of wood, flora and fauna of the country.

In order to propose a solution, the causes of the problem are firstly analyzed and they suggest to find energy substitutions to traditional fuels and work on the improvement of the actual cooking appliances (Figure I). Therefore, the main focus of this thesis is to research energy alternatives to wood cooking biomass and to study new technological applications.

[2] Traditional fuels or non-commercial biomass are represented by wood, charcoal, coal, crop residues, animal dung, and other waste materials, while the term modern fuels refers to electricity, liquid fuels, such as kerosene, gaseous fuels, such as liquefied petroleum gas (LPG) and natural gas, and to biogas and biofuels.

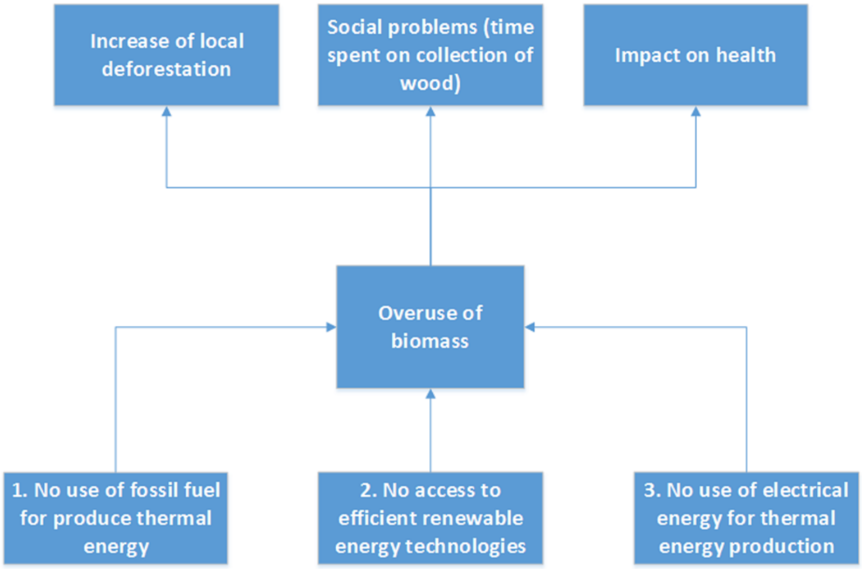


Figure I - Analysis of main Problems.

Firstly, the available energy resources in Burundi and their technical application are studied. Specifically, hydroelectric potential and solar power have found to be worthy of further analysis while fossil fuels are discarded because their extremely high costs and their weak supply chain.

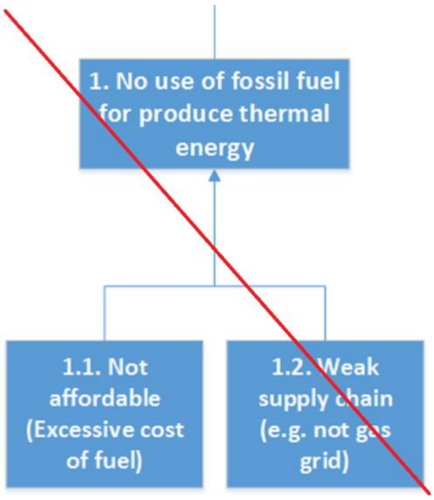


Figure II –Cause discarded.

Secondly, once selected the most available and favorable energy alternatives, the goal is to identify a first application in loco and the related problems. The location where the highest consumption of wood cooking biomass takes place and suitable for the first feasibility study was found to be the Hospital *Centre de Santé* on the Burundian hill of Mutoyi where Vispe works. After a personal assessment work in loco, the causes that actually prevent the use of local energy resources are considered (Figure III) and they are followed by a deep assessment of wood needs and an energy performance evaluation of the actual technological set-up of the Mission.

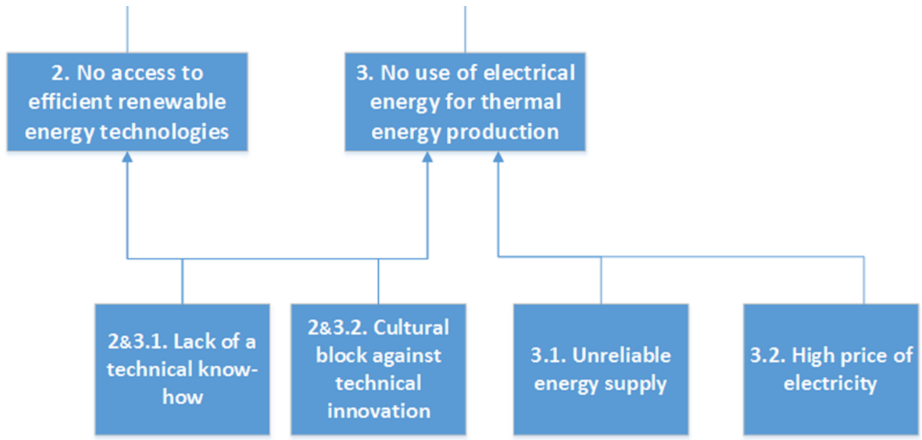


Figure III – Local problems.

The problems related to the electricity supply will be solved by Vispe with a project concerning the realization of a hydroelectric plants of 700kW. It will supply the Mission with free electricity and it will guarantee the maintenance and the fix of the electric line. This thesis provides for the lack of technical know-how in the Mission and the focus is on the research and the analysis of the most appropriate technologies for reducing the local use of wood biomass using the local available energy resources. The criteria considered to analyze the technical alternatives are the wood savings, economic revenues and costs, and the environmental benefits in terms of less greenhouse emissions. Concerning the solar devices, the tool utilized is TRNSYS Software simulator of transient systems, through which it is possible to observe the operation of solar thermal plants. The problem concerning the cultural block of people against technical innovation has to be considered for the choice of the most appropriate technology in the implementation phase. On the other hand, it is a fundamental aspect that has prevented the technological alternative concerning solar stoves to be subject to risked forecasts. Therefore, they are dealt differently from the other alternatives through a prefeasibility study which investigates if homemade solar cookers could be an appropriate solution.

In conclusion, for the present work, the strategy suggested by the problem analysis identify four main goals:

1. to evaluate the entity of the problem of deforestation and make an in-depth survey of all the energy resources in Burundi as alternatives to wood biomass;
2. to make an analysis of the local context in terms of performance of the actual technology set-up of the Mission and through the evaluation of the yearly wood cooking biomass consumption and needs;
3. to identify a new appropriate technology set-up for reducing the local use of wood for cooking with the local energy alternatives. The research includes an experimental phase with the aim to investigate the possible use of homemade solar cookers through the test of two self-built devices;
4. to make the energy, economic and environmental analysis of the technologies and to propose a final decision making process.

In Chapter 1, an overview of access to energy is carried out, with a particular attention to the theme of the overuse of biomass in developing countries and its pressure on the problem of deforestation. In Chapter 2, Burundi is presented from a socio-economic point of view, as it is a very problematic country as far as the process of deforestation linked to the overuse of wood biomass by Burundian people. Moreover, an in-depth research of its energy resources alternative to wood biomass is carried out with a particular focus on the hydroelectric and solar power potentials. Then, a possible area of intervention through a pilot project has been analyzed in Chapter 3. The actual wood needs, supplies and technologies at Mutoyi Mission have been observed during the personal work in the Mission and the energy performance of the actual stove set-up are then evaluated. Because there are no data about the yearly wood consumption, a tentative approach to extend the observed data is carried out thanks to energy consideration and analyses. In Chapter 4, a new technological set-up is identified and described after the consideration about the location and the available energy resources. Because of the difficulties to make forecasts, for the solution concerning the solar cookers an experimental analysis was necessary. After a short state of art, two models of cookers were self-built and subject to a scientific test with the aim to investigate the thermal properties and forecast the eventual future use in the Mission. In Chapter 5, the energy, economic and environmental analyses of all the technologies are developed with the help of TRNSYS software and a proposal of choice is suggested.

1 Access to energy

1.1 Introduction

Energy is at the heart of most critical economic, environmental and developmental issues facing the world [1]. It drives human progress, and now more than ever the world needs to ensure that the benefits of modern energy services are available to all and provided as cleanly, safely, affordably, and efficiently as possible. The issue of access to energy is central in developing world [2], they particularly need to expand access to reliable, affordable and modern energy services if they are to reduce poverty and improve their citizens' health, while at the same time increasing productivity, enhancing competitiveness and promoting economic growth. Therefore, the nexus between energy and sustainable development needs to be better explored in order to evaluate the multiple positive effects energy can have on poverty reduction, gender equality promotion, health, water, food security, education, job creation, and all the challenges involve especially the developing countries.

1.1.1 Link between energy and human development

Today, the correlation between access to energy and development is well known, for billions of poor people the opportunity to overcome the development divide is strongly affected by the lack of access to energy. The United Nations High Level Panel of Eminent Persons[3] has recommended that universal access to modern energy services be included in the Post-2015 Development Agenda. Moreover, 77 developing countries have signed up to the UN Sustainable Energy for All (SE4All) initiative, including many of those with the largest populations lacking access to modern energy [4].

In 2012, the "International year for energy for all" and the Rio+20 Conference held in Rio de Janeiro recognized energy as a key driver for sustainable development [5] with a launch of a set of Sustainable Development Goals (SDGs) that include energy access as a global challenge.

[3] It is an team of 27 members of a High-level Panel composed by in July 2012 and announced by Secretary-General Ban Ki-moon with the aim to advise on the global development framework beyond 2015, the target date for the Millennium Development Goals (MDGs) [3] "HLP on on the Post-2015 Development Agenda," http://www.post2015hlp.org/about/..

In confirmation of this, the link between energy and development is evident through the correlation between the Human Development Index (HDI) and Energy Development Index (EDI) indicators (**Error! Reference source not ound.**).

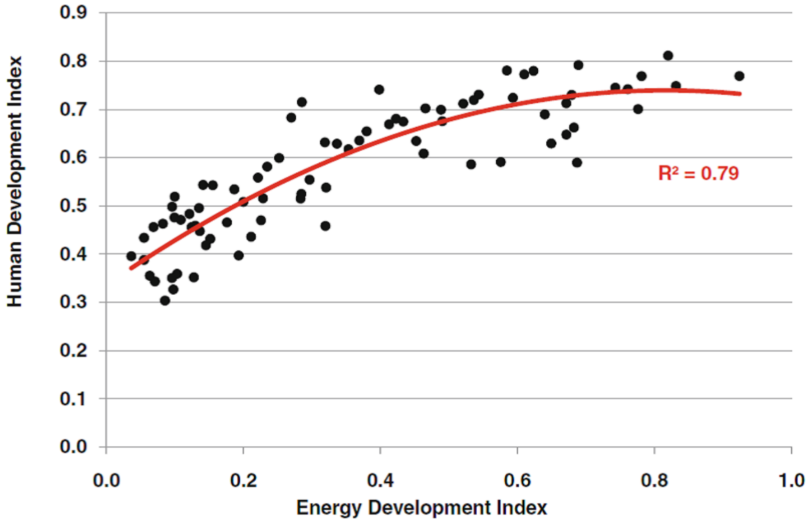


Figure 1.1 - Comparison of the HDI to the EDI, according to data available. IEA evaluates EDI for low and medium HDI only [6].

HDI was first presented in the United Nation Development Programme (UNDP) Human Development Report (HDR) in 1990 [1] with the aim of "to shift the focus of development economics from national income accounting to people centered policies". It is defined as a composite indicator, which combines the evaluation of health, education and living standards.
EDI has been introduced by International Energy Agency (IEA) [7] and traces progress in a country's or region's transition to modern energy access. It is made up of four other indicators, each of which identifies a specific aspect of potential energy poverty mainly related to electricity and modern fuel. They are:

- per-capita commercial energy consumption: linked to the overall economic development;
- per-capita electricity consumption in the residential sector: related to the reliability of electricity, and to consumers' possibilities to pay for it;
- share of modern fuels in total residential sector energy use: an indicator of the level of access to clean cooking facilities;
- share of population with access to electricity.

The EDI is then calculated as the arithmetic mean of the four values evaluated for each country.

1.1.2 Energy Poverty and Total Energy Access

Energy poverty includes lack of access to modern energy services [8]. It refers to a condition in which people cannot afford to use or have access to enough energy for their daily needs (i.e. cooking, lighting, heating, transportation, etc.). Energy poverty is widely recognized as a fundamental constraint to socio-economic development for the poor and “must be combined with other poverty eradication goals” [9]. In determining how we could tackle energy poverty, it is important to give a definition of energy access. The UN Secretary General’ Advisory Group on Energy and Climate Change (AGEEC) defines energy access as “access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses” [10]. A more complete and thorough definition is given by Practical Action in the Poor People Energy Outlook (2013) that resumes the concepts introduced in previous reports (Figure 1.2) defining energy access as the accomplishment of the following condition: “Households, enterprises and community services have sufficient access to the full range of energy supplies and services that are required to support human social and economic development” [11].

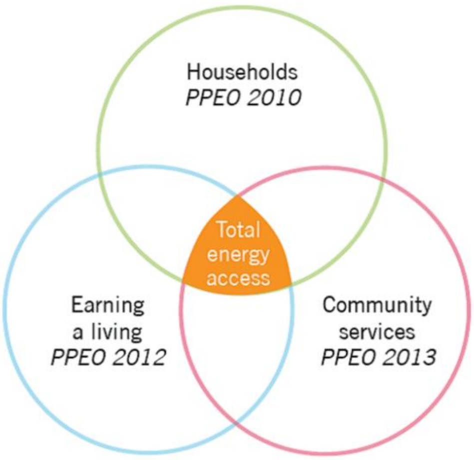


Figure 1.2 - Total Energy access.

1.2 Energisation

It is evident how the concept of energy poverty is not only referred to as a lack of "electricity" but also to an affordable access to clean cooking facilities.

According to IEA, the first meaning to provide access to modern energy requires a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional level [12]. This definition of electricity access, including a period of growing consumption, is a clear attempt to reflect the fact that eradication of energy poverty is a long-term endeavor [12].

The access to modern cooking facilities should be harmless to the health of people in the household, environmentally sustainable and efficient. Modern cook stoves answer these requirements, while the traditional ones have higher emissions and higher specific wood consumption that force people to use a lot of biomass and spend a lot of time for the collection.

Therefore, a process in an attempt to develop the access to energy has to be named Energisation that refers more directly to the definition of energy access but also to sustainable development and includes the following [5]:

- Matching of energy needs with appropriate energy resources;
- Improving the quantity and quality of energy supply;
- Promoting a combination of cleaner and more efficient fuels;
- Promoting mainly, though not exclusively, renewable energy;
- Aligning to the Millennium Development Goals;
- Meeting household needs, providing community services and promoting economic development;
- Emphasizing cultural and social aspects and local empowerment.

1.2.1 Global Dimension of Universal Access to Energy

Modern energy for all is far from being achieved. As indicated in the World Energy Outlook 2013 by the IEA, nearly 1.3 billion people, or 18% of the world population, do not have access to electricity, 2.6 billion people, or 38% of the global population, rely on traditional use of biomass[4] for cooking such as

[4] Traditional fuels or non-commercial biomass are represented by wood, charcoal, coal, crop residues, animal dung, and other waste materials.

firewood, and 1.0 billion people are connected with unreliable electric grids [4]. As is shown in Table 1.1, sub-Saharan Africa is the region in the World that accounts for the largest share of population which relies on traditional use of biomass for cooking and without access to electricity, 79% and 68% respectively.

Table 1.1 - Number of people without access to modern energy services by region, 2011 (million). (Source: WEO 2013 [4]).

	Without access to electricity		Traditional use of biomass for cooking*	
	Population	Share of population	Population	Share of population
Developing countries	**1 257**	**23%**	**2 642**	**49%**
Africa	600	57%	696	67%
Sub-Saharan Africa	599	68%	695	79%
Nigeria	84	52%	122	75%
South Africa	8	15%	6	13%
North Africa	1	1%	1	1%
Developing Asia	615	17%	1 869	51%
India**	306	25%	818	66%
Pakistan	55	31%	112	63%
Indonesia	66	27%	103	42%
China	3	0%	446	33%
Latin America	24	5%	68	15%
Brazil	1	1%	12	6%
Middle East	19	9%	9	4%
World* **	**1 258**	**18%**	**2 642**	**38%**

WHO reports that in 2012 around 4.3 million people died as a result of air pollution exposure, which is more than double the previous estimates, and confirms that air pollution is now the world's largest single environmental health risk [4, 13]. This number is going to increase because this deteriorating situation is primarily due to population growth outpacing improvements in the provision of clean cooking facilities.

In the New Policies Scenario[5], the number of people without access to electricity is projected to decline by more than one-fifth to around 970 million in 2030.

5 A scenario in the World Energy Outlook that takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse-gas emissions and plans to phase out fossil-energy subsidies, even if the measures to implement these commitments have yet to be identified or announced. This broadly serves as the IEA

Around 1.7 billion people are expected to gain access over the period to 2030 but, in many cases, these gains are offset by population growth (increases by 1.4 billion to 2030). On the other hand, the number of people relying on the traditional use of biomass for cooking is projected to drop slightly, to just over 2.5 billion in 2030.

While there is an improving global picture, the regional trends are very diverse. For example, sub-Saharan Africa is the only region where the number of people without access to electricity and rely on traditional use of biomass increase over the Outlook period (Table 1.2).

Table 1.2 - Number of people without access to modern energy services by region in the New Policies Scenario, 2011 and 2030 (million).

	Without access to electricity		Without access to clean cooking facilities	
	2011	2030	2011	2030
Developing countries	**1 257**	**969**	**2 642**	**2 524**
Africa	600	645	696	881
Sub-Saharan Africa	599	645	695	879
Developing Asia	615	324	1 869	1 582
China	3	0	446	241
India	306	147	818	730
Latin America	24	0	68	53
Middle East	19	0	9	8
World	**1 258**	**969**	**2 642**	**2 524**

On the other hand, in terms of the share of population relying on traditional use of biomass for cooking and without access to electricity, we could see an improvement in all the regions of the world (Figure 1.3). Despite this, the sub-Saharan Africa's condition remains the worst one.

baseline scenario [14] IEA. "publications: Scenarios and Projections," http://www.iea.org/publications/scenariosandprojections/.

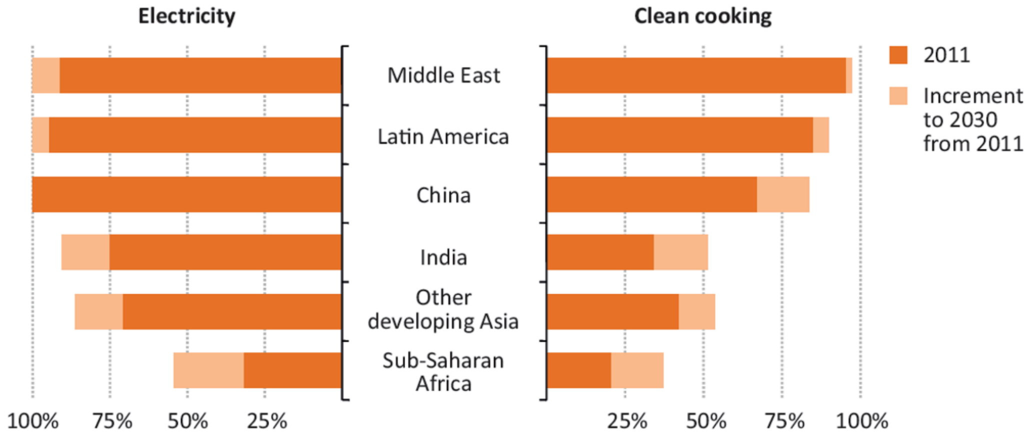


Figure 1.3 - Shares of population with access to electricity and clean cooking facilities by region in the New Policies Scenario [4].

1.2.2 Renewable Energy to promote local development

Among all the different sources of energy, renewable ones were the first to satisfy human energy needs and now they play a key role in unleashing local sustainable development. For better understanding, we have to clarify that sustainability implies three aspects: the economic, the environmental and the social one. As a consequence of this, sustainable energy must assure economic, environmental and social sustainability, where the environmental one is represented by the guarantee of natural resources' availability also for future generations, and the social one implies the welfare for all the people.

With this precondition, is clear how renewable energy promotion in developing countries could promote local development. Firstly, penetration of modern energies based on renewable sources can contribute to cost effectiveness reducing dependency on the cost of centralized electricity of imported fuels, allowing distributed generation and consequently reducing the discontinuity of supply and the need for batteries, improving quality and quantity of products, increasing earnings through new market opportunities. This can contribute to promoting new earning opportunities through new business options for micro, small or medium enterprises in the manufacturing, agricultural, livelihood and service sectors mainly in remote areas.

Secondly, local possibilities of new earnings in rural areas may mitigate the social problem of mass migration to urban areas. Furthermore, Renewable Energy Systems (RES) induce a more participative and inclusive approach that increases people's capacity building and human skills, it promote ownership and empowerment.

Last but not least, RES offer the preservation of the human living environment and better management of resources such as animal and agricultural waste.

1.3 Focus on the overuse of biomass for cooking in DCs

The lack of clean cooking facilities in most of developing countries is a condition which refers to the 38% of people in the world that rely mainly on solid fuels (coal and traditional biomass) for their cooking needs. In particular 40% of people living in developing countries rely primarily on wood for cooking [15], with little or no access to modern fuels such as natural gas, liquefied petroleum gas (LPG), diesel and renewable fuels (biodiesel and bio-ethanol). This also gets worse by the fact that traditional fuels are burned in Traditional Cook Stoves with very low thermal efficiency and high air pollution emission rate.

At present, developing countries differ widely with respect to access to modern fuels, but the vast majority of people who rely on solid fuels for cooking are concentrated in sub-Saharan Africa (Figure 1.4) that accounts for more than 20% of people relying on solid fuels as their primary cooking fuel [15].

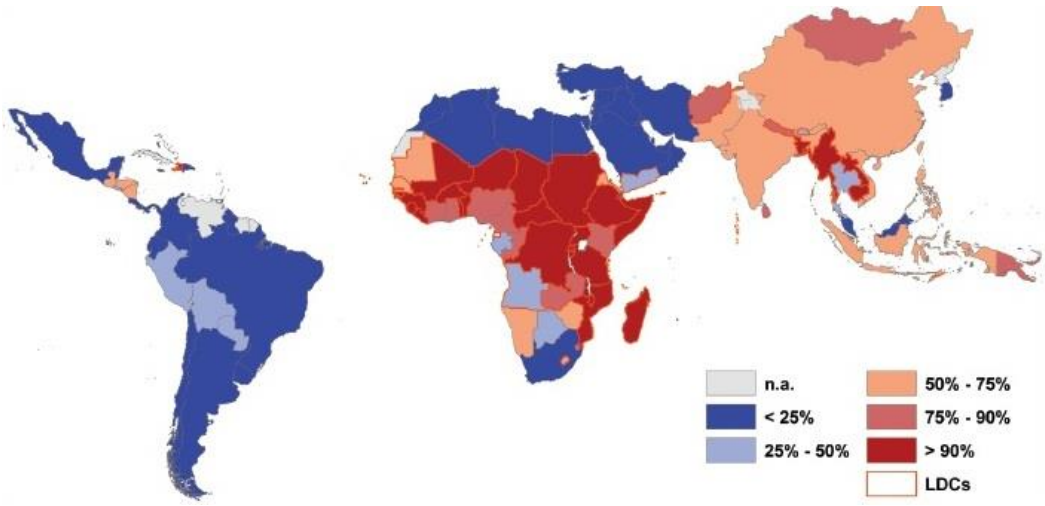


Figure 1.4 - Share of population lacking access to modern fuels in developing countries (Source [15])

Moreover, access to modern fuels for cooking also varies dramatically among developing countries in the same region (Figure 1.5). For instance, in sub-

Saharan Africa, less than 1% of people in Burundi, Liberia, Mali, Rwanda, Somalia, or Uganda have access to modern fuels, but 83% of people in South Africa have it.

Besides this, the share of people having access to modern fuels dramatically varies between rural and urban areas in the same country. In developing regions, while about 70% of urban people rely on modern fuels, just the 19% of rural people has access. In particular, in LDCs and sub-Saharan Africa, rural access to modern fuels is even lower (3% and 5%, respectively) [15].

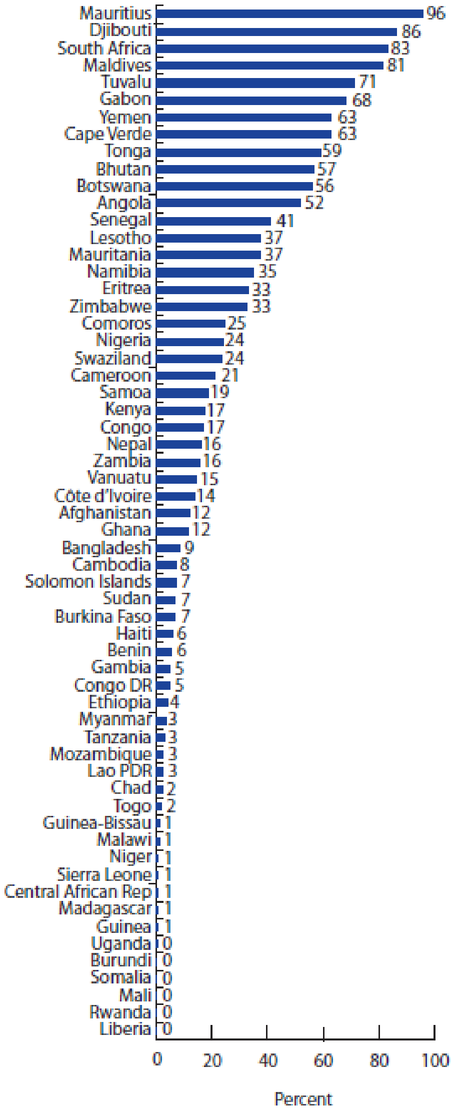


Figure 1.5 - Share of population with access to modern fuels in LDCs and SSA countries (Source [15])

Similarly, also the numbers about the use of traditional stoves are disconcerting perhaps because several factors, such as availability, acceptability and affordability of the best alternative guaranteed by Improve Cook Stoves (ICSs). These stoves provide numerous advantages: they double or triple the thermal efficiency of traditional systems, reduce the harmful effects of poor ventilation, and may also provide some electricity [10]. In absence of a diversified supply of fuel for cooking, ICSs represents the best alternative in term of reduction of health and environmental problems caused by current practices.

Fewer than 30% of people in developing countries who rely on solid fuels for cooking use ICSs. Moreover, access to ICSs is even more limited in sub-Saharan Africa, where only 4% of people who use traditional biomass and coal for cooking have access to improved stoves (Figure 1.6) and varies dramatically among developing countries in the same region with a list who still accounts Burundi at the bottom of the ranking [10].

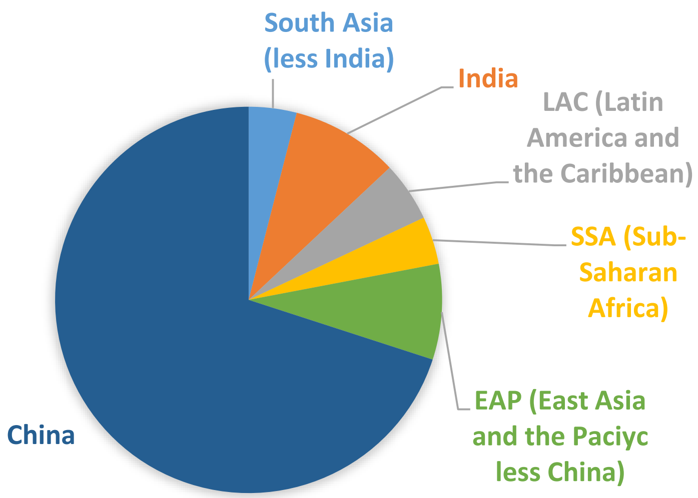


Figure 1.6 - Distribution of people with access to ICS by developing regions (Source [10]).

1.3.1 Health impacts of household energy use

The most important direct health effects of a lack of access to clean, efficient, modern energy in the home result from the air pollution caused by burning solid fuels, often indoors on simple stoves. The indoor use of open fires or inefficient stoves in households releases large amounts of smoke from incomplete combustion of solid fuels, primarily wood, but in many cases coal, animal dung, and crop wastes. Breathing this smoke affects the health of all members of the family, but especially women and children [10, 16]. Smoke from incomplete combustion of solid fuels contains many substances known to be toxic to human health and principal causes of three important disease: child pneumonia [17], chronic obstructive pulmonary disease (COPD), and lung cancer [10] that cause 4.3 million premature deaths each year, especially women and children. As it is reported in [13], among these deaths:

- 12% are due to pneumonia
- 34% from stroke
- 26% from ischaemic heart disease
- 22% from chronic obstructive pulmonary disease (COPD), and
- 6% from lung cancer.

According to previous section, sub-Saharan Africa accounts for the highest number of premature deaths because of household air pollution [15]. Moreover, Figure 1.7 shows how the intensity of the problem has doubled in four years. The extent of the problem is underlined by the fact that it has exceed even HIV, Malaria and Tubercolosis deaths that are the most recurring cause of death in developing countries.

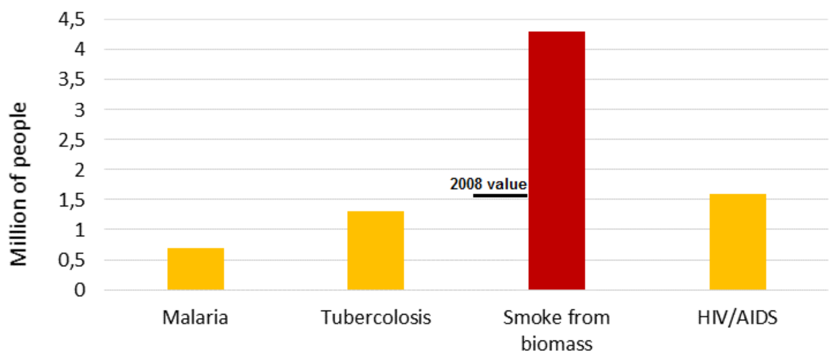


Figure 1.7 - Premature deaths from different causes in 2012 (Source [13, 18, 19]).

1.3.2 Impacts on global deforestation

Deforestation is one of the most widespread and important changes that people have made to the surface of the earth. Over a period of 5,000 years, today the cumulative loss of forestland worldwide is estimated at 1.8 billion hectares, an average net loss of 360,000 hectares per year [20]. Global effects associated with this extended and constant process include loss of biodiversity and changes in the carbon cycle [21]. Locally, the loss of tree coyer can cause soil erosion which causes the loss of soil fertility and land that can be cultivated, destabilize the hydrologic cycle, leading to drier climate, and increased flood risks in downstream areas [22]. The trajectory of global deforestation has more or less followed the global growth rate of the human population, although the pace of deforestation was more rapid than population growth prior since 1950, and has been slower since then. In the last twenty years, this phenomenon has involved mainly sub-Saharan Africa and South America (Figure 1.8).

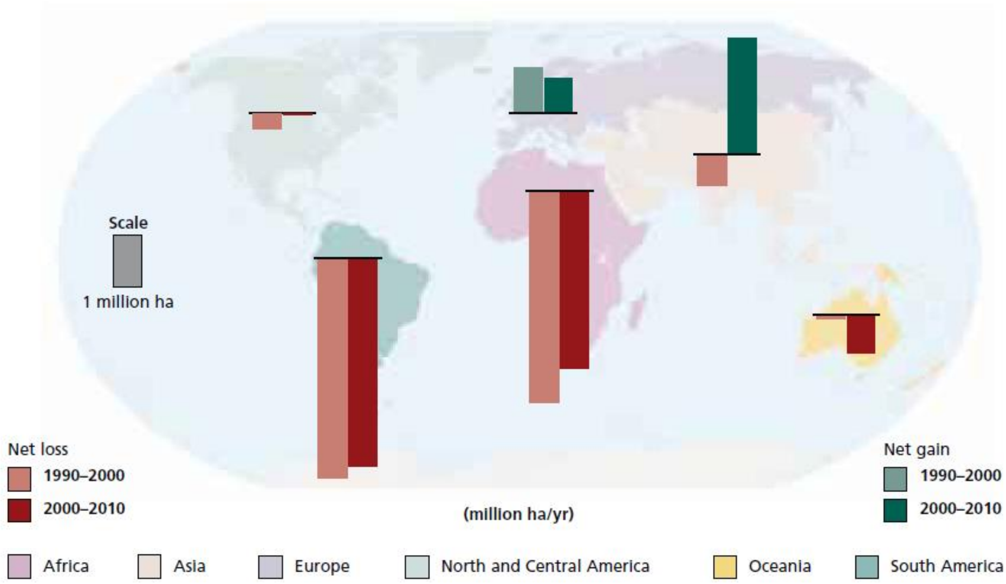


Figure 1.8 - Annual change in forest area by region, 1990 - 2010 (Source [23])

Firewood collection by the rural poor communities puts considerable pressure on forests [24-27]. Although the use of traditional biomass such as wood or charcoal for cooking is not the only contributor to deforestation, in some countries as sub-Saharan Africa, Brazil and South-East Asia the link is more direct and evident, but this link is subject to an international debate (Figure 1.9, Figure 1.10).

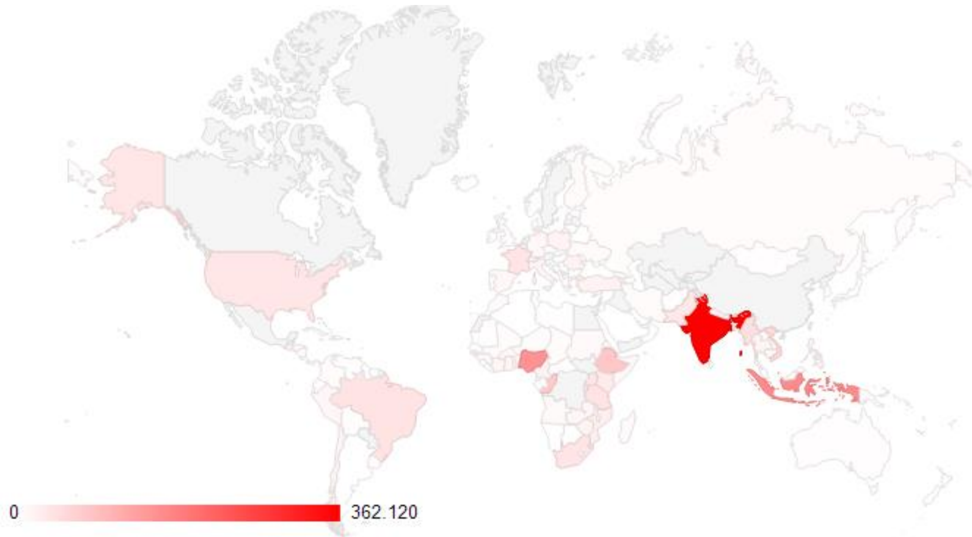


Figure 1.9 - Fuelwood, consumption by households in the world in 2010 (thousand cu. meters) (Source [28]).

Figure 1.10 – Countries with large net changes in forest area up to 2012 (elaborated from [29]).

India's largest consumption of fuelwood appears to be in contrast with a zero deforestation rate. This anomaly is due to the implementation of the social forestry and large-scale afforestation programs cause the shift of fuelwood production from forests to non-forest areas along roads, canals, farmlands, and wasteland [30].

As one might expect, according to all the best available evidence, deforestation is a real trend in almost all developing countries although the magnitude of the problem varies substantially [25]. Their rapid population growth, expansion of cropland, and intensive harvesting of forests for fuelwood and wood ex-port contribute to deforestation.

In conclusion, the severity of environmental damage and wood shortages attributable to deforestation and the nexus with low developing countries remind the need to clamp down on this dangerous process. According to World Bank [31], international agencies have to finalize their revised approach to forests issues, in recognition of the fact that forests and the fight against deforestation play an increasingly important role in poverty alleviation, economic development and for providing local as well as global environmental services.

2 Burundi: a socio-economic and energy overview

2.1 Introduction

Burundi is one of the smallest countries in Africa with a surface area of 2,784 square kilometers [28]. It is a landlocked country in the African Great Lakes region of Southeast Africa bordered by United Repubblica of Tanzania to the South-East, Rwanda to the North, Democratic Republic of Congo (DRC) and Tanganyka Lake to the West. It is located at latitude and longitude 3°30’ S and 30°00’ E proximity to the equator and in southern hemisphere (Figure 2.1).

Figure 2.1 – Map of Burundi

Burundi presents a population of 9,850,000 people. Its currency is the Burundian Franc (FBU): 1 € is about 2,000 FBU [32]. Its official language is French and Kirundi, but roughly 90% of the population speaks only Kirundi. In the capital, Swahili is also widely spoken. Most people are Catholic Christian (65%), and the remaining are Protestant.

The origins of Burundi are known thanks to a mix of verbal history and archaeology that narrates the origin of the Burundi Kingdom in XVII century. In the second half of the XIX century, it saw a period of one hundred years of colonization from Germany and then from Belgium [33]. It finally got independence in 1962 and it became a Republic in 1966 with capital city in Bujumbura, after four years of a constitutional monarchy. The end of the colonization caused the widespread of the hate between two major ethnic groups that live in the country known as Hutu and Tutsi. Thirty years of isolated episodes of violence led to the long civil war that affected the country between 1994 and 2006 with gory carnages and terror. Now, with the next presidential elections in 2015, the fear of a trigger of a new genocide is high [34].

Burundi is a resource-poor country with an underdeveloped manufacturing sector. For this reason, the economy is predominantly based on agriculture and breeding that accounts for just over 30% of Gross Domestic Product (GDP) and employs more than 90% of the population (Figure 2.2). Due to its lack of resources, primary exports are coffee and tea, which account for 90% of foreign exchange earnings. Exports are a relatively small share of GDP. Now, Burundi remains heavily dependent on aid from bilateral and multilateral donors - foreign aid represents 42% of Burundi's national income, the second highest rate in Sub-Saharan Africa [35].

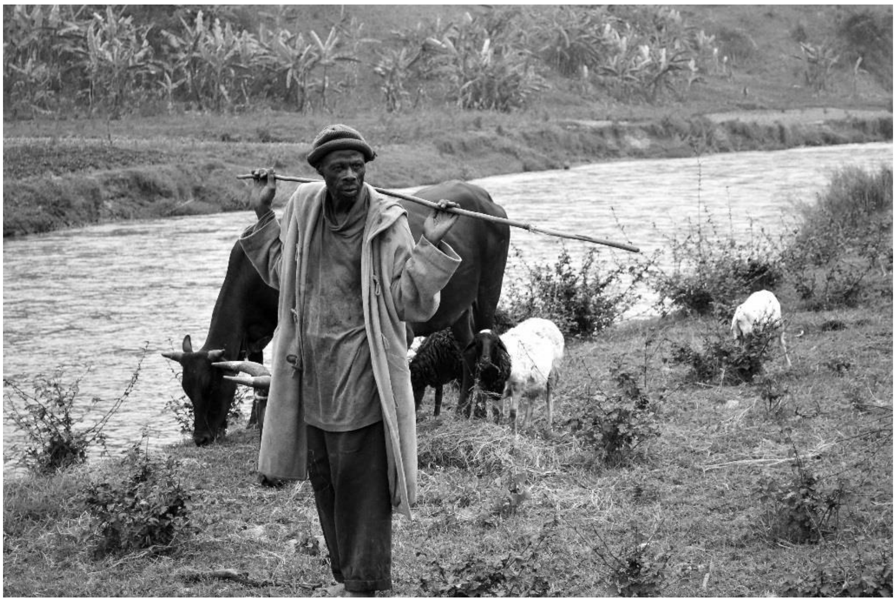


Figure 2.2 – A Burundian shepherd (August 2013).

This unfavorable situation puts the country at the fourth from the bottom of the GDP per capita world ranking (excluding San Marino tax heaven) [36] and at the twentieth from the bottom of the HDI world ranking [37]. Therefore, Burundi is still considered a Low Developing Country (LDC) [15] with more than 90% of the population lives on less than US $ 2 per day [38].

2.2 Economic and social condition

The aim of this section is to show the social and economic status of the country through the evaluation of the actual value of some indicators, their trend over the years and the comparison with other countries.

2.2.1 Economic indicators

The economic dimension of Burundi is better highlighted by data reported in Table 2.1.

Table 2.1 – Burundian economic data (Source [36])

Country	***BURUNDI***
Gross Domestic Product (current US $)	2,472,384,864
Gross Domestic Product per capita (current US $)	251.0
Gross Domestic Product per capita, PPP (current $)	749.7
Gross National Income (current US $)	2,463,262,258
Gross National Income per capita (current US $)	240.0

The Burundian GDP is less than US $ 2.5 billion and it is tenth from the bottom of GDP African ranking of fifty-two countries' data. At the top of the ranking there is Nigeria with a GDP of US $ 459.6 billion. Nevertheless, in terms of GDP per capita, Burundi is the last African country with only US $ 251 compared with an average of US $ 2,692 and a top value of US $ 24,036 of Equatorial Guinea (96 times higher than Burundi).

On the other hand, if GDP per capita PPP is analyzed, things change. GDP PPP, which stands for Purchasing Power Parity, is the GDP converted into international dollars, and not US dollars, using purchasing power parity rates. An international dollar has the same purchasing power in the considered country as the US dollar has in the United States. The GDP per capita PPP in international dollars is higher than the one in US dollars: it is almost thrice ($ 750). With the PPP application, the disparity in GDP per capita between different income countries decreases. To confirm this effect, the distance from Equatorial Guinea (38,184 current international dollars) is reduced (51 times higher than Burundi).

Moreover, in terms of Gross National Income (GNI), the difference between GDP is small. GDP is defined as the overall value of finite goods and services produced at national level of the considered country in a fixed time period. GNI accounts for finite goods and services produced by countries' entities all over the world. For a country, a small difference between the two values could find explanation in two factors:

1. Burundian people are concentrated only in their country with no or very little emigration and consequently zero remittance.
2. No internal enclaves, a typical consequence of the trade with multinational corporations that exploits some areas of a country with low labour costs that causes an increase of GDP (high internal production) but a decrease of GNI (low remuneration of work) [39].

Finally, it would be interesting to analyze the economic growth of the country all over the years and to compare it with the one of other African countries using an intensive indicator as GDP per capita.

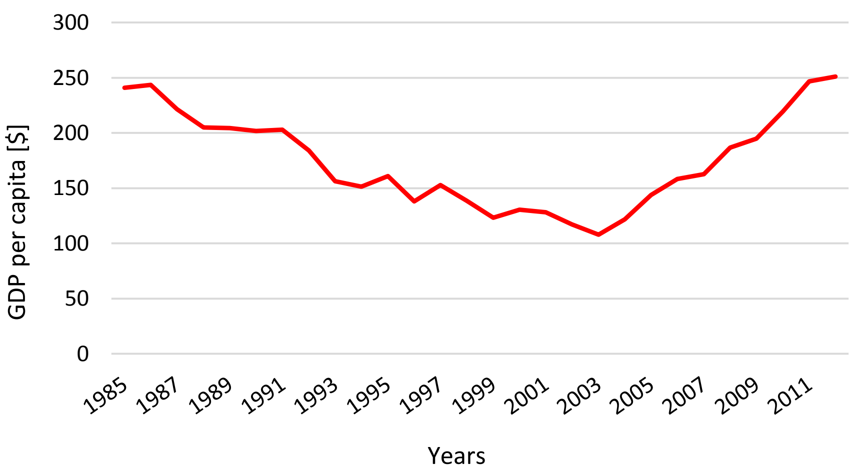


Figure 2.3 – Burundian GDP per capita trend (Source [36]).

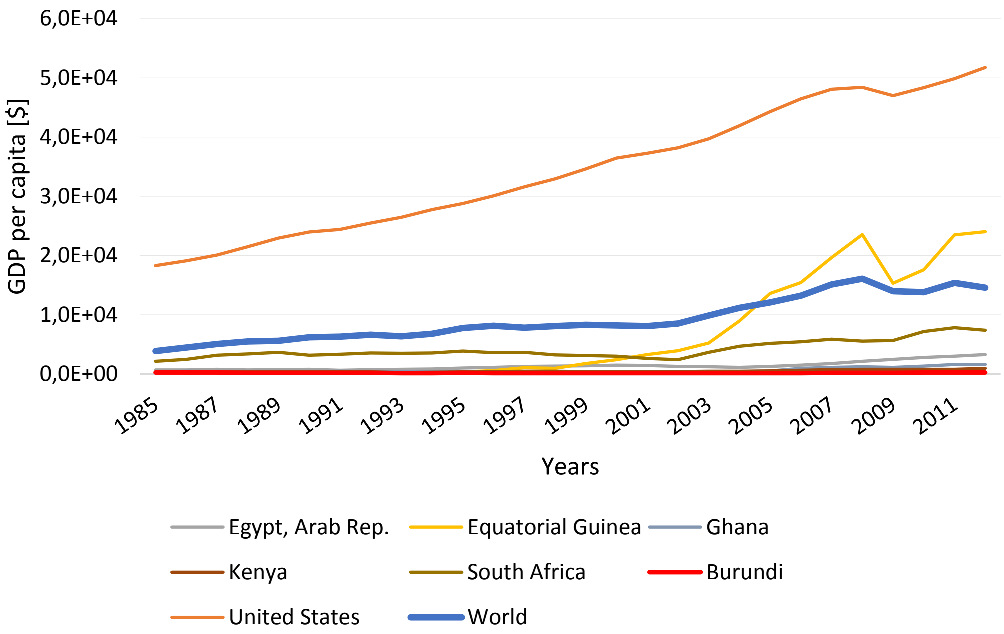


Figure 2.4 - GDP per capita trend for Burundi and other countries (Source[40]).

It is evident how Burundian GDP per capita is much lower if compared with the average value of the whole world and with the values of other African countries (Figure 2.4).

In Figure 2.3 we can see an evident decrease of that value during the years of the war and the economic embargo imposed by Burundi's neighbouring countries in reaction to a new military coup [41] that reduced people in a still worst economic condition.

2.2.2 Social indicators

It is important to give an idea of the social situation of Burundi through some indicators such as the growth of population, the access to health facilities and education.

In the last decade, the population of Burundi has been growing with a rate of more than 3% (in Italy and in Europe&Central Asia the rate is respectively 0.34% and 0.1% [42]), reaching the present value of almost 9.8 million people. More than 88% of them live in rural areas [36] (Figure 2.5). It is interesting to see in Figure 2.6 how the share of people living in rural areas is slowly decreasing while the share of the urban population in growing. This is a consequence of a slow urban migration. Many people leave rural areas to go to the bigger cities, hoping to find a better life through a formal or frequently an informal job [39].

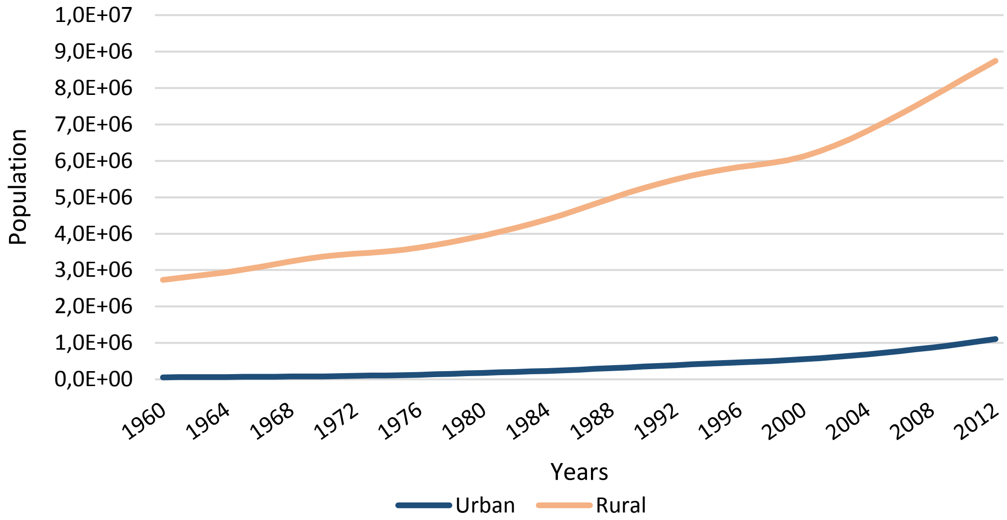


Figure 2.5 – Urban population and rural population trend (Source [36]).

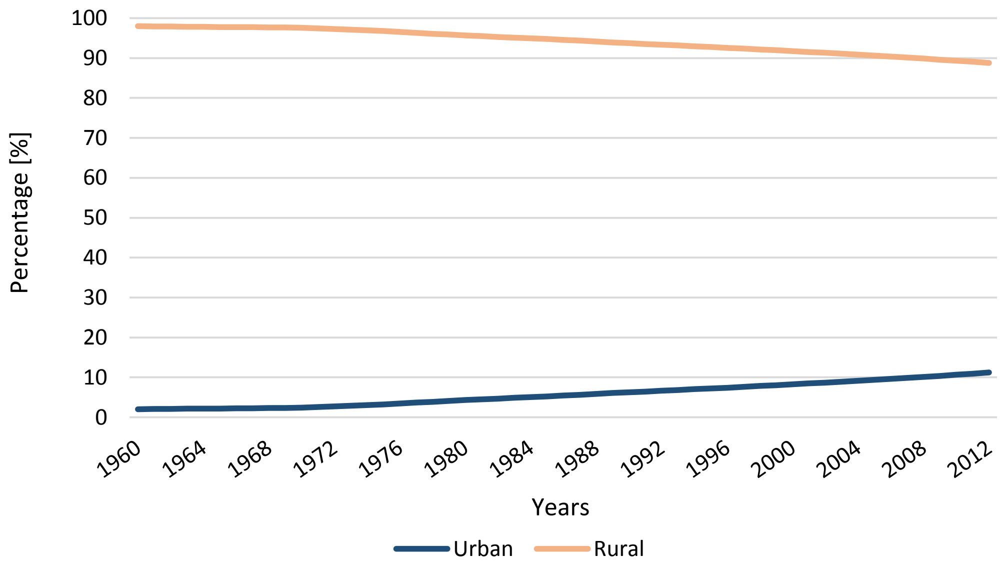


Figure 2.6 – Share of urban and rural population trend (Source [36]).

The second indicator is the access to improved sanitation facilities. According with the World Bank, sanitation is fundamental to human development. Many international organizations use hygienic sanitation facilities as a measure for progress in the fight against poverty, disease, and death. Access to proper sanitation is also considered to be a human right, not just a privilege, for every man, woman, and child. Countries that do not take urgent action to redress sanitation deficiencies will find their future development and prosperity impaired [40].

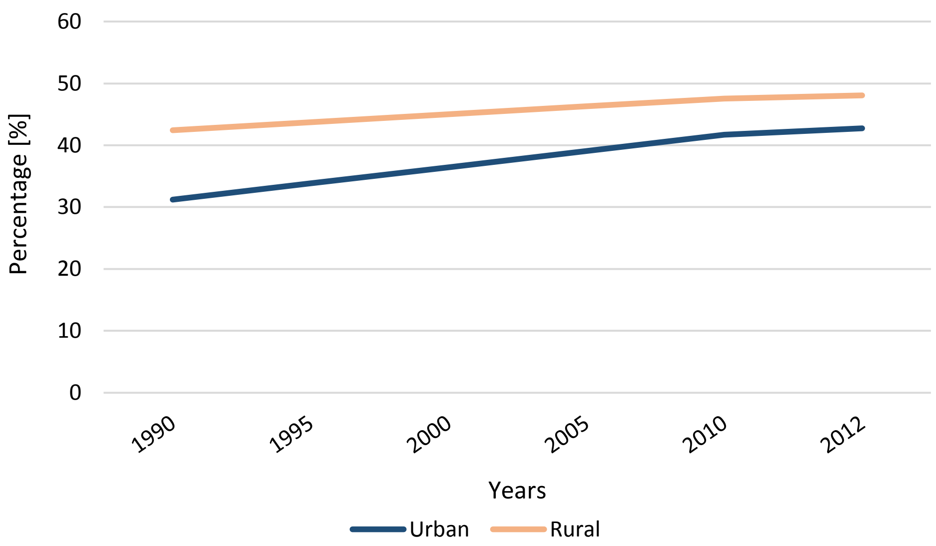


Figure 2.7 - Percentage of the population with access to improved sanitation facilities in Burundi (Source [36]).

Figure 2.7 shows that the number of people having access to improved sanitation facilitates in Burundi is slightly increasing and, surprisingly, in rural areas rather than in cities. This is mainly due to a larger presence of Non Governmental Organizations (NGOs) located in the rural areas where they lead health activities in hospitals, dispensaries and social support structures. Moreover, this is a consequence of an uncontrolled process of urbanization involves mainly the capital city of Bujumbura.

The last social indicator analyzed is the rate of enrolment in secondary schools that is the ratio of people, regardless of age, who are enrolled in the secondary school to the population of the corresponding official school age. This choice is due to the typical situation of the less developed country where the primary school is free causing the congestion of the schoolrooms, lack of teachers and structures, and a low level of enrolment.

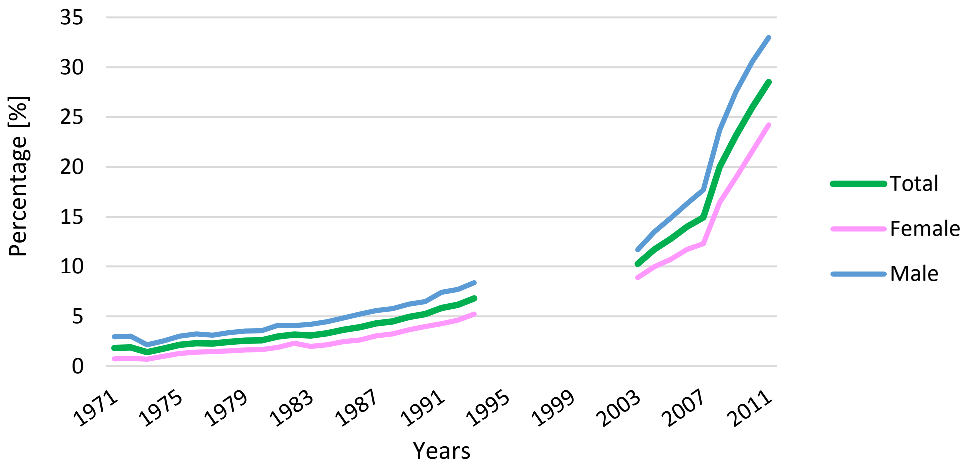


Figure 2.8 - Enrolment in the secondary school in Burundi (Source [36]).

Figure 2.8 shows that the number of people who are enrolled in the secondary schools in Burundi is rapidly increasing but it remains one of the lowest value of the African ranking (Table 2.2).

The lack of data between 1993 and 2004 is due to the civil war in the country where a decrease of the ratio is expected. Focusing on the female enrollment, data confirm the situation of women in Burundi where they are victims of discrimination, inequality and most affected by poverty [43].

Table 2.2 - Rate of enrolment in the secondary school in most of African countries in 2012 (Source [36]).

Country Name	*[%]*
South Africa	100
Mauritius	96
Cabo Verde	93
Comoros	73
Sao Tome and Principe	71
Ghana	58
Congo, Rep.	54
Lesotho	53
Mali	51

Country Name	***[%]***
Cameroon	50
Congo, Dem. Rep.	43
Guinea	38
Madagascar	38
Tanzania	35
Malawi	34
Rwanda	32
Eritrea	30
Burundi	**28**
Mauritania	27
Burkina Faso	26
Mozambique	26
Chad	23
Central African Republic	18
Niger	16

2.2.3 Human Development Index

The 2013 Human Development Report presents HDI values and ranks 187 countries and UN-recognized territories. An overall view of the World situation is given by Figure 2.9.

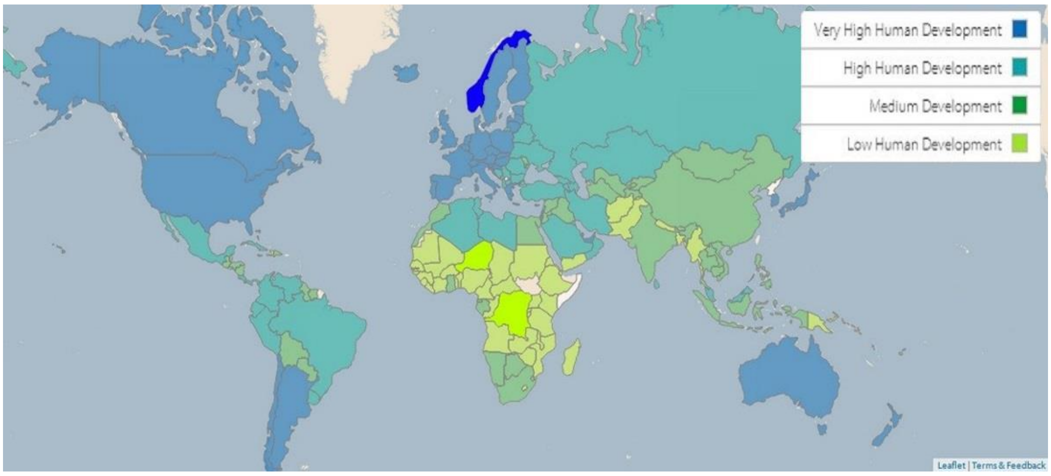


Figure 2.9 – Map of the global HDI situation in the World, UNDP Data (Source [44]).

Observing the map, is evident how the worst situation for HDI is concentered in the Sub-Saharan Africa. DRC and Niger, in fact, are the countries with the lowest HDI with a value of 0.304. On the contrary, Norway is at the top of the HDI ranking with a value of 0.955.

Burundi's HDI value for 2012 is 0.355 positioning the country at 178th place within the lowest human development category. Figure 2.10 shows the HDI trend between 1980 and 2012 with an average annual increase of about 1.6% and an evident stagnation during the civil war. Focusing on the three components of the index, looking the Figure 2.11, two comments about the life expectancy and education can be made:

1. In 2012, the average life expectancy for a newborn in Burundi is almost 54 years. It is in the 36th place of forty-eight Sub-Saharan African countries analyzed by World Bank [36]. The figure clearly shows a decrease of this value during the civil war.
2. The index of education in Burundi is now growing fast. This could be interpreted as a good sign for development but it is mostly due to a reform of the actual President Pierre Nkurunziza that makes primary school free for all children. The consequence of this are the congestion of the schoolrooms, the lack of teachers, structures and services (e.g. only 2% of primary schools have electricity [11]). All these aspects cause an insufficient level of enrolment.

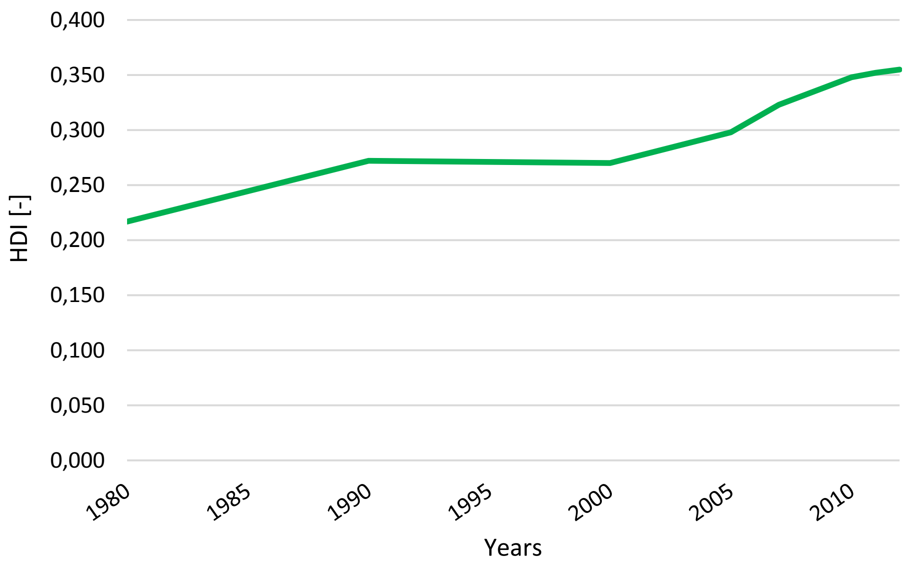


Figure 2.10 - Human Development Index trends of Burundi between 1980 and 2012. UNDP Data (Source [44]).

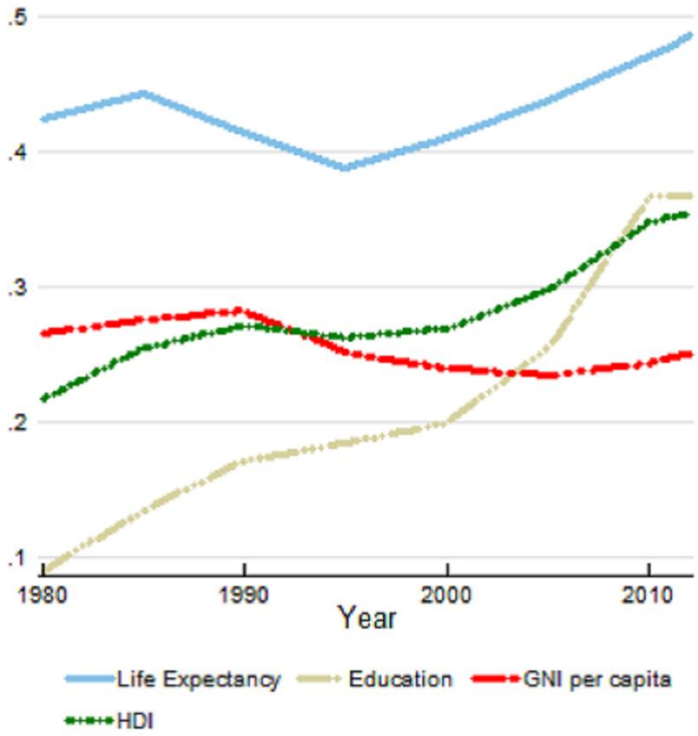


Figure 2.11 - Trends in Burundi’s HDI component indices between 1980-2012 (Source [44]).

2.3 Energy assessment

Burundi is one of the sub-Saharan African country with the worst rate of access to energy. In 2014, only 4% of the population of ten million currently has access to electricity, marking some of the lowest access rates anywhere in the world [45]. Figure 2.12 shows that it is one of the countries with the highest shortfall in modern cooking and heating access in Africa and Asia [46] that involves the 99% of the Burundian people [15].

Africa		Asia	
Top 5 countries by % population without access			
Liberia	>99%	Laos	>95%
Mali	>99%	Myanmar	>95%
Burundi	>99%	Cambodia	>90%
Madagascar	>99%	Bangladesh	>90%
Somalia	>99%	Afghanistan	>85%

Figure 2.12 - Countries with the Highest Shortfall in Modern Cooking/Heating Access in Africa and Asia (Source [46]).

2.3.1 General overall of the country

The key elements about Burundi's energy assessment are synthesized in Table 2.3. The International Renewables Energy Agency (IREA) gets the only available data referred to 2009.

Table 2.3 - Burundi's energy indicators (Source [47]).

Country	***BURUNDI***
Total Primary Energy Supply	2,345.47 ktoe
Rate of renewables	97.2 %
Energy self-sufficiency	97.3 %
Electricity generation	20.77 ktoe
Rate of renewables	98.2 %

Total Primary Energy Supply (TPES) is provided almost of renewable energy sources. This is due to a total absence of fossil resources in the country and to a low dependence on imported expensive fuels. Only diesel is principally consumed by the transport sector. Moreover, the distinguishing feature concerning renewable energy use in Burundi is the widespread use of wood and charcoal by households. 96% of all energy needs are met by traditional biomass, comprised of wood fuel, solid wastes and charcoal (Figure 2.13).

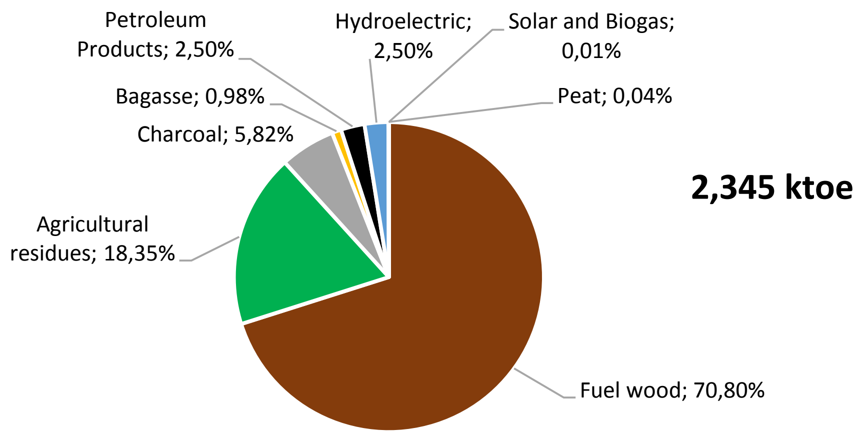


Figure 2.13 - Burundi’s TPES by source in 2009 (Source [48]).

Biomass is totally used for the thermal energy supply that is mainly necessary to cook and heat water. On the other hand, focusing only on electricity generation, the total installed capacity is 37 MW, of which 85% comes from hydropower plants.

2.3.2 Renewable energy potential of the Country

The aim of this section is to examine in depth all the opportunities to exploit the renewables potential of Burundi.

Hydroelectric power

Burundi is an equatorial and mountainous country and it benefits from an extremely interesting hydropower potential, coupled with favorable rain conditions and many waterfalls. Burundi’s hydroelectric power potential was evaluated in 1983 to be of 1,700 MW of which approximately 300 MW were economically exploitable. The potential could be even greater today, as the recent evaluation of certain sites has demonstrated a capacity higher than the one initially calculated in 1983 [49]. At the present time, there are 156 potential hydroelectric power sites about to be equipped (Figure 2.14). Detailed engineering and design studies of existing plants could allow for rehabilitation and improvement of capacity. New technologies allow for optimal use of components, pipelines, turbines, and transformers, thus reducing friction and losses and improving the transfer of energy.

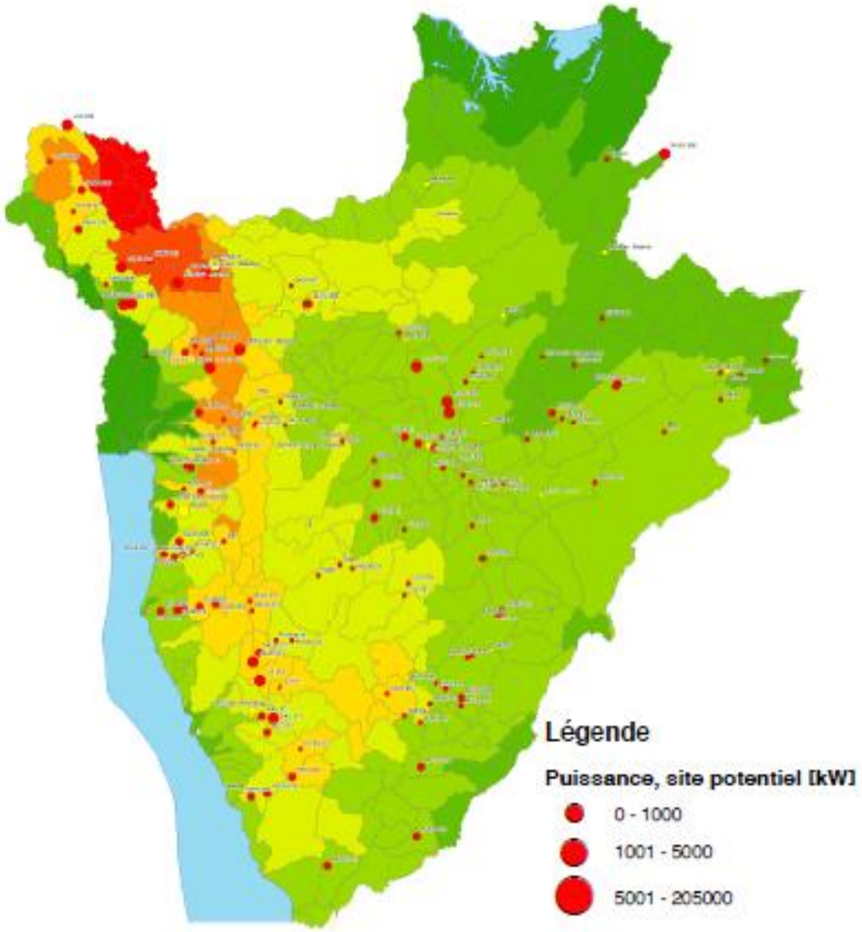


Figure 2.14 – Burundi’s hydropower potential (Source [50])

Solar Power

Burundi has a very interesting solar energy potential. The average annual sunshine fraction in Burundi is close to 2,000 kWh/m^{2}year, equivalent to the sunniest European regions around the Mediterranean. Despite significant cloudy weather and rainy seasons due to Burundi’s equatorial location, the development of solar energy in Burundi is a very interesting option [49].

Table 2.4 – Monthly Averaged Insolation Incident On A Horizontal Surface in Burundi [kWh/m²/day] (Source [51]).

Jan	Feb	Mar	Apr	May	Jun
4.93	5.24	5.16	5.01	4.87	5.00
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
5.31	5.42	5.32	4.93	4.76	4.83

There is a large potential for photovoltaic electricity generation in rural parts of Burundi [48] and it is suitable for the electrification of remote centers. To develop the rural electrification of dispersed populations, supplying photovoltaic solar home systems could be a solution. A lot of remote public or private infrastructures (health centers, schools, hotels, telecommunication towers) could be powered by solar energy.

Solar thermal potential is suitable as well as electric power generation. It would be a fulfilling source to meet the domestic demand for cooking, heating and drying needs. It is estimated that by 2003, a total of 140,000 m² of solar heat collectors were placed. Although the largest applications have been in the hospitality sector, solar collectors have also been in use in some urban households [48].

Biomass

According to the official statistics, about 6% of Burundi's land is forested [36]. This area represents the largest stock of people's most-used fuel. Forestlands supply an abundant amount of energy resources but without any regulation and afforestation Programme, the growing demand for wood products will cause a rapid drop in land covered by forests. Wood is often used for producing charcoal that has a higher low heating value and it burns more efficiently than wood but the global energy balance often causes a greater consumption of wood.

It is known that biomass could be used for power generation using urban waste, peat and bagasse [49]:

1. The use of household and/or industrial waste for incineration and methanisation requires the existence of a waste management system. A project is currently under discussion to evaluate the waste potential in Bujumbura.
2. Burundi possesses potential estimated at 600 million tons of peats. The use of peat for electrical production is possible but it is advisable to carry

out feasibility studies to better analyze the technology, its impact on the economy, environmental and land issues related to the technology.

3. Bagasse is used in a 4 MW cogeneration plant owned by The Moso Sugar Company (SOSUMO) that is fuelled with sugar cane residues and it is operational during the entire sugar season. Unfortunately, this turbine is linked only to the SOSUMO factory and its administrative buildings but it has not been ruled out the possibility to connect the plant to the national grid.

Figure 2.15 – Burundian woman who transport timber for cooking (Source [49]).

Wind power

Wind power is more or less completely unexploited in Burundi. In fact, only two mechanic wind machines have been installed in the last few decades, on the Imbo plain [49].

It seems that no feasibility studies on wind power have been carried out in Burundi. According to NASA Langley Research Center Atmospheric Science Data Center [51], the monthly average wind speed at 50 meters above the surface of the earth for 3-hour intervals of Greenwich Mean Time (GMT) during a given month is less than 4.8 m/s. Moreover, the Monthly Averaged Wind Speed is always less than 4 m/s [52]. Consequently, it would be difficult to develop industrial wind turbines.

However, Burundi's varying altitudes, the existence of a substantial size lake and the topography of the country, could prove to be favorable conditions at certain sites [49]. More studies are necessary to verify Burundi's wind potential. To develop wind power parks, challenges relating to improvement and adaptation of roads and availability of cranes should be addressed. If such measures are not taken, only small-scale wind power could be developed.

Geothermal

Burundi is located in the Great African Rift Valley. This geological area is a region that has geothermal potential on an international scale.

Unfortunately, the temperatures measured in approximately fifteen hot springs are at a maximum of 70 °C and there do not appear to be any sources with established fumaroles with higher temperatures. There are no geothermal applications with these low temperatures.

2.4 Electrical assessment

Despite a very dense hydro-graphic network which provides Burundi with a hydroelectric potential energy supply of 6,000 GWh/year [53], the country faces a chronic shortage of electricity. These difficulties in the supply stem from the unfavorable climatic effects of recent years and recurrent social conflicts and unrest that resulted in substantial damage to the electrical system and subsequent deterioration because of lack of maintenance.

The aim of this section is to present an overview of the electrical sector in Burundi with a focus on the current electrification of the country and the future programmes of increase in generation capacity and extension of the electric grid.

2.4.1 Institutional level

The responsible for Burundi's energy sector is the Ministry of Water, Energy and Mines (MWEM). The mission of the Ministry is to formulate and implement energy policy, as well as to consolidate and manage the energy sector. The policies and programs are then implemented through the General Directorate of Water and Energy (DGEE) and the General Directorate of Water and Rural Energies (DGHER). The DGEE is responsible for preparing sector policy and legislative and regulatory texts. It plans and coordinates the sector's activities, defines priorities, formulates investment programs, controls operation of the power utility, oversees the permanent secretariat of the national energy commission, and prepares tariff policy. The DGHER is responsible for coordinating NGOs operating in the sector, rural electrification, biomass and alternative energy.

Decrees and laws enacted in 1968 and 1969 established a monopoly for the production and supply of electricity nationwide by creating the Régie de Production et de Distribution d'Eau et d'Electricité, known as REGIDESO, which is responsible for the public electricity and water service in urban areas. REGIDESO is a public utility with an autonomous judicial and financial status that operates under the supervision of the Ministry of Water, Energy and Mines.

A decree issued in 1997 clarified the responsibilities of the DGHER and REGIDESO. The DGHER is responsible for the provision of electricity and water in rural areas, leaving REGIDESO responsible for serving urban areas.

In August 2000, the Government adopted a law liberalizing and regulating electricity with the follow principles [54]:

a) The production, transmission and distribution of electricity are all public services. These public services can be assigned in various ways (including leasing or concession) to public or private entities.
b) Self-production (including production, transmission and distribution) are permitted for private use after authorization is obtained.
c) Creating transmission lines to serve third parties is allowed if public service does not yet exist where such arrangements are proposed.
d) Self-producers can sell their surplus to public service managers through a price agreement.
e) Similarly, the use of public transmission lines is possible through a price agreement.
f) The exporting of self-generated energy is allowed.
g) In remote areas, private production, transmission and distribution is permitted.

It also abrogated the 1968 Order in Council that granted REGIDESO a monopoly over public drinking water and electricity supply. According to this new law, the production, supply and distribution of electric energy are industrial and commercial public services under the responsibility of the Government. Along with the DGHER, REGIDESO became a delegated public service provider operating under the control and authority of the regulatory body to be established [53].

In order to complete the process of liberalization of the energy sector, with the Decree No. 100/320, a control and regulation entity was established in 2011 [49]. This entity, called the Control and Regulation Agency for the Water and Electricity Sectors in Burundi, has as a main mandate to ensure the development of an orderly and profitable water and electricity sector in Burundi. It should control, regulate and monitor activities related to water and electricity in order to ensure compliance with contract conditions for delegation as well as specifications and additional clauses on the part of operators. It should also ensure the implementation, monitoring and application of tariffs in accordance with the pricing principles that have been established by regulation.

At the same time, the Burundian Agency for Rural Electrification (ABER) was established. The objective of this entity is to develop and implement rural electrification projects and programmes, including small-scale hydroelectric power, solar and wind energy, as well as other forms of energy that can improve electricity access for the rural population.

At the regional level, there is a history of cooperation between Burundi, Rwanda and the DRC with the creation of the International Electricity Company of the Great Lakes Countries (Socie´te´ Internationale d’Electricite´ des Pays des Grands Lacs - SINELAC). It was created in 1983 by a treaty ratified by the Governments of Burundi, Rwanda, and Zaire to build and operate the Rusizi II hydroelectric power plant located on the border between Rwanda and DRC [55]. The intention was to provide electricity generation for Rwanda, DRC and Burundi from the power generating stations on the Rwanda-DRC border [56] and work at the development of the electrification of the region.

2.4.2 Electricity generation and demand

The electricity production is mostly handled by the REGIDESO, which has an installed capacity of 35.8 MW, of which 30.8 MW are hydroelectric power plants and 5.5 MW are thermal units located in Bujumbura, constituting 97% of the national installed capacity (Figure 2.16). In addition to the hydroelectric power plants managed by the REGIDESO, a number of micro plants are managed by ABER (formerly DGHER), and the private sector such as the Burundi Tea Office and various religious missions [49].

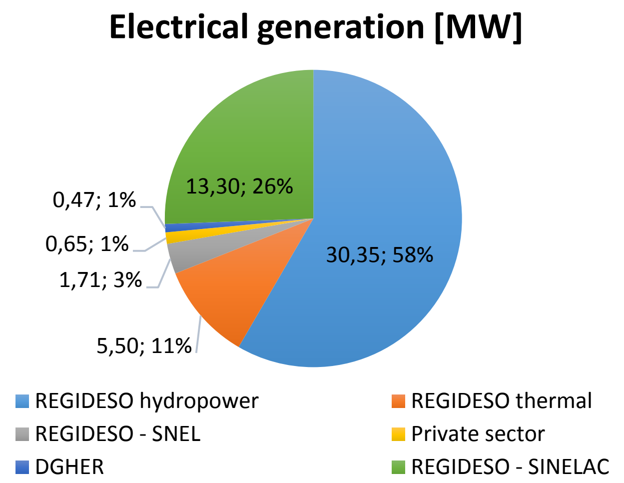


Figure 2.16 – Distribution of electrical production in MW (Source [50]).

It is evident how almost all of the electric energy produced in Burundi comes from the use of the hydro resources. Moreover, Figure 2.16 shows that the supply from external hydroelectric generation through the agreements of REDIGESO with SINELAC and the National Electricity Company of the Democratic Republic of Congo (SNEL). This need to import energy will increase because of the growth in consumption higher than national production (Figure 2.17). This substantial energy deficit in Burundi forced the REGIDESO to lease a diesel generation of 10 MW in 2010 and 2011 [49].

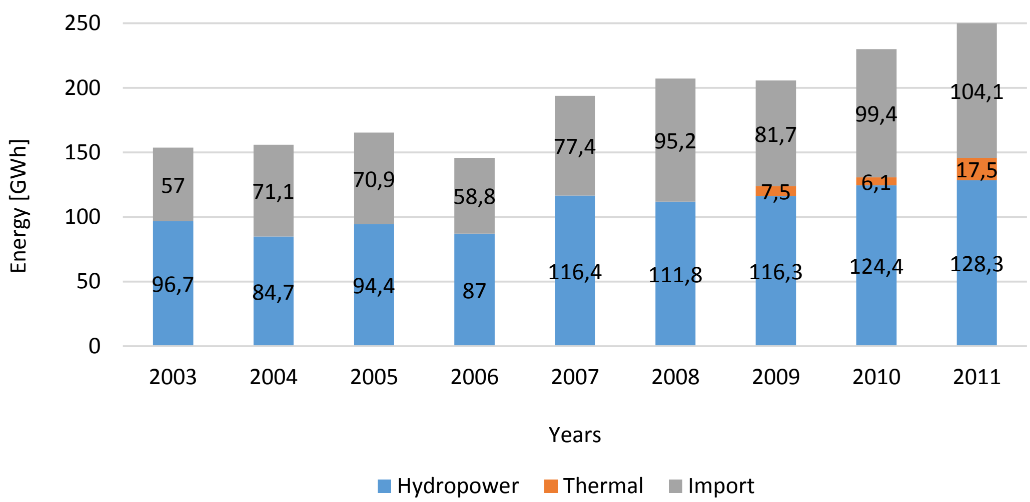


Figure 2.17 – REGIDESO's electric production (Source [49]).

It is thus evident that the need to increase capacity is urgent and massive to supply the total electricity needs of productive and industrial activities, households and other consumers (Figure 2.18).

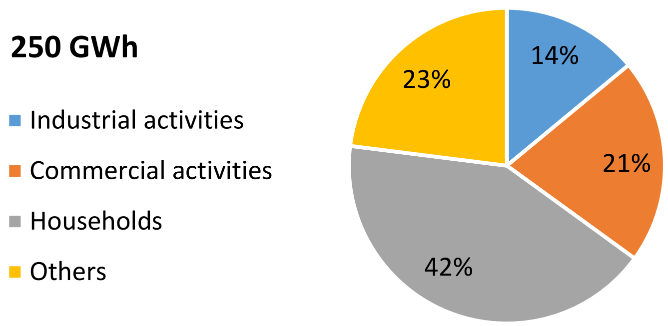


Figure 2.18 – Distribution of REGIDESO clients in 2011 (Source [57]).

Focusing on the total production, Table 2.5 shows in detail the composition of existing electric generation capacity and the production in Burundi.

Table 2.5 - Existing Utilization of Generation Capacity Utilization and Electricity Production in Burundi (Source [50, 53, 58]).

Electric Capacity	**Installed Capacity [MW]**	**Electricity production (kWh)** 2011	2012
Thermal plant	5.5	12,904,805	2,887,600
Rwegura	18	57,543,700	63,732,800
Mugere	8	46,575,633	51,328,778
Ruvyironza	1.27	4,996,500	6,594,710
Nyemanga	1.44	11,101,201	9,316,445
Gikonge	0.85	5,140,390	5,240,150
Kayenzi	0.85	1,546,620	1,191,495
Marangara	0.24	1,476,480	1,393,836
Buhiga	0.24	unknown	unknown
Remote DGHER plants	0.47	unknown	unknown
Private plants	0.65	unknown	unknown
Total national	*37.51*	*140,928,706*	*141,685,814*
Ruzizi II	12.30	79,612,000	81,979,000
Ruzizi I	28	24,508,983	22,310,567
Total imports	*40.30*	*104,120,985*	*104,289,567*

Current data show the total electricity supply equal to 246 GWh in 2012 with a percentage of imported energy equal to 42.4 on the total. Moreover, data in the table confirm that the share of hydroelectric plants on the total national capacity is more than 85%. Focusing on the availability of the plants, the evaluation of equivalent hours shows that the utilization of the installed capacity is almost 43%. This value compared with the 31% recorded in 2008 [53], reveals a clear improvement in the electrical sector thanks to the rehabilitation of equipment destroyed during the civil war in the 1990s and the reinforcement of staff training, and an increase in consumption.

Due to this low utilization, Burundi’s available electricity generation capacity is severely constrained and is likely to remain so for several more years. The supply deficit currently varies between 13 MW during the wet season and 23 MW during the dry season when the country’s main hydropower plants are running at reduced capacity. Peak demand occurs during the evening hours (Figure 2.19) and emanates mainly from household lighting needs, but the shortage of generation capacity and resulting load shedding is having a major impact on economic growth and business activity. The shortfall in available power is exacerbated by technical and non-technical losses, caused in part by lack of maintenance. In 2007, these losses were estimated at 48 GWh, equivalent to a supply loss of about 24.4%. A large portion is made up of technical losses, given the poor condition of the network, the high and medium voltage stations, and the low voltage distribution posts. The number of power interruptions is high, both on low voltage and on the high and medium voltage backbone network. The quality of electricity delivered suffers from poor frequency and significant voltage deviations estimated to be in excess of the normal 10% below and above 220 volts [53].

Observing the curve of the daily electric load obtained thanks to personal communication with the office of Minister of Energy and Mines, it is evident how the situation is completely turned around during the night (Figure 2.19). The electric load is not only lower than the total domestic electric capacity, but also lower than the hydroelectric one equal to 32 MW. As a consequence, in Burundi there is a surplus of hydroelectric nominal potential on the order of 1 to 10 MW from 11 p.m. to 7 a.m.. This surplus is not obviously always available because of the outages of the plants, maintenance and dry seasons, the plants never produce electricity at the nominal power. However, the number of nights when this electric surplus is available could be estimated.

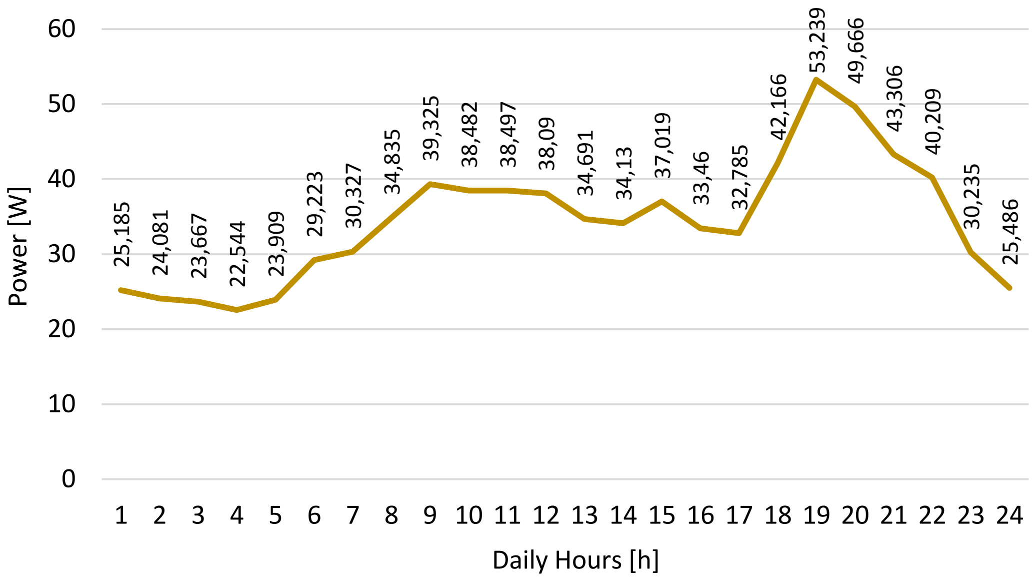


Figure 2.19 - Electric Load interconnected to the REDIGESO Network at 10 of October 2013 (Source [58], Ministry of Energy and Mines - Bujumbura).

From Table 2.5, the calculation of equivalent hours of national hydroelectric plants is as follows:

$$h_{eq} = \frac{E_{hydro}}{W_{hydro}} \qquad (2.1)$$

with E_{hydro} the total energy production from the national hydroelectric plants in 2012 was equal to 138.8 GWh, and W_{hydro} the national nominal hydroelectric capacity was equal to 31.5 MW. With these values, h_{eq} is equal to 4,336 hours that represents the hours of the year when all the plants generate electricity at the nominal power. As previously stated, W_{hydro} is higher than the daily electric load during 7 night hours. As a consequence, with the hypothesis of daily electric load approximately equal to the one represented in Figure 2.19 every day of the year, if we divide the found value of h_{eq} by 24 hours, this gives the number of nights where a surplus of renewable energy of 7 hours is available:

$$number\ of\ nights = 181$$

The cost of electricity, tariffs are under the responsibility of REGIDESO and they are different for each final user and the brackets of energy (Table 2.6).

Table 2.6 - Tariff for the supply of electricity in low voltage by REGIDESO from 1/3/2012 (Source REGIDESO – Bujumbura, August 2013).

	Range [kWh]	***Tariff per kWh***		***Fixed bonus***	
		FBU/kWh	*€/kWh*	*FBU/two-months*	*€/two-months*
Households	0 - 100	73	0.035	-	-
	101 - 300	138	0.067	-	-
	> 301	260	0.126	6,497	3.144
Trade and industry	0 - 200	93	0.045	3,989	1.931
	201 - 500	149	0.072	8,000	3.872
	> 501	190	0.092	12,000	5.808
Administrations	one-price	149	0.072	-	-
Street lighting	one-price	151	0.073	-	-
DGHR	one-price	141	0.068	-	-

2.4.3 Electrification

A key feature of the power sector in Burundi is the very low level of electrification. Total connections to the REGIDESO network have increased by about 10,000 since 2000 and now stand at about 36,000 with an average increase of almost 5% a year. Assuming that all the DGHER connections are rural households, only 34,700 households have access to electricity. This means that only 2% of the 1.6 million households in the country are currently electrified. Moreover, almost 80% of the households that do have access to electricity are located in Bujumbura. Only 8,000 households in the rest of the country are electrified.

The electrification in Burundi began with a 70 kV overhead electrical line from Rusizi I Small Hydropower Plant (SHP) in Congo for the supply of the capital Bujumbura in 1959 [48]. With the first constructions of hydroelectric power plants, the national electric sector has been increasing up to the actual the current situation. The total length of the main transmission lines located in Burundi is actually about 265 km long and it includes a part of a 383 km main transmission line that links Rwanda to the DRC. Overall, the electrical transmission system is made up of high-voltage lines (70 and 110 kV) and medium-voltage lines (10, 15, 30 and 35 kV) which is the exclusive responsibility of REGIDESO (Figure 2.20) in terms of maintenance, extension and tariffs [49].

As for the distribution network, low voltage is supplied at the following levels: 6.6 kV, 10 kV, 15 kV, 30 kV and 35 kV. The network is overloaded in several areas of the country, 30 kV lines are being used to connect urban centers, provide access to rural areas and connections to local production centers. 10 kV or 6.6 kV lines, with a preference for the 10 kV, provide supply within urban areas [53].

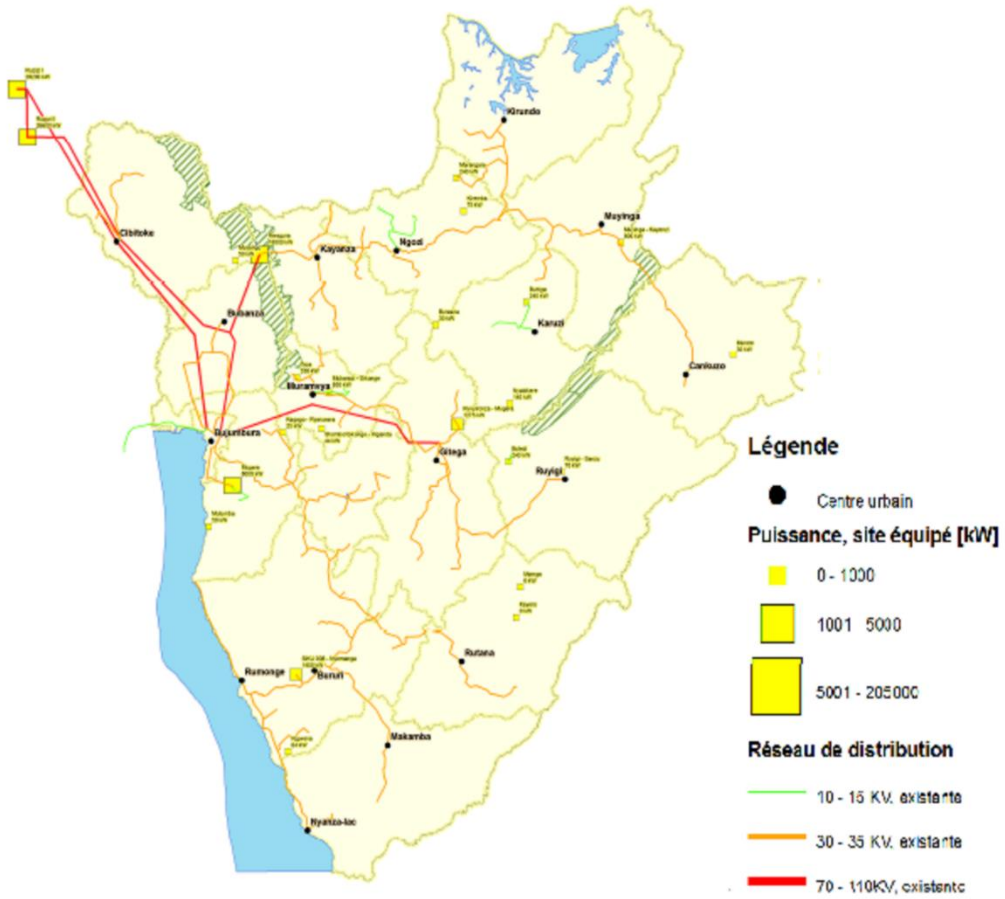


Figure 2.20 - Burundi’s existing electricity grid (Source [50]).

The actual lack of growth in the grid extension and in the number of connections is a big barrier mainly for possible new business opportunities in Burundi. Consumption of electricity per business connection has not grown during 2000-2008 [53], which, along with the minimal change in the number of connections, points to weak growth in business activity. Moreover, the distribution system is equally in poor state with much of the essential switch gear beyond repair due to limited availability of spare parts and lack of resources for maintenance. Key load centers such as Bujumbura are already heavily saturated, resulting in increased technical losses for the utility and poor quality of supply. As an indication of the network's state, the amount of unplanned power outages in the main grid increased by nearly 200% in 2007 to 200 hours, compared to earlier years [48]. Some of outages are due to the complete lack of spinning reserve and the high dependence on regional generation that offers little flexibility to bridge sudden supply interruptions. This state of the electric system, the unreliable supply of electricity are the major deterrents to private investors. Moreover, in 2009 firms in Burundi experienced an average of 12 electrical power outages per month, 40% of the time in a typical year [36]. As a consequence, a large percentage of firms in Burundi have their own back-up generator, or share access to one with high overheads: back-up generators typically cost US$ 0.40 to US$ 0.50 per kWh to run, cutting into business profits and reducing the ability of local business to compete in regional and international markets.

2.4.4 Future development of grid extension and capacity increase

According to [49, 53], the demand projections set out below, suggest supply requirements of about 3,600 GWh by 2030 (Figure 2.21), which translates into required available capacity in the range of 700 MW. Over the next 20 years, Burundi will therefore need access to an additional 650 MW of new capacity, either domestic or via imported power, to meet domestic demand.

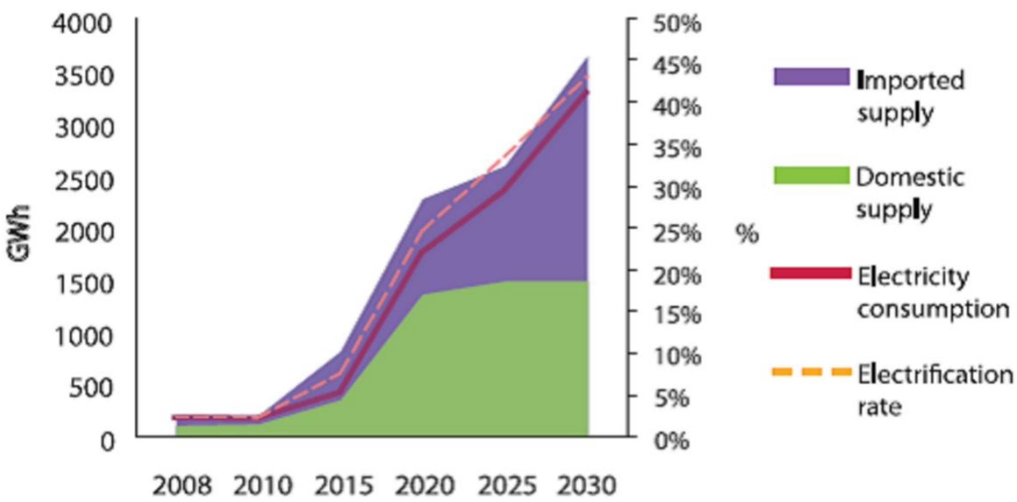


Figure 2.21 - Scenario of the future electrical power and consumption (Source [49]).

All the details about the development of the implementation of the power sector Programme are explained in [50, 53]. In Table 2.7 the future generation plants are listed.

Table 2.7 - Electricity Supply and Demand Balance until 2030 (Source [53]).

	2007	2010	2015	2020	2025	2030
Installed domestic capacity (MW)						
Existing plants	35,2	39,1	39,1	39,1	39,1	39,1
Proposed new REGIDESO plants						
Kaganuzi		-	5,0	5,0	5,0	5,0
Other small hydro plants		0,3	0,3	0,3	0,3	0,3
Sub-total	-	0,3	5,3	5,3	5,3	5,3
Proposed new private plants						
Mpanda			10,4	10,4	10,4	10,4
Kabu 16			20,0	20,0	20,0	20,0
Mulembwe				115,0	115,0	115,0
Kabulantwe				67,0	67,0	67,0
Rushiha		-	-	15,0	15,0	15,0
Ruzibazi		-	-	-	7,0	7,0
Sub-total	-	-	30,4	227,4	234,4	234,4
Total	35,2	39,4	74,8	271,8	278,8	278,8
Installed regional project capacity (MW)						
Rusizi I	28,0	28,0	28,0	28,0	28,0	28,0
Rusizi II	12,3	12,3	12,3	12,3	12,3	12,3
Resumo Falls			20,5	20,5	20,5	20,5
Rusizi III			48,3	48,3	48,3	48,3
Rusizi IV				87,0	87,0	87,0
Total	40,3	40,3	109,1	196,1	196,1	196,1
Total installed capacity (MW)	75,5	79,7	183,9	467,9	474,9	474,9
Available capacity (MW)						
Existing domestic plants	15,7	16,0	16,8	16,8	16,8	16,8
Proposed new domestic plants		0,2	23,2	151,2	155,8	155,8
Existing regional projects	8,8	9,7	10,1	10,1	10,1	10,1
Proposed new regional projects		-	95,4	286,0	286,0	286,0
Total	24,5	25,9	145,5	464,1	468,6	468,6
Electricity balance sheet (GWh)						
Supply	188,8	196,0	814,2	2 269,5	2 392,0	2 392,0
Demand	188,8	196,0	470,8	1 981,0	2 585,7	3 631,5
Surplus/deficit	0,0	0,0	343,4	288,5	(193,8)	(1 239,5)

Looking at the figure, three considerations can be made:

1. All the domestic plants predicted are hydroelectric power sites to minimize the need for expansion of costly thermal generation capacity to supply the short and medium-term demand growth.
2. The 40% of the total electricity supply will be imported by regional hydroelectric plants.
3. At the end of 2030, there will be a deficit of 1,239 GWh in the electricity balance of the country.

As regards to the expansion of the transmission grid, a number of specific initiatives aimed at strengthening regional trade in electricity are already under way. The African Development Fund (ADF) recently approved a Programme of loans and grants to finance the interconnection of electric grids among the five Nile Equatorial Lake countries which includes Burundi, Kenya, Uganda, DRC and Rwanda. This project includes constructing and upgrading a total of 262 km of transmission lines that will connect Burundi with the hydroelectric plants of the region and the construction and reinforcement of a number of transformer stations, including one in Burundi.

The accompanying map (Figure 2.22) indicates the location of the existing and proposed new power grid for Burundi and the locations of existing and new generation stations. The key features would be a 220 kV network with the following linkages:

- A 220 kV line of some 200 km from Resumo Falls to Gitega where it would link with the existing transmission line from Gitega to Bujumbura. These lines would link Burundi's network with the national networks of Rwanda and Tanzania, thereby enhancing the opportunities for trade of power supplies with the other EAC members.
- Upgrade the existing 110 kV line from Bujumbura to Gitega to 220 kV. The cost of the upgrade of the approximate 70 km would be in the range of $8 million.
- With the construction of Rusizi III, the transmission link to Bujumbura would be upgraded to 220 kV.
- The transmission line from Bujumbura to Mpanda and Rwegura would be extended through Butare and Nyanza in Rwanda to link to the main grid of that country.
- A new 220kV line would also be built as part of the Rusizi IV project to link this plant to the above-mentioned 220 kV line from Rusizi III.
- A 220 kV transmission line from Gitega to Bururi and Makavda, continuing across the border to Kigoma in Tanzania. The length of this line that would be located in Burundi would be about 135 km.

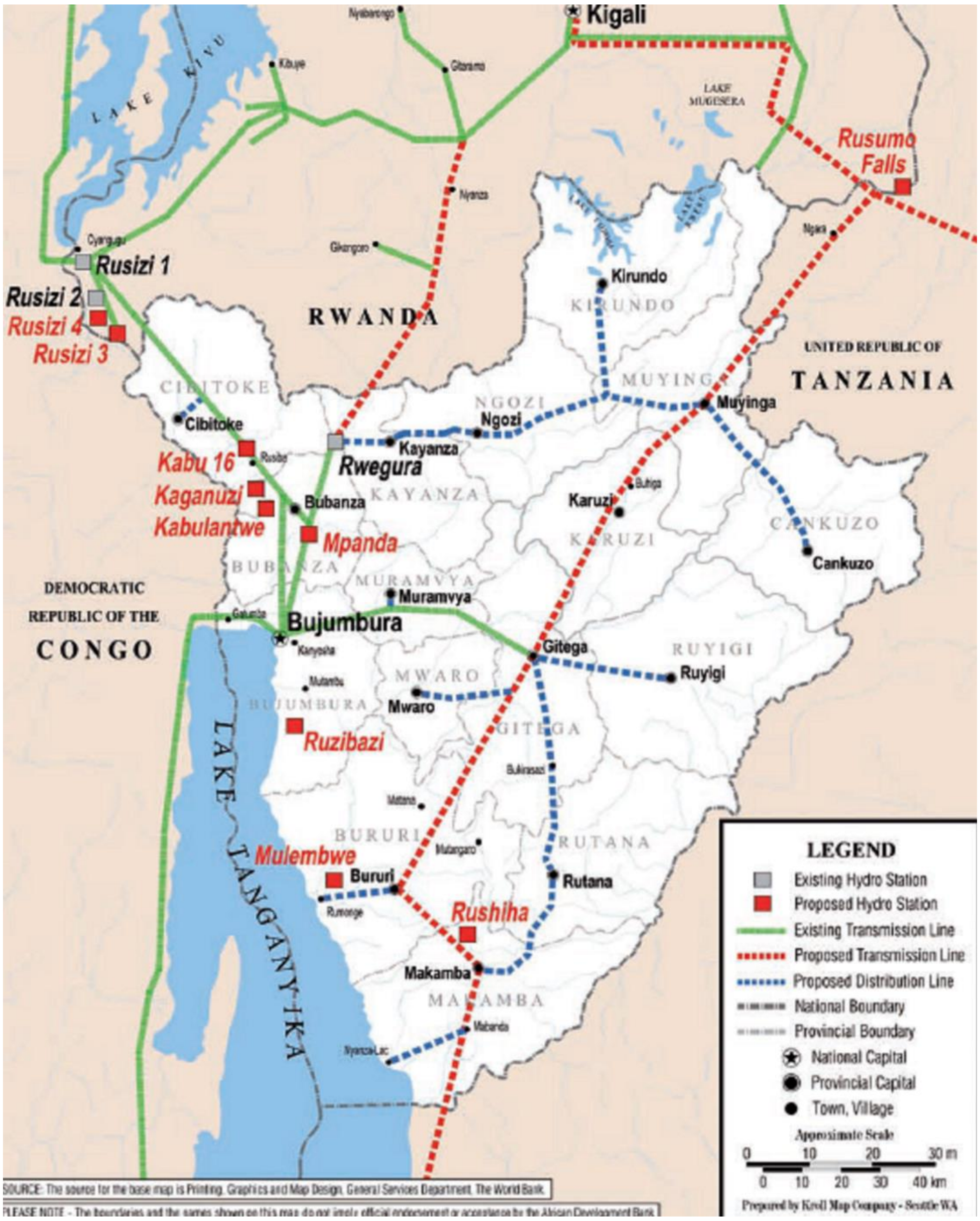


Figure 2.22 - Power stations and transmission grid for Burundi (Source [53]).

From the Figure 2.22, it is shown also the future extension of the distribution line. A cornerstone of the proposed distribution program is to provide 110 kV lines with necessary substations to all 13 of provincial capitals by 2015. Completion of this distribution grid at that time would lay the foundations for the electrification of 85% of urban centers by 2020 and would ensure that a very large part of the business community throughout the country had access to reliable supplies of electricity. The number of household and business connections is projected to rise to about 550,000 by 2020 and 1.2 million by 2030 with the aim to achieve the Government's targeted level of access to electricity for 25% of the population by 2020.

2.5 Deforestation in Burundi

The aim of this section is to present the status of natural forests in Burundi with a focus on the rate of deforestation and the problems related caused by a growing demand for wood products and expansion of agricultural land.

2.5.1 Forest situation

Historically, between one-half and one-third of Burundi's territory was originally estimated to be under forest cover [59]. Now, 6.5% of Burundi's total land (1,700 km^2) is forested [36] with about 14% made up of natural forests and the remaining 86% are plantation forests [60].

The largest remaining natural reserve are the Kibira and Ruvubu National Parks that are under nominal protection (Figure 2.23) but are actually being threatened. Kibira Park is feared to be subjected to extensive harvesting of timber, fuelwood, bamboo, forest products, and bush meat [61].

Figure 2.23 – Kibira and Ruvubu National Park locations.

In Burundi, the history of forest plantations dates back to the early twentieth century with the objective of meeting fuelwood demand. Around the 1930s, during the colonial period, forest plantations aimed at protecting the remaining natural forests against further encroachments and protecting farmlands from soil erosion [60].

After independence, reforestation efforts also relatively declined. However, as wood products became progressively scarce in the late 1960s, the Government had to act in order to define a clear forest policy and consequently a forestry sector development white paper was produced in 1969. Official efforts in forest conservation and rehabilitation continued in the 1980s and environmental protection legislation was initiated by the government [60].

By 1992, total forest cover had expanded to around 2,700 km^2 which is nearly 10% of the country area [36] thanks to the cooperation of several donors including World Bank, Belgium, Saudi Arabia, France, European Union, IDA, UNDP and many others. Unfortunately, starting from October 1993, the interruption of the afforestation efforts with the civil war and the gradual deforestation have reduced the forest cover to the actual value of 6%.

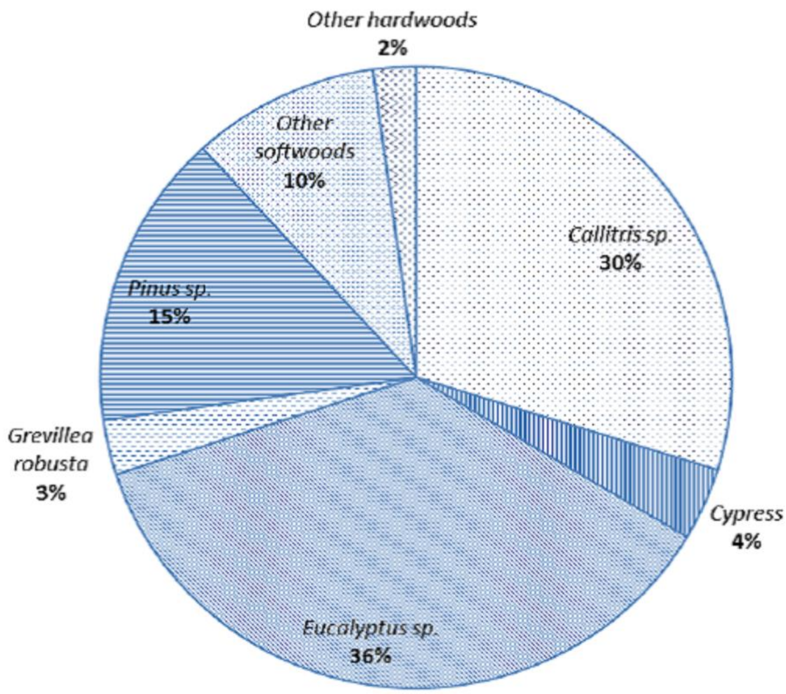


Figure 2.24 - Distribution of major tree species in public forest plantations (Source [60]).

2.5.2 Causes of deforestation

Burundi has the highest rate of deforestation in Africa as a result of land conversion for crops and grazing and the heavy reliance on wood for fuel [61, 62]. During the 1990s it was suggested that Burundi was experiencing the highest deforestation rate in the world, at 9% [63]. In the last years, the process is slowing down but it does not seem to be stopping (Figure 2.25).

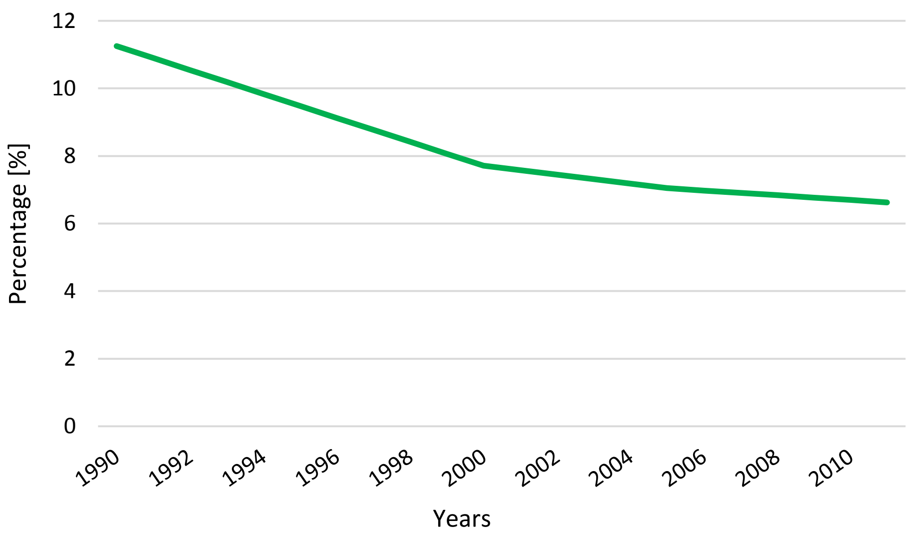


Figure 2.25 – Decrease of the forest area of Burundi as percentage of the total land (Source [36]).

There are many factors that contribute to the deforestation and degradation of forestland. In the Paragraph 2.3.1 it is said that about 96% of all energy needs are met by traditional biomass, comprised mainly of wood fuel. This huge demand of wood energy through firewood in the rural areas and production of charcoal for the urban centers exert a strong pressure on the wood resources of the country and the pace of deforestation for domestic consumption and for timber is faster than that of renewal [53, 60].

Moreover, some groups and individuals are using forested areas (including parks and reserves) as the main source for income generation and wood products [64]. Firewood is not only used in the home, but also used for charcoal making, brick making, palm oil extraction and other small industrial uses. Wood products are also used for furniture and construction materials.

Table 2.8 - Wood removals (m^3) from plantations and natural forests 2010 (Source [60, 65]).[6]

Forest plantation/Managment unit	Industrial round wood	Domestic poles	Firewood and charcoal	Total
State Forest Plantation	191,496	14,185	1,701,187	1,906,868
Commune Forest Plantation	38,732	2,869	344,281	385,882
Sub-total (public sector)	230,228	17,054	2,046,468	2,293,750
Tea factories, prisons, schools, etc.	19,186	-	341,078	360,264
Out-grower/other woodlots	134,299	15,349	4,434,013	4,583,661
Sub-total (private sector)	153,485	15,349	4,775,091	4,943,925
Grand total	383,713	32,403	6,821,559	7,237,675

Unfortunately, forecasts are everything but comforting and they foresee a continuous huge use of firewood with resulting deforestation (Table 2.9).

Table 2.9 - Current and future demand of plantation and natural forest wood (1,000 m^3) (Source [60]).[7]

Forest product plantations/woodlots	2010	2015	2020	2025	2030
Woodfuel (firewood and charcoal)	6821	7907	9167	10422	11849
Industrial roundwood	381	445	516	586	667
Sawnwood	98	111	129	205	233
Domestic poles	171	198	229	261	296

[6] The total population of Burundi was estimated to be 8.5 million in 2010 and the assumption was that all wood needs are met through local wood removals. It should be noted that this might not be true because some fuel needs are met through other means, such as crop residues, prunings and thinnings that are not accounted for in forest production. Moreover, for industrial round wood and poles, some demands are supplemented through imports from other countries.

[7] The projections of wood products demand is based on 2010 baseline and population increment of 3% per annum reducing to 2.6% by 2020 and afterwards, increasing from 25% to 35% sawn wood conversion efficiency by 2020.

Another major cause of deforestation is the conversion of forestland to cultivation or pasture due to population pressures and a strong dependence on agriculture for livelihoods [63].

Finally, another devastating effect on forests are the numerous wildfires that are started from the prevalent practice of burning pastures to provide a short term flush of nutrients for new growth. This practice is not only destructive to forestland but in the long term is also detrimental to the soil fertility of the pasture and grasslands [63].

2.5.3 Problems related to deforestation

There are many problems related to the huge process of deforestation in Burundi and one of this is the degradation and loss of protected areas that has been on the increase since the war started in 1993. For example, during the years of war people began encroaching on previously enforced buffer zones around the lakes on the Northeast of the country to the point that cultivation now occurs right up to the water’s edge. This more intensified agriculture and the consequent cutting of trees are impacting water quality, flow regime and the fish stocks in these lakes, as well as diminishing nesting and foraging sites for birds [63]. Moreover, in natural areas, deforestation has impacted Burundi’s diverse biological resources and ecosystems, and has contributed to the extirpation of both gorillas and elephants [62].

The rapid siltation of Lake Tanganyika waters is another example of the impact of deforestation on the sources of water that continues to threat both aquatic ecosystems and freshwater supplies. This is caused by another problem related to the intensification of agriculture and deforestation that are soil erosion and desertification [61] that cause a loss of soil fertility with a progressive loss of land that can be cultivated by people. Moreover, the increasing desertification affects also another social aspect of people’s life: time for the collection of wood. Since deforestation causes an increase in distance to woodlands, Burundian women and children who have the task of the supply of wood for households have to collect further away, spending more time on collection [66].

Soil erosion produces sedimentation in aquatic systems [67], too. In fact, erosion from the hillsides and cultivation adjacent to streams contribute sediment to the streams, lakes and wetlands and this in turn reduces the aquatic productivity and habitat for fish and other aquatic dependent organisms [63]. Other consequences are the loss of wetland and marshland that in Burundi support habitat for birds, wildlife, amphibians, fish, insects and plant life that is not found in other ecosystems. In addition, many birds, fish and wildlife use these important habitats for a part of their life cycle, even if they do not reside in the wetlands permanently [63].

Finally, soil erosion is followed by the erosion of roads that in Burundi are severely compacted with no proper drainage and they continue to erode and cause deep rutting on the road surface. During the rainy season runoff from severely eroding roads can be a large source of sedimentation to waterways [63].

3 Analysis of the local context: actual needs, supplies and technologies at Mutoyi Mission

3.1 Introduction

After the research of the energy resources of the country that could be used as alternative to wood biomass, the focus of this chapter is on the identification and the analysis of the local context where it is possible to implement a first technological application.

Despite of the apparent indifference of the public institutions, the problem concerning the overuse of wood biomass and deforestation appeal to the awareness of some NGOs that are present locally. One of them is called Vispe that is acronym of Volontari Italiani Solidarietà Paesi Emergenti. It is an Italian NGO and it works in the Mission of Mutoyi, in Gitega province, since 1969 [68] (Figure 3.1). The main activity of the Mission is the Hospital *Centre de Santé* that houses a daily annual average of three hundred patients. It also supports their industrial cooperative companies that give job to Burundians.

Moreover, Vispe shows a great interest in the problem of energy supply for the mission, in the rational use of the energetic resources and in the problem of deforestation caused by an intensive use of wood for cooking. Using their words, "hills around Mutoyi are being stripped of trees under one's very eyes". Recently it started to collaborate with the Italian labour union of electrical enterprises called FLAEI (Federazione Lavoratori Aziende Elettriche Italiane) for the implementation of a local energy project called *Burundi Energie Saine et pour Tous* concerning the building of an hydroelectric power station with a total capacity of about 700 kW.

Mutoyi is located in a rural area where the overuse of biomass is high and it is accelerating the process of the deforestation, the access to electricity is only reserved to the Mission, and the night surplus of hydroelectric power will be marked after the implementation of the *Burundi Energie Saine et pour Tous* Project. With the aim to attempt to mitigate the problem of deforestation and optimize the use of energy sources, Vispe and FLAEI asked me to do an internship in Burundi in August 2013 to investigate a solution within the framework of the Mission.

Figure 3.1 – Position of Mutoyi Mission, district of Bugendana, province of Gitega, Burundi; 3°12'58.78"S, 29°58'40.92"E.

During my stay in Mutoyi, the size of problem concerning the overuse of biomass was identified and it was possible to conclude that the locations at the Mission with the highest consumption of wood for cooking are the Hospital and the local food center called PaMu (*Pâtisserie de Mutoyi*). In the hospital there are two places where people cook food: the kitchen inside the building where the attendants burn wood to cook tea and milk for the patients every day, and the external place with a simple big stone plate where the relatives of the patients can cook for themselves and the dinner for their hospitalized loved ones.

Therefore, the aim of this chapter is describing the analysis of the context firstly in terms of the actual technological assessment of both the structures. Secondly, the analysis and forecasts of their needs have been done on the strength of the number of patients that are monthly accounted for in the registers of the hospital. Since there are no plans of expansion of the hospital, all the needs that are evaluated are supposed to be the same in the future years.

It is important to underline the difficult problem concerning data collection. In fact, most of the data refer only to the month of the stay in Mutoyi and they need to be elaborated as proxies for the following forecasts.

3.1.1 Precondition: *Burundi Energie Saine et pour Tous*

The specific objective of the Project is "to increase and improve access to modern energy services, affordable and lasting for 344,000 poor people in rural areas and common Gihogazi Bugenyuzi (Karuzi Province) Bugendana (Gitega Province) through hydropower production and awareness of the benefits of the use of electricity. VISPE would be responsible for the technical construction of mini hydroelectric plant at Masabo (rated at 782 kW) and training of in-site personnel. The Ministry of Energy and Mines in the project is the national co-applicant. Within its remit, it has currently started a programme of rural electrification and it has ensured the electrification of new routes by giving work to REGIDESO: first-line Masabo Bugenyuzi, and second line Masabo-Rusamaza-Gihogazi-Mutoyi. The partner in this project is the Mutoyi Foundation for Solidarity Progress. In this project, the Foundation Mutoyi will be responsible for the management of the hydroelectric plant.

All production of the plant will be sold to REGIDESO with conditions to be defined in the agreement to be concluded. If annual energy consumed would be less than the production, the difference would be a profit for the Foundation.

With the aim to achieve the project objectives a strategy based on achieving three results are proposed:

1) The construction of the hydroelectric power central of Masabo and the installation and connection of Masabo-Rusamaza-Gihogazi-Mutoyi lines and Masabo-Bugenyuzi lines. The new hydroelectric Masabo plant (782 kW) will be built in correspondence to a site identified by a government study as suitable for the installation with power of less than 1 MW. The project and the laying of lines will be entrusted to REGIDESO; plant is confirmed to be connected to the national grid.

2) Centers of Masabo-Rusamaza-Gihogazi and the availability and energy services in centers and community development of Mutoyi and Bugenyuzi will be improved.

3) 17,000 people will participate in outreach activities in the use of energy and its impact on the environment from the communities of Mutoyi and Bugenyuzi.

During the mission of August 2013, it has been possible to account the total energy consumption of Mutoyi Mission and its branches. The annual total electric consumption are reported below.

Table 3.1 – Yearly energy consumption of Mutoyi and branches.

Energy consumption [kWh]	750,000

The estimated annual energy production of the plant reported in Table 3.2 confirm the fact that the Mission would benefit from a large surplus of free energy that could be sold to REGIDESO:

Table 3.2 – Yearly energy production of Masabo plant.

Energy production [kWh]	2,643,591

3.2 Performance analysis of the actual technological set-up

3.2.1 Current stoves assessment

The main goal of a cook stove is to provide sufficient heat to prepare food and, if necessary, to warm and light the household. Cook stoves could be fueled by biomass charcoal, kerosene, natural gas, or by electricity and solar energy. The traditional stoves are mainly fed by non-commercial or traditional biomass such as wood, dung, crop residues. These cooking systems are very simple in design and consist of a cylindrical chimney through which the hot gases, produced by combustion, go out and heat the bottom of a cookpot, which usually has a diameter much larger than the mouth of the chimney itself (Figure 3.2).

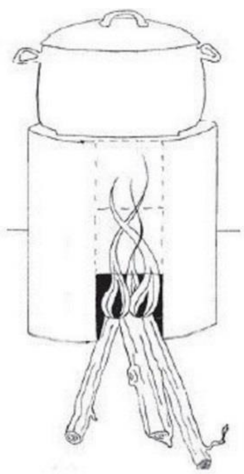


Figure 3.2 - Stove configuration (Source [69]).

Traditional cook stoves are designed and constructed using semi-empirical guidelines, without taking into consideration the analysis of heat transfer mechanisms. With depleting energy resources and rising energy costs, there is now a growing need to design these cook stoves with the incorporation of scientific understanding of their working principles, with the ultimate goal of the improvement of thermal efficiency. In the last decades, some stoves have been studied and consequently developed, becoming the so-called ICSs. There is not a precise definition of ICSs, but they can be identified as cook stoves that have lower levels of emissions and of fuel consumption than the traditional three stone fire. This reduction is due to an improvement in the combustion that can be achieved through different techniques, such as an optimized designed fire chamber, an enhanced air convection, or the usage of better fuel, in terms of both a major heating value and a minor pollutant content.

ICSs can be classified accordingly to different criteria as fuel type, function, construction material, portability and number of pots. Besides this, one of the largest partition of ICSs has been done by The Global Alliance for Clean Cookstoves (GACC), which was found in September 2010, from an initiative of Hillary Clinton, whose main aim is to provide 100 million homes with clean and efficient stoves and fuels by 2020. It identifies fifty ICSs [70], which are indicated and tested by Aprovecho Research Center, a research group made up of consultants who have been designing and testing improved cooking devices since 1976, in more than 60 countries worldwide [71].

This classification has been useful to identify the stoves used in Mutoyi, but it is clear that it cannot thoroughly classify them. The configuration of PaMu and the Hospital are the same and represented in Figure 3.3.

Figure 3.3 – Stoves used at PaMu and the Hospital (August 2013).

The first stove has been classified by Aprovecho Center as a Large Square Justa with solid *Plancha* and large channels for hot flue gases under the griddle, commonly named as *Plancha*. It is in fact characterized by a structure made of bricks, a metal plate with potholes, the door which opens into the combustion chamber, and a flue which drive the smoke outside. Pots are put on the metal plate and they receive heat from the bottom.

The second stove is a particular *Rocket* Stove. It is diffusely illustrated in [70, 72-76] and it was first conceived by Dr. L. Winiarsk, from the Aprovecho Research Center. He defined principles that *Rocket* stoves have to respect, reported in [77]. It is described as a stove with an opening on one side near the bottom for fuel to be inserted and for air to enter the combustion chamber; draft is created by the large temperature difference between the air entering the bottom of the stove and the hot combustion gases exiting from the top of the vertical combustion chamber. Some *Rocket* stoves have a metal skirt around the sides of the pot for improved heat transfer from the hot combustion gases to the pot (Figure 3.4). As *Plancha*, it has a chimney and it does not pollute the indoor air.

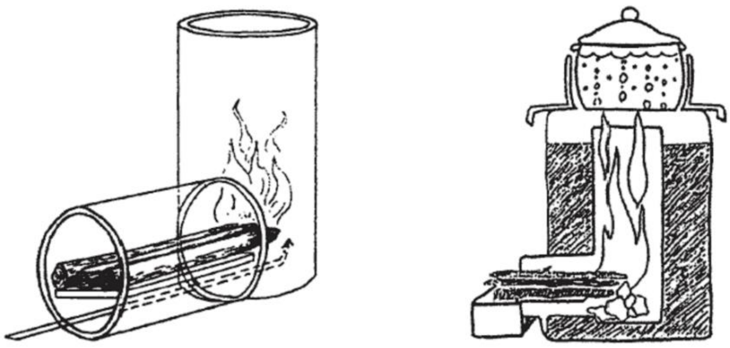


Figure 3.4 – Diagram of *Rocket* Stove (Source [74]).

The term *Rocket* Stove identifies a lot of configuration typical of the ICSs [75] and it is not a specific model. The stove owned by PaMu and the Hospital, for example, is a particular *Rocket* Stove with an unusual very short combustion chamber and it is endowed with a sunken pot and internal skirt surrounding the pot itself. The water capacity is exactly 100 liters.

The stoves used by patients' relatives could be defined as a "long open fire stove" with a brick long base and a metal grill (Figure 3.5).

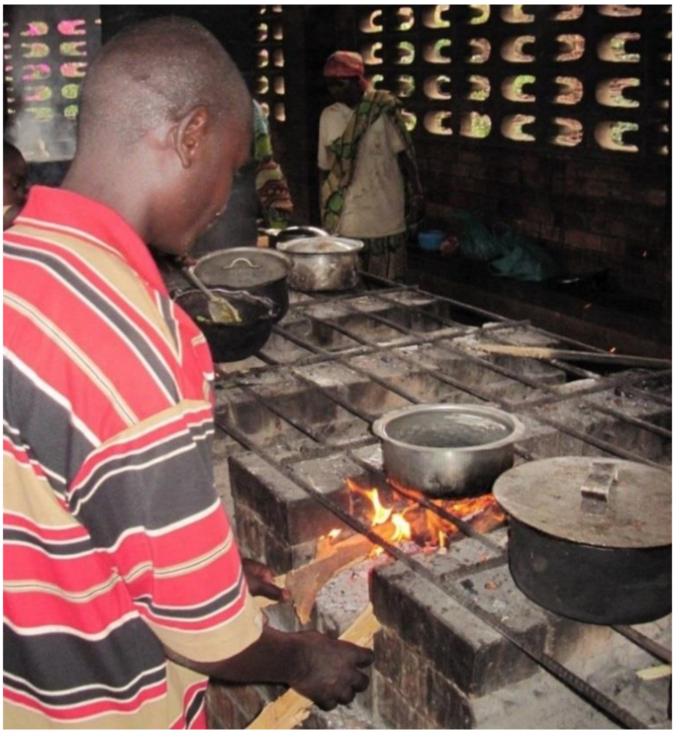


Figure 3.5 – Stove used by patients' relatives (August 2013).

Open fire stove is the most traditional cooking device, and it is commonly used in developing countries. It presents a very low performance, both in terms of fuel consumption and of pollutant emissions because of the absence of chimneys [75, 78, 79]. It is estimated to guarantee 40 hobs.

3.2.2 Efficiency of the stoves

In order to evaluate the efficiency of the stoves, several methods are available, but the most widely recognized is the Water Boiling Test (WBT), written and continually revised by the cooperation of international experts in the field [70]. It is a laboratory standardized and replicable protocol, which can be used to assess and compare the performance of different models of stoves in various contexts. The latest version of the WBT was released in April 2013 by The Global Alliance for Clean Cookstoves which is a public-private partnership that seeks to save lives, improve livelihoods, empower women, and protect the environment by creating a thriving global market for clean and efficient household cooking solutions [80]. This version is named Cookstove Emissions and Efficiency in a Controlled Laboratory Setting.

The WBT is composed of three phases [81]: cold-start, hot-start, and simmer phase; the amount of fuels used and emissions generated for the three stages are measured and evaluated as a weighted average to define the WBT key indicators as specific consumption and emissions.

One of the most useful results of the WBT for this work is the calculation of the thermal efficiency of the stoves. Thermal efficiency is described by the Test Protocol [81] as a measure of the fraction of heat produced by the fuel that made it directly to the water in the pot. The remaining energy is lost to the environment from the stove and the pot (Figure 3.6).

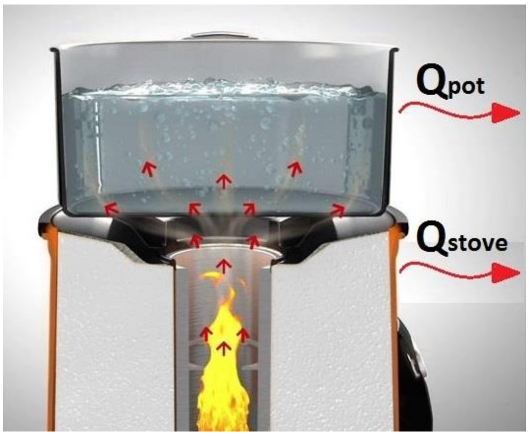


Figure 3.6 – Thermal losses that condition the efficiency value.

Therefore, a higher thermal efficiency indicates a greater ability to transfer the heat produced into the pot. Figure 3.7 reports a research of Berkeley Air Monitoring Group, a social venture dedicated to protecting global health and climate, and leading monitoring and evaluation partner for clean cookstove and fuel programs in developing countries [82]. It shows the thermal efficiencies for the most common stoves obtained with the WBT.

It is important to remember that the WBT overestimates the real efficiencies of the stoves because it is done in laboratory with only water. When stoves are used in a real context for preparing food, the efficiency is observed to be lower. However, this work considers only the values obtained with the WBT found in literature; in fact they have a more scientific support and the results obtained with that values are more conservative (see Paragraph 0).

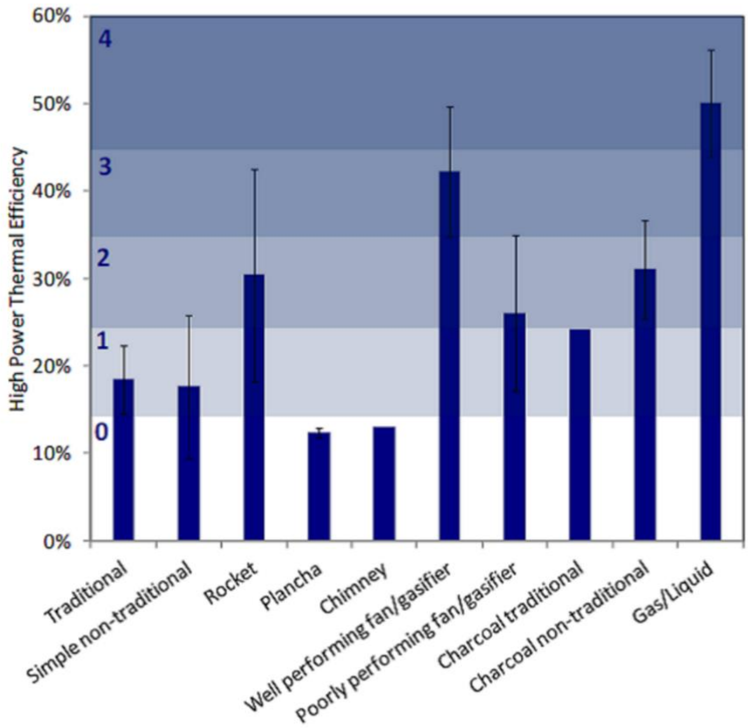


Figure 3.7 - Thermal efficiency for key stove/fuel classes (Source [83]).

*Plancha* stove

Plancha model's performances are analyzed in [70, 76, 83-86] and sketched in Figure 3.8.

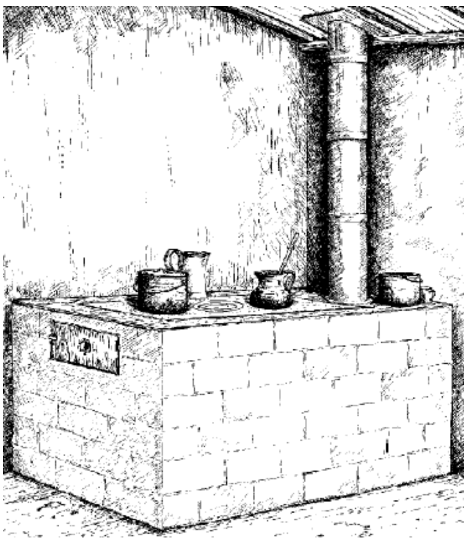


Figure 3.8 – A typical *Plancha* Stove (Source [84]).

To define the efficiency of the stove with only one number is too restrictive. For this reason, a range of values studied in literature is more representative of reality. Its main features are synthesized in Table 3.3.

Table 3.3 - Data of *Plancha*.

Construction materials	bricks, metal
Thermal efficiency	8% – 12%

Figure 3.7 confirms how *Plancha* is one of the stove with the lowest value of thermal efficiency. An explanation of this could be the fact that these stoves are not designed to boil water as their primary task [83] but to prepare tortillas which do not requires water [84].

Rocket stove

The second stove owned by the Mission has been defined as a *Rocket* Stove that is a wide category of different stoves. Figure 3.7 expresses clearly this fact reporting a range of possible efficiency values between 18% and 42%. The lower value is typical of the little stoves with no chimney and made of a metal sheet. The highest value is reached by particular *Rocket* stoves called Institutional *Rocket* stoves described in [87] with a large surface area of the sunken pot which is in contact with the hot gases [70] and an outer wall made of bricks.

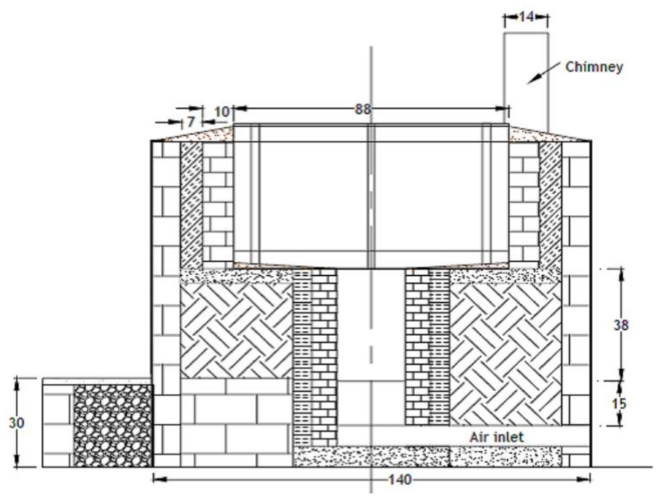


Figure 3.9 – Institutional *Rocket* Stove (Source [87]).

The stoves owned by PaMu and the Hospital are similar to this one but they do not have the outer wall and they have an unusual very short combustion chamber. Nevertheless, for a more conservative result, the efficiency range has been maintained between 30% [70] and 42%.

Table 3.4 - Data of *Rocket* Stove.

Construction materials	bricks, steel, inner pot
Thermal efficiency	30% – 40%

Open Fire Stove

As *Rocket* Stoves, the term Open Fire indicates a large categories of different models. The same feature is the direct contact between the pot and the flame and the absence of a combustion chamber. This characteristic allows these stoves to be able to eventually better transfer heat to the pot than stoves with chimneys because the exhaust gases are directly in contact with more of the pot and they do not remain sealed inside the stove before exiting the chimney [70]. For this reason, the stove used by patients' relatives is more efficient than *Plancha*. Different models of open fires stoves are compared in [72, 75, 76, 79, 84]. They report values of efficiency that could be summarize in Table 3.5.

Table 3.5 – Data of Open Fire Stove.

Construction materials	bricks base, metal grill, open combustion
Thermal efficiency	10% - 18%

Because the stove has no chimney and the emissions are emitted directly in the air, from [70] it has been possible to obtain values concerning the levels of emissions of the stoves (Table 3.6). Similar values could be found in [76, 78, 88, 89]. However, because the stove is in an open space structure, the smoke of the fire is rapidly scattered in the air without polluting the environment under the roof.

Table 3.6 – Emissions of Open Fire Stove.

CO emissions to complete WBT	35 - 80 mg/g_{FUEL}
PM emissions to complete WBT	1-2 mg/g_{FUEL}

3.3 Analysis of the physical properties

It was not possible to determine some of the physical properties which are necessary to this work because the short stay in Mutoyi mission. For this reason, they have been rationally estimated starting from literature.

3.3.1 Low Heating Value

The most important property which had to be calculated is the Low Heating Value (LHV) of the wood used in the Mission. LHV is defined as the amount of heat produced by the unit of mass of a given fuel when this burns completely and decreased by the heat of condensation of the water vapor formed during the combustion [90]. This value greatly varies accordingly to the kind of wood utilized and its conditions. The LHV of wood is strongly influenced by its moisture content and the ash composition. This effect can be evaluated through the equation below [91]:

$$LHV = LHV_{dry} * \left(1 - y_{ash} - y_{H_2O}\right) - \ y_{H_2O} * \Delta H_{EVA} \qquad (3.1)$$

where LHV is the Lower Heating Value for wood as it is when burnt in the stove, LHV_{dry} is the value for perfectly dried wood, y_{H_2O} is wood moisture content (as a percentage of substance as received), y_{ash} is the ash content, and ΔH_{EVA} is water heat of vaporization (around 2,440 kJ/kg [92]).

The term LHV_{dry} allows taking into account the kind of wood used. In order to achieve a realistic value for the present case, it is necessary to consider which type of wood is most utilized in the zone under analysis. The stay in the Mission confirmed data found in [60] that consider *Eucalyptus* the tree species most diffuse in the country. A large amount of wood used at the Mission is *Eucalyptus* but I was informed that recently a new species of wood has been introduced in small quantities. Local people call it with the Kirundi name of *Icaratrici*, a kind of

Ash. The theoretic LHV for dry *Eucalyptus* is evaluated to be around 18 MJ/kg [93-95]. The same value is reported in [96, 97] for *Ash*. As a consequence, because the absence of data about the *Icaratrici*, it is assumed to have the same properties of *Eucalyptus* that represents the major part of wood used. Therefore, the effective LHV, that is the value which should be employed in the calculations, can be evaluated knowing the moisture content. Form Phyllis database for biomass and waste of the Energy Research Centre of the Netherlands [95], recurrent values of the moisture content for different *Eucalyptus* are included between a range of 7 and 13%. The moisture content of wood is directly related to the humidity and temperature of the surrounding air; therefore, the Equilibrium Moisture Content (EMC) occurs when the wood has reached a water content equilibrium with its environment and is no longer gaining or losing moisture. For this reason, if the relative humidity and the temperature of the air are known, it is possible to calculate the effective moisture content of wood[8]. In collaboration with the United States Department of Agriculture, the Forest Service and the Forest Products Laboratory, the moisture content could be calculated with the following equation [98]:

$$EMC = \frac{1{,}800}{W} * \left(\frac{KRH}{1 - KRH} + \frac{K_1 KRH + 2K_1 K_2 K^2 RH^2}{1 + K_1 KRH + K_1 K_2 K^2 RH^2}\right) \tag{3.2}$$

where T is temperature, RH is relative humidity, EMC is moisture content (% on the dry mass), and W, K, $K1$, and $K2$ are coefficients of an adsorption model developed by Hailwood and Horrobin (1946) [99] and depending on the temperature (in °C):

$$W = 349 + 1.29T + 0.0135T^2$$

$$K = 0.805 + 0.000736T - 0.00000273T^2$$

$$K_1 = 6.27 - 0.00938T - 0.000303T^2$$

$$K_2 = 1.91 + 0.0407T - 0.000293T^2$$

The present formula could be applied independently from the wood species. Only wood species with a high extractive content show real EMC values that are

[8] The main hypothesis is that rain does not wet the wood but it is realistic if we think that in the Mission the wood is stored in a warehouse during the wet season.

substantially different from the values calculated, but this is the case of western red cedar and some particular tropical species [100].

All these coefficients have been calculated from the value of monthly mean data of relative humidity and temperature for Mutoyi that are available from the NASA Database [51][9].

Table 3.7 – Temperature and relative humidity at Mutoyi (Source [51]).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RH [%]	73.6	70.2	77.1	77.0	56.9	45.3	41.4	41.3	48.1	69.9	80.4	78.9
Daily mean temperature [°C]	20.1	21.3	21	20.3	22.1	23.3	23.8	25.1	24.9	21.8	20	19.8

Implementing the method:

Table 3.8 – EMC calculation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W	380.4	382.6	382.0	380.8	384.1	386.4	387.3	389.9	389.5	383.5	380.2	379.8
K	0.819	0.819	0.819	0.819	0.820	0.821	0.821	0.822	0.822	0.820	0.819	0.819
K1	5.959	5.933	5.939	5.955	5.915	5.887	5.875	5.844	5.849	5.922	5.961	5.965
K2	2.610	2.644	2.635	2.615	2.666	2.699	2.713	2.747	2.742	2.658	2.607	2.601
EMC[%]	**14.05**	**13.13**	**15.04**	**15.04**	**10.37**	**8.45**	**7.85**	**7.80**	**8.84**	**13.04**	**16.18**	**15.67**

The values of EMC are calculated as percentage of the dry mass. Therefore, wood moisture content y_{H_2O} as a percentage of substance as received is calculated as follow:

$$y_{H_2O} = \frac{100 * EMC}{(100 + EMC)} \tag{3.3}$$

Table 3.9 – Moisture Content.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
y_{H_2O} [%]	12.32	11.61	13.07	13.07	9.40	7.79	7.28	7.24	8.12	11.53	13.93	13.55

[9] It is so respected the validity conditions of the research that recommend using the monthly averages of the daily morning and afternoon value for the relative humidity and the monthly averages of the normal daily temperatures.

Only the ash content is left. It is calculated as an average of the values presented in [95, 101-104] that are included between a range of 0.5 and 2% as a percentage of substance as received. Using an average is a good approximation because it causes an error below of the 1% that is negligible in respect to the approximation introduced until now.

Applying the Equation *(3.1)*, the LHV of the wood as burned during the years is represented in Table 3.10.

Table 3.10 – LHV of the *Eucalyptus* [MJ/kg].

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LHV	15.34	15.48	15.19	15.19	15.93	16.26	16.36	16.37	16.19	15.50	15.01	15.09

3.3.2 Boiling Temperature

The second important property that has been determined is the water boiling temperature. In fact, Mutoyi is 1,512 meters high and barometric pressure of atmospheric air is lower in respect to sea level. From ASHRAE Handbook [105] a correlation between altitude and the atmospheric pressure is found:

$$p = 14.696 * (1 - 6.8754 * 10^{-6} * Z)^{5.2559} \qquad (3.4)$$

with 14.696 that is the standard barometric pressure in *psia* at sea level and Z the altitude in *feet*.

Applying the formula to the altitude of Mutoyi, the result shows a barometric pressure of 12.246 psia that correspond to 0.8443 bar. Tables reported in the latest edition of Perry's Chemical Engineers' Handbook [106] relate the boiling temperature to the atmospheric pressure. At 0.8443 bar, it shows a water boiling temperature equal to 94.94 °C.

Table 3.11 – Altitude and Boiling Temperature at Mutoyi

Altitude [m]	1512
Boiling Temperature [°C]	94.94

3.4 Analysis of consumption and supplies

The aim of this section is to describe the three main structures where the higher consumption of wood biomass and hot water take place and to estimate their needs. The stay in August 2013 allowed me to collect data about that period. This section explains the energy analysis used to extend forecast over the 12 months of the year that is necessary for the estimation of wood savings that will be calculate in Chapter 5.

3.4.1 Hospital "Centre de Santé"

The Hospital was the first activity Vispe started in Mutoyi Mission in 1981 [68]. Now it is one of the most well-known hospitals in Burundi with a daily annual mean of three hundred patients [107]. Thanks to Vispe it has been possible to consul the hospital reports from 2009 to 2013 that gives the statistics of these years [107] (Figure 3.10).

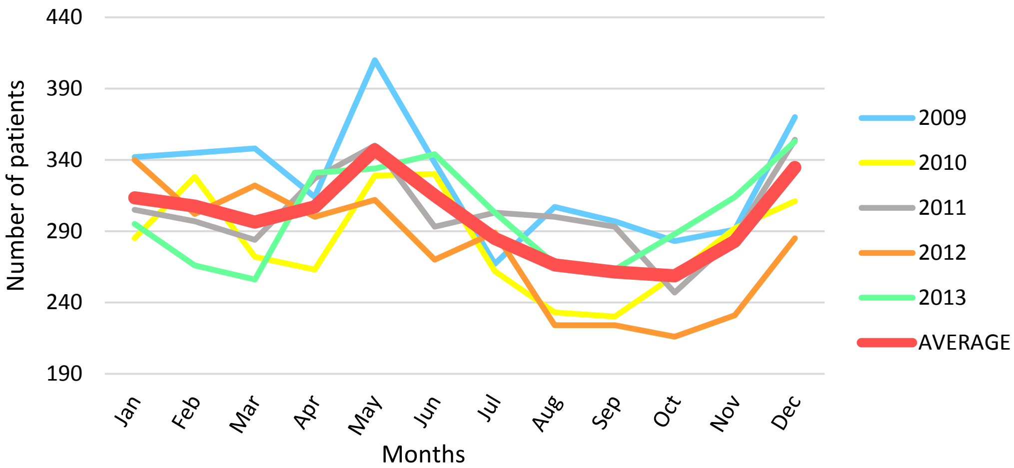


Figure 3.10 – Statistics of the Hospital “Centre de Santè” in Mutoyi (Source [107]).

From Figure 3.10, it is evident how the alternation of dry and wet season makes the number of patients foreseeable over the years (e.g the wet weather in May causes a widespread infection of malaria). In fact, the trend of the number of patients of the years is almost the same for all the five periods. Because of the lack of further data, the average is therefore the most statistical representative value for the future analyses. Moreover, the value of August in the mean curve shows the same value reported in 2013. As a consequence, all the forecasts of the water and wood supply are allocated on the base of the values of August in the mean curve that are equal to the real values observed during the work at Mutoyi.

Table 3.12 – Average of the monthly mean value of daily number of patients from 2009 to 2013 (Source [107]).

	Jan	Feb	Mar	Apr	May	Jun	Jul	**Aug**	Sep	Oct	Nov	Dec
Daily number of patients	313	308	296	307	347	315	285	**266**	261	259	283	335

An intensive use of wood is directly and indirectly linked to the hospital. The daily meals for all the patients are provides by Pamu (the local restaurant) that use wood to cook. Furthermore, every day the patients are served tea in the morning and afternoon, and the water is boiled with burning wood.

All the patients are served with a full cup of about 0.3 liters of tea twice a day. On the contrary, dried milk is served only for an average of one fifth of the patients in the boiling water. Moreover, the water left is used for the night pap for the infants. Water is always brought to a boil. The following data are referred to a number of patients equal to 266 that is the daily mean of the number of patients registered in August 2013 during the internship:

Table 3.13 – Water needs in the hospital in August 2013.

	Daily boiling water [l]
TEA	160.2
MILK	32.04
PAP[10]	20
TOT	**212.24**

Water is boiled firstly in the *Rocket* stove. *Plancha* is used if the amount of water exceed 100 liters both the morning and the afternoon and for making tea and milk.

[10] It is approximately the same quantity equal to 20l

Figure 3.11 – Stoves equipment at the hospital.

The use of wood has not been differentiated:

Table 3.14 – Water and wood used in *Plancha* and *Rocket* stoves in the hospital.

	Daily boiling water [l]	Wood [kg]
Plancha	27.48	45
Rocket	200	

Multiplying the daily quantity of water (0.3 liters twice a day) for each person by the monthly mean value of daily number of patients and adding the water for infant's pap, find the monthly average of the quantity of water heated every day can be found. As a consequence, it is possible to plot the monthly needs of water during the year for the two stoves (Figure 3.12).

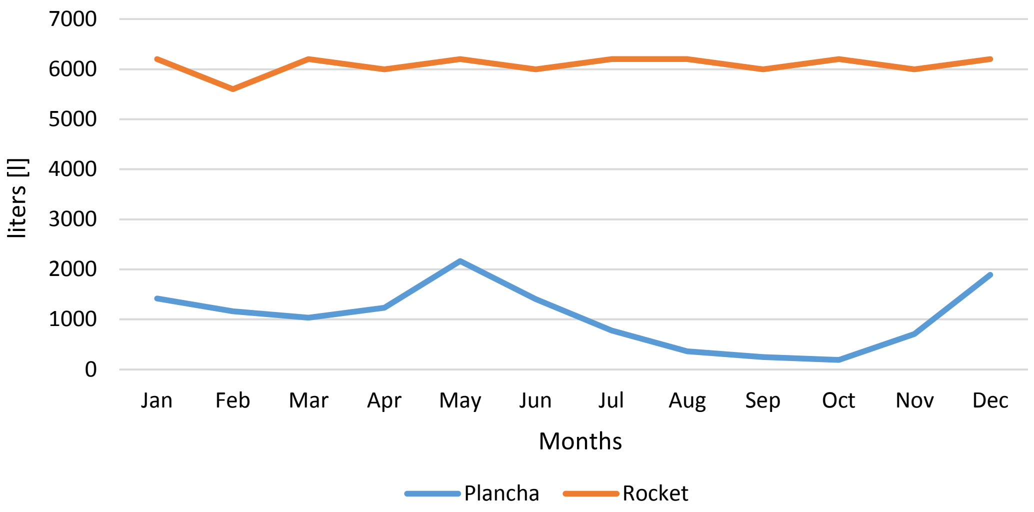


Figure 3.12 - Monthly water need for the two stoves at the hospital.

Primary energy is used for heat and to maintain the water at the boiling temperature, and partially lost in the environment. As a consequence, this is the following equation:

$$E_I = E_{II} + E_{BOIL+LOSS} \qquad (3.5)$$

with E_I the primary energy given by wood, E_{II} the secondary energy that heats the water, and $E_{BOIL+LOSS}$ the sum of the energy used to maintain the water at the boiling temperature and the energy lost in the environment.

The first two terms could be expressed as follows:

$$E_I = m_{wood} * LHV \qquad (3.6)$$

$$E_{II} = m_{water} * C_p * \Delta T \qquad (3.7)$$

where LHV is the Low Heating Value of the wood, m_{water} and m_{wood} are the amount of water heated and wood burnt, C_p is specific heat capacity of the water, and ΔT is the thermal drop that the water experiences.

Thanks to data collected during the stay at the Hospital it is possible to calculate those two values for August:

$E_{I_{AUG}} = 744.94\ MJ$

$E_{II_{AUG}} = 68.32\ MJ$

and subtracting:

$E_{BOIL+LOSS_{AUG}} = 676.62\ MJ$[11]

If the Equation *(3.5)* is divided by the secondary energy E_{II} we obtain:

$$x = 1 + z \qquad (3.8)$$

where x is the term $\frac{E_I}{E_{II}}$ and z is the term $\frac{E_{BOIL+LOSS}}{E_{II}}$.

Now it is introduced the hypothesis that the ratio called z is always constant. This is reasonable because if the amount of water increases, energy needs to maintain the temperature and the losses increase, too. On the other hand, if the amount of water increases, *Plancha* stove is better covered by pots and the heat transfer waste less energy. This is a preventive hypothesis because it will overestimate the real needs of wood during the year, and consequently it will underestimate the eventual savings that could be obtained heating the water in a more efficient way. Its value is:

$z = 9.90$

As a consequence, from Equation *(3.6)*, adding this value to 1 we obtain the ratio between the primary energy and the secondary energy that is consequently constant in each month:

$x = 10.90$

Knowing the amount of water represented in Figure 3.12 and using the Equation *(3.7)*, the secondary energy for each month could be calculated; the primary energy is calculated through the ratio x and, dividing by the LHV we obtain the amount of wood for each month.

[11] This term is 90% of the primary energy but it is a reasonable value. In fact, if we consider only the losses, the low efficiencies of the stoves cause a loss of the 90% for *Plancha* and 70% for *Rocket*.

Table 3.15 – Wood needs at the Hospital of Mutoyi.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Wood [kg]	1723	1515	1653	1652	1822	1580	1480	1391	1339	1431	1550	1860

Hospital do not buy wood. In fact, poor patients who cannot pay the treatment are allowed to pay by means of bundles of almost 3 kilograms of wood instead of money (Table 3.16). Moreover, a lot of wood comes from volunteers of local scout groups. Technological alternatives to reduce the needs of wood must not prevent the exclusion of poor patients from the hospitalization. As a consequence, all the bundles have to be collected anyway. Not-burned wood could be amassed and consumed by Vispe for other uses decreasing the need of cutting more and more trees (e.g. wood for the uses of the missionaries, free supply for PaMu, brick manufacture, etc.).

Table 3.16 – Values of treatments paid by means of bundles in five months of 2013.

	Numbers of bundles	**Values of treatments [FBU]**	**Values of treatments [€]**
March	780	1,572,000 FBU	760.8 €
April	635	1,275,000 FBU	617.0 €
May	825	1,650,775 FBU	798.9 €
June	599	1,198,000 FBU	579.8 €
July	612	1,225,000 FBU	592.9 €

3.4.2 PaMu (Patisserie de Mutoyi)

Pamu is a food center in Mutoyi and it is one of the cooperative companies of the Mission. It is mainly a restaurant of Burundian food with a daily mean of 50 customers but also a pastry shop and bakery. It offers a service of cooking meals for the hospital, too. This activity is separated from the rest of the kitchen with a separate pantry, cooks, stoves and menu. All the cooking activities use stoves that are heated by wood and a big wood-burning oven for cooking bread.

Patients 'meals

Meals for patients are cooked on the bases of the number of sick people that is daily reported to PaMu by the hospital. During the stay in Mutoyi, it was possible to observe the real amount of wood and water that they use during the preparation of meals. The first important consideration is reporting the type of food they cook:

- *beans* are cooked every day in the afternoon;
- *rice*, *banana* and *potatoes* are cooked in succession every three day;
- side dish of vegetables, fish and palm oil are prepared every day.

As a consequence, three menu are in succession every day. In Table 3.17, different consumption of wood and water have been reported on the strength of the type of stove they use. In fact, they usually use the *Rocket* stove when the water has reached almost the 55°C on the *Plancha* stove while they brown vegetables. The water is taken from the aquifer at almost 18°C. Data are referred to a number of patients equal to 266 that is the daily average of the number of patients registered in August 2013 during the internship.

Figure 3.13 - Stoves equipment at PaMu.

Table 3.17 – Amount of water and wood that are used at PaMu for the three menus in a typical day in August[12].

		Hot water (from 18 to 55 °C) [l]	Boiling water (from 55 to 100 °C) [l]	Hot water left [l][13]	Wood [kg]
BANANA MENU	*Plancha*	90	13	50	35.4
	Rocket	0	27		9.5
	TOT	90	40		44.9
POTATO MENU	*Plancha*	90	13	50	28.6
	Rocket	0	27		9.4
	TOT	90	40		38
RICE MENU	*Plancha*	97	0	0	17.8
	Rocket	0	97		17.3
	TOT	97	97		35.1
BEANS[14]	*Plancha*	0	0	0	0
	Rocket	35	35		18
	TOT	35	35		18

From the table it is evident one of the habits of cooking that is pre-heating the water on *Plancha* and using *Rocket* stove only for completing the cooking and boiling the water (except for preparing rice). Because the three menus are repeated every three days, they are cooked ten times in a month, apart from beans that they are cooked every day. The water and wood needs in the month of August are calculated multiplying the previous values by ten (the values of beans are multiplied by thirty).

It is now fundamental to introduce a way to allocate the use of wood and water in the other months on the base of the number of patients reported in the previous section. At PaMu, in fact, water is used for cooking food and it is impossible to find the quantity of water for each patient as in the hospital.

[12] Bananas and potatoes need the same amount of water; potatoes need more cooking time and primary energy as a consequence.

[13] Hot water left is used for washing the pots and the floor.

[14] Beans are cooked every day in the afternoon.

Therefore, it is only possible to consider these two cases that will be relevant and explained in next Paragraph for the final consideration:

1. Wood and water remain almost constant because of little variation in the number of patients.
2. Wood change proportionally and water remain constant.

Table 3.18 - Allocation of water and wood during the year. Case of constant water and wood.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	***Aug***	*Sep*	*Oct*	*Nov*	*Dec*
***Plancha* water (15 → 55 °C) [l]**	2770	2770	2770	2770	2770	2770	2770	**2770**	2770	2770	2770	2770
***Plancha* water (55 → 100 °C) [l]**	267	267	267	267	267	267	267	**267**	267	267	267	267
***Plancha* wood [kg]**	818	818	818	818	818	818	818	**818**	818	818	818	818
***Rocket* water (15 → 55 °C) [l]**	1082	1082	1082	1082	1082	1082	1082	**1082**	1082	1082	1082	1082
***Rocket* water (55 → 100 °C) [l]**	2588	2588	2588	2588	2588	2588	2588	**2588**	2588	2588	2588	2588
***Rocket* wood [kg]**	920	920	920	920	920	920	920	**920**	920	920	920	920

Table 3.19 – Allocation of water and wood during the year. Case of constant water and wood proportional to the number of patients.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	***Aug***	*Sep*	*Oct*	*Nov*	*Dec*
***Plancha* water (15 → 55 °C) [l]**	2770	2770	2770	2770	2770	2770	2770	**2770**	2770	2770	2770	2770
***Plancha* water (55 → 100 °C) [l]**	267	267	267	267	267	267	267	**267**	267	267	267	267
***Plancha* wood [kg]**	964	946	911	944	1067	969	876	**818**	804	795	870	1029
***Rocket* water (15 → 55 °C) [l]**	1082	1082	1082	1082	1082	1082	1082	**1082**	1082	1082	1082	1082
***Rocket* water (55 → 100 °C) [l]**	2588	2588	2588	2588	2588	2588	2588	**2588**	2588	2588	2588	2588
***Rocket* wood [kg]**	1084	1064	1025	1062	1200	1089	985	**920**	904	894	978	1157

<u>Restaurant's meals</u>

PaMu is also a local restaurant. In this case, it is impossible to forecast the use of water and wood because of an absence of sufficient data concerning people who eat there. However, during the stay in Mutoyi, it has been possible to see that the number of covers they prepare is almost the same and it has been confirmed by the local cooks. In fact, they use the same doses of food and water, and wood as consequence. Variations are included in a little range around the average of 40 covers and 50 liters of milk and tea. Therefore, the difference in terms of wood and water is reasonably overlooked. Moreover, possible oscillations above and below the mean value are reciprocally compensated in the period of one month. The average is therefore the most statistical representative value.

At PaMu, they cook the same typical Kirundi food they prepare for the hospital. They prepare milk and tea at breakfast and they use a wood oven to prepare bread every day. Wood and water need are summarized in Table 3.20.

Table 3.20 – Wood and water daily needs at PaMu for the restaurant service.

	Water [l]	Wood [kg]
Kirundi meals	60	
Milk	50	65
Tea	50	
Wood oven	-	135

It is now important to know how PaMu is supplied with wood. Trees are bought on the hills around Mutoyi. They are cut down and carried to PaMu where they are cut in logs ready to burn. Data about costs of wood in 2012 have been collected and reported in Table 3.21.

Table 3.21 – Cost of the supply of wood at PaMu in 2012.

	FBU	€
835 Trees	2,087,500	1010.3
Transport	720,000	348.5
Breaking	641,480	310.5
Crumbling	401,423	194.3

3.4.3 Patients' relatives

Behind the hospital there is a long square stone where relatives of patients prepare meals for themselves and dinner for their loved ones with their personal wood. Almost 40 hobs have been estimated. There are no data concerning the number of meals that are daily prepared, obviously; in agreement with Vispe, these hypothesis could be assumed:

1. 90% of patients are visited by their family;

2. 70% of this percentage prepare food at the hospital; those who remain bring food from home.

As a consequence, the kitchen is used two times a day for the preparation of a daily meal monthly average that depends on the number of patients and hypothesis 1 and 2:

Table 3.22 – Daily number of meals cooked by patients' relatives.

	Jan	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Daily number of patients	313	308	296	307	347	315	285	266	261	259	283	335
Meals (dinner and lunch)	395	388	373	387	437	397	359	335	329	326	356	422

Estimating wood needs of the relatives would be too approximate and unrealistic because there are too many variables:

- Type of food cooked that is not always beans;
- Each meal is prepared for a different number of people (e.g. cooking for a patient and one relative is different than preparing meal for a patient and 3 relatives);
- Different habits and the quantity of food for each person.

Moreover, scientific literature provides little information about the specific consumption of wood per kilograms of food. For example, wood needs for cooking beans on an open fire stove are estimated in [84, 108] and they are estimated in an approximated range of 6-12 kg of wood for a kilogram of beans.

For this reason, wood and water needs cannot be evaluated.

3.5 Discussion

From the analysis of the energy performance of the current stove set-up and the water and wood needs, it is possible to make the following consideration about the strong and weak points of the current situation at the Mission:

Table 3.23 – Considerations about the current stove set-up at the Mission.

Strong points	***Weak points***
1. *Rocket* stove has got a very high thermal efficiency. Especially at the Hospital, it is used most frequently than *Plancha* stove. 2. *Plancha* stove is need at PaMu for browning vegetables and fishes. *3.* Vispe recently bought the *Rocket* stove and they do not intend to replace it.	1. *Plancha* stove has got a very low thermal efficiency especially for heating the water. 2. *Open Fire* stove has got a very low thermal efficiency.

The strong points of the stoves suggest that the current set-up at PaMu and the Hospital is not going to change. As a consequence, all the technological improvements must avoid a replacement of the stoves. Since the most of energy losses originates from the process of water heating (especially for *Plancha)*, the only way to reduce wood consumption is an alternative form to heat water more efficiently. A different consideration can be made for the patients' relatives' kitchen where the *Open Fire* stoves could be replaced. In fact, they are characterized by very low values of thermal efficiencies during the cooking. An eventual replacement of the actual set-up with more efficient devices could bring many benefits in terms of wood saving.

The previous consideration upholds the two ways used in the previous Paragraph for evaluating the water and wood needs at PaMu (*water constant and wood proportion to the number of patient during the year* and *water and wood constant during in all months of the year*). In fact, since technological improvements must not replace the stoves but introduce a new way to heat water, wood will be reduced because less energy is used to pre-heat the water. This information helps to define the wood savings in any month as follow:

$$\Delta m_{wood_i} = \frac{E_{II_i}}{\eta_{STOVE}} * \frac{1}{LHV} = \frac{\Delta m_{water_i} * C_p * \Delta T}{\eta_{STOVE}} * \frac{1}{LHV} \qquad (3.9)$$

where the subscript is referred to the month *i*, E_{II} is the secondary energy that heats the water, η_{STOVE} is the efficiency of the stove, LHV is the Low Heating

Value of the wood, Δm_{water} is the amount of water heated, C_p is specific heat capacity of water, and ΔT is the thermal drop that the water experiences.

Dividing to the amount of wood use in the month *i* we obtain the percentage of wood savings S:

$$S_i = \frac{\Delta m_{water_i} * C_p * \Delta T}{\eta_{STOVE}} * \frac{1}{LHV} * \frac{1}{m} \qquad (3.10)$$

The second step consists of writing the amount of wood and water as a proportion of the supplies observed in August. Proportions are represented with the coefficient ***b*** and ***c****:*

$$S_i = \frac{\boldsymbol{b} * \Delta m_{water_{AUG}} * C_p * \Delta T}{\eta_{STOVE}} * \frac{1}{LHV} * \frac{1}{\boldsymbol{c} * m_{wood_{AUG}}} \qquad (3.11)$$

It is evident that all the terms are constant except for *b* and *c*. Therefore:

$$S_i \propto \frac{\boldsymbol{b}}{\boldsymbol{c}}$$

It remains to define these coefficients. We introduce the term ***k*** that represent the ratio between the number of patients in the month *i* and in August:

$$\boldsymbol{k} = \frac{patients_i}{patients_{AUG}}$$

Therefore, it is possible to make these considerations:

$1 \leq c \leq k$	when the number of patients in the month *i* is more than in August	With this hypothesis it is asserted that the variation of wood in the month *i* in respect to August is between zero and proportionally to the number of patients at the limit (not more because our daily experience confirms that if I double the quantity of food the water increases less than twice and as a consequence the primary energy, too).
$k \leq c \leq 1$	when the number of patients in the month *i* is less than in August	

$1 \leq b \leq c$ when the number of patients in the month *i* is more than in August

$c \leq b \leq 1$ when the number of patients in the month *i* is less than in August

With this hypothesis, it is asserted that the variation of water in the month *i* in respect to August is between zero and the same variation of wood. This is because if we double the water, the wood has to increase more than twice because there is also more food to cook.

If we represent the real trend of savings in a graphic, it could be roughly forecast with a straight line with angular coefficient proportional to $\frac{\boldsymbol{b}}{\boldsymbol{c}}$ included in the two extremes indicated as 1) and 2) earlier. They are represented by a horizontal straight line and a line with a coefficient proportional to $\frac{\mathbf{1}}{\boldsymbol{k}}$ respectively.

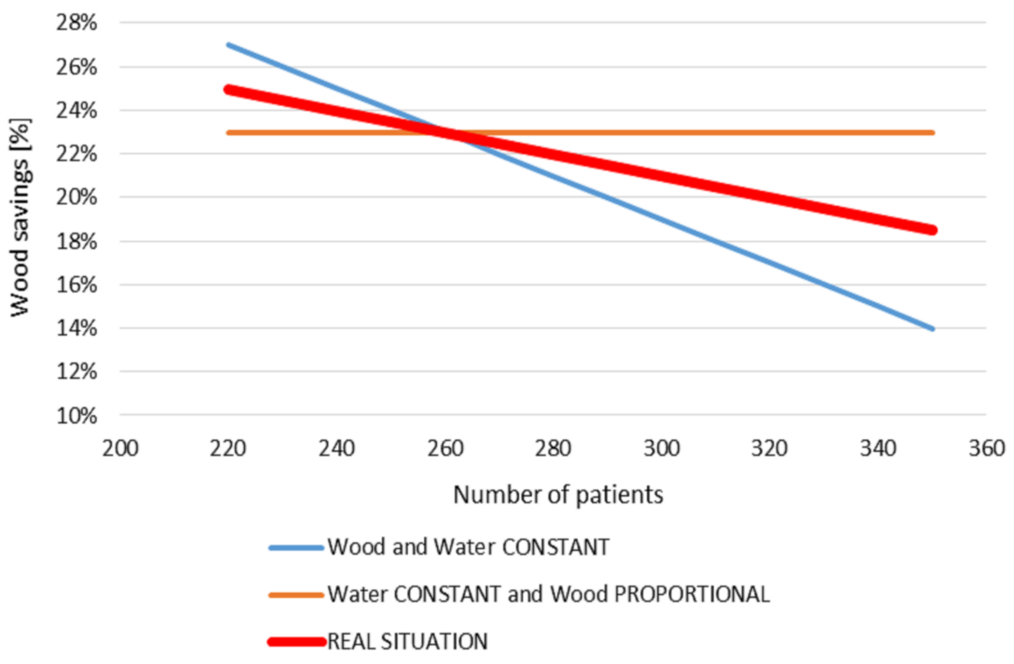


Figure 3.14 – Forecast of wood savings.

In fact:

$$\text{if } \; N.patients_i > N.patients_{AUG} \quad (k,b,c) > 1 \quad \rightarrow \quad \frac{1}{k} \leq \frac{b}{c} \leq 1 \qquad \text{Because} \begin{cases} b \geq 1 \\ c \;\leq k \\ b \leq c \end{cases}$$

$$\text{if } \; N.patients_i < N.patients_{AUG} \quad (k,b,c) < 1 \quad \rightarrow \quad 1 \leq \frac{b}{c} \leq \frac{1}{k} \qquad \text{Because} \begin{cases} b \leq 1 \\ c \;\geq k \\ b \geq c \end{cases}$$

For all the months, in one case the needs of water and wood will be the same it respect to August (Table 3.18). In the second case, wood changes proportionally to the number of patients and water remain constant (Table 3.19). The correct value of savings will be inside that range.

4 Proposal of new technologies and prefeasibility study with test of homemade solar cookers

The aim of this chapter is to identify and examine in-depth all the appropriate technological alternatives analyzed with the aim to improve the problem of the overuse of wood biomass at the Mutoyi Mission.

In Paragraph 1.2.2 we saw that Renewable Energy could represent a solution to provide access to energy in DCs. Technically, the aim could be achieved through a change of paradigm. Common energy systems design are based on the most suitable and efficient ‘‘Demand-Supply’’ coupling. In developing countries, while dealing with appropriate technologies, the coupling may also be referred to as ‘‘Need-Resource’’ coupling, thus underlining the relevance of the local context. Behind a demand there is a (specific) need and in order to provide a supply, a (specific) resource must be used [6].

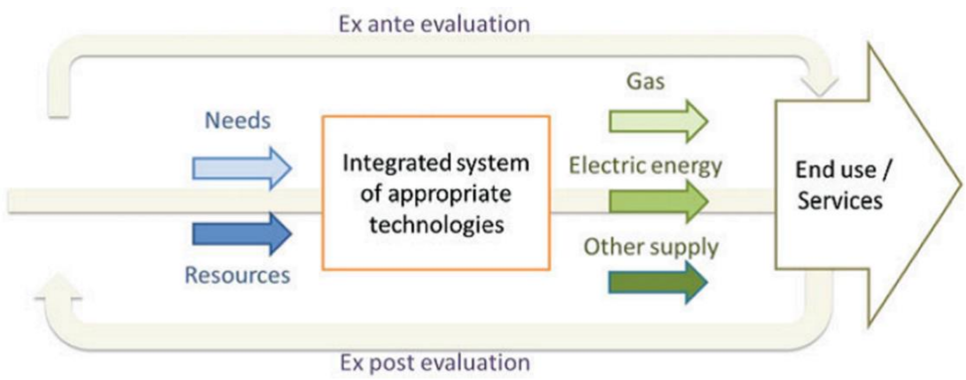


Figure 4.1 – Need-resource or demand-resource based scheme for integrated renewable energy systems [6].

This different approach leads to the choice of the best appropriate technologies. Viewed in this way, appropriate technology cannot be seen simply as some identifiable technical device. It is an approach to community development consisting of a body of knowledge, techniques, and an underlying philosophy [109]. Appropriate technology means simply any technology that makes the most economical use of a country's natural resources and its relative proportions of capital, labor and skills, and that furthers national and social goals [110]. It is a set of techniques which makes optimum use of available resources in a given environment [111] and is appropriate for existing factor endowments [112]. Moreover, it provides technical solutions appropriate to the economic structure of those influenced: to their ability to finance the activity, to their ability to operate and maintain the facility, to the environmental conditions involved, and to the management capabilities of the population [113]. In conclusion, appropriate technology is now also recognized as the generic term for a wide range of technologies characterized by any one or several of the following characteristics: low investment cost per workplace, low capital investment per unit of output, organizational simplicity, high adaptability to a peculiar social and cultural environment, sparing use of natural resources, low cost of final product or high potential for employment [114].

Following this approach and considering the Problem Analysis described in the Introduction, renewable energy resources of Burundi and their technological application could provide a solution against the problem concerning the overuse of biomass. From Paragraph 2.3.2 and 2.4, it is evident how the most abundant renewable resource in Burundi is the hydroelectric energy. In Chapter 2, it has been estimated that during almost 50% of Burundian nights there is an unused available energy surplus that varies from 1 to 10 MW and it is expected to increase with the future development of Burundian electrical sector. Moreover, the realization of the new hydroelectric plant will supply Mutoyi Mission with free electricity and will consider a strong revamping of the grid which supplies electricity to the Mission. In fact, at the present time the grid suffers from an average of 5 black-outs a week that are resolved in almost two minutes.
In the same Paragraph, solar potential is described as suitable for thermal applications and it is estimated that since 2003, a total of 140,000 m² of solar heat collectors were placed [48]. Finally, a use of wood in more efficient devices could bring a lot of benefits in terms of wood saving.

In conclusion, thanks to the consideration made in the end of the previous chapter about the actual stove set-up of the Mission, it has been possible to identify the following technological solutions described in the section below:

- Electrical Water Heater;
- Heat Pump Water Heater;
- Integration with solar collectors;
- Improved Cook Stoves;
- Solar Cooker.

The first three technologies that are listed provide only an alternative way to heat water more efficiently at PaMu and the Hospital. On the other hand, the technological solutions for the area used by patients' relatives permits the replacements of the actual open fire stoves with a use of more efficient technologies as the last two listed. It has been thought the possibility to use charcoal. Unfortunately, remembering Paragraph 2.3.2, the benefits of charcoal are not as evident and they have to be better explored. In fact this highly depends on the efficiency of the stoves and the way the Burundian people use it to produce charcoal [115]. Technology for heating water has been considered not appropriated for this area for the reasons listed below:

1. There are too many different people with different habits every day (e.g. people cook beans by putting the vegetables directly in the cold water);
2. The open space is dangerous because of possible theft but also incidents because of too many people and children.

In conclusion, the implementation of ICSs and Solar Cookers is more challenging because they could be diffused among households in the future. Other devices cannot certainly be diffused among people.

In the following Paragraph 4.1, the chosen technologies are analyzed only in terms of energy performances and consumptions. For this purpose, real commercial devices are considered. Because this work represents a first attempt of analysis, a second more detailed study will be necessary implemented with the real devices data. As regards the Solar Cookers, they are very different from the common stoves because they completely alter the habits of cooking showing themselves to be often a failure because of their non-acceptance. Therefore, we have limited ourselves to report a short state of art of the technology and evaluate only the possible use in Burundi through the performance analysis and test of two homemade models. They are diffusely discussed in Paragraph 4.2.

4.1 Appropriate technological alternatives: description and consumption

4.1.1 Electrical water-heater

The first technology analyzed is an electrical water heater with storage. From an economic point of view, it is the cheapest solutions. It is also similar to the common boilers used in the Mission. There are not any enterprises that sell those devices in Burundi. Volunteers at the Mission confirm that it is possible to find something like that at the Asian district in Bujumbura. Most of the goods are sold is secondhand and/or imported from China. A better survey with aim to check the effective choice and status of the products has to be carried out. Actually, the best solution considers the import of a new and efficient device from Italy.

The capacity of the heater has been chosen on the bases of the daily quantity of water used. At PaMu, the highest quantity of water used is when they prepare rice and beans. In respect to the data reported in Chapter 3 and considering a use of water proportional to the number of patients during the months, water needs are estimated in Table 4.1.

Table 4.1 – Daily water needs at Pamu during the year.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water for hospital's meals	155	153	147	152	172	156	141	132	130	128	140	132
Water for restaurant's meals	160	160	160	160	160	160	160	160	160	160	160	160
TOTAL	**315**	**313**	**307**	**312**	**332**	**316**	**301**	**292**	**290**	**288**	**300**	**292**

When they prepare rice, water need peak exceeds 300 liters. Commercial catalogues offer an extended choice of models with a capacity of 400 liters. They always guarantee the supply of water needs and the amount of water that is not used could be recovered in the storage for the day after. For example, one of the models considered is LIKE series ISS 400l model [116] (Table 4.2).

Table 4.2 – Technical Data of LIKE series ISS 400l (Source [116]).

V [L]	Price [€]	Power [kW]	Voltage [V]	Time Heating ΔT=50°C	Thermal losses [kWh/24h][15]	Max Temp. [°C]	Pressure [MPa]
400	1150	4.0	400/3[16]	367 min	2.80	75	1.0

At the hospital, the water needs are obtained by Paragraph **Error! Reference ource not found.** and showed in Table 4.3.

[15] They correspond to a loss of 6 °C/24h with 400 liters of water.

[16] At PaMu there is three-phase connection.

Table 4.3 - Daily water needs at the Hospital during the year.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water for tea and milk	246	241	233	241	270	247	225	212	208	206	224	261

The water needs never exceed 300 liters. For example, one of the models considered is LIKE series ISS 300l model [116]. Technical data are reported in Table 4.4.

Table 4.4 - Technical Data of LIKE series ISS 300l (Source [116]).

V [L]	Price [€]	Power [kW]	Voltage [V]	Time Heating ΔT=50°C	Thermal losses [kWh/24h][17]	Max Temp. [°C]	Pressure [MPa]
300	910	3.0	230	367 min	2.40	75	1.0

Knowing the time necessary to heat water it is possible to calculate the electrical energy that is daily consumed. The gap of temperatures that the device has to provide is 57 degrees because it heats water from 18 °C (temperature of the aquifer) to 75 °C. Linearizing the fifth value of the tables, it is possible to estimate a time value equal to 7 hours that is the same for both devices.

Multiplying the nominal electrical power absorbed by the water heater by the time of use, we obtain the energy consumed every day[18] (Table 4.5).

Table 4.5 – Daily energy consumed by the electrical water heater.

	PaMu	Hospital
Power [kW]	4.0	3
Time [h]	7.00	
Energy [kWh]	28	21

[17] They correspond to a loss of 6.9 °C/24h with 300 liters of water.

[18] In the case of PaMu it overrates the real consumption because the full capacity of the device is not emptied every day, and the heating process does not start from the temperature of the aquifer; but it is a conservative result because costs of energy will not exceed the values forecasted.

4.1.2 Heat Pump Water Heater

The second technological solution that has been analyzed is a Heat Pump Water Heater that is a heat pump with an integrated water tank. It uses a thermodynamic cycle to heat the water contained in the boiler through the air sucked from the group thermal reversing the natural flow of heat. The R134a fluid, by means of state changes and cycles of compression and expansion, uses the heat contained in the air at a lower temperature and gives it to the domestic water at a higher temperature.

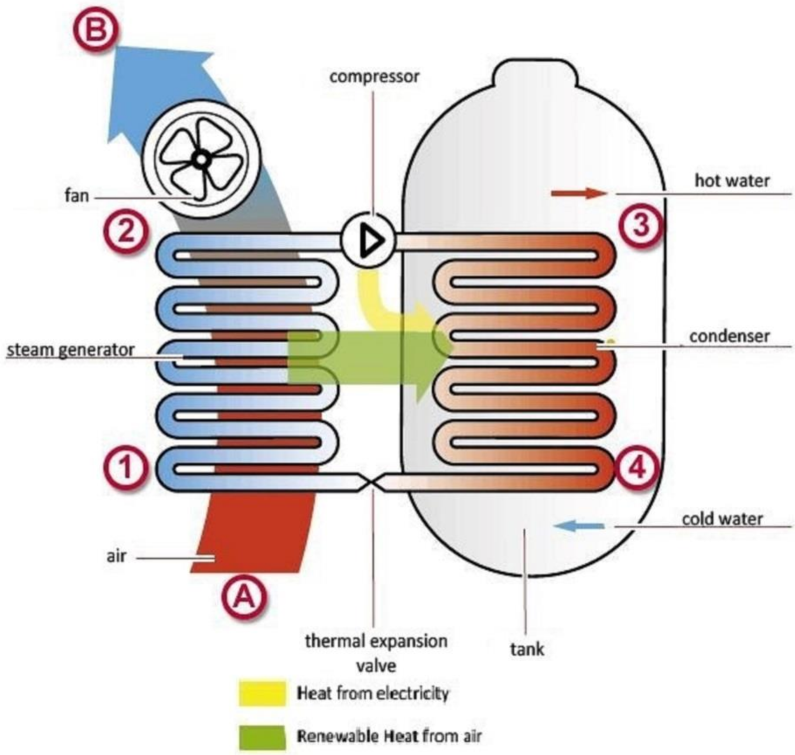


Figure 4.2 – Functioning plane of a heat pump (elaborated from [117]).

Performances of a heat pump are defined with a parameter named Coefficient Of Performance (COP) which compares the total heat produced and transferred Q_u (heating rating) with the electrical power consumed W_{el}.

$$COP = \frac{Q_u}{W_{el}} \tag{4.1}$$

The higher it is, the higher the savings of electricity would be thanks to renewable heating of air. COP values supplied by the heat pump water heaters are lower (2.6 – 3) than those of the common heat pumps for heating (3 – 4)[19]. This fact does not indicate less performance technology, but is due to the different temperature at which these devices work. The current European Regulations on energy labeling for products dedicated to the production of domestic hot water (*ERP water heaters*) define heat pump water heaters with the previous values of COP as the Best Available Technology in the sector of commercial water heaters.

The COP parameter is strongly influenced by external temperature of the air. The lower the temperature is, the lower heat transferred from air to the fluid is in the steam generator. For this reason, heat pumps work at high performance where the weather is warm like Mutoyi where the night temperature does not decrease under 15°C [51].

From an economic point of view, this solution is not cheap. It would be a good compromise in the case of missed realization of *Burundi Energie Saine et pour Tous* project. It is more complicated in respect to the electrical water heater and it requires a more expert maintenance, but it would create more capacity building. As the water heater, the best solution considers the import of a new and efficient device from Italy.

The most common integrated devices do not exceed the 200 liters. As a consequence, for PaMu two models of ARISTON NUOS EVO SPLIT 200l has been considered. Technical data are reported in Table 4.6.

Table 4.6 - Technical Data of ARISTON NUOS EVO SPLIT 200l (Source [117]).

V [L]	Price [€]	Heating rating [kW][20]	Electrical power [kW][20]	COP[20]	Time Heating HP[20]	Voltage [V]	Thermal losses [kWh/24h][21]	Max Temp. HP [°C]
200	2x2471	2.45	0.68	3.6	203 min	220-240	0.52	55

Moreover, inside the tank there are electrical resistances that allow heating the water up to 75 °C (Table 4.7). The power of the resistances is used only if

[19] UNI EN 16147.

[20] Water temperature between 15-55°C and air at 20°C (EN 255-3).

[21] They correspond to a loss of 2.23 °C/24h with 200 liters of water.

necessary, that is for heating the water from the highest temperature reached by the heat pump (55°C) to 75°C.

Table 4.7 – Data of the internal electrical resistances (Source [117]).

Heating element power [kW]	Time Heating from 55 to 75°C[22]	Max Temp. [°C]
1.5 + 1	112 min	75

There exists on the market devices with 300 liters of storage, ARISTON NUOS EVO SPLIT 300l has been chosen for the hospital. Technical data are reported in Table 4.8, while the system of electrical resistance is the same as the previous device with a time required for heating the water equal to 167 minutes.

Table 4.8 - Technical Data of ARISTON NUOS EVO SPLIT 300l (Source [117]).

V [L]	Price [€]	Heating rating [kW]	Electrical power [kW]	COP	Time Heating HP	Voltage [V]	Thermal losses [kWh/24h][23]	Max Temp. HP [°C]
300	3413	2.45	0.68	3.6	360 min	220-240	0.63	55

In a different way from the water heater, the way to calculate electrical energy consumption of the heat pump depends on the COP that changes on the strength of the outdoor temperature of the air.

The operation of the device is forecasted to be during the night when the temperature reaches its minimum. From NASA Database the monthly minimum temperature of the air has been observed and reported in Table 4.9.

Table 4.9 – Monthly lower temperature at Mutoyi (Source [51]).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp. [°C]	14.8	15.6	16.2	15.8	15.8	15.9	15.9	17.1	17.2	16.3	15.6	15.2

In handbooks of both the devices the same relation between COP and temperature of the air is reported and elaborated in Figure 4.3.

[22] Calculated as ratio between the energy necessary to heat the water from 55 to 75°C and the heating power of resistances, assuming the unit efficiency of the resistance.

[23] They corresponds to a loss of 1.81 °C/24h with 200 liters of water.

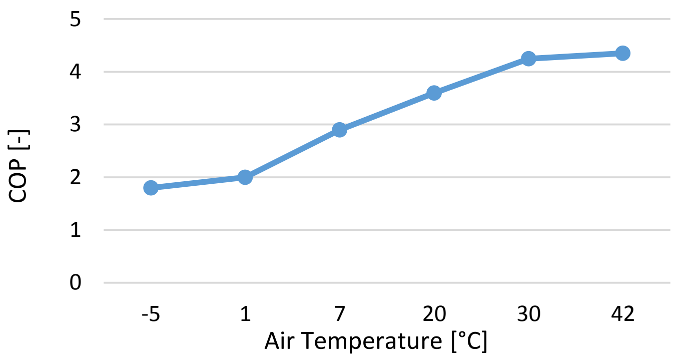


Figure 4.3 – Trend of COP on the strength of the air temperature (Source [117]).

Confronting Table 4.9 and the figure above, it can be seen that the monthly lower temperature at Mutoyi are included in the range between 7°C and 20 °C where the trend of COP is linear. As a consequent, the mean COP could be easily calculated at each monthly temperature. Moreover, the same linearization has to be done for the heating rating Q_u and time of heating. Q_u has to be linearized between the values of 2.1kW and 2.45 kW reported at 7°C and 20°C respectively in the handbook. Time between the values of 268 and 203 minutes for the 200 liters, and 456 and 360 minutes for the 300 liters model reported at 7°C and 20°C respectively. By Equation *(4.1)* the monthly mean electrical consumption for the two heat pumps can be estimated.

Table 4.10 – Monthly consumption of two ARISTON NUOS EVO SPLIT 200l[24].

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temp. [°C]	14.8	15.6	16.2	15.8	15.8	15.9	15.9	17.1	17.2	16.3	15.6	15.2
Time [h]	3.8	3.8	3.7	3.7	3.7	3.7	3.7	3.6	3.6	3.7	3.8	3.8
Q_u [kW]	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.4	2.4	2.4	2.3	2.3
COP	3.2	3.2	3.3	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.2	3.2
W_{el} [kW]	0.722	0.722	0.722	0.722	0.722	0.722	0.722	0.721	0.721	0.721	0.722	0.722
Energy [kWh]	170	152	166	162	168	162	166	162	156	166	162	170
W_{res} [kW]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Time [h]	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
Energy [kWh]	289.8	261.8	289.8	280.6	289.8	280.6	289.8	289.8	280.6	289.8	280.6	289.8
Energy [kWh]	459.8	413.8	455.8	442.6	457.8	442.6	455.8	451.8	436.6	455.8	442.6	459.8

[24] Costs are for 2 devices.

Table 4.11 – Monthly consumption of ARISTON NUOS EVO SPLIT 300l.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temp. [°C]	14.8	15.6	16.2	15.8	15.8	15.9	15.9	17.1	17.2	16.3	15.6	15.2
Time [h]	6.6	6.5	6.5	6.5	6.5	6.5	6.5	6.4	6.3	6.5	6.5	6.6
Q_u [kW]	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.4	2.4	2.4	2.3	2.3
COP	3.2	3.2	3.3	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.2	3.2
W_{el} [kW]	0.722	0.722	0.722	0.722	0.722	0.722	0.722	0.721	0.721	0.721	0.722	0.722
Energy [kWh]	149	132	145	141	146	141	146	142	137	144	142	147
W_{res} [kW]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Time [h]	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79
Energy [kWh]	216.2	195.3	216.2	209.3	216.2	209.3	216.2	216.2	209.3	216.2	209.3	216.2
Energy [kWh]	365.2	327.3	361.2	350.3	362.2	350.3	362.2	358.2	346.3	360.2	351.3	363.2

4.1.3 Solar integration

Combined with the previous solutions, solar collector have two advantages:

1. Reach higher temperatures up to 95°C that electrical resistances cannot reach.
2. Use the renewable energy of sun in place of electricity.

The first argument is always an advantage independently from the success of *Burundi Energie Saine et pour Tous* Project. The second one would be the fundamental advantage only in the case of an eventual missed implementation of the above mentioned Project.

Solar panels integrated with an electrical boiler and heat pumps are common. As opposed to other solutions, solar plants need a tank that has to be greater in respect to water needs. There are many commercial solar tanks and the following could be a solution: PUFFER 1 600l for PaMu and the Hospital [118]. The integration with the heat pump required a buffer with two coils, one for the solar exchanger and the other for the heat pump: two CORDIVARI BOLLYTERM HPI 300l for PaMu and the Hospital [118].

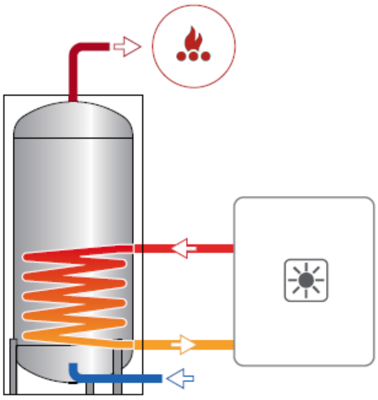


Figure 4.4 – Plan of electrical water heater with solar integration (adapted from [118]).

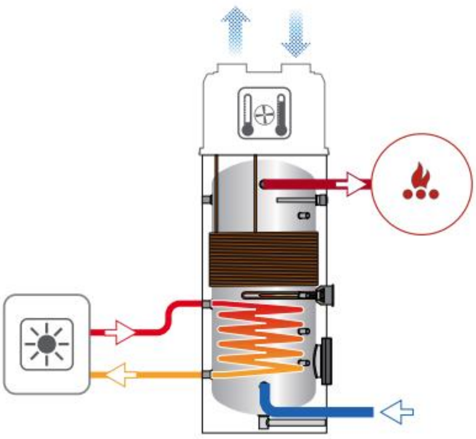


Figure 4.5 - Plan of heat pump with solar integration (adapted from [118]).

For the solar collectors, the choice has been the RIELLO CS 25 R Plus [119]. Technical data of the fundamental elements are reported in Table 4.12, Table 4.13 and Table 4.14:

Table 4.12 - Technical Data of CORDIVARI BOLLY 1 AP 400l and 300l (Source [118]).

V [L]	Price [€]	Power [kW]	Voltage [V]	Thermal losses [kWh/24h][25]	Max Temp. [°C]
600	821	4	400/3	2.35	75

[25] They correspond to a loss of 5 °C/24h and 5.36°C/24h with 400 liters of water respectively.

Table 4.13 - Technical Data of CORDIVARI BOLLYTERM HPI 300l (Source [118]).

V [L]	Price [€]	Heating rating [kW][26]	Average electrical power [kW][20]	COP[20]	Voltage [V]	Max Temp. [°C]
2x300	2x2220	2.427	0.639	3.8	230	60

The real value of COP is lower with water from 15 to 60 °C. Technical data do not report the values of COP on the strength of the outdoor temperature of the air. As a consequence, the same values of the previous EVO SPLIT have been considered because of the similarity of both devices.

Table 4.14 - Technical Data of RIELLO CS 25 R Plus (Source [119]).

A_{coll} [m²]	Price [€]	Solar control unit and circulation group [€]	IAM (50°)	Optical efficiency (η_0)	Coefficient of losses a_1 [W/m²K]	Coefficient of losses a_2 [W/m²K²]
2.29	650	355	0.85	0.751	3.62	0.0083

The number of collectors is determined by following common role used for the first dimensioning of the solar plants [120]:

$$A = \frac{V}{K} \tag{4.2}$$

with A the area of solar field in m², V the volume of the buffer associated and K a number between 50 and 70. With the aim to have the best advantages with the most extended are, the choice is 50.

Now it is possible to calculate the area of the solar field required by the tank of Table 4.12 and the numbers of collectors:

Table 4.15 – Numbers of solar collectors required.

V [l]	600
A [m²]	12
A_{coll} [m²]	2.29
N_{coll}	**6**

[26] Water temperature between 15-45°C and air at 15°C (EN 255-3).

The estimation of electrical consumption of the plants depend on the solar irradiation and the energy produced by the collectors. As a consequence, a simulator of the operation is needed and it will be introduced and diffusely used in section 5.2.

4.1.4 Improved Cook Stoves

An ICS has been defined as a stove with a higher efficiency than the traditional three stone fire stove and a lower level of specific emission. A lot of Stove Dissemination Programs have been launched in the last thirty years. The reasons of the success required usually these conditions [121]:

- The stove saves fuel, time, and effort;
- Stoves are designed with assistance from local artisans;
- Local or scrap materials are used in production of the stove, making it relatively inexpensive;
- Similar to traditional stove;
- Stove or critical components are mass produced.

Obviously, every Stove Dissemination Program is independent of the others and strongly conditioned by the local context, but the list above allow us to make the following considerations and to choose the best possible solution:

1. Avoid the import of new efficient devices that are completely different from the actual stove assessment;
2. Support the use of local production of stoves with local materials and not as different from the traditional ones.

As a consequence, the most appropriate choice turns out to be a simple traditional stove with a coating around the flames (Figure 4.6). These types of stoves are described and tested in [70, 76, 122-125]. They show an efficiency that is included in a range between 20% and 30%. The most elevated is typical of the stoves that cover the pot because they decrease thermal losses from the wall of the pot reducing fuel emissions by 20-30% [70, 126].

Concerning the emissions, since the stove does not have a combustion chamber, merely an open space for the fire, and because the fire is close to the pot, emissions are rather high, often more than the open fire. Generally, stoves that include the pot as *Sawdust/Mud Stoves* have specific CO emissions that could be up to 30% higher than open fire, and PM emissions double. The other stoves that simply cover the flames laterally, generally have the same CO and PM range of emissions of the open fire stoves [70].

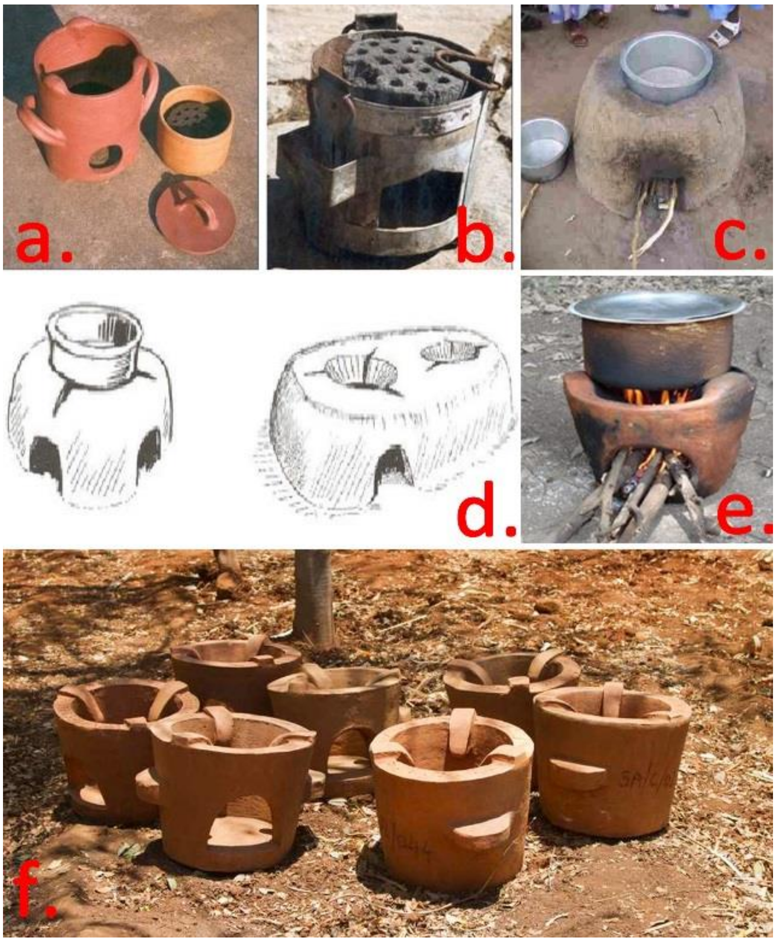


Figure 4.6 – *a) Clay Stove*; *b) Metal Stove*; *c) Mud/Sawdust Stove*; *d) Jiko Sanifu [123]; e*) *Mud and Clay Upesi Stove [124]*; *f) Chitetezo Mbaula [125].*

ICSs could be a solution in the kitchen used by patients' relatives. It would allow the decrease of the use of wood but also the emissions breathed by people. Vispe confirmed the presence of local artisans who made and sell these kind of stoves. However, these stoves could be homemade with clay in the same way they build their home. Moreover, one of the biggest challenges could be the improvement of the actual assessment. In fact, the brick plane might be covered with clay with only the holes for inserting the pot with an improvement of the efficiency.

4.2 Analysis and test of homemade solar cookers

The analysis of solar cookers requires a prefeasibility study with the aim to forecast the possible use of this technology at Mutoyi Mission. This technology lends itself to be easily self-feasible involving local people with their local materials. Particularly, these devices have been thought to be disseminated in the kitchen used by patients' relatives in the Hospital. This location makes a possible use of solar cookers interesting. In fact, solar stoves are characterized by the fact that they take some hours for cooking, for example while people are assisting their ill relatives in the hospital. In the next section, we will see how difficult solar cookers are accepted by people. As a consequence, every predictions of wood savings, money and emissions would be pretentious. This work examines only the self-construction and test that are needed to decide if solar cookers could be an appropriate solution at Mutoyi Mission.

4.2.1 Classification of the existing models recognized

Cooking with the sun has become a potentially viable substitute for fuelwood in food preparation in much of the developing world [127] [128] through particular devices called Solar Cookers. A solar cooker is a device which uses energy of direct and indirect sunlight to heat, cook or pasteurize food or drink [129]. According to [130], the first scientist to experiment with solar cooking was a German physicist named Tschirnhausen (1651 - 1708). He used a large lens to focus the sun's rays and boil water in a clay pot. The second known person to build a box to solar cook food was Horace de Saussure, a Swiss naturalist who published his work in 1767 [131].

Present design of solar cooker started evolving in the 1950s. A number of top engineers, scientist and researcher were hired to study different aspects of solar cooking designs. These studies concluded that properly constructed solar cookers not only cooked food thoroughly and nutritiously, but were quite easy to make and use [131].

There are different types of solar cookers that have been developed all over the world. However, we can broadly categorize solar cooker in three different ways as it is shown in Figure 4.7.

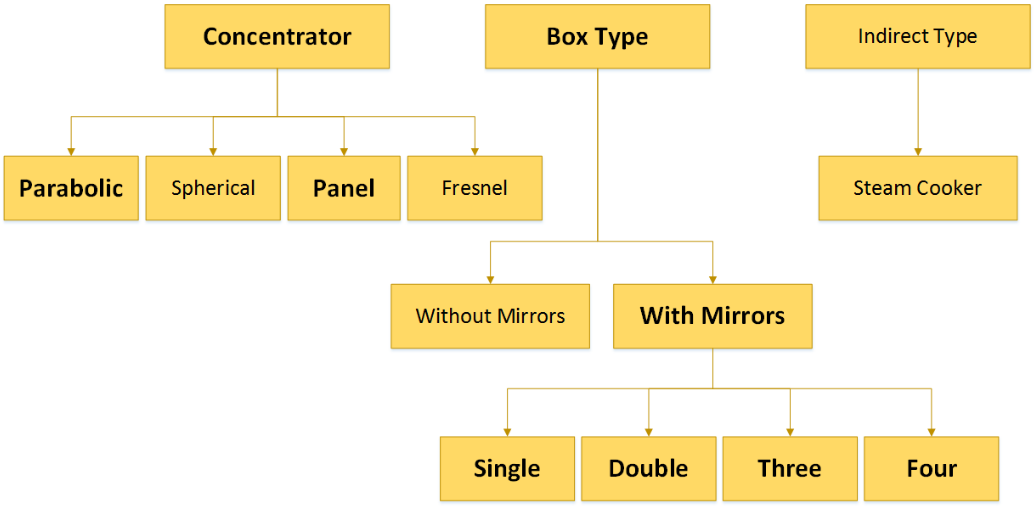


Figure 4.7 - Classification of solar cookers (elaborated from [131]).

The boldface devices are the most common and explained below. The others are rarely used and only cited. Spherical ones are similar to parabolic but with a different form. Fresnel Cookers do not reflect the solar rays but they channel them through a lens which concentrates and refracts the sun power on an underlying pot. Steam Cooker is a common thermal panel that produce hot water or steam used after for cooking.

<u>Box Cooker</u>

Box type solar cookers are becoming more popular in many countries [131]. They basically consist of an insulated box with a transparent glass cover and reflective surfaces to direct sunlight into the box [132] (Figure 4.8). The inner part of the box is painted black in order to maximize the sunlight absorption. It often accommodates multiple pots. Each component of the box cooker has a significant influence on cooking power. Therefore, optimization of these parameters is vital for obtaining maximum efficiency [133]. Researches show that solar box cookers could reach temperatures higher than 100°C on the inner black plate [131, 133-135] and boil water.

Box type solar cookers are slow to heat up because of they do not concentrate the rays on the pot. On the contrary, they work satisfactory where there is diffuse radiation, convection heat loss caused by wind, intermittent cloud cover and low ambient temperature [136] thanks to their good insulation.

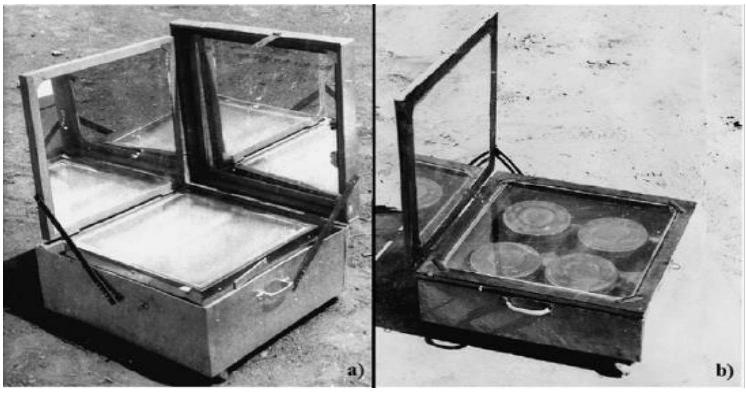


Figure 4.8 - (a) Double reflector solar box cooker and (b) conventional hot box solar cooker (Source [137]).

Panel Cooker

They are generally recognized as the most common type of solar cookers, since they have a widespread distribution, thanks to low costs and ease of construction [133]. On the other hand, they can provide just small amount of thermal power, as it is generated simply by the sunlight concentration on the pot above [138] which is eventually enclosed in a transparent plastic bag or bin (Figure 4.9).

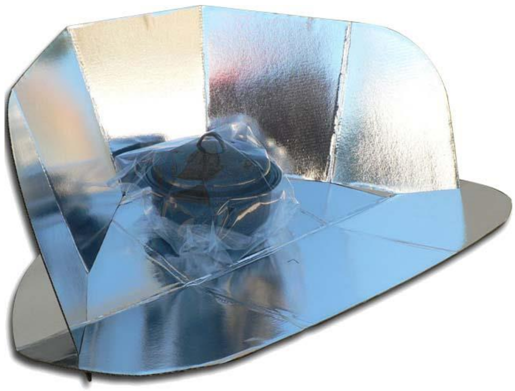


Figure 4.9 - Solar panel cooker of Dr. Roger Bernard (CooKit) (Source [139]).

Parabolic Cooker

They are simply parabolic reflectors in which the pot is located at the focus point, thanks to a stand system to support it. The main advantage of this model is the excellent performance that allows it to reach very high temperatures more quickly than the other two devices. On the other hand, it leads also to significant risks of scalds and of burning food and it requires a frequent manual tracking every 5 minutes. The first model was designed by Ghai [140] in the 1950s in India. Thereafter, other parabolic cookers were developed, such as a small portable one, a cooker with a tracking system, and a recycled fiberglass satellite dish.

Figure 4.10 - A South African woman cooking with a parabolic cooker (Source [141]).

4.2.2 Advantages and disadvantages

The great advantages related to the use of solar cookers are essentially a reduction in the use of biomass. In Burundi, for example, rural consumption of wood and charcoal by households is about 3 kg per person per day [53]. A possible use of solar cookers could reduce this quantity and obtaining these benefits:

1. Pollutant savings in terms of CO, PM, SO_2, fly ash, smoke with important benefits on indoor air quality and household health.
2. Reductions in direct emission of CO_2 from the combustion of wood and indirect emission. In fact, trees, if not cut, absorb carbon dioxide and provide oxygen for all of us. If burnt, in addition to emitting CO_2, they will not be able to absorb this CO_2 [142].
3. It could contribute to reduce the problem of shortage of firewood that, according to United Nations Food and Agricultural Organization, will involves even more people with serious nutritional and health consequences [143].
4. Wood cost savings due to a shortage of fuelwood in many places that forces users to pay high prices. In Kenya, for example, low-income households

spend more than 20% of their total income on energy [144] among which wood for cooking.

5. Time saved in collecting wood. In many places, children walk many miles to collect fuelwood [66].
6. Reduced impact of deforestation. Optimists have estimated that 36% of the developing world's use of fuelwood could be replaced by solar stoves. This would save 246 million metric tons of wood from the flames with a market value of as much as US$20 billion per year [127].

In spite of these environmental advantages, solar oven use has not become very popular. Firstly, there is the economic aspect related to the cost of the stoves. If they are bought, they have comparatively high cost (from US$25–30 to US$300) [127, 128]. On the other hand, many devices could be built with waste materials that cut the costs, especially for panel stove. The real barriers against the diffusion of solar stoves are the social and cultural aspects [127] such as:

- lack of information;
- lack of confidence;
- impossibility to make breakfast;
- limited time of day when it can be used;
- it takes longer;
- it cannot fry meals;
- there are fuel subsidies but no subsidies for solar ovens;
- unexpected changes in weather disrupt cooking;
- high interest rates making borrowing difficult;
- insufficient space or too shaded or children play where oven would need to be put;
- both husband and wife work;
- no strong motivation to change current way of cooking;
- conflict with the important tradition of three stone fire, symbol of a united family;
- food outside the home may be meddled with by people, birds or livestock;
- manufacturers unknown.

As a consequence, the "acceptance" of solar cookers is the critical point. Research that have studied the acceptance of these devices among people in developing country could be found in [128, 145-147] and it is possible to resume these results:

- solar cookers have generally been promoted in areas where fuel wood shortages are experienced such as rural areas and refugee camps;
- they need an adequate storage space for the solar cooker;

- there must be adequate motivations to use the cookers. Potential savings were the most important motivation mentioned by users to purchase and use their solar cookers while an element of curiosity was also found to be conducive to encourage the purchase of a solar cooker;
- successful solar cooking requires a basic form of training and being exposed to a solar cooking demonstration was rated highly by users to ensure cooking success and therefore on-going use;
- using solar cookers requires adaptation mostly in terms of kitchen management;
- solar cookers should be well-made products, comparable to other household cooking appliances. The product must instill confidence in the user and be well made, finished and packaged;
- promote solar cookers as an additional cooking option and not as a replacement of conventional cooking fuels and appliances;
- end-user finance mechanisms through normal credit channels or tailor-made micro-finance options are essential to enable very poor households to purchase solar cookers. Without access to credit, solar cookers will not reach the poorest segments of the market, and the households that need them most.

4.2.3 Construction and optimization of homemade solar cook stove

All the three stoves analyzed above could be self-built. On the other hand, parabolic cooker required a lot of time and particular waste materials such as used parabola and solid metal support. Moreover, they are more expensive if bought (US$300) and dangerous. In fact, if their optical focus is not placed on the pot, concentrated rays could burns something or blind people. This is the reason it requires a frequent azimuthal tracking. Since kitchen used by relatives is placed in an open garden with many people, patients and playing children, this preliminary work does not consider the construction of this model. As a consequence, the two models realized are *box* and *panel* models.

Panel model

The first homemade stove has been a particular model called Celestino Solar Funnel Cooker. The name derives from Celestino Rodrigues Ruivo, professor *Instituto Superior de Engenharia da Universidade do Algarve*, Campus da Penha in Portugal [141]. Since becoming “well contaminated with the virus of solar cooking” at the 2006 International Solar Cookers Conference in Spain, he has become an important advocate for solar cooking in Portugal and beyond. During a meeting on 27 March 2014 at Politecnico of Milan, Celestino was invited for a workshop on solar cooking and he built with students his funnel solar stove.

This efficient solar panel cooker was developed in 2007 using only recycled materials. It benefits from low cost reproduction in every part of the world using local available common materials, intuitive and practical use, it is water rain and wind resistant and free from risks for fire ignition. It is constituted by:

– recipient: black pot;
– greenhouse devices: two re-used windows of clothes washing machines;
– two corrugated polypropylene plates or simply papers of 90x65 (cm), thickness 3 a 5 mm;
– reflective foil;
– adhesive tape;
– support below the pot (e.g. of recycled cartons of milk);
– two twines to block it on the ground;
– iron thread.

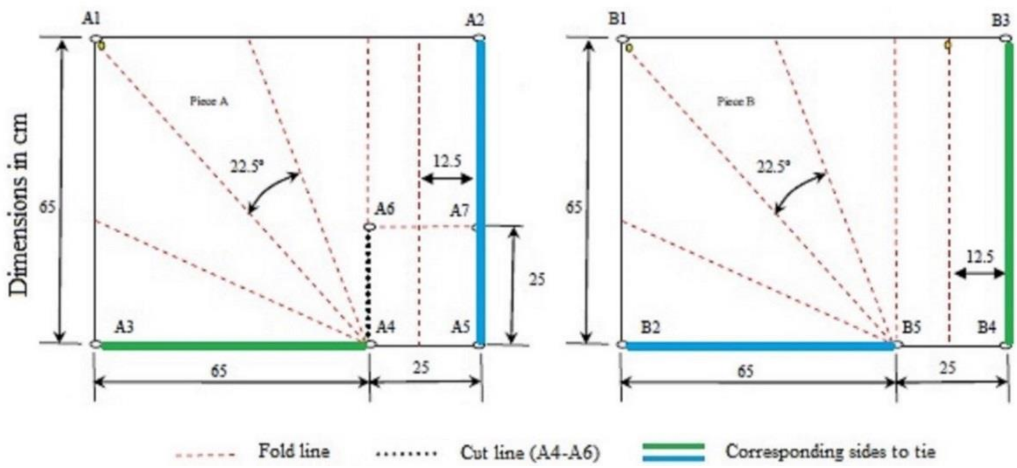


Figure 4.11 – Sketch of the construction of Celestino Solar Funnel Cooker.

The final operating result is shown in Figure 4.12. This solution is better than the classical CooKit of Figure 4.9 because it concentrates sunrays on the pot in a better way. Moreover, better than parabolic cooker, the azimuth (see Figure 5.1) of this solution needs to be manual tracked every 15-20 minutes.

Figure 4.12 – Celestino Solar Funnel Cooker (self-built).

Zenith angle has not to be tracked. In fact, with the winter and summer layout it is possible to cook food without changing the zenith angle (Figure 4.13).

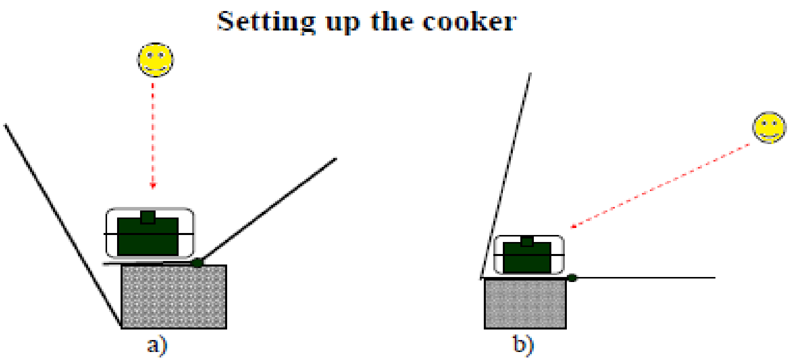


Figure 4.13 - Cooking with: a) high sun angle (summer); and b) low sun angle (winter).

Box model

While Celestino Ruivo has already optimized the geometry of the previous cooker, the following box stove is a personal model and a prior study of optimization is needed. As we can see in [133], the optimization of a solar box concerns the correct inclination of the mirror so that the sunrays could be reflected inside the box. The realization and optimization of the stove followed these first criteria:

1) The first parameter is the orientation of the glass. As we can see in Figure 4.14, the more directly the glass faces the sun, the greater the solar heat gain. Although the glass is the same size in box 1 and box 2, more sun shines through the glass on box 2 because it faces the sun more directly. On the other hand, box 2 has more wall area and inlet space with an increase of conductive and convection thermal losses. Moreover, the construction is quite difficult. As a consequence, model with flat glass has been chosen.

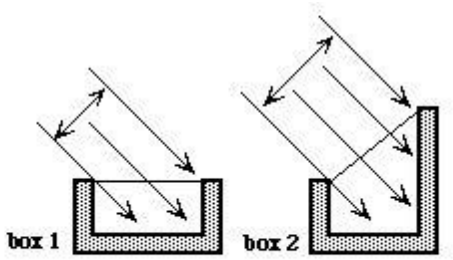


Figure 4.14 – Glass orientation of solar box stove.

2) Secondly, the stove has been chosen to have four mirrors and the internal walls to be covered by reflecting papers.
3) All the optimizations of the angles have been done supposing the use of the stove between 10 a.m. and 2 p.m. for lunch preparation.
4) Because of the internal walls are covered by reflecting papers, it is enough for sunrays to cross the transparent cover. In fact, rays that hit the walls are reflected on the absorption plate or on the pot, too.
5) The two lateral mirrors are not optimized because a correct optimization would need a tridimensional simulation. As a consequent, they have been made short and slighted sloped so that the rays reflected would easily hit the principal reflective mirror and finally be reflected on the plate.
6) Thanks to the frequent azimuthal tracking each 15 – 20 minutes, the study of the reflections on the other two mirrors could be studied one-dimensionally. The stove is therefore supposed to be always directed toward the sun with the azimuth angle equal to zero.

Now it is possible to explain the equation used for calculating the angles of inclination of the first mirror named “reflecting cover” and second one opposite to that. Firstly, thanks to the online database found in [148] it has been possible to resume the values of the solar altitude α_s (see Figure 5.1) related to Mutoyi in Table 4.16.

Table 4.16 – Monthly mean solar altitude α_s at Mutoyi (Source [148]).

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
10:00	40.6	41.0	42.7	43.3	41.3	38.6	38.2	41.1	45.7	48.4	46.9	43.2
11:00	53.8	55.4	57.7	57.3	53.8	50.4	50.4	54.6	60.5	63.1	60.2	55.7
12:00	65.3	69.2	72.7	70.1	63.9	59.6	60.4	66.4	74.8	77.4	71.2	65.9
13:00	71.8	79.6	87.4	77.0	67.9	63.5	65.2	72.7	83.7	83.6	74.3	69.9
14:00	68.3	75.1	77.3	70.2	62.9	59.8	62.0	68.0	72.7	70.9	66.1	64.6

First reflecting cover

The worst situation is represented in Figure 4.15 in the morning when the sun altitude is the lowest. Considering the figure, if the represented situation is respected at 10 a.m., all the rays are reflected by the cover inside the box when the solar angle grows. Moreover, from Table 4.16, we can individuate that July is the month when the solar altitude at 10 a.m. is the lowest. As a consequence, the slope of the reflecting cover has to be higher than the angle β obtained at 10 a.m. in the month of July.

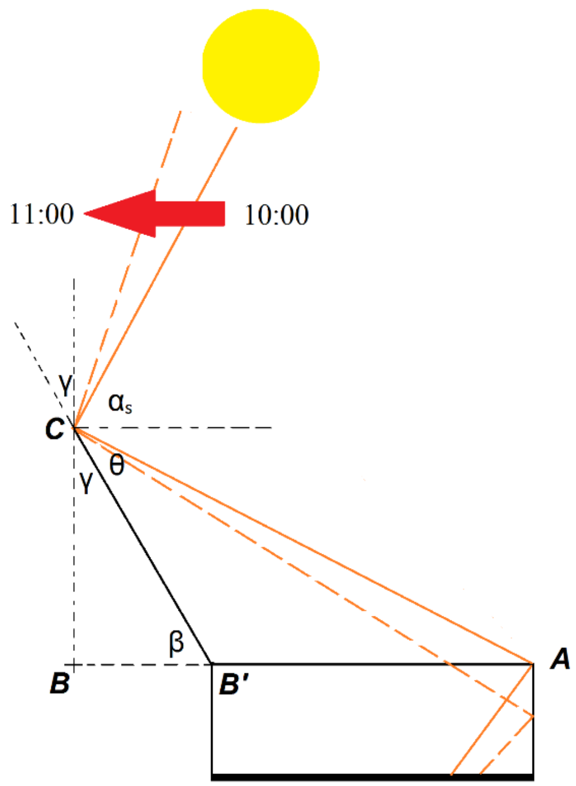


Figure 4.15 - Model for the optimization of reflecting cover angle.

These following are the geometrical considerations about angles and sides:

$\gamma = 180 - 90 - \beta = 90 - \beta$

$\theta = \gamma + (90 - \alpha_s)$

$\widehat{ACB} = \gamma + \theta = \gamma + \gamma + 90 - \alpha_s = 270 - 2\beta - \alpha_s$

$AB = AB' + CB' * \cos(\beta)$

$BC = CB' * \sin(\beta)$

with α_s the minimum value of July equal to 38.18°. Thanks to trigonometric formula:

$\frac{AB}{BC} = \tan(\widehat{ACB})$

and finally, considering that $AB' = CB'$:

$$\frac{1 + \cos(\beta)}{\sin(\beta)} = \tan(270 - 2\beta - \alpha_s) \qquad (4.3)$$

Solving the equation, we could obtain the minimum value of the slope β of the cover equal to 94.55° approximated to **95°**.

<u>*Second mirror*</u>

On the contrary, for the second reflector, the worst situation represented in Figure 4.16 is in the afternoon when the sun altitude is the highest. From Table 4.16, the highest elevation for each month is at 1 p.m.. Considering the figure, if the represented situation is respected at 1 p.m., when the solar angle is lower, all the rays are reflected by the cover inside the box. Moreover, we can individuate that March is the month with the highest elevation at 1 p.m.. Since March is in the middle of the wet season, differently from the previous optimization, the referential highest solar altitude has been chosen between the months of June, July and August (dry seasons) at 1 p.m.. As a consequence, the slope of the reflecting cover has to be higher than angle β obtained at 1 p.m. in August.

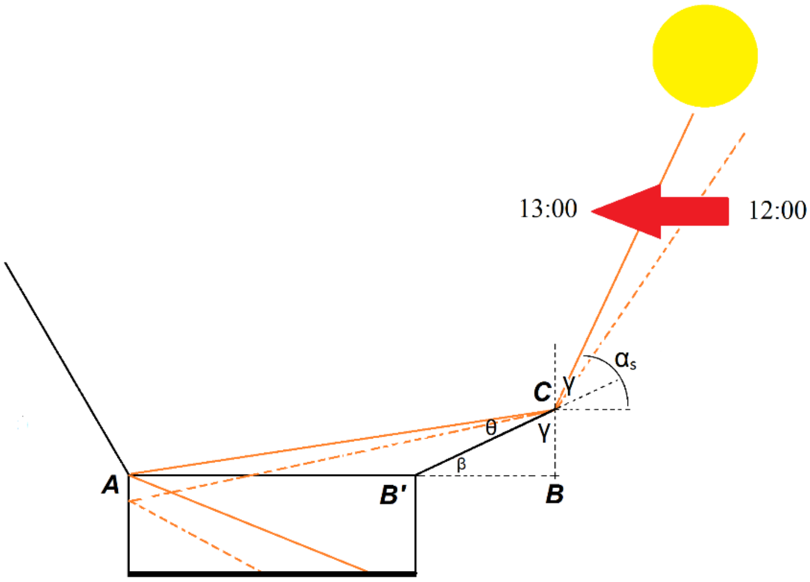


Figure 4.16 - Model for the optimization of the second mirror.

$\gamma = 180 - 90 - \beta = 90 - \beta$

$\theta = \gamma - (90 - \alpha_s)$

$\widehat{ACB} = \gamma + \theta = \gamma + \gamma - 90 + \alpha_s = 90 - 2\beta + \alpha_s$

$AB = AB' + CB' * \cos(\beta)$

$BC = CB' * \sin(\beta)$

with α_s the maximum value of August equal to 72.73°. Using the same trigonometric formula used above:

$$\frac{AB' + CB' * \cos(\beta)}{CB' * \sin(\beta)} = \tan(90 - 2\beta + \alpha_s) \qquad (4.4)$$

Differently from before, CB' is shorter than AB'. The second mirror has been chosen to be built as 2/3 of the length of the plane:

$$\frac{1 + \frac{2}{3} * \cos(\beta)}{\frac{2}{3} * \sin(\beta)} = \tan(90 - 2\beta + \alpha_s) \qquad (4.5)$$

Solving the equation, we could obtain the minimum value of the slope β of the cover equal to 45.3°. In Table 4.16, we can see that this angle is higher than the solar altitude in the morning and it creates the phenomenon of shadowing. As a consequence, the slope β is reduced to the minimum solar altitude in July equal to **38°**.

Finally, the transversal section of the box is the following represented in Figure 4.17.

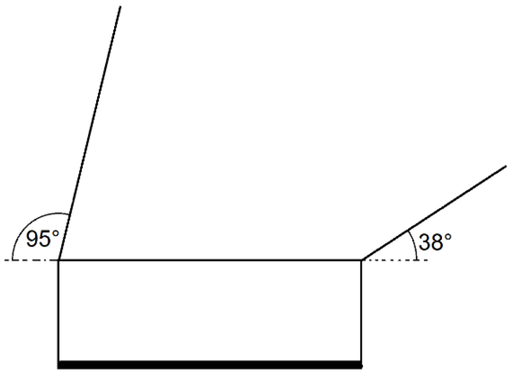


Figure 4.17 – Transversal section of the optimized solar box cooker.

The box has been built using cheap and available materials:

- because of the cost of the glass and its fragility, the cooker has been chosen to have a fixed Poly(methyl methacrylate), our common ‘Plexiglass’, a transparent thermoplastic often used as a lightweight or shatter-resistant alternative to glass.
- wood as material of the structure; waste wood is abounded at Mutoyi Mission, particularly in the carpenters’ workshop that is one of the cooperative companies supervised by Vispe. Moreover, wood is a better thermal insulator in respect to iron, and it requires less expensive insulating materials inside the box.
- aluminum plate; aluminum is abounded at Mutoyi Mission particularly in the pots’ workshop that is one of the local cooperative companies supervised by Vispe.
- black not-toxic paint;
- reflecting paper;
- pieces of Styrofoam for isolating the bottom of the stove;
- screws, nails, glue and joints;

The building took two full days and the passages and the result are illustrated in Figure 4.18.

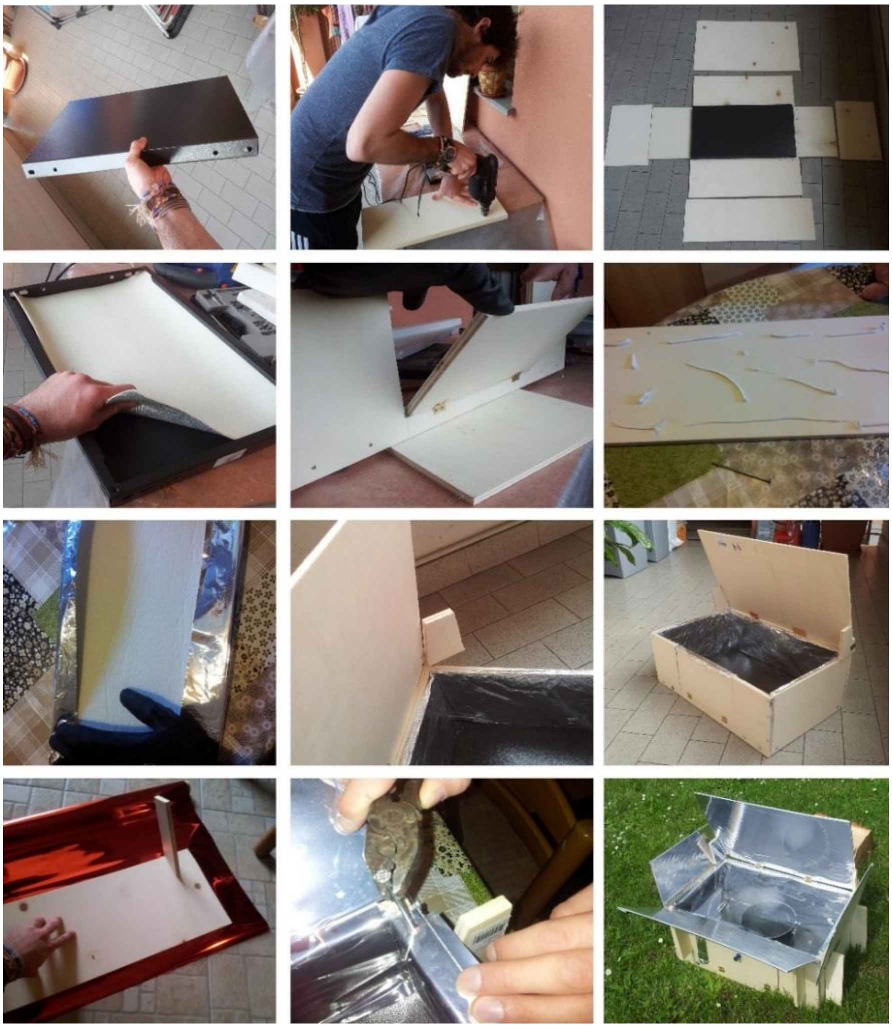


Figure 4.18 – Building of the box solar cooker.

4.2.4 Scientific test of the cookers: procedure and results

Various tests are available to compare solar cookers (see below). Not everyone in the solar cooking community agrees on how to best test solar cooker variations, and how to report the results of these tests. Some argue for a standardized test with standard measurements calibrated to report absolute results. Others argue for a more low-tech approach that measures only the relative difference between cookers or cooker variations when tested side-by-side [141]. Examples of scientific tests found in literature are available in [136, 149-155]. The most scientifically consolidate test appears to be the procedure started by the researcher Paul Funk who consolidated solar cooking researches for his doctorate in Agricultural Engineering at the University of Arizona. His dissertation work eventually led to the development of an international standard "Evaluating the international standard procedure for Testing solar cookers and reporting performance" published by Elsevier in 1999 and internationally acknowledged [152]. His work has been finally enhanced by the American Society of Agricultural Engineers (ASAE) that published the final procedure named "Testing and Reporting Solar Cooker Performance" in 2013 [151]. This has been the procedure followed for testing our two homemade solar cookers.

The Procedure

All the phases and the variables of the tests that have to be controlled and measured are reported below:

Uncontrolled (weather) variable

- Wind: tests shall be conducted when wind is less than 1.0 m/s, measured at the elevation of the cooker being tested and within ten meters of it. Should wind exceed 2.5 m/s for more than ten minutes, discard that test data.
- Ambient temperature: tests should be conducted when ambient temperatures are between 20 and 35 °C.
- Water temperature: test data shall be recorded while cooking vessel contents (water) are at temperatures between 5 °C above ambient and 5 °C below local boiling temperature.
- Insolation: available solar energy shall be measured in the plane perpendicular to Direct Normal Irradiation (DNI) (the maximum reading) using a radiation pyranometer. Variation in measured insolation greater than 100 W/m^2 during a ten-minute interval, or readings below 450 W/m^2 or above 1100 W/m^2 during the test shall render the test invalid.
- Solar zenith and azimuth angle: tests should be conducted between 10 a.m. and 2 p.m.. Exceptions necessitated by solar variability or ambient temperature shall be specially noted.

Controlled (cooker) variables

- Loading: cookers shall have 7000 grams potable water per square meter intercept area distributed evenly between the black cooking vessels supplied with the cooker.

- Water mass: the mass of water should be determined with an electronic balance to the nearest gram using a pre-wetted container.
- Tracking: azimuth angle tracking frequency should be appropriate to the cooker’s acceptance angle. Box-type cookers typically require adjustment every 15 to 30 minutes or when shadows appear on the absorber plate. Concentrating-type units may require more frequent adjustment to keep the solar image focused on the cooking vessel or absorber. With box-type cookers, zenith angle tracking may be unnecessary during a two hour test conducted at mid-day. Testing should be representative of local conditions.
- Temperature sensing: water and air temperature should be sensed with thermocouples. Each thermocouple junction shall be immersed in the water in the cooking vessel(s) and secured 10 mm above the bottom, at center. Thermocouple leads should pass through the cooking vessel lid inside a thermally nonconductive sleeve to protect the thermocouple wire from bending and temperature extremes.

Test protocol

- Recording at intervals not to exceed ten minutes: the average water temperature (°C) of all cooking vessels, solar insolation (W/m^2), ambient temperature (°C), and wind speed (m/s)
- Record and report the frequency of attended (manual) tracking, if any.
- Report azimuth angle(s) during the test and the test site latitude and the date(s) of testing.

Calculating cooking power

The change in water temperature for each ten-minute interval shall be multiplied by the mass and specific heat capacity of the water contained in the cooking vessel(s). This product shall be divided by the 600 seconds contained in a ten-minute interval, as:

$$P_i = \frac{m * C_p * (T_2 - T_1)}{600}$$

where:

$P_i =$ cooking power [W]
$T_2 =$ final water temperature [°C]
$T_1 =$ initial water temperature [°C]
$m =$ water mass [kg]

$C_p =$ heat capacity $[4186\ \mathrm{J/kg} * \mathrm{K}]$

Calculating interval averages

The average insolation, average ambient temperature, and average cooking vessel contents temperature shall be found for each interval.

Standardizing cooking power

Cooking power for each interval shall be corrected to a standard insolation of 700 W/m^2 by multiplying the interval observed cooking power by 700 W/m^2 and dividing by the interval average insolation recorded during the corresponding interval.

$$P_s = P_i * \frac{700}{I_i}$$

where:

$P_s =$ standardized cooking power [W]
$P_i =$ interval cooking power $[W]$
$I_i =$ interval average solar insolation $[W/m^2]$

Temperature difference

Ambient temperature for each interval is to be subtracted from the average cooking vessel contents temperature for each corresponding interval.

$$T_d = T_w - T_a$$

where:

$T_d =$ temperature difference [°C]
$T_w =$ water temperature [°C]
$T_a =$ ambient air temperature [°C]

Plotting and regression

The standardized cooking power P_s is to be plotted against the temperature difference T_d for each time interval. A linear or quadratic regression of the plotted points shall be used to find the relationship between cooking power and temperature difference. No fewer than 30 total observations from three different days shall be employed. The coefficient of determination (R^2) should be higher than 0.75 or specially noted.

Single measure of performance

The value for standardized cooking power P_s shall be computed for a temperature difference T_d of 50 °C using the regression relationship found above.

Reporting

A plot of the relationship between standardized cooking power and temperature difference shall be presented with the equation, following the example in Figure 4.19. The report shall also state the standardized cooking power at a temperature difference of 50 °C.

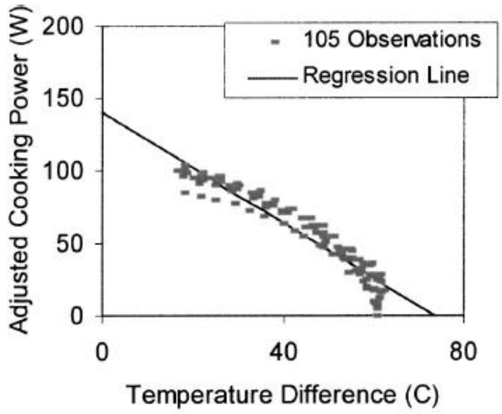


Figure 4.19 – Example of plot of test's results.

Test and results

All the tests have been carried out in Energy Department, Politecnico of Milan, Via Lambruschini 4, 45° 30' 8.959" N and 9° 9' 15.739" E, in July 2014 on Friday 11th, Tuesday 15th, Wednesday 16th, Thursday 17th, Friday 18th. Data about the ambient temperature and the direct irradiation has been collected by the meteorological station on the roof of the Department[27]. Stoves have been protected by wind with screens. The data logger used to scan data has been Agilent 34970A Data Acquisition with the free 34825A BenchLink Data Logger 3 graphic interface available from the website of Agilent (now Keysight Technologies from 2013) at [156]. Data logger has been coupled with two T-type thermocouples.

[27] The pyranometer of the station does not measured directly the direct normal irradiation; it is obtained as an interpolation between the global and diffuse irradiation on the horizontal directly measured by the instruments.

Figure 4.20 – Photos of tests.

Before reporting the results, it is important to report the way to calculate the intercept area of the stoves that has been necessary to obtain the testing water load. According to the Procedure [151], the intercept area is defined as the sum of the reflector and aperture areas projected onto the plane perpendicular to direct beam radiation. Because of the frequent tracking every 15 minutes, the direction of the direct beam radiation could be approximately considered parallel to the orientation of the stove. As a consequent, for the box model, the intercepted area has been calculated one-dimensionally as explained in Figure 4.21.

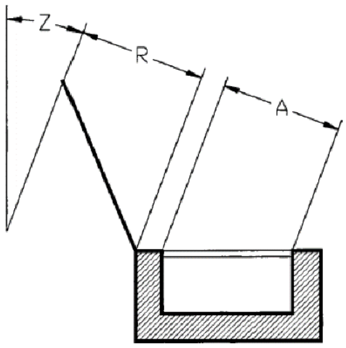


Figure 4.21 - Determining the intercept area (Source [151]).

Since the test has been carried out in Milan, the stove has been optimized and built using the solar elevation typical of the our latitude in the summer period (following the procedure of Paragraph 0, the optimal angles of the two mirrors for a use in Milan are 95° and 41°). The angle Z in the figure is the mean zenith angle of the Sun during the hours and the day of the tests. It has been calculated from the same database used before in [148]:

Table 4.17 – Zenith angle during the test.

[hours]	**Friday 11th July**	**Tuesday 15th July**	**Wednesday 16th July**	**Thursday 17th July**	**Friday 18th July**
10:00	48.23	48.7	48.83	48.96	49.09
11:00	38.25	38.75	38.88	39.02	39.16
12:00	29.61	30.17	30.32	30.47	30.63
13:00	24.16	24.75	24.91	25.08	25.26
14:00	24.27	24.82	24.97	25.13	25.3
AVERAGE	***29.62***	***29.77***	***29.93***	***30.09***	***33.89***

On the contrary, panel stove is not composed by simple geometrical mirrors with known slopes. Therefore, the calculation of aperture areas appears to be quite complicated. Firstly, before the tests, the aperture area of the cooker has been photographed. Knowing the days of the tests, the camera was pointed in the focus of the solar cooker at the same inclinations of the mean solar zenith of these days. Then, the largest horizontal distance has been measured. Photos have been printed out and shown illuminated surfaces will then be segmented to easy-to-calculate rectangles and triangles and finally summed [157].

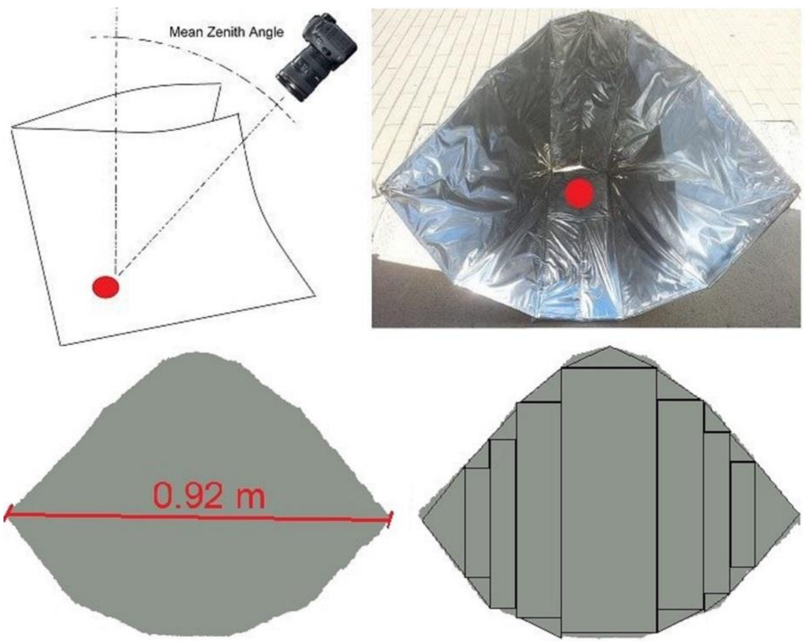


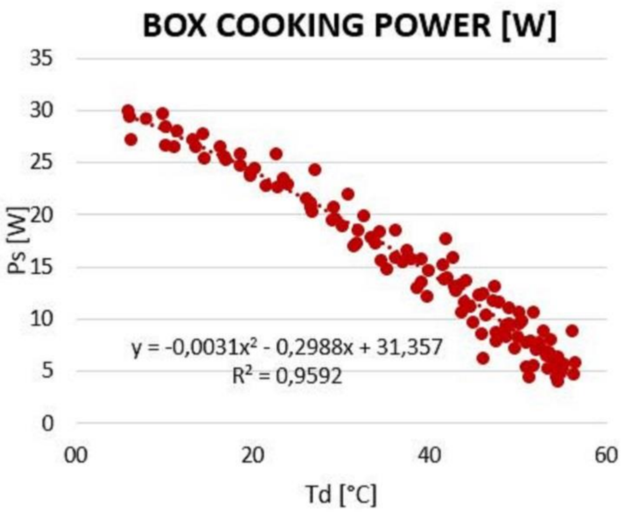
Figure 4.22 – Procedure for calculating the aperture area of the panel cooker.

Secondly, the water load has been evaluated. The value of 7 kg of water per m^2 of aperture area suggested by the Procedure has not been used because of the limited volume of the pot. Therefore, it has reduced to 5. All the results are reported in Table 4.18:

Table 4.18 – Aperture Area and Water Load for both the stoves during for tests.

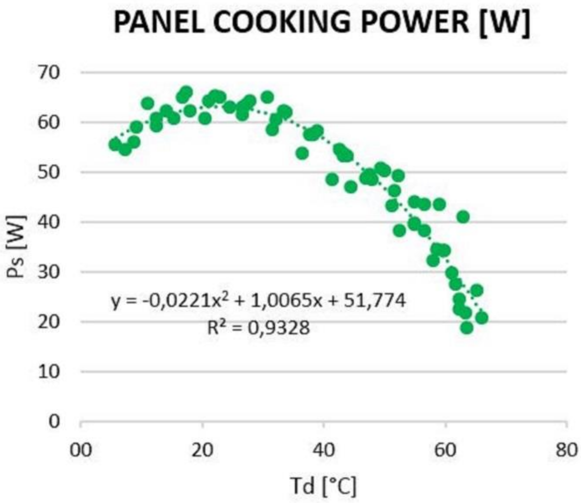
	Box Stove		**Panel Stove**	
	Aperture Area [m^2]	*Water Load [kg]*	*Aperture Area [m^2]*	*Water Load [kg]*
11/07/2014	0.219	1.095	0.365	1.825
15/07/2014	0.218	1.090	0.365	1.825
16/07/2014	0.218	1.090	0.365	1.825
16/07/2014	0.217	1.090	0.365	1.825
16/07/2014	0.217	1.085	0.365	1.825

All the detailed results could be observed in the APPENDIX B. The main output of the test could be observed below:



$P_s\|_{50°C}$ [W]	8.667
n° of observations	117

Figure 4.23 - Results of solar cooking tests for the box model.



$P_s\|_{50°C}$ [W]	46.849
n° of observations	60

Figure 4.24 - Results of solar cooking tests for the panel model.

The main results of the test represent a confirmation of the best performance of the Panel Cooker. Its cooking power is five times higher when compared with the Box one. Moreover, it is quicker to reach the stagnation temperature when the entering power is all dissipated by thermal losses. Moreover, the box stove in 4 hours never reached 85°C.

Cooking power is reported as the value obtained at a temperature difference equal to 50°C. This is because it represents the mean power observed during the test for heating water between 5 °C above ambient and 5 °C below local boiling temperature. In fact, for the panel stove, if we calculate the total energy transmitted to the water and dividing by the time required, we obtain a value near $P_s|_{50°C}$. For the box stove, the values are different because tests finished before the cooker has reached a temperature of 5 °C below local boiling one.

Evaluation of the efficiencies

One of the particularity is that the cooking power curve found by using the international test standard appeared to be independent of location and date provided the protocol could be followed (clear skies, low wind) [152]. As a consequence, performances and efficiency of the stoves should be the same at Mutoyi in Burundi. In fact, saying that the cooking power curve is always the same independently from the latitude means that the sequence of cooking power points P_s is constant. In other words, dividing by a constant area A, we could say that also the punctual efficiency is independent from the location:

$$P_s = P_i * \frac{700}{I_i} * \frac{1}{A} = const \quad \text{with} \quad \frac{P_i}{I_i * A} \text{ the puntual efficiency } \eta_i$$

Following a proposal for a new world standard for testing solar cooking found in [154], a referential constant area A of box cooker is the sum of area of reflector and 'glazed window', while in case of panel cooker it is to be taken as area of rectangle formed by the folded assembly. For our two models, they are respectively 0.4964 m^2 and 0.81 m^2. Both the efficiency curves have been drawn in Figure 4.25.

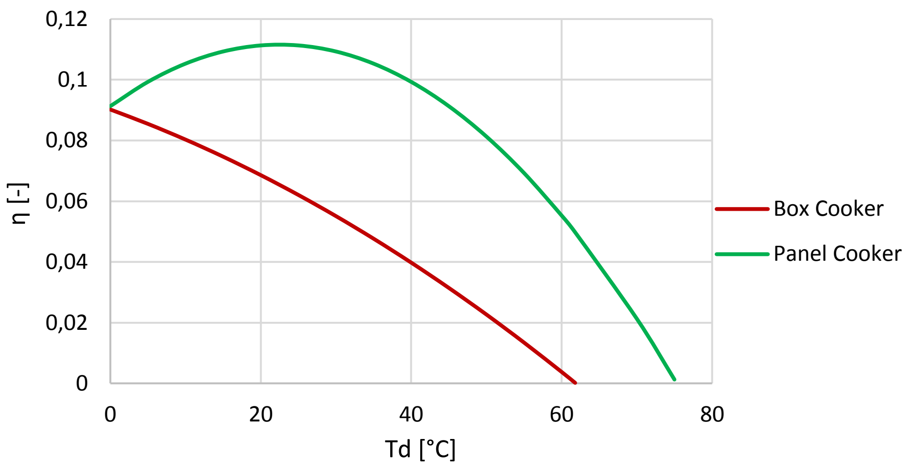


Figure 4.25 – Cookers efficiency curves.

Since these curves are equal to the power curves decreased by a constant ($\frac{A}{700}$), the mean efficiency will be evaluated at $T_d = 50°C$:

$\eta_{BOX} = 2{,}27\%$

$\eta_{PANEL} = 8{,}13\%$

Moreover, from the figure of the efficiency the stagnation temperatures of the cookers equal to 61.9 and 75.3 degrees over the air temperature are evident.

4.2.5 Cooking test

Forecasts

One of the main problem of the previous test is the lack of information about the possibility to make cooking forecasts with the curves. As a consequence, all the passages below are an attempt to make a forecast.

Previous tests have been useful to compare the stoves. In fact, we saw that the panel stove has a cooking power and an efficiency respectively five and three times higher than the box stove. In terms of temperature, the panel stove has a stagnation temperature of 75°C over the air temperature while the box one only 62°C. Therefore, box stove never reaches the boiling temperature if the outside temperature is less than 40°C. Moreover, with a mean irradiation of 850 W/m^2 observed during the tests, the stove never exceeds 85°C in 4 hours. Considering that in Burundi the monthly mean irradiation at midday is about 700 W/m^2 [51] during sunny days in the central months, we could estimate the time. At this irradiation, the mean cooking power is equal to 8.667 W. Considering a mean air temperature of 24°C [51], the stagnation temperature it is estimated equal to 86°C. Dividing the energy required to heat 1 kg of water between the air to the stagnation temperature by cooking power, we obtain a time equal to 8 hours. As a consequence, box stove apparently does not seem to be an appropriate technology to be tested in field. On the contrary, panel cooker shows a quicker ability to heat water and it seems to be suitable to cook food. From this point, it will be the only one analyzed.

From the previous test, it is useful to trace the temperature trends obtained between 25 and 90°C.

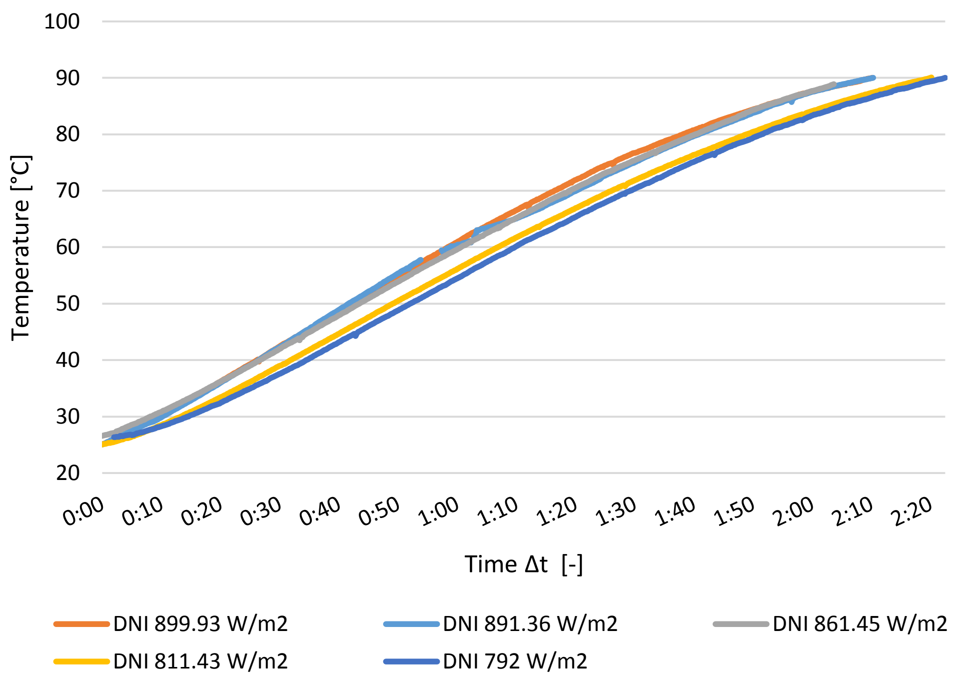


Figure 4.26 – Values of temperatures inside the pot observed during the five days of tests for panel cooker.

For every curve, the mean temperature has been calculated as an integral average as follow:

$$T_m = \frac{\int_0^{end} T dt}{\Delta t} \quad (4.6)$$

For all the five curves, the following results have been obtained:

Table 4.19 - Mean temperature reached in the panel cooker during tests.

	11/7/'14	15/7/'14	16/7/'14	17/7/'14	18/7/'14
DNI [W/m^2]	899.93	891.36	861.45	811.43	792
Mean Temperature [°C]	61.42	60.68	59.46	59.86	59.71

We could conclude that changing the mean irradiation, the mean temperature does not change significantly. In fact, from the graph we can see that the lowest is the irradiation, the highest is time required to reach 90°C and the curves stretch to the right maintaining the same trend. As a consequence, the integral mean temperature is about the same. For the forecast in Burundi, we could approximately set at 60°C the main temperature inside the pot when it is heated from 25°C to 90°C.

Thanks to personal observation, the most common food cooked by relatives in the Hospital at Mutoyi Mission are beans. They cook beans by putting them directly in the cold water and it is an advantage because in the panel stove food is cooked in the same way. In fact, waiting for the boiling temperature would require too much time perhaps without reaching the target. Fresh beans require a lot of time to cook. Our common "borlotti" require almost 35-40 minutes at 100°C [158]. Time of cooking is inversely proportional to the temperature. Data reported in Table 4.20 have been collected.

Table 4.20 – Times for cooking beans at different mean temperatures[28] (Source [158-160]).

Mean Temperature [°C]	79	100	120
Time [min]	50	35 - 40	15 - 25

[28] The referential quantity is 1 kg.

These data have been graphed in Figure 4.27 with the aim to find a correlation and finally forecast the time for cooking beans at 60 °C. The two curves represent the ranges of times reported in the previous table.

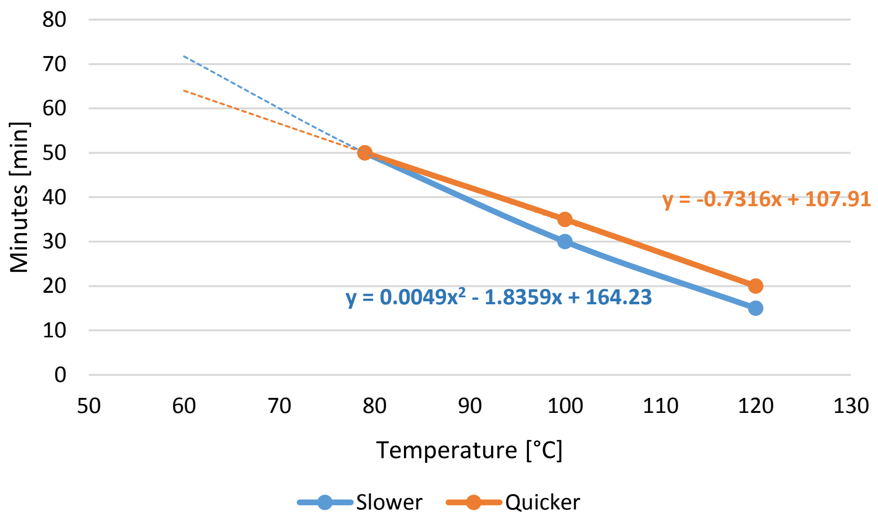


Figure 4.27 - Times for cooking beans at different mean temperatures (elaborated from Table 4.20).

Thanks to the interpolations, the time required to cook beans at a mean temperature of 60°C is included in a range between 60 and 72 minutes. This time has to be compare to the time of cooking required by the panel stove. In fact, it must be remembered that the temperature of 60°C is the time integral average of the cooker when it is heated by sun from 25°C to 90°C. As a consequence, the first passage is calculating a forecast of the operation time required by the stove in Burundi. After this, we can make these considerations:

1. Operation time is longer than the one required to cook beans at a mean temperature of 60°C found before. In this case, when the stove reach the 90°C, the beans are added to the dish.
2. Operation time is shorter than the one required to cook beans at a mean temperature of 60°C found before. In this case, it is necessary to wait for the end of that range of time (60 - 72 minutes)[29].

[29] Probably less because the temperature in the pot continues to increase and time integral average, too.

Following the same procedure used at the beginning of this section, time required by the panel cookers to reach a temperature of 90°C has been forecasted (Table 4.21). Thanks to personal observations and the helps of local people, we could estimate an average of two relatives per patient for a total of 0.3 kg of beans cooked in 0.4 liters of water[30]. The energy required is obtained by the following balance:

$$E = Q_w + Q_b \qquad (4.7)$$

where Q_w is the product between the mass of water m_w (0.4 kg), the specific heat C_w(4186 J/kgK) and the temperature difference $90°C - 25°C$; Q_b is the product between the mass of beans m_b (0.3 kg), the specific heat C_b(3500 J/kgK [162]) and the same temperature difference. The value of E we obtained is $177.086\ kJ$.

Table 4.21 – Forecast of time required for cooking 0.3 kg of beans in 0.4 liters of water with Panel Stove at Mutoyi

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Midday DNI [W/m²]	742	704	719	610	732	722	749	664	613	677	742	621
Days	4	3	7	4	6	15	8	13	10	8	5	2
Multiplying by the efficiency 8.13% and referential area 0.81 m²:												
Cooking power [W]	48.8	46.4	47.3	40.2	48.2	47.6	49.3	43.7	40.4	44.6	48.9	40.9
Dividing the energy E by the cooking power:												
TIME [min]	61	64	63	74	62	63	60	68	74	67	61	73

As we can see, the mean time for cooking beans is inside the range estimated before. As a consequence, considering the upper more conservative extreme, we could forecast that in 85 sunny days in Burundi the panel stove could be used for cooking 0.3 kg of beans in 0.4 liters of water in 73 minutes straddling noon.

[30] The quantity of water used is suggest by [161] AK Aremu, and R Akinoso, "Use of solar cooker in Nigeria," *International Food Research Journal,* vol. 20, no. 5, pp. 2881-2886, 2013..

Bean test

My panel stove has been used for cooking beans three times. Temperatures and time have been monitored with a thermometer. Quantities of water and beans were not the same of the previous forecast because the cooking test was taken before. In fact, it does not want to be a scientifically relevant confirmation of the previous procedure but only an indication. In the following Table 4.22, tested and forecasted results obtained with the procedure of the previous section are reported.

Table 4.22 – Real and forecasted results of the beans cooking test.

	17/05/2014	***11/06/2014***	***13/06/2014***
Hours	10:30 - 12:20	10:20 - 12:20	10:00 - 11:40
Beans [kg]	0.450	0.225	0.225
Water [kg]	1	1	1
Midday DNI [W/m²]	947	751	859
Cooking power [W]	62	49	57
Energy required [J]	374465	323278	323278
TIME FORECASTED [min]	**101**	**109**	**96**
TIME REAL [min]	**110**	**120**	**100**
Difference[31][%]	+8%	+9%	+4%

Figure 4.28 – Pictures during and at the end of the solar bean cooking tests.

[31] Difference between the real and the forecasted time as a percentage of the real ones.

All three tests suggest that the time for cooking beans in a solar stove bringing the water from 25 to 90°C is a slighted greater than the expected one. However, there is a low difference of at least 10 minutes. Although they do not represent a scientific test, they are good indicators about the possible validity of the model. Moreover, they confirm the crucial role of water: an excess of it could cause a great increase in the required time.

4.2.6 Discussion

This focus on solar cookers examines only the self-construction and test that are needed to decide if they could be an appropriate solution at the kitchen used by patients' relatives in the Hospital of Mutoyi Mission. If it is so, a pilot project will be necessary to test an effective utilization. Therefore, from this prefeasibility study these following consideration could be taken about the stoves:

1. Box stove seems not to be an appropriate solution for cooking food. Besides taking too much time to heat water with the typical solar irradiation of Burundi, it shows these following disadvantages:
   - it is more expensive than the panel cooker;
   - it never reaches the boiling temperature;
   - it is more complicate to build.

   However, solar box has some advantages that make it useful for other applications. Without a pot, panel stove does not heat anything because rays are absorbed. Differently from it, thanks to the black plate and the insulation, temperature reached inside the box cooker is uniform and it could be used as a heat storage. Moreover, it could accommodate two pots and the little door built on the side makes their insertion and extraction easier. As a consequence, cookers could be used for heating an already cooked food without burning wood. They could be sunned in the morning for heating the internal box. People who only need to warm the food could put their pots inside the cookers and go to visit their patients. Food without water (e.g. potatoes or bananas) could be warmed without the pot cover. This allows food to receive the irradiation directly without fogging the transparent cover of the stove.
2. Panel stove seems to be a useful solution for cooking food in sunny days. They are cheap and easy to build and they showed the best performance. In fact, 0.3 kg of beans in 0.4 liters of water could be cooked in less than one hour and half that is a reasonable time. Unfortunately, we saw that days without clouds are at least 80 [163]. They are surely a small fraction

of the entire year but a future success would have a big impact on people: more time with patients, new knowledge and capacity building, and possible diffusion between households.

Furthermore, the time for cooking has been observed to be highly dependent on the type and quantity of food, and principally the amount of water. In conclusion, cookers have been tested with a covered black pot. Most pots in Burundi are made of aluminum and covers are not always used.

All these considerations confirm the impossibility to make reliable forecast about the benefits that could be reached with these technologies. On the contrary, this analysis shows the need to test the cookers in field and confirm their compatibility with the real habits of people.

5 Energy, economic and environmental analysis of technologies

Differently from solar cookers, the other technologies analyzed in the previous chapter could be subject to an energy, economic and environmental analysis. Therefore, the aim of this chapter is to calculate and report all the benefits of technologies in terms of wood and CO_2 savings, and associated costs. A way has been proposed to choose the most appropriate technology for PaMu and the Hospital. For the kitchen used by relatives the unique appropriate solutions are the ICSs (solar cookers will be pre-evaluated only, and they need a direct in field Programme of testing and acceptation). The evaluation of the appropriate solar technologies will be done with the help of the software TRNSYS that allows to simulate solar plants.

5.1 Methodology and physical approach

This section aims to introduce the way used to evaluate the energy benefits of technologies, an economic analysis of costs and savings, and the greenhouse emissions.

5.1.1 Energy evaluation of wood savings

Energy evaluation has been done in terms of wood saved for cooking food. Since wood and water consumption have been monthly evaluated, all the following equations are referred to one month. The approach has been different on the strength of the three areas of implementation. However, for all the methodologies we need to introduce these variables of Table 5.1.

<u>PaMu</u>

In Paragraph 3.4.2, it was said that at PaMu the real wood savings obtained for the hospital meals would be calculated inside a range obtained with the hypothesis of constant wood and water through the year, and wood proportionally to the number of patients and constant water. As a consequence, for both the scenarios, knowing the amount of water used in each stove it is possible to evaluate the secondary energy.

Table 5.1 – Table of abbreviations.

$\boldsymbol{LHV}$	Low Heating Value of wood
$\boldsymbol{C_p}$	Specific Heat of water
$\boldsymbol{T_{boil}}$	Boiling temperature of water
$\boldsymbol{T_{aquifer}}$	Temperature of the aquifer
$\boldsymbol{T_{heat}}$	Temperature of preheating of the water
$\boldsymbol{T_{tech}}$	Maximum temperature reached by technology
$\boldsymbol{\eta_{Plancha}}$	Effieciency of $Plancha$ stove
$\boldsymbol{\eta_{Rocket}}$	Effieciency of $Rocket$ stove
$\boldsymbol{\eta_{OF}}$	Effieciency of $Open\ Fire$ stove
$\boldsymbol{m_{hot\ water_{Plancha}}}$	Water heat from $\mathrm{T_{aquifer}}$ to $\mathrm{T_{heat}}$ on $Plancha$
$\boldsymbol{m_{boil\ water_{Plancha}}}$	Water boiled on $Plancha$
$\boldsymbol{m_{hot\ water_{Rocket}}}$	Water heat from $\mathrm{T_{aquifer}}$ to $\mathrm{T_{heat}}$ on $Rocket$
$\boldsymbol{m_{boil\ water_{Rocket}}}$	Water boiled on $Plancha$
$\boldsymbol{m_{water_{Plancha}}}$	Water heat from $\mathrm{T_{aquifer}}$ to $\mathrm{T_{boil}}$ on $Plancha$ for the restaurant
$\boldsymbol{m_{wood_{PaMu}}}$	Total wood actually burned at PaMu
$\boldsymbol{m_{wood_{Hospital}}}$	Total wood actually burned at the Hospital
$\boldsymbol{E_{II_{Plancha}}}$	Secondary energy saved for heating the water up to on $Plancha$
$\boldsymbol{E_{II_{Rocket}}}$	Secondary energy saved for heating the water up to on $Rocket$
$\boldsymbol{\Delta m_{Plancha}}$	Wood saved for heating the water on $Plancha$
$\boldsymbol{\Delta m_{Rocket}}$	Wood saved for heating the water on $Rocket$
$\boldsymbol{S_{PaMu}}$	Percentage of wood savings at PaMu
$\boldsymbol{S_{Hospital}}$	Percentage of wood savings at the Hospital
$\boldsymbol{S_{Relatives}}$	Percentage of wood savings by patients′ relatives

The secondary energy is calculated as the product between the mass of water, its heat capacity and the relative differences of temperatures.

$$E_{II_{Plancha}} = m_{hot\,water_{Plancha}} * C_p * \left(T_{heat} - T_{aquifer}\right) + m_{boil\,water_{Plancha}} * C_p * (T_{tech} - T_{heat})^{32} \quad (5.1)$$

$$E_{II_{Rocket}} = m_{hot\,water_{Rocket}} * C_p * \left(T_{heat} - T_{aquifer}\right) + m_{boil\,water_{Rocket}} * C_p * (T_{tech} - T_{heat})^{32} \quad (5.2)$$

Dividing by the two extremes of the efficiency ranges of the stoves evaluated in Paragraph 3.2.2, it is possible to calculate the primary energy saved. Dividing further for the Low Heating Value, we find the amount of wood saved by the stoves:

$$\Delta m_{Plancha} = \frac{E_{II_{Plancha}}}{\eta_{Plancha}} * \frac{1}{LHV} \quad (5.3)$$

$$\Delta m_{Rocket} = \frac{E_{II_{Rocket}}}{\eta_{Rocket}} * \frac{1}{LHV} \quad (5.4)$$

Adding these two values and dividing by the total use of wood estimated in Paragraph 3.4.2 we find the percentage of wood savings by PaMu for both the scenarios in every month:

$$S_{PaMu} = \frac{\Delta m_{Plancha} + \Delta m_{Rocket}}{m_{wood_{PaMu}}} \quad (5.5)$$

At PaMu, wood savings would be obtained also for the preparation of meals at the restaurant. In Paragraph 3.4.2, it was stated that for the restaurant they only use *Plancha* where they bring water to the boiling point. As a consequence:

$$E_{II_{Plancha}} = m_{water_{Plancha}} * C_p * \left(T_{tech} - T_{aquifer}\right) \quad (5.6)$$

---

[32] If $T_{tech} < T_{heat}$ the second term is 0, and T_{heat} of the first parenthetical is substituted by T_{tech}.

Wood savings and their relative percentages will be evaluated in the same way as above.

Hospital

In the hospital, the solution is a bit easier to calculate because there is not the need to evaluate a range of solutions (see Paragraph 3.4.1). Moreover, there is not the need to distinguish the energy necessary to heat the water from energy to boil it because all the water is brought to the boiling point always on the same stove. Therefore, the secondary energy could be easily calculated as follows:

$$E_{II_{Plancha}} = (m_{hot\,water_{Plancha}} + m_{boil\,water_{Plancha}}) * C_p * (T_{tech} - T_{aquifer}) \quad (5.7)$$

$$E_{II_{Rocket}} = (m_{hot\,water_{Rocket}} + m_{boil\,water_{Rocket}}) * C_p * (T_{tech} - T_{aquifer}) \quad (5.8)$$

Wood savings and their relative percentage will be evaluated in the same way used for PaMu.

Patients' relatives

Since wood and water needs cannot be evaluated (see Paragraph 3.4.3), savings that could be reached with a future action would be expressed only in terms of percentage. In fact, as opposed to PaMu and the Hospital, technological solutions for this area could consider the use of ICSs with higher efficiencies than the open fire stove. If we consider the same secondary energy for cooking meals, ceteris paribus the following equation could be written:

$$E_{II_{OF}} = E_{II_{ICS}} \quad (5.9)$$

with E_{II} the secondary energy for cooking meals, the subscripts OF and ICS specify the open fire stove and the improved cook stove.

Knowing the efficiency of the stoves, from E_{II} it is possible to go back to the primary energy:

$$E_{I_{OF}} * \eta_{OF} = E_{I_{ICS}} * \eta_{ICS} \quad (5.10)$$

$$m_{wood_{OF}} * LHV * \eta_{OF} = m_{wood_{ICS}} * LHV * \eta_{ICS} \quad (5.11)$$

Simplifying and arranging the equation:

$$\frac{m_{wood_{ICS}} - m_{wood_{OF}}}{m_{wood_{OF}}} = 1 - \frac{\eta_{OF}}{\eta_{ICS}} \tag{5.12}$$

The term on the left of the equation represents the saving of wood that a future use of ICSs could achieve:

$$S_{Relatives} = 1 - \frac{\eta_{OF}}{\eta_{ICS}} \tag{5.13}$$

5.1.2 Economic evaluation

The economic evaluation reported for each technology takes into account the investment, the annual economic revenues for the supply of wood and the cost of energy. In fact, both in the case of available energy thanks to *Burundi Energie Saine et pour Tous* Project and in the case of missed implementation, electrical energy represents a cost. In the first case, it is a missed opportunity cost because less surplus energy would be remunerated by REGIDESO to the Mission (see the end of Paragraph 3.1.1). In the second one, it is an operating cost.

For each technology, the revenues obtaining by subtracting the following two terms are reported:

1. The cost of energy obtained by multiplying the energy consumption evaluated in Paragraph 4.1 by the specific cost of energy equal to 190 FBU/kWh (0.092 €/kWh, see Paragraph 2.4.2).
2. The amount of money savings for the supply of wood. Thanks to data collected during the Mission of August 2013 and reported in Paragraph 3.4.2, it was possible to know the costs of the supply chain of wood at PaMu (the hospital does not buy wood).

5.1.3 Greenhouse gases

The last information that needs to be evaluated is the CO_2 balance. In fact, every technology will provide CO_2 savings that are a consequence of less burned wood. With the aim to evaluate these savings, the first step would be the evaluation of the amount of CO_2 produced by the combustion of wood. A global reaction for the combustion of a biomass fuel in air might take the following form, where the first reactant compound is a biomass fuel [94]:

$$C_{x1}H_{x2}O_{x3}N_{x4}S_{x5}Cl_{x6}Si_{x7}Ca_{x9}Mg_{x10}Na_{x11}P_{x12}Fe_{x13}Al_{x14}Ti_{x15} + n_1H_2O + n_2(1+e)(O_2 + 3.76N_2) = n_3CO_2 + n_4H_2O + n_5O_2 + n_6N_2 + n_7CO + n_8CH_4 + n_9NO + n_{10}NO_2 + n_{11}SO_2 + n_{12}HCl + n_{13}KCl + n_{14}K_2SO_4 + n_{15}C + \cdots$$

The second reactant term expresses the moisture in the fuel, which can be extremely variable, at least within limits. The third term is air represented by the simple binary mixture of oxygen and nitrogen in the volume ratio of 21% to 79%. Air, of course, includes many more constituents, but these are not as important in a gross analysis. The product side of the reaction is complex. The main products are those appearing first, but there are a host of products important to the successful operation of a commercial biomass combustion system, including criteria atmospheric pollutants such as CO, hydrocarbons (HC), oxides of nitrogen and sulfur. There are also reactions among inorganic species leading to the fouling and slagging, such as the alkali chlorides, sulfates, carbonates and silicates [94].

As seen in the reaction above, the stoichiometric combustion which converts all the organic carbon of the fuel in CO_2 is an ideal situation. In fact, incomplete combustion can lead to high emissions of unburnt pollutants such as CO [164]. Parts of carbon is converted in methane and released in ashes. It is such a complex phenomenon that is very difficult to estimate the greenhouse emission from the combustion of 1 kg of wood. However, research found in literature approximately confirms the same value that typically recurs in processes of combustion in closed wood stoves: about 95% of carbon on molar basis contained in the biomaterial is volatilized as CO_2 [78, 79, 94, 165, 166]. Multiplying by the molar mass of the carbon dioxide (44 kg/kmol) and dividing by the molar mass of carbon (12 kg/kmol) it is possible to find the mass ratio x_{CO_2}during the process of combustion.

$$x_{CO_2} = 0.95 \left[\frac{kmol_{CO_2}}{kmol_C}\right] * \frac{44\left[\frac{kg_{CO_2}}{kmol_{CO2}}\right]}{12\left[\frac{kg_C}{kmol_C}\right]} = 3.48 \left[\frac{kg_{CO_2}}{kg_C}\right] \qquad (5.14)$$

The carbon content y_C of wood varies from about 47% to 53% due to varying lignin and extractives content [167]. For *Eucalyptus*, the content is calculated as an average of the values presented in [95, 101-104] that confirm these values reported below:

Table 5.2 – Carbon content in *Eucalyptus* (Source [95, 101-104]).

	As received (y_C)	Dry (including ash)	Dry and Ash free
Carbon content [%wt]	46.2	50.3	51.1

Knowing the amount of wood normally used by PaMu and the Hospital it is possible to calculate the actual value of the CO_2 emission throughout the months by using the following equation:

$$m_{CO_2} = m_{wood} * y_c * x_{CO_2} \quad (5.15)$$

Multiplying $m_{CO_2}$by the future wood savings calculated following the previous Paragraph 5.1.1 it is possible to obtain the future CO_2 savings.

For patients' relatives the values of the emissions are not calculated because the values of the present wood consumptions cannot be estimated. We can only say that greenhouse emissions will decrease with the same percentage of wood savings.

To complete the balance of CO_2, it is necessary to consider the greenhouse emissions related to the use of hydroelectric plants[33]. The hydroelectric plants of the country are run-to-river plants with no reserves. Thanks to [168, 169], it is possible to estimate the emissions of a small hydroelectric run-to-river plants from 0.3 – 13 gCO_2-eq./kWh. For a more preventive result, the value of 13 gCO_2-eq./kWh will be used. Therefore, it is possible to go back to the emissions of the plants multiplying the amount of energy consumed by the specific emissions of the plants and by a coefficient equal to 1.05 that considers the grid losses [58].

5.2 Pre-evaluation of solar solutions using TRNSYS software

5.2.1 Introduction

TRNSYS is an extremely flexible graphically based software environment used to simulate the behavior of transient systems. It is made up of two parts. The first is an engine (called the kernel) that reads and processes the input file, iteratively solves the system, determines convergence, and plots system variables. The

[33] We saw that the production is almost all hydroelectric during the night.

kernel also provides utilities that (among other things) determine thermo physical properties, invert matrices, perform linear regressions, and interpolate external data files. The second part of TRNSYS is an extensive library of components, each of which models the performance of one part of the system. The standard library includes approximately 150 models ranging from pumps to multizone buildings, wind turbines to electrolyzers, and weather data processors to economics routines. Models are constructed in such a way that users can modify existing components or write their own, extending the capabilities of the environment [170].

For the aim of this work, the software will be used for simulating the operation of the solar plants and evaluating the benefits. Therefore, it is necessary to remember that it is not used for the optimization of the solar plants.

5.2.2 Input of the software

TRNSYS substantially needs four inputs:

1. Weather data are fundamental parameters that allow simulating the global incident radiation on the collectors and thermal losses. Data are downloaded from global meteorological database for solar energy and applied climatology called METEONORM [163]. They are referred to the city of Bujumbura and include the following information for each hour of the year:
   - Air temperature;
   - Zenith solar angle;
   - Azimuth solar angle;
   - Diffuse Irradiation on the horizontal;
   - Direct Normal Irradiation.

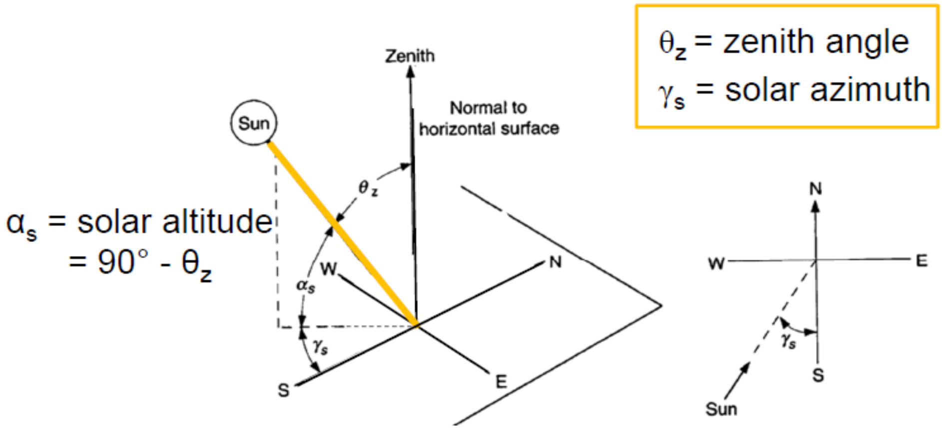


Figure 5.1 – Solar angles (Source [171]).

Thanks to this information, TRNSYS is able to calculate the Global Irradiation for any tilted surface.

2. The tilt of solar collectors allows evaluating the incident angle on the surface. The optimal tilt depends on the elevation of the Sun that depends in turn on the locality. For example, near the equator, the sun could reach an elevation of 90° and panel should stay horizontal. In Burundi, the optimal tilt has been evaluated during the winter seasons from January to February and from July to August when the weather is sunny. The Solar Electricity Handbook [172] reports the optimal tilt for each city of the World for each season of the year. In Burundi, it corresponds to 20° on the horizontal.
3. Collectors' data are needed to evaluate the hourly efficiency through which TRNSYS could calculate thermal power directly transferred to the fluid inside the panels. These parameters are fundamentally the optical efficiency, both the coefficient of losses and the IAM parameter that have been reported in Paragraph 4.1.3.
4. Data of the storage are read by the software with the aim to evaluate the heat transfer between the internal serpentines, the heat generated by eventual resistances and the water. They are fundamentally the dimensional parameters and information about the materials downloaded from the manual.
5. Hourly water needs in terms of removals from the storage has to reproduce reality. As a consequence, it has been defined on the strength of the daily water needs seen during the mission in August. At PaMu, about 80% of water is consumed between 6.30 a.m. and 11.30 a.m. and

the remaining is used in the afternoon for cooking beans. At the Hospital, water is half used from 6 a.m. to 8 a.m. and from 1 p.m. to 3 p.m..

6. TRNSYS does not simulate the heat pump operation. As a consequence, the operation of the device has been simulated as an auxiliary heater. Using the equation of the COP trend interpolated from Figure 4.3 it has been possible to calculate the real electricity consumption.

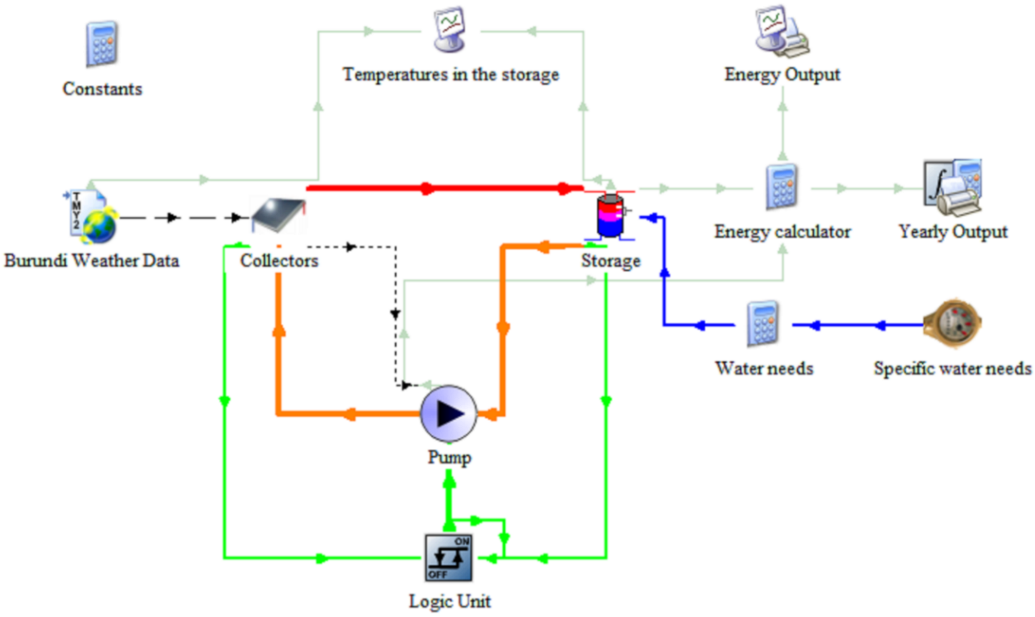


Figure 5.2 - TRNSYS simulation of the solar plant.

In conclusion, these following six plants have been simulated:

1. Solar collectors with storage at PaMu;
2. Solar collectors with electrical water at PaMu;
3. Solar collectors with heat pump at PaMu;
4. Solar collectors with storage at the Hospital;
5. Solar collectors with electrical water at the Hospital;
6. Solar collectors with heat pump at the Hospital.

5.2.3 Output of the software

The first main output of the software is the temperature reached in the buffer during the day. Because the water is used in both the structures from 6 a.m. to 3 p.m., the daily mean temperature of the water in the storage has been calculated in this time range. After this, these values have been averaged during the month. This is because the energy balances and equations that have been written in Paragraph 5.1.1 are referred to one month. Knowing the monthly mean temperature that the solar technology could reach we can evaluate the secondary energy provided by all the technologies. For example, it is reported the graphic output in both the cases with and without the electrical water heater respectively:

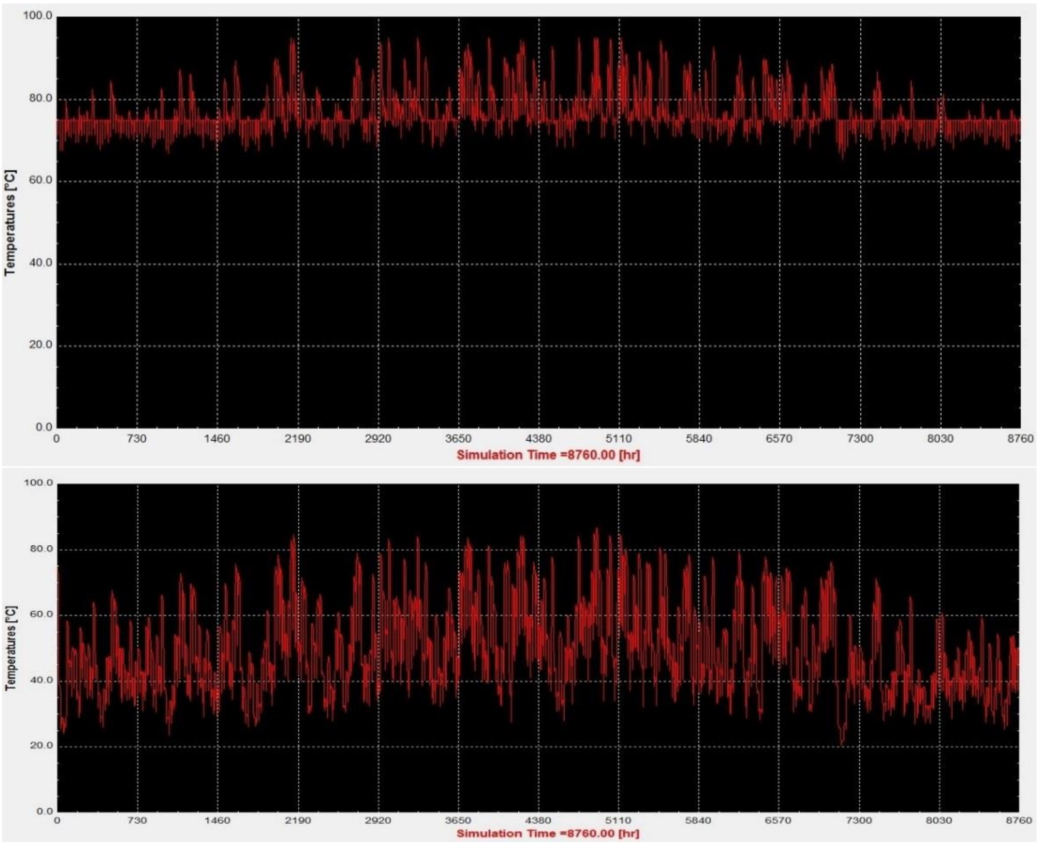


Figure 5.3 – Trend of Temperatures in the storage with electrical water heater and only solar collectors at PaMu (TRNSYS Output).

Table 5.3 – Monthly mean higher temperatures that can be reached in the storages [°C].

	Hospital			PaMu		
	Only solar collectors	*Solar collectors and electrical water heater*	*Solar collectors and heat pump*	*Only solar collectors*	*Solar collectors and electrical water heater*	*Solar collectors and heat pump*
Jan	47.9	75.5	64.4	47.9	75.4	63.3
Feb	50.1	76.1	65.7	50.1	75.9	64.4
Mar	53.2	77.9	69.3	53.2	77.3	66.9
Apr	54.8	77.8	69.6	54.8	77.1	66.6
May	60.2	79.0	73.3	60.2	78.2	69.4
Jun	65.4	81.8	78.2	65.4	80.4	73.4
Jul	61.7	79.9	74.7	61.7	78.9	70.7
Aug	62.5	80.7	75.8	62.5	79.4	71.6
Sep	56.7	78.7	71.7	56.7	78.0	68.4
Oct	54.6	78.0	71.1	54.6	77.5	67.4
Nov	45.9	75.8	64.2	45.9	75.6	62.8
Dec	45.8	75.2	62.8	45.8	75.1	62.2

For each plant, the monthly mean temperatures reached in the buffer are reported in Table 5.3. A first look at the table allows us to make the following considerations:

1. The solar integration applied to the electrical water heater permits it to reach a temperature 5°C higher than the solution without solar collectors.
2. The solar integration applied to the heat pump permits it to reach a temperature 15°C higher than the solution without solar collectors.
3. Increasing the size of the storage and the number of collectors could be done with the aim to reach higher temperatures but, considering that they have just doubled compared to the daily water needs, the system would be over dimensioned with a lot of hours of stagnation.

The second output is the electrical consumption of the solutions. Electricity consumed by plants with no boilers is due to the solar pumps (Table 5.4).

Table 5.4 – Monthly mean electrical energy consumed by the plants [kWh].

	Hospital			**PaMu**		
	Only solar collectors	*Solar collectors and electrical water heater*	*Solar collectors and heat pump*	*Only solar collectors*	*Solar collectors and electrical water heater*	*Solar collectors and heat pump*
Jan	2.9	386.7	57.3	2.9	562.5	91.2
Feb	2.6	312.0	44.6	2.6	469.1	74.3
Mar	2.9	307.0	45.5	2.9	469.2	72.4
Apr	2.8	283.0	38.9	2.8	442.3	63.6
May	2.9	207.1	21.2	2.9	364.7	42.9
Jun	2.8	153.8	18.9	2.8	294.2	31.7
Jul	2.8	199.9	23.1	2.8	354.7	44.2
Aug	2.9	190.0	21.3	2.9	341.7	40.9
Sep	2.8	254.8	35.5	2.8	411.1	58.6
Oct	2.9	307.4	46.7	2.9	466.9	70.4
Nov	2.8	397.2	64.0	2.8	571.2	97.8
Dec	3.0	408.0	62.3	3.0	584.8	96.5

In conclusion, the errors on the global yearly energy balance is reported in Table 5.5:

Table 5.5 – Energy balance errors.[34]

	Hospital			**PaMu**		
	Only solar collectors	*Solar collectors and electrical water heater*	*Solar collectors and heat pump*	*Only solar collectors*	*Solar collectors and electrical water heater*	*Solar collectors and heat pump*
ε [%]	-6%	-6%	-9%	-6%	-4%	-6%

[34] As percentage of energy inputs.

5.3 Results for all the technological alternatives

This section summarizes the results obtained with all the technologies seen above. It reports the yearly benefits that could be obtained at PaMu and the Hospital (monthly details are reported in APPENDIX A). Because the range of stove efficiency has been chosen, it is important to remember that the solution would be included in a range of values. They are represented with light red and yellow that are referred respectively to the lowest and the highest extremes of efficiency range of the stoves. Moreover, considering both the activities of PaMu (meals for the hospital and for the restaurant which includes the preparation of bread in the big wood oveb), the two hypothesis of *wood and water constant*, and *water constant and wood proportion to the number of patient during the year* cause at least a difference of 2%. As a consequence, it is handier to average the values. However, all the details are reported in APPENDIX A.

Table 5.6 – Table of yearly results of all the technologies at PaMu.

P.A.M.U.					
	Cost of technology [€]	***S [%]***	***Electrical Energy [kWh]***	***Revenues [€]***	**CO_2 [ton]**
Electrical water heater	1150	16.9%	10220	-625.5	-26.4
		11.5%		-726.3	-17.9
Heat Pump with resistances	2x2471	16.9%	5375	-179.8	-26.5
		11.5%		-280.6	-18.0
Heat Pump	2x2471	12.0%	1963	44.0	-18.9
		8.1%		-29.2	-12.8
Electrical water heater with solar integration	4721	17.4%	5332	-166.6	-27.3
		11.8%		-270.8	-18.5
Heat Pump with solar integration	8300	14.9%	784.45	206.4	-23.5
		10.1%		116.2	-15.9
Only solar collectors and storage	3500	11.0%	35	202.5	-17.4
		7.4%		135.0	-11.7

Table 5.7 - Table of yearly results of all the technologies at the Hospital.

HOSPITAL					
	Cost of technology [€]	***S [%]***	***Electrical Energy [kWh]***	***Revenues [€]***	**CO_2 [ton]**
Electrical water heater	910	31.5%	7665	-704.8	-9.6
		24.7%			-7.5
Heat Pump with resistances	3413	31.5%	4258	-391.5	-9.7
		24.7%			-7.6
Heat Pump	3413	20.4%	1712	-157.4	-6.3
		16.0%			-4.9
Electrical water heater with solar integration	4721	33.1%	3407	-313.4	-10.2
		26.0%			-7.9
Heat Pump with solar integration	8300	28.6%	479	-44.1	-8.8
		22.5%			-6.9
Only solar collectors and storage	2610	20.3%	36	-3.3	-6.2
		15.9%			-4.9

For the solution concerning the kitchen used by patients' relatives, using the range of efficiency found in Paragraph 4.1.4, for each use of the ICSs we obtain wood and CO_2 savings reported in Table 5.8 below.

Table 5.8 – Range of wood savings obtained with ICSs for kitchen used by patients' relatives.

Worst forecast	Best forecast
10%	67%

5.4 Discussion

The end of this chapter represents a proposal of choice of the most appropriate technological solutions. The choice will affect only the alternatives for PaMu and the Hospital because the only feasible solution for the kitchen used by patients' relatives is represented by the ICSs. The main hypothesis behind the following choice is that Vispe will implement the *Burundi Energie Saine et pour Tous* Project as it seems to be actually undergoing.[35]

In Paragraph 1.2.2 it has been stated that sustainable energy must assure economic, environmental and social sustainability. All these three aspects have to be quantified through indicators that could be applied to all the technologies. It is necessary to find a hierarchy that permits us to organize the priorities and to find the most appropriate technology. In order to define these priorities we need to consult the stakeholders that are:

1. Vispe that supervise and manage all the activities of the Mission among which includes the Hospital and PaMu;
2. Workers at PaMu;
3. Workers at the Hospital.

Workers would be the effective users of the plants and it is important to assure their willingness to collaborate actively. During the Mission of 2013, workers at PaMu showed a great interest in the project, and they contributed actively to data collection. Workers at the hospital did not show the same interest but they are used to new technologies installed and they are subject to a marked and continuous supervision of Vispe. Because they would be only the users of the plants, their single priority is that the future technology will not obstacle and extend their work. Considering all the technological alternatives, it is clear how they meet the interests of the workers in the same way. Furthermore, they would even reduce the time needs to heat the water. As a consequence, the priorities and their relative indicators have been draft only with Vispe and they are:

- Reduction in the use of wood biomass;
- Investments;
- The amount of money savings for the supply of wood (only for PaMu because in the hospital does not buy wood);
- Cost of operating[36];

[35] At this time, all the authorizations have been reached and some of the civil work has been started. The definite beginning of the work depends on the available economic resources of Vispe. The Project has been presented at the call of ACP-EU Energy Facility at 2014 but it is only a matter of time and scheduling independently from the results. This hypothesis allows us to remove a strong variable that is the cost of electricity.

[36] Because of the hypothesis of free and available energy, operating cost represents the missed opportunity cost that could be obtained if the electricity will not consumed but sold to REGIDESO.

- Creation of Capacity Building and dissemination of new technical know how.

Thanks to the following consideration it has been possible to exclude the fourth indicator. In fact with *Burundi Energie Saine et pour Tous*, Vispe will benefit from an yearly surplus of 1,890 MWh that corresponds to 174,000€ if it is sold to REGIDESO. As a consequence, the higher missed opportunity cost related to the solution concerning the electrical water heater represents the 0.94% of this value which is reasonably paltry and negligible. Therefore, the cost of operating can be excluded from priorities.

Moreover, for a more reliable analysis, it will be based only on the first three quantitative indicators. The last one will be used only for keeping into consideration some non technological issues that are relevant in the cooperation field.

Thanks to results obtained and reported in Table 5.6, Table 5.7 and in the APPENDIX A, the impact of technology on the three previous indicators can be ordered from 1 (the best) to 5 (the worst) in Table 5.9.

Table 5.9 – Table of technologies and their impact on the indicators.[37]

	Reduction in the use of wood	**Investments**	**Money savings for the supply of wood**
Electrical Water Heater	**2** (21.15%)	**1** (2060€)	**2** (263.6€)
HP + Electrical Resistors	**2** (21.15%)	**3** (8355€)	**2** (263.6€)
HP	**4** (14.13%)	**3** (8355€)	**4** (187.6€)
Electrical Water Heater + Solar	**1** (22.08%)	**4** (9442€)	**1** (266.5€)
HP+ Solar	**3** (19.03%)	**5** (16600€)	**3** (233.5€)
Only solar and buffer	**5** (13.65%)	**2** (6110€)	**5** (172.2€)

[37] They are the yearly mean values calculated from the tables of results in the previous Paragraph and in the APPENDIX A.

Excluding the technologies that excel in neither of the two dimension, the choice is between the electrical water heater with or without solar integration that reach the highest wood and money savings. From the table, we could see that solar integration allows the water heater to reach mean yearly percentages of wood savings of 0.93% (1.6% and 0.4% higher respectively at the Hospital and PaMu) and 3€ higher that do not justify an investment of almost 7000€ higher. Moreover, the electrical water heater is the simplest technology and the most compact solution that requires the maintenance competences typical of electricians and plumbers. As the consequence, the electrical water heater is most appropriate solution for the particular situation of Mutoyi.

The importance of the last qualitative indicator is considered for the second step of this decision making process if we consider the important role of the pilot project in this work and the possibility to replicate it in other structures. In this case, the hypothesis of free supply of electricity would be lost. Therefore, the cost of energy becomes a crucial parameter and the difference between this cost and the amount of money savings for the supply of wood has to be considered. In this case, the only solutions that could guarantee an economic revenue are the solar collectors with or without the heat pump. Moreover, if we think about the possibility to receive a financing by an external donor, the cost of investment is no longer a constraint and the heat pump with solar integration becomes the most suitable solution because it guarantees the highest value of wood savings. In addition, solar panel technology often lends itself to be a homemade solution. For example, in collaboration with Engineering Without Borders [173], the construction and test of cheap homemade solar panels for communities and households are in progress. An eventual success could represent the beginning of the dissemination of new technical skills and capacity building. A possible and direct outcome could be the birth of local micro-enterprises for the construction and development of these devices.

In conclusion, the electrical water heater is surely the most appropriate solution for the particular context of Mutoyi and particularly for the Hospital. At PaMu, where percentages of wood savings are less divergent, the challenging heat solar pump could act as a springboard for the future spread of this technology in the Burundian rural area of Mutoyi with a positive impact on the surroundings. Because of the high cost of investment of the heat pump and collectors, the solution with the reduced capacity of the buffer equal to the daily water load has been simulated with TRNSYS. Using Equation *(4.2)*, the number of solar collectors is reduce to 4 for PaMu and 3 for the Hospital. The results summarized in Table 5.10.

Table 5.10 – Results for Heat Pump with solar integration with a smaller storage.

	Cost of Technology [€]	***S [%]***	***Electrical Energy [kWh]***	**Revenues [€]**	**CO_2 [ton]**
		P.A.M.U.			
Heat Pump with solar integration	6940	14.5%	1115	167.1	-22.77
		9.8%		79.7	-15.40
		HOSPITAL			
Heat Pump with solar integration	4170	25.0%	793	-72.9	-7.71
		19.6%			-6.03

With no external financings, this consideration could be useful. In fact, the solution concerning a smaller storage and less solar collectors has not a big impact on wood savings at PaMu (0.2% fewer) but it would entail the savings of 1300€. In the Hospital, wood savings are of 3% lower but the money savings are 4140€.

Conclusion

The final goal of this thesis was to individuate an appropriate cooking technological set-up based on the energy resources that could be used in Burundi to limit the overuse of wood cooking biomass and contribute to reduce its pressure on local deforestation. The location where this first feasibility study has been carried out is Mutoyi where the local ONG Vispe works in its Mission. The rural area of Mutoyi is totally inhabited by poor people that have no electricity access and use wood for cooking meals in low efficiency stoves. The Hospital *Centre de Santé* and the cooperative companies of the Mission are the only places with access to electricity and contemporarily they are the locations where the highest consumption of wood for cooking takes place. Starting with a feasibility study made for this kind of structure could have a great influence on the numerous similar places and people throughout Burundi.

Therefore, the main aims of this thesis were the following:

- to evaluate the entity of the problem of deforestation and to take an in-depth survey of all the energy resources in Burundi;
- to investigate and to evaluate the wood cooking biomass consumption and needs, and to make a performance analysis of the actual technological set-up of Mutoyi;
- to revamp the actual set-up thanks to a research of a new appropriate one for reducing the local wood use with local alternative energy resources;
- to evaluate the technologies through an energy, economic and environmental analysis and propose a final decision making process.

In order to achieve these goals:

- a socio-economic and energy assessment of the selected country has been carried out and the entity of the problem of deforestation has been analyzed. Hydroelectric generation and solar power are found to be the most available energy resources.
- a general assessment of the chosen location where a first feasibility study would be implemented has been made, especially in terms of wood needs and supply, and energy performance of the actual technological set-up.
- after this local assessment and the analysis of the local available and affordable energy resources, the appropriate technological alternatives for the selected structures have been individuated: electrical water

heaters, heat pumps, solar collectors with storage, ICSs and solar cookers. Electrical and solar devices are suitable for heating water for cooking. ICSs and Solar Cookers could also find an application in the hospital and replacing the actual stove with low efficiency. Since the difficulties to make forecasts with solar cookers, an experimental analysis of two devices was necessary for investigating the thermal properties and forecasting the eventual future use in the Mission. The two models were built and tested following the *International standard procedure for testing solar cookers and reporting performance* developed by the American Society of Agricultural Engineers. The panel cooker showed high performances and the ability to cook a typical Burundian meal of beans in one hour and half. On the contrary, the box cooker was found to be unsuitable for cooking but it could find some application as a chafing dish. The analysis shows the need to test the cookers in field and confirms the impossibility to make reliable forecast about the benefits that could be reached with these technologies.

- except for solar cookers, all the technologies have been analyzed from an energy, economic and environmental point of view. For the electrical devices, the energy evaluation is taken in terms of wood savings during the process of preheating of the water, while for the ICSs it is taken for the entire process of cooking meals. With the aim to estimate the solar benefits, the software TRNSYS helped to simulate the operation of the solar plants. The economic study was in terms of investment, revenues in wood expenditures and incremented cost of electricity. Thanks to an estimation of the greenhouse emissions from the combustion of *Eucalyptus* and from the hydroelectric generation, the global CO_2 balance is evaluated.

The results show that ICSs could guarantee wood savings between the 10% and 60% and confirm that they could be an appropriate solution to test in the particular kitchen used by patients' relatives. The final decision making process applied to the technologies for PaMu and the Hospital has been based on the analysis of quantitative and qualitative indicators that have been chosen with the stakeholders. The first main step has considered only the evaluation of three main quantitative indicators that are the cost of investment, the wood and money savings. Since Mutoyi would be supplied by free electricity thanks to the realization of a hydroelectric plant owned by Vispe, the cost of electricity is not considered as a constraint. The solutions that would guarantee the highest wood savings and the lowest cost of investment are the electrical water heaters with and without solar integration. Since the solar integration allows the water heater to reach a percentage of wood savings of only 0.9% and 3€ higher, this benefit does not justify an investment of almost 7000€ higher. As the consequence, the electrical water heater seems to be the most appropriate solution for the particular context of Mutoyi.

The second step of the final decision making process has considered a qualitative indicator that is the Creation of Capacity Building and dissemination of new technical know-how. In the field of cooperation, in fact, the impact of a project in the local context and the possibility to extend it on a large scale have to be considered. In this case, the operating cost of energy becomes a crucial parameter for the locations with no access to free electricity. Moreover, considering the possibility to receive an external financing, the technology of the heat pump with solar integration could enhance what we define as some challenges of the sustainable development. These challenges are to increase the access to clean cooking facilities, create new local capacities building for building homemade solar panels and technical skills for managing the operation of the heat pump, and start a local entrepreneurship.

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APPENDIX A

This section reports in detail the results summarized in Paragraph 0 concerning the evaluation of technological alternatives for PaMu and the Hospital. Particularly, the range of solutions concerning the preparation for meals for the hospital at PaMu is further expanded because of the two hypothesis of *wood and water constant*, and *water constant and wood proportion to the number of patient during the year* seen in Paragraph 3.4.2.

Electrical water heater

<u>*PaMu*</u>

Table A.11 – Results for PaMu with *Water constant and wood proportion to the number of patient during the year* with the water heater.

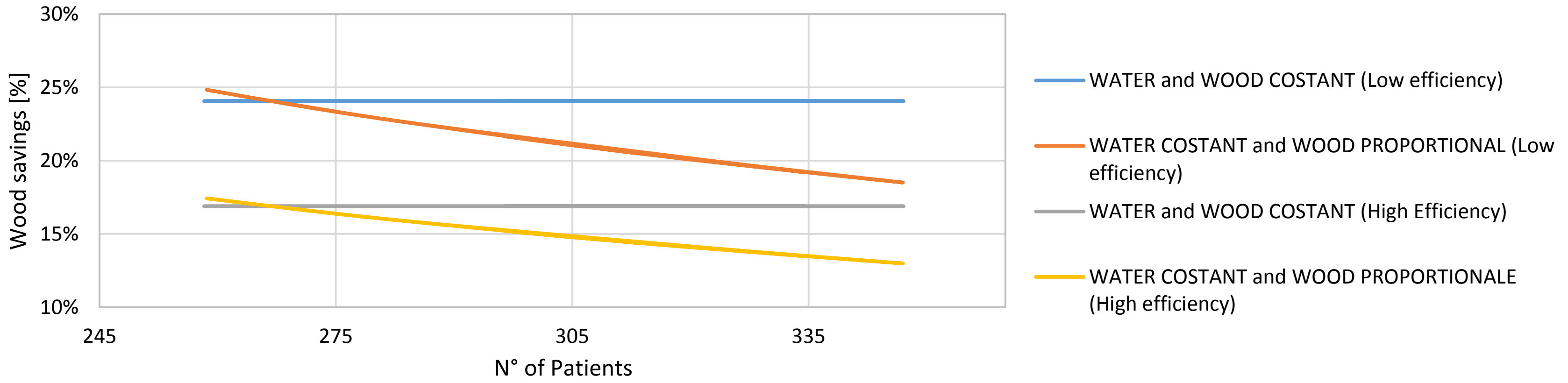
	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} $[°C]$	75											
LHV $[MJ/kg]$	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{hot\ water_{Plancha}}$ $[l]$	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770
$m_{boil\ water_{Plancha}}$ $[l]$	267	267	267	267	267	267	267	267	267	267	267	267
$E_{II_{Plancha}}[MJ]$	451	451	451	451	451	451	451	451	451	451	451	451
$\Delta m_{Plancha}[kg]$	364	360	367	367	350	343	341	341	345	360	372	370
	242	240	245	245	233	229	227	227	230	240	248	246
$m_{hot\ water_{Rocket}}[l]$	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$m_{boil\ water_{Rocket}}[l]$	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581
$E_{II_{Rocket}}[MJ]$	384	384	384	384	384	384	384	384	384	384	384	384
$\Delta m_{Rocket}[kg]$	82	82	83	83	79	78	77	77	78	82	84	84
	71	70	71	71	68	67	66	66	67	70	72	72
$m_{wood_{PaMu}}[kg]$	2177	2117	2080	2154	2321	2065	1855	1733	1720	1778	2007	2362
S_{PaMu} [%]	20.5%	20.9%	21.7%	20.9%	18.5%	20.4%	22.6%	24.1%	24.6%	24.8%	22.7%	19.2%
	14.4%	14.7%	15.2%	14.7%	13.0%	14.3%	15.8%	16.9%	17.2%	17.4%	15.9%	13.5%

For the hypothesis of *Water and wood constant during the year,* the mathematical results are equal to the previous table; the last two rows change only:

Table A.12 - Results for PaMu with *Water and wood constant during the year* with the water heater.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$m_{wood_{PaMu}}[kg]$	1855	1837	1873	1873	1786	1750	1739	1733	1757	1836	1895	1885
S_{PaMu} [%]	24.1%	24.1%	24.1%	24.1%	24.1%	24.1%	24.1%	24.1%	24.1%	24.1%	24.1%	24.1%
	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%



It is the figure has been forecasted at Paragraph 3.4.2. It would not reported for all the technologies because the most representative figure is the following one:

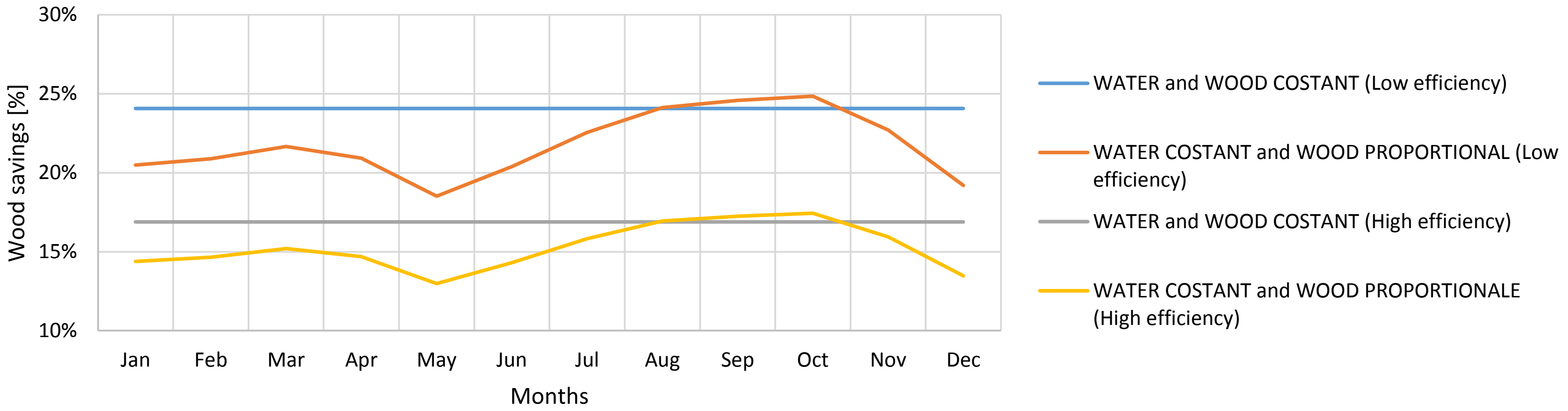


Figure A.1 - Trend of wood savings for PaMu during the year with the electrical water heater.

Table A.13 - Results for PaMu for meals of the restaurant with the water heater.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
T_{tech} [°C]	75											
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{Plancha}$ [l]	4960	4480	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960
$E_{II_{Plancha}}$ [MJ]	1183	1069	1183	1145	1183	1145	1183	1183	1145	1183	1145	1183
$\Delta m_{Plancha}$ [kg]	954	853	963	932	918	871	894	894	874	944	943	969
	636	569	642	621	612	581	596	596	583	629	629	646
$m_{wood_{PaMu}}$ [kg]	2101	1880	2122	2053	2023	1918	1970	1969	1926	2079	2077	2135
S_{PaMu} [%]	45.4%	45.4%	45.4%	45.4%	45.4%	45.4%	45.4%	45.4%	45.4%	45.4%	45.4%	45.4%
	30.3%	30.3%	30.3%	30.3%	30.3%	30.3%	30.3%	30.3%	30.3%	30.3%	30.3%	30.3%

Now, considering all the activities of PaMu, we can approximately estimate the yearly wood saving in as follow:

Table A.14 – Mean yearly wood savings at PaMu only for meals preparation with the water heater [38].

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
S_{PaMu} [%]	34.1%	33.7%	34.5%	34.0%	33.4%	34.1%	35.2%	35.8%	35.7%	35.7%	34.6%	33.4%	34.5%
	23.1%	22.9%	23.4%	23.1%	22.7%	23.2%	23.9%	24.3%	24.3%	24.3%	23.5%	22.7%	23.4%

[38] Considering both the activities of PaMu (meals for the hospital and for the restaurant), the two hypothesis of *wood and water constant*, and *water constant and wood proportion to the number of patient during the year* cause a differences of 2% at least. As the consequence, it is more handy to average the values.

Considering also the high consumption of wood for the brad oven that consumes approximatively the 50% of total wood provided at PaMu:

Table A.15 – Global mean yearly wood savings at PaMu considering all the activities with the water heater.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
S_{PaMu} [%]	16.9%	17.0%	17.0%	17.0%	16.4%	16.3%	16.7%	16.8%	17.0%	17.2%	17.3%	16.8%	16.9%
	11.4%	11.5%	11.6%	11.5%	11.2%	11.1%	11.3%	11.4%	11.5%	11.7%	11.7%	11.4%	11.5%

Concerning the economic analysis:

Table A.16 – Operating cost for PaMu considering all the activities with the water heater.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	868	784	868	840	868	840	868	868	840	868	840	868	10220
Monthly Cost of Electricity [EUR]	79.81	72.09	79.81	77.24	79.81	77.24	79.81	79.81	77.24	79.81	77.24	79.81	939.72
Savings of Wood [EUR]	26.20	26.39	26.47	26.42	25.51	25.29	25.90	26.10	26.35	26.70	26.80	26.12	314.19
	17.76	17.92	17.95	17.94	17.32	17.19	17.60	17.74	17.91	18.15	18.22	17.76	213.40
TOTAL [EUR]	-53.61	-45.70	-53.34	-50.82	-54.30	-51.95	-53.91	-53.71	-50.89	-53.11	-50.44	-53.69	-625.47
	-62.05	-54.17	-61.86	-59.30	-62.49	-60.05	-62.21	-62.07	-59.33	-61.66	-59.02	-62.05	-726.32

Finally the CO_2 balance:

Table A.17 – CO_2 savings at PaMu considering all the activities with the water heater.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	868	784	868	840	868	840	868	868	840	868	840	868	10220
CO_2 from Hydroplants [kg]	11.8	10.7	11.8	11.5	11.8	11.5	11.8	11.8	11.5	11.8	11.5	11.8	139.503
Savings of CO_2 because of lees wood [kg]	-2295	-2125	-2298	-2259	-2253	-2139	-2148	-2131	-2099	-2223	-2257	-2348	-26575
	-1556	-1443	-1559	-1533	-1529	-1453	-1459	-1448	-1427	-1511	-1534	-1597	-18050
TOTAL BALANCE [kg]	-2283	-2114	-2286	-2247	-2241	-2127	-2136	-2119	-2088	-2211	-2245	-2336	-26436
	-1544	-1432	-1547	-1522	-1517	-1442	-1447	-1436	-1416	-1499	-1523	-1585	-17911

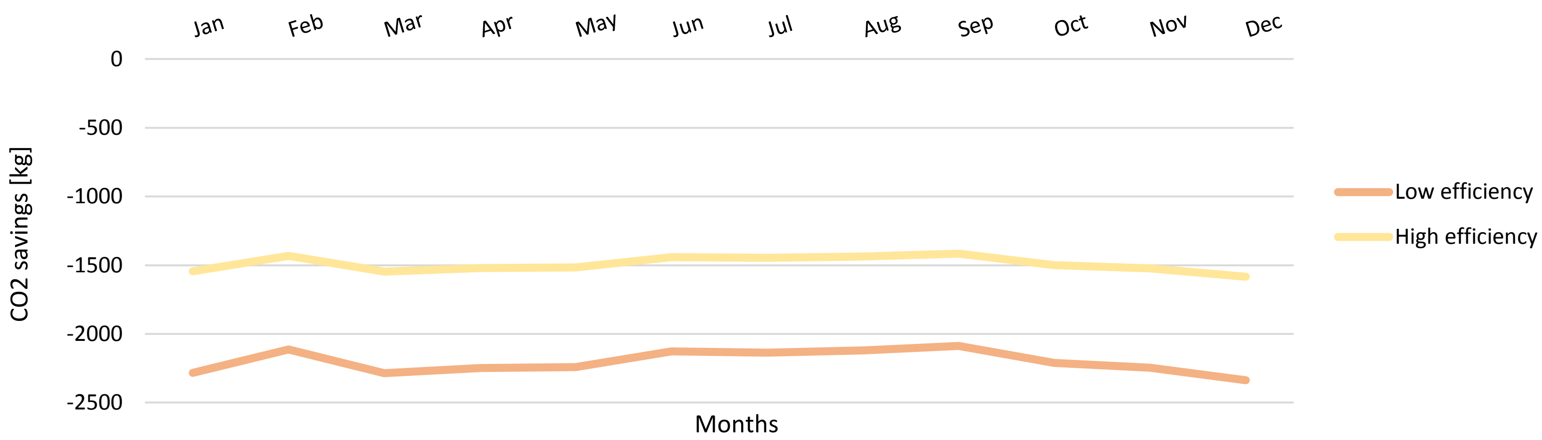


Figure A.2 – CO_2 savings for PaMu during the years with the water heater.

Hospital

Table A.18 – Results for the Hospital with the water heater.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} [°C]	75											
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{boil\ water_{Plancha}}$ [l]	1415	1161	1036	1231	2165	1404	777	362	246	192	708	1888
$E_{II_{Plancha}}$ [MJ]	338	277	247	294	517	335	185	86	59	46	169	451
$\Delta m_{Plancha}$ [kg]	272	221	201	239	401	255	140	65	45	37	139	369
	181	147	134	159	267	170	93	43	30	24	93	246
$m_{boil\ water_{Rocket}}$ [l]	6200	5600	6200	6000	6200	6000	6200	6200	6000	6200	6000	6200
$E_{II_{Rocket}}$ [MJ]	1479	1336	1479	1432	1479	1432	1479	1479	1432	1479	1432	1479
Δm_{Rocket} [kg]	318	284	321	311	306	290	298	298	291	315	314	323
	272	244	275	266	262	249	255	255	250	270	269	277
$m_{wood_{Hospital}}$ [kg]	1723	1515	1653	1652	1822	1580	1480	1391	1339	1431	1550	1860
$S_{Hospital}$ [%]	34.2%	33.4%	31.6%	33.3%	38.8%	34.5%	29.6%	26.1%	25.1%	24.5%	29.2%	37.2%
	26.3%	25.8%	24.8%	25.8%	29.1%	26.5%	23.6%	21.5%	20.9%	20.5%	23.4%	28.1%

YEAR	
31.5%	24.7%

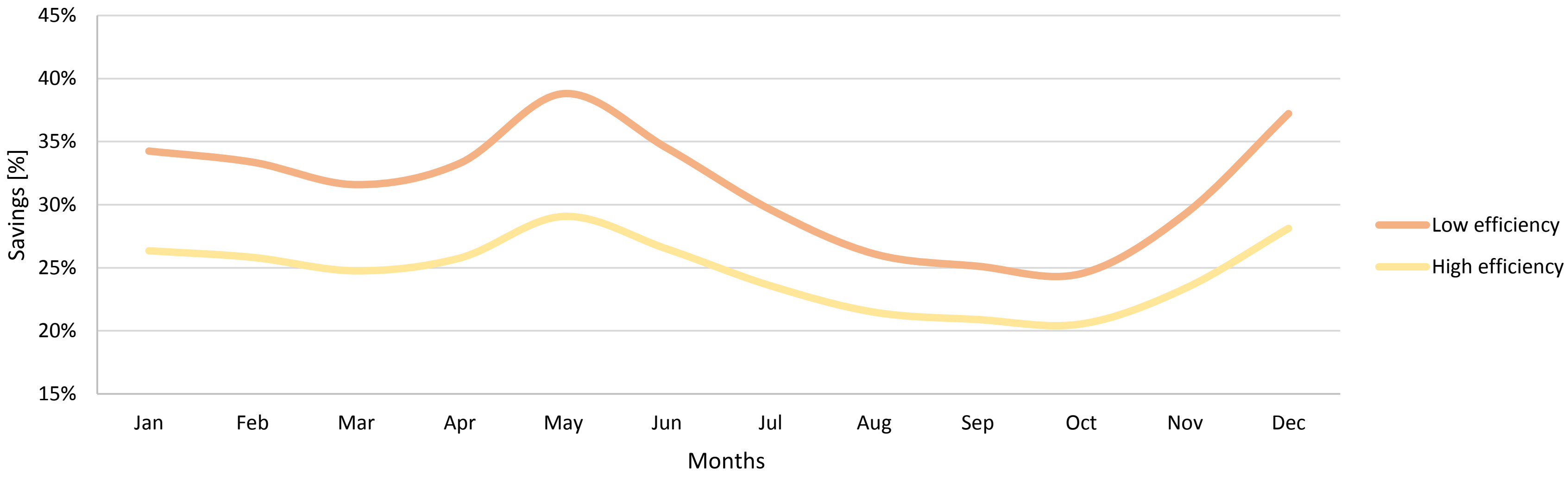


Figure A.3- Trend of wood savings for the Hospital during the year with the water heater.

Table A.19 - Operating cost for the Hospital with the water heater.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	651	588	651	630	651	630	651	651	630	651	630	651	7665
TOTAL [EUR]	-59.9	-54.1	-59.9	-57.9	-59.9	-57.9	-59.9	-59.9	-57.9	-59.9	-57.9	-59.9	-704.8

Table A.20 - CO_2 savings at the Hospital with the water heater.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	651	588	651	630	651	630	651	651	630	651	630	651	7665
CO_2 from Hydroplants [kg]	8.9	8.0	8.9	8.6	8.9	8.6	8.9	8.9	8.6	8.9	8.6	8.9	104.6
Savings of CO_2 because of lees wood [kg]	-949	-813	-839	-884	-1137	-876	-704	-584	-541	-565	-729	-1113	-9733
	-730	-629	-658	-684	-851	-673	-561	-480	-450	-473	-582	-841	-7612
TOTAL BALANCE [kg]	-940	-805	-831	-875	-1128	-867	-696	-575	-532	-556	-720	-1104	-9628
	-721	-621	-649	-676	-843	-664	-552	-471	-441	-464	-574	-832	-7508

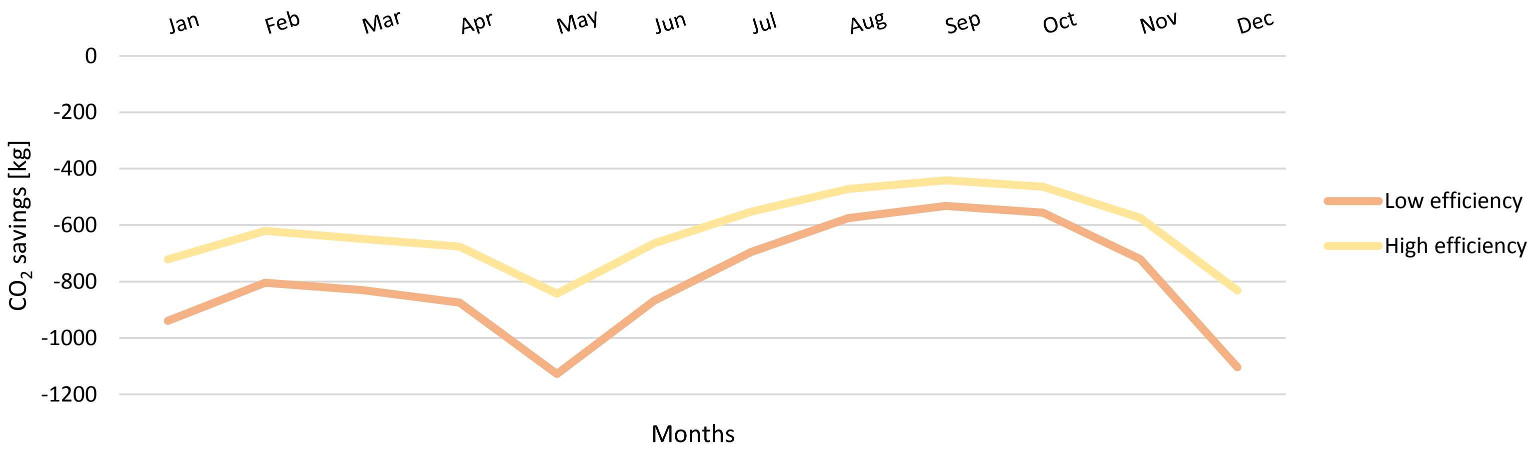


Figure A.4 - CO_2 savings for the Hospital during the years with the water heater.

Heat pump with electrical resistances

Because of this configuration reaches the same temperature of the alternative above, the wood savings are the same.

PaMu

Table A.21 - Global mean yearly wood savings at PaMu considering all the activities with heat pumps and electrical resistances.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
S_{PaMu} [%]	16.9%	17.0%	17.0%	17.0%	16.4%	16.3%	16.7%	16.8%	17.0%	17.2%	17.3%	16.8%	16.9%
	11.4%	11.5%	11.6%	11.5%	11.2%	11.1%	11.3%	11.4%	11.5%	11.7%	11.7%	11.4%	11.5%

Table A.22 - Operating cost for PaMu considering all the activities with heat pumps and electrical resistances.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	459.8	413.8	455.8	442.6	457.8	442.6	455.8	451.8	436.6	455.8	442.6	459.8	5374.8
Monthly Cost of Electricity [EUR]	42.36	38.01	41.87	40.66	42.01	40.62	41.98	41.56	40.18	41.84	40.72	42.22	494.03
Savings of Wood [EUR]	26.20	26.39	26.47	26.42	25.51	25.29	25.90	26.10	26.35	26.70	26.80	26.12	314.19
	17.76	17.92	17.95	17.94	17.32	17.19	17.60	17.74	17.91	18.15	18.22	17.76	213.40
TOTAL [EUR]	-16.16	-11.62	-15.4	-14.24	-16.5	-15.33	-16.08	-15.46	-13.83	-15.14	-13.92	-16.1	-179.8
	-24.6	-20.09	-23.92	-22.72	-24.69	-23.43	-24.38	-23.82	-22.27	-23.69	-22.5	-24.46	-280.6

Table A.23 - CO_2 savings at PaMu considering all the activities with heat with pumps and electrical resistances.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	459.8	413.8	455.8	442.6	457.8	442.6	455.8	451.8	436.6	455.8	442.6	459.8	5374.8
CO_2 from Hydroplants [kg]	6.3	5.6	6.2	6.0	6.2	6.0	6.2	6.2	6.0	6.2	6.0	6.3	73.4
Savings of CO_2 because of lees wood [kg]	-2295	-2125	-2298	-2259	-2253	-2139	-2148	-2131	-2099	-2223	-2257	-2348	-26575
	-1556	-1443	-1559	-1533	-1529	-1453	-1459	-1448	-1427	-1511	-1534	-1597	-18050
TOTAL BALANCE [kg]	-2289	-2119	-2292	-2253	-2247	-2133	-2142	-2125	-2093	-2217	-2251	-2342	-26502
	-1550	-1437	-1553	-1527	-1523	-1447	-1453	-1442	-1421	-1505	-1528	-1591	-17977

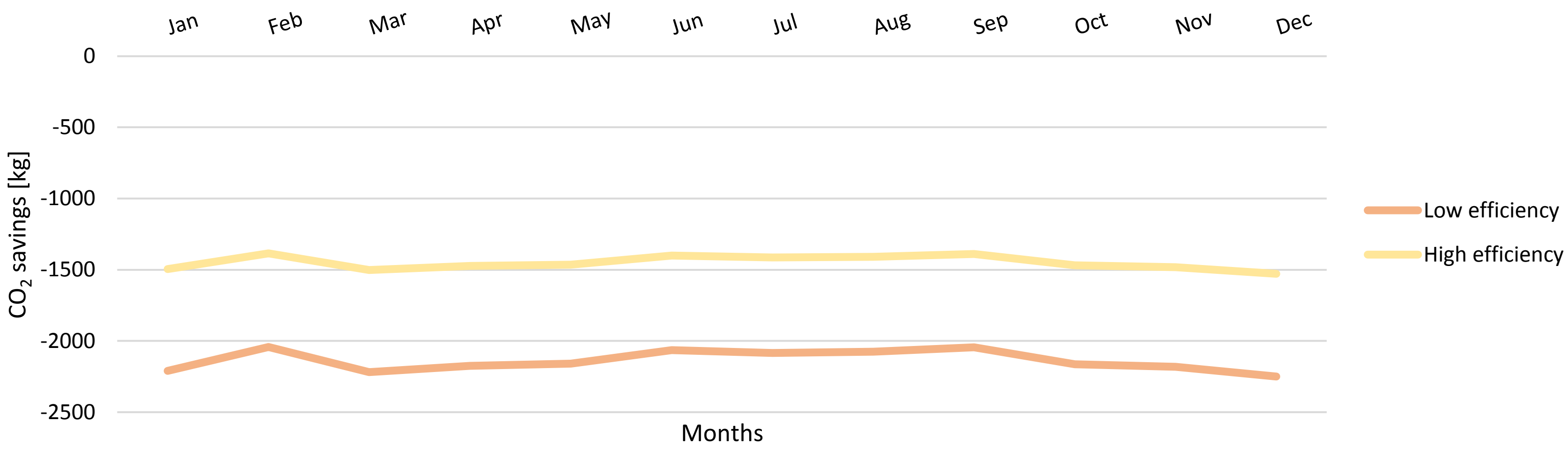


Figure A.5 - CO_2 savings for PaMu during the years with pumps and electrical resistances.

Hospital

Table A.24 - Mean yearly wood savings at the Hospital with heat pumps and electrical resistances

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
$S_{Hospital}$ [%]	34.2%	33.4%	31.6%	33.3%	38.8%	34.5%	29.6%	26.1%	25.1%	24.5%	29.2%	37.2%	31.5%
	26.3%	25.8%	24.8%	25.8%	29.1%	26.5%	23.6%	21.5%	20.9%	20.5%	23.4%	28.1%	24.7%

Table A.25 - Operating cost for the Hospital with heat pumps and electrical resistances.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	365.2	327.3	361.2	350.3	362.2	350.3	362.2	358.2	346.3	360.2	351.3	363.2	4257.9
TOTAL [EUR]	-33.6	-30.1	-33.2	-32.2	-33.3	-32.2	-33.3	-33.0	-31.9	-33.2	-32.3	-33.4	-391.5

Table A.26 - CO_2 savings at the Hospital with heat with pumps and electrical resistances.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	459.8	413.8	455.8	442.6	457.8	442.6	455.8	451.8	436.6	455.8	442.6	459.8	5374.8
CO_2 from Hydroplants [kg]	5.0	4.5	4.9	4.8	4.9	4.8	4.9	4.9	4.7	4.9	4.8	5.0	58.1
Savings of CO_2 because of lees wood [kg]	-949	-813	-839	-884	-1137	-876	-704	-584	-541	-565	-729	-1113	-9733
	-730	-629	-658	-684	-851	-673	-561	-480	-450	-473	-582	-841	-7612
TOTAL BALANCE [kg]	-944	-808	-835	-879	-1132	-871	-700	-579	-536	-560	-724	-1108	-9675
	-725	-625	-653	-680	-846	-668	-556	-475	-445	-468	-577	-836	-7554

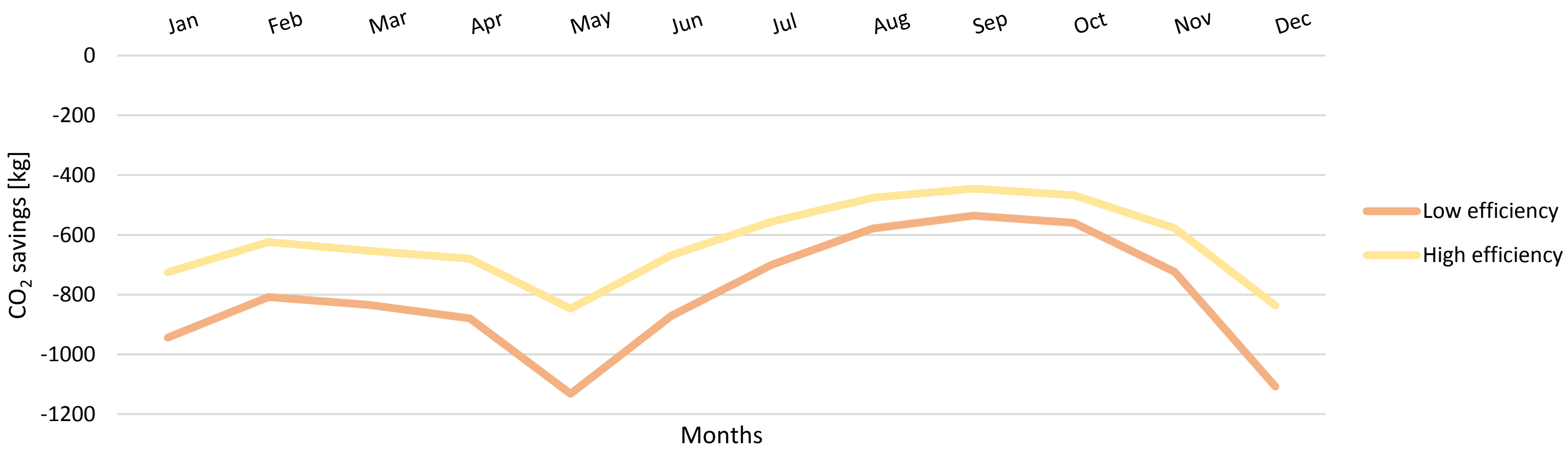


Figure A.6 - CO_2 savings for the Hospital during the years with pumps and electrical resistances.

Heat pump

PaMu

Table A.27 - Results for PaMu with *Water constant and wood proportion to the number of patient during the year* with the heat pump.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} $[°C]$	55											
LHV $[MJ/kg]$	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{hot\ water_{Plancha}}$ $[l]$	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770
$m_{boil\ water_{Plancha}}$ $[l]$	267	267	267	267	267	267	267	267	267	267	267	267
$E_{II_{Plancha}}$ $[MJ]$	429	429	429	429	429	429	429	429	429	429	429	429
$\Delta m_{Plancha}$ $[kg]$	346	342	349	349	333	326	324	324	328	342	353	351
	230	228	233	233	222	217	216	216	218	228	235	234
$m_{hot\ water_{Rocket}}$ $[l]$	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082
$m_{boil\ water_{Rocket}}$ $[l]$	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581
$E_{II_{Rocket}}$ $[MJ]$	168	168	168	168	168	168	168	168	168	168	168	168
Δm_{Rocket} $[kg]$	36	36	36	36	35	34	34	34	34	36	37	37
	31	31	31	31	30	29	29	29	29	31	32	31
$m_{wood_{PaMu}}$ $[kg]$	2177	2117	2080	2154	2321	2065	1855	1733	1720	1778	2007	2362
S_{PaMu} $[\%]$	17.5%	17.9%	18.5%	17.9%	15.8%	17.4%	19.3%	20.6%	21.0%	21.2%	19.4%	16.4%
	12.0%	12.2%	12.7%	12.3%	10.8%	11.9%	13.2%	14.1%	14.4%	14.5%	13.3%	11.2%

Table A.28 - Results for PaMu with *Water and wood constant during the year* with the heat pump.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
$m_{wood_{PaMu}} [kg]$	1855	1837	1873	1873	1786	1750	1739	1733	1757	1836	1895	1885
S_{PaMu} [%]	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
	14.1%	14.1%	14.1%	14.1%	14.1%	14.1%	14.1%	14.1%	14.1%	14.1%	14.1%	14.1%

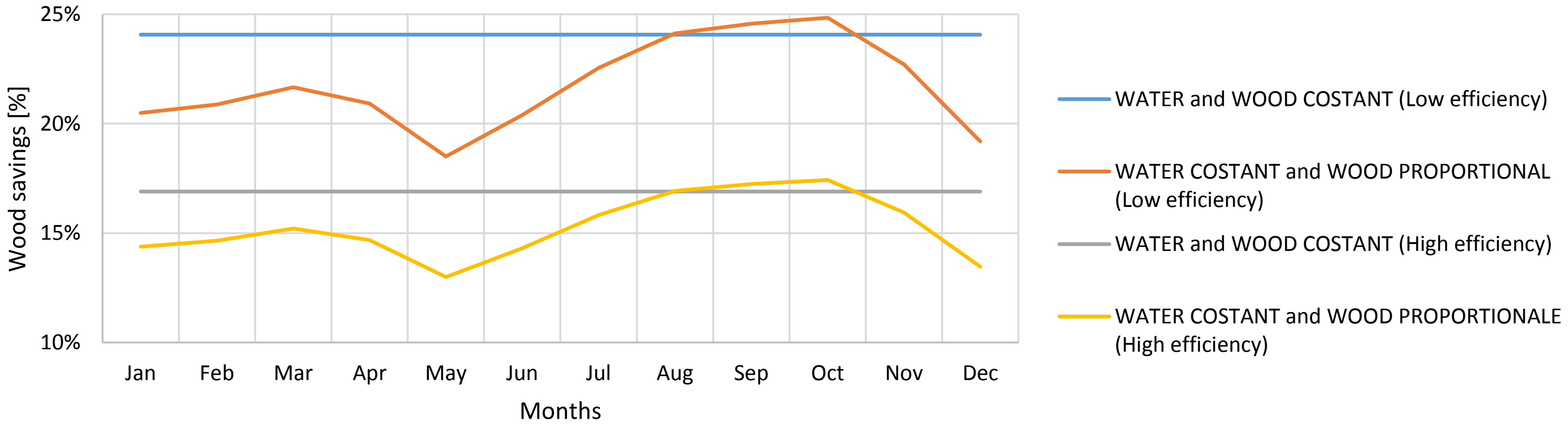


Figure A.7 -Trend of wood savings for PaMu during the year with heat pump.

Table A.29 - Results for PaMu for meals of the restaurant with the heat pump.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{tech} [°C]	55											
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{Plancha}$ [l]	4960	4480	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960
$E_{II_{Plancha}}$[MJ]	768	694	768	743	768	743	768	768	743	768	743	768
$\Delta m_{Plancha}$[kg]	619	554	625	605	596	565	580	580	568	613	612	629
	413	369	417	403	397	377	387	387	378	408	408	419
$m_{wood_{PaMu}}$[kg]	2101	1880	2122	2053	2023	1918	1970	1969	1926	2079	2077	2135
S_{PaMu} [%]	29.47%	29.47%	29.47%	29.47%	29.47%	29.47%	29.47%	29.47%	29.47%	29.47%	29.47%	29.47%
	19.65%	19.65%	19.65%	19.65%	19.65%	19.65%	19.65%	19.65%	19.65%	19.65%	19.65%	19.65%

Table A.30 - Mean yearly wood savings at PaMu only for meals preparation with heat pump.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
S_{PaMu} [%]	24.3%	24.2%	24.7%	24.4%	23.7%	24.2%	24.9%	25.3%	25.4%	25.5%	24.9%	24.0%	24.6%
	16.4%	16.3%	16.6%	16.4%	16.0%	16.3%	16.8%	17.1%	17.1%	17.2%	16.8%	16.1%	16.6%

Table A.31 - Global mean yearly wood savings at PaMu considering all the activities with heat pump.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
S_{PaMu} [%]	12.1%	12.2%	12.2%	12.2%	11.7%	11.6%	11.8%	11.9%	12.0%	12.3%	12.4%	12.1%	12.0%
	8.1%	8.2%	8.2%	8.2%	7.9%	7.8%	7.9%	8.0%	8.1%	8.3%	8.4%	8.1%	8.1%

Table A.32 - Operating cost for PaMu considering all the activities with heat pump.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	170	152	166	162	168	162	166	162	156	166	162	170	1963
Monthly Cost of Electricity [EUR]	15.71	13.94	15.22	14.86	15.36	14.83	15.32	14.91	14.39	15.18	14.93	15.57	180.22
Savings of Wood [EUR]	18.73	18.96	18.95	18.96	18.13	17.95	18.32	18.46	18.70	19.06	19.26	18.72	224.20
	12.61	12.78	12.76	12.77	12.21	12.09	12.34	12.43	12.60	12.84	12.98	12.61	151.00
TOTAL [EUR]	3.02	5.02	3.73	4.10	2.77	3.12	3.00	3.55	4.31	3.88	4.33	3.15	43.98
	-3.10	-1.16	-2.46	-2.09	-3.15	-2.74	-2.98	-2.48	-1.79	-2.34	-1.95	-2.96	-29.22

Table A.33 - CO_2 savings at PaMu considering all the activities with heat pump.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	170	152	166	162	168	162	166	162	156	166	162	170	1962.0
CO_2 from Hydroplants [kg]	2.3	2.1	2.3	2.2	2.3	2.2	2.3	2.2	2.1	2.3	2.2	2.3	26.8
Savings of CO_2 because of lees wood [kg]	-1641	-1526	-1646	-1621	-1601	-1518	-1520	-1507	-1490	-1587	-1622	-1683	-18961
	-1105	-1029	-1108	-1092	-1078	-1022	-1023	-1015	-1004	-1069	-1093	-1133	-12772
TOTAL BALANCE [kg]	-1638.5	-1524.3	-1643.2	-1618.4	-1598.6	-1515.5	-1517.3	-1505.0	-1488.3	-1584.4	-1620.0	-1680.6	-18934
	-1102.8	-1026.6	-1106.0	-1089.5	-1076.0	-1020.2	-1021.2	-1012.9	-1001.9	-1066.4	-1090.6	-1131.2	-12745

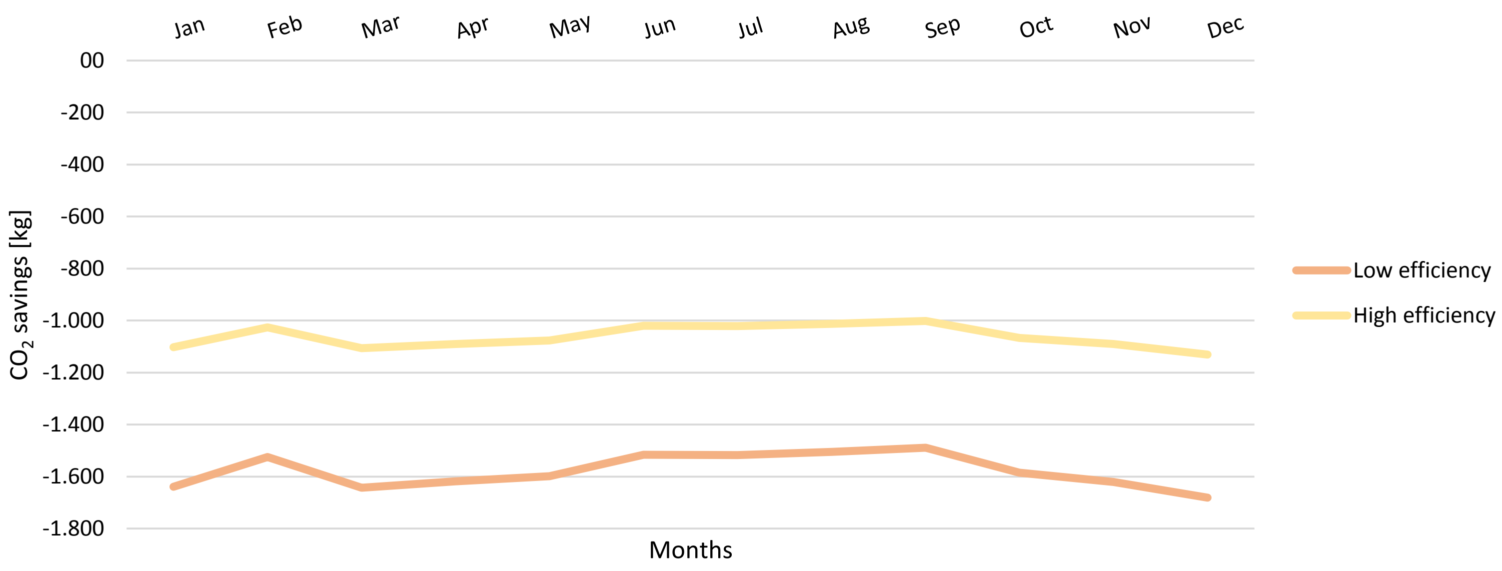


Figure A.8 - CO_2 savings for PaMu during the years with the heat pump.

Hospital

Table A.34 – Results for the Hospital with heat pump.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} $[°C]$	75											
LHV $[MJ/kg]$	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{boil\ water_{Plancha}}$ $[l]$	1415	1161	1036	1231	2165	1404	777	362	246	192	708	1888
$E_{II_{Plancha}}[MJ]$	219	180	160	191	335	217	120	56	38	30	110	292
$\Delta m_{Plancha}[kg]$	177	144	131	155	260	165	91	42	29	24	90	240
	181	147	134	159	267	170	93	43	30	24	93	246
$m_{boil\ water_{Rocket}}[l]$	6200	5600	6200	6000	6200	6000	6200	6200	6000	6200	6000	6200
$E_{II_{Rocket}}[MJ]$	960	867	960	929	960	929	960	960	929	960	929	960
$\Delta m_{Rocket}[kg]$	206	185	208	202	199	188	193	193	189	204	204	210
	177	158	179	173	170	162	166	166	162	175	175	180
$m_{wood_{Hospital}}[kg]$	1723	1515	1653	1652	1822	1580	1480	1391	1339	1431	1550	1860
$S_{Hospital}$ $[\%]$	22.2%	21.7%	20.5%	21.6%	25.2%	22.4%	19.2%	16.9%	16.3%	15.9%	19.0%	24.2%
	17.1%	16.8%	16.1%	16.7%	18.9%	17.2%	15.3%	13.9%	13.6%	13.3%	15.2%	18.3%

YEAR	
20.4%	16.0%

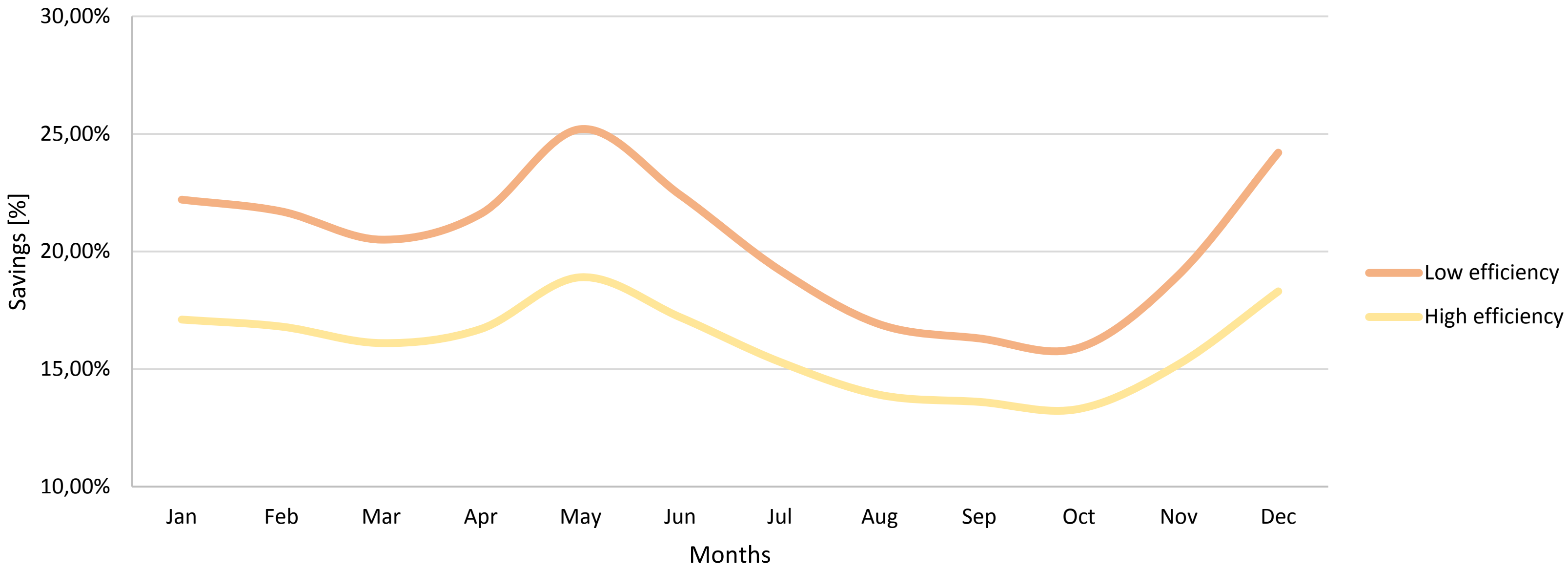


Figure A.9 - Trend of wood savings for the Hospital during the year with heart pump.

Table A.35 - Operating cost for the Hospital with heat pump.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	149	132	145	141	146	141	146	142	137	144	142	147	1712.0
TOTAL [EUR]	-13.7	-12.2	-13.3	-13.0	-13.4	-13.0	-13.4	-13.1	-12.6	-13.3	-13.0	-13.6	-157.4

Table A.36 - CO_2 savings at the Hospital with heat pump.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	149	132	145	141	146	141	146	142	137	144	142	147	1712
CO_2 from Hydroplants [kg]	2.0	1.8	2.0	1.9	2.0	1.9	2.0	1.9	1.9	2.0	1.9	2.0	23.4
Savings of CO_2 because of lees wood [kg]	-616	-528	-545	-574	-738	-569	-457	-379	-351	-366	-473	-722	-6318
	-474	-408	-427	-444	-553	-437	-364	-312	-292	-307	-378	-546	-4941
TOTAL BALANCE [kg]	-614	-526	-543	-572	-736	-567	-455	-377	-349	-364	-471	-720	-6294
	-472	-406	-425	-442	-551	-435	-362	-310	-290	-305	-376	-544	-4918

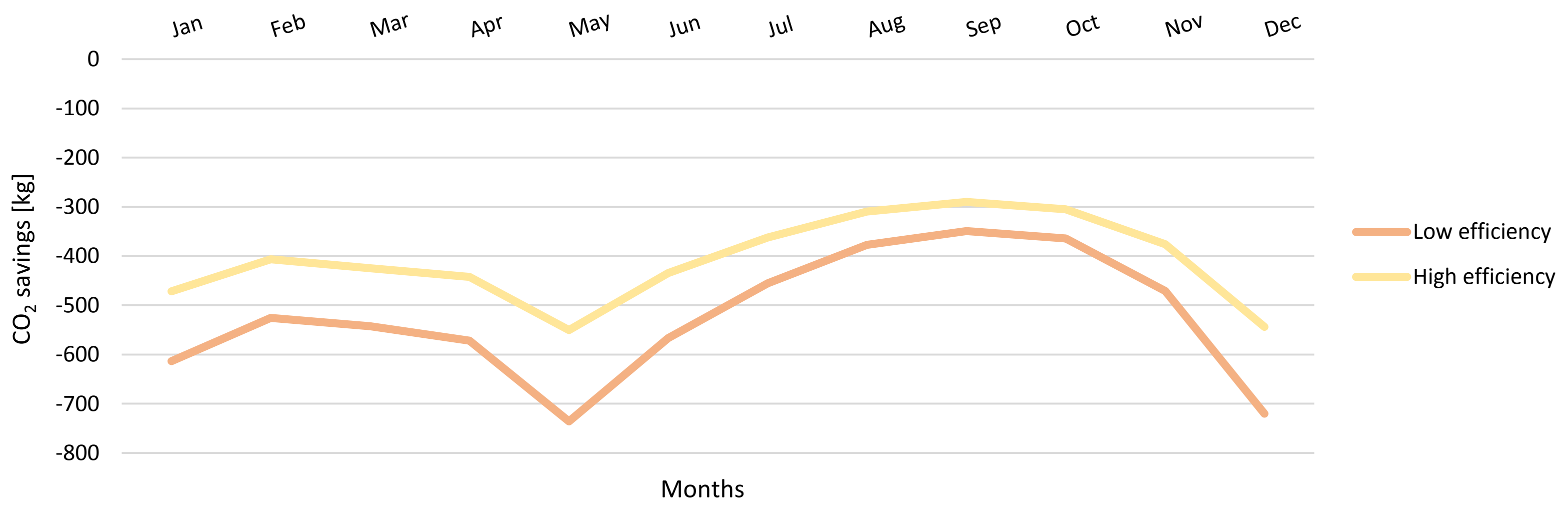


Figure A.10 - CO_2 savings for the Hospital during the years with heat pump.

Electrical water heater with solar integration

PaMu

Table A.37 - Results for PaMu with *Water constant and wood proportion to the number of patient during the year* with electrical water heater and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} $[°C]$	75.39	75.88	77.31	77.1	78.15	80.36	78.85	79.38	78.02	77.48	75.65	75.06
LHV $[MJ/kg]$	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{hot\ water_{Plancha}}$ $[l]$	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770
$m_{boil\ water_{Plancha}}$ $[l]$	267	267	267	267	267	267	267	267	267	267	267	267
$E_{II_{Plancha}}$ $[MJ]$	452	452	454	454	455	457	456	456	455	454	452	451
$\Delta m_{Plancha}$ $[kg]$	364	361	369	369	353	348	344	345	347	362	372	370
	243	241	246	246	235	232	229	230	231	241	248	246
$m_{hot\ water_{Rocket}}$ $[l]$	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082
$m_{boil\ water_{Rocket}}$ $[l]$	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581
$E_{II_{Rocket}}$ $[MJ]$	388	393	409	406	418	441	425	431	416	410	391	384
Δm_{Rocket} $[kg]$	83	84	89	88	86	90	86	87	85	87	86	84
	71	72	76	76	74	77	73	74	73	75	73	72
$m_{wood_{PaMu}}$ $[kg]$	2177	2117	2080	2154	2321	2065	1855	1733	1720	1778	2007	2362
S_{PaMu} $[\%]$	20.5%	21.0%	22.0%	21.2%	18.9%	21.2%	23.2%	24.9%	25.1%	25.3%	22.8%	19.2%
	14.4%	14.8%	15.5%	14.9%	13.3%	14.9%	16.3%	17.5%	17.7%	17.8%	16.0%	13.5%

Table A.38 - Results for PaMu with *Water and wood constant during the year* with electrical water heater and solar integration.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
$m_{wood_{PaMu}} [kg]$	1855	1837	1873	1873	1786	1750	1739	1733	1757	1836	1895	1885
S_{PaMu} [%]	24.1%	24.2%	24.5%	24.4%	24.6%	25.0%	24.7%	24.8%	24.6%	24.5%	24.2%	24.1%
	16.9%	17.0%	17.2%	17.2%	17.3%	17.6%	17.4%	17.5%	17.3%	17.2%	17.0%	16.9%

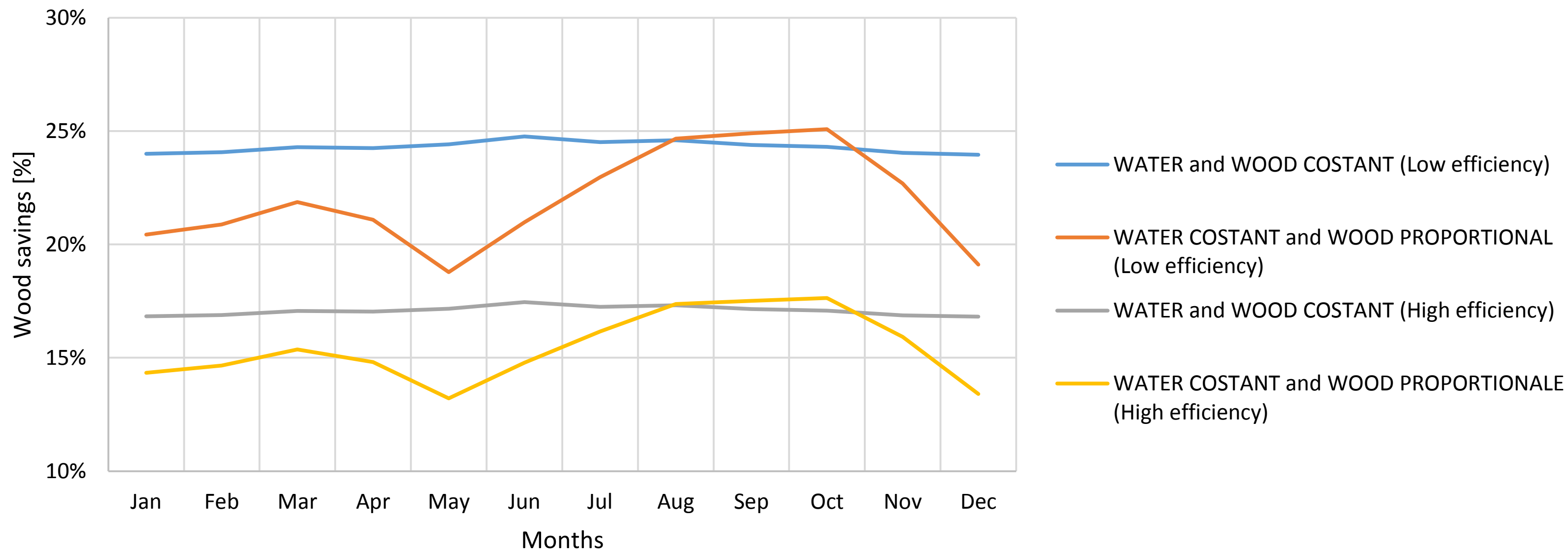


Figure A.11 - Trend of wood savings for PaMu during the year with electrical water heater and solar integration.

Table A.39 - Results for PaMu for meals of the restaurant with electrical water heater and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{tech} [°C]	75.39	75.88	77.31	77.1	78.15	80.36	78.85	79.38	78.02	77.48	75.65	75.06
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{Plancha}$ [l]	4960	4480	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960
$E_{II_{Plancha}}$[MJ]	1192	1085	1231	1187	1249	1253	1263	1274	1206	1235	1158	1185
$\Delta m_{Plancha}$[kg]	960	866	1002	966	969	953	954	962	921	985	954	970
	640	578	668	644	646	635	636	642	614	657	636	647
$m_{wood_{PaMu}}$[kg]	2101	1880	2122	2053	2023	1918	1970	1969	1926	2079	2077	2135
S_{PaMu} [%]	45.71%	46.10%	47.24%	47.07%	47.91%	49.67%	48.46%	48.88%	47.80%	47.37%	45.91%	45.44%
	30.47%	30.73%	31.49%	31.38%	31.94%	33.11%	32.31%	32.59%	31.87%	31.58%	30.61%	30.30%

Table A.40 - Mean yearly wood savings at PaMu only for meals preparation with electrical water heater and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
S_{PaMu} [%]	34.2%	34.0%	35.7%	35.1%	34.7%	36.4%	36.8%	37.6%	36.9%	36.9%	35.1%	33.5%	35.5%
	23.2%	23.1%	24.2%	23.8%	23.5%	24.7%	24.9%	25.5%	25.0%	25.0%	23.8%	22.7%	24.1%

Table A.41 - Global mean yearly wood savings at PaMu considering all the activities with electrical water heater and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
S_{PaMu} [%]	17.0%	17.2%	17.6%	17.5%	17.1%	17.4%	17.4%	17.7%	17.5%	17.8%	17.5%	16.9%	17.4%
	11.5%	11.7%	12.0%	11.9%	11.6%	11.8%	11.8%	12.0%	11.9%	12.1%	11.9%	11.4%	11.8%

Table A.42 - Operating cost for PaMu considering all the activities with electrical water heater and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	562.5	469.1	469.2	442.3	364.7	294.2	354.7	341.7	411.1	466.9	571.2	584.8	5332.38
Monthly Cost of Electricity [EUR]	51.7	43.1	43.1	40.7	33.5	27.1	32.6	31.4	37.8	42.9	52.5	53.8	490.33
Savings of Wood [EUR]	26.34	26.67	27.38	27.25	26.50	26.96	27.04	27.43	27.23	27.60	27.14	26.21	323.75
	17.86	18.11	18.57	18.49	17.98	18.30	18.35	18.61	18.48	18.72	18.41	17.77	219.56
TOTAL [EUR]	-25.38	-16.46	-15.76	-13.42	-7.03	-0.10	-5.58	-3.98	-10.57	-15.34	-25.39	-27.56	-166.58
	-33.86	-25.03	-24.57	-22.18	-15.55	-8.75	-14.27	-12.80	-19.32	-24.22	-34.12	-36.01	-270.76

Table A.43 - CO_2 savings at PaMu considering all the activities with electrical water heater and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	562.5	469.1	469.2	442.3	364.7	294.2	354.7	341.7	411.1	466.9	571.2	584.8	5332.4
CO_2 from Hydroplants [kg]	7.7	6.4	6.4	6.0	5.0	4.0	4.8	4.7	5.6	6.4	7.8	8.0	72.8
Savings of CO_2 because of lees wood [kg]	-2307.9	-2147.5	-2377.5	-2329.6	-2339.9	-2279.6	-2242.2	-2239.9	-2169.6	-2297.9	-2285.3	-2356.1	-27373
	-1564.6	-1457.8	-1612.5	-1580.5	-1587.3	-1547.7	-1521.2	-1519.9	-1472.3	-1558.6	-1550.0	-1597.2	-18570
TOTAL BALANCE [kg]	-2300.2	-2141.1	-2371.1	-2323.5	-2335.0	-2275.5	-2237.4	-2235.2	-2163.9	-2291.5	-2277.5	-2348.1	-27300
	-1557.0	-1451.4	-1606.1	-1574.5	-1582.4	-1543.7	-1516.4	-1515.2	-1466.7	-1552.2	-1542.2	-1589.2	-18497

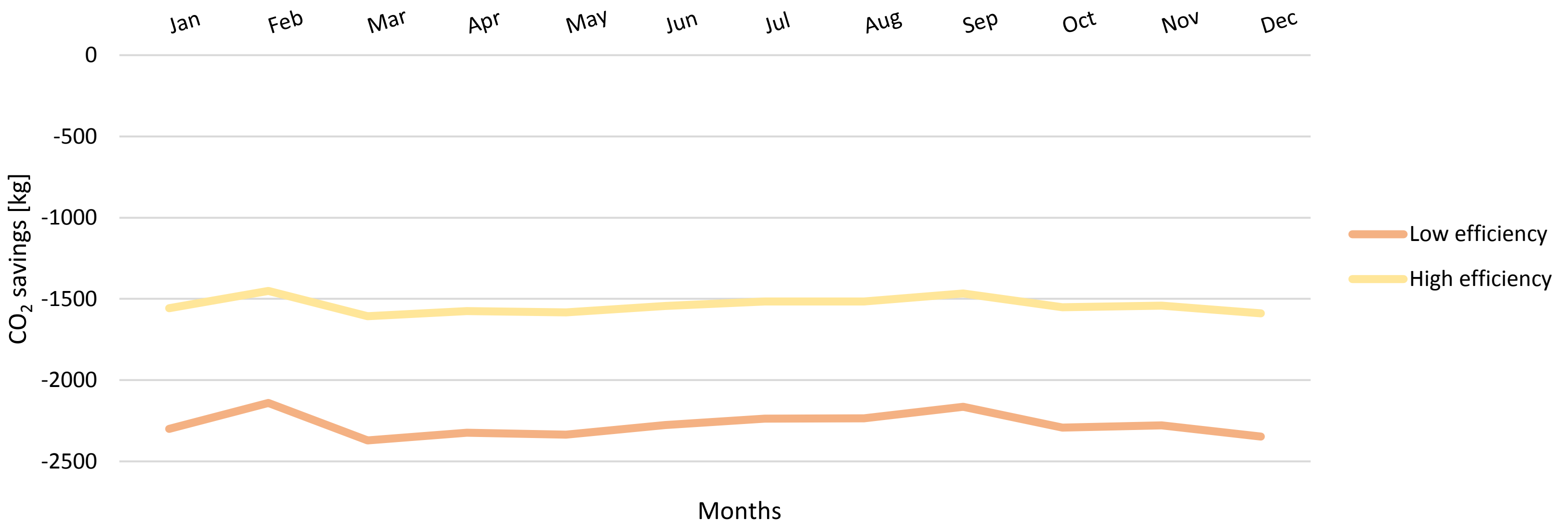


Figure A.12 - CO_2 savings for PaMu during the years with electrical water heater and solar integration.

Hospital

Table A.44 – Results for the Hospital with electrical water heater and solar integration.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} [°C]	75.5	76.1	77.9	77.8	78.9	81.8	79.9	80.7	78.7	78.0	75.8	75.2
LHV $[MJ/kg]$	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{boil\ water_{Plancha}}$ $[l]$	1415	1161	1036	1231	2165	1404	777	362	246	192	708	1888
$E_{II_{Plancha}}[MJ]$	341	282	260	308	552	375	201	95	63	48	171	452
$\Delta m_{Plancha}[kg]$	275	225	211	251	428	285	152	72	48	38	141	370
	181	147	134	159	267	170	93	43	30	24	93	246
$m_{boil\ water_{Rocket}}[l]$	6200	5600	6200	6000	6200	6000	6200	6200	6000	6200	6000	6200
$E_{II_{Rocket}}[MJ]$	1493	1361	1554	1502	1580	1602	1606	1628	1524	1557	1452	1483
$\Delta m_{Rocket}[kg]$	321	290	337	326	327	325	324	328	310	331	319	324
	275	248	289	279	280	278	277	281	266	284	273	278
$m_{wood_{Hospital}}[kg]$	1723	1515	1653	1652	1822	1580	1480	1391	1339	1431	1550	1860
$S_{Hospital}$ [%]	34.6%	34.0%	33.2%	34.9%	41.4%	38.6%	32.1%	28.7%	26.7%	25.8%	29.7%	37.3%
	26.6%	26.3%	26.0%	27.0%	31.0%	29.6%	25.6%	23.6%	22.2%	21.6%	23.7%	28.2%

YEAR	
33.1%	26.0%

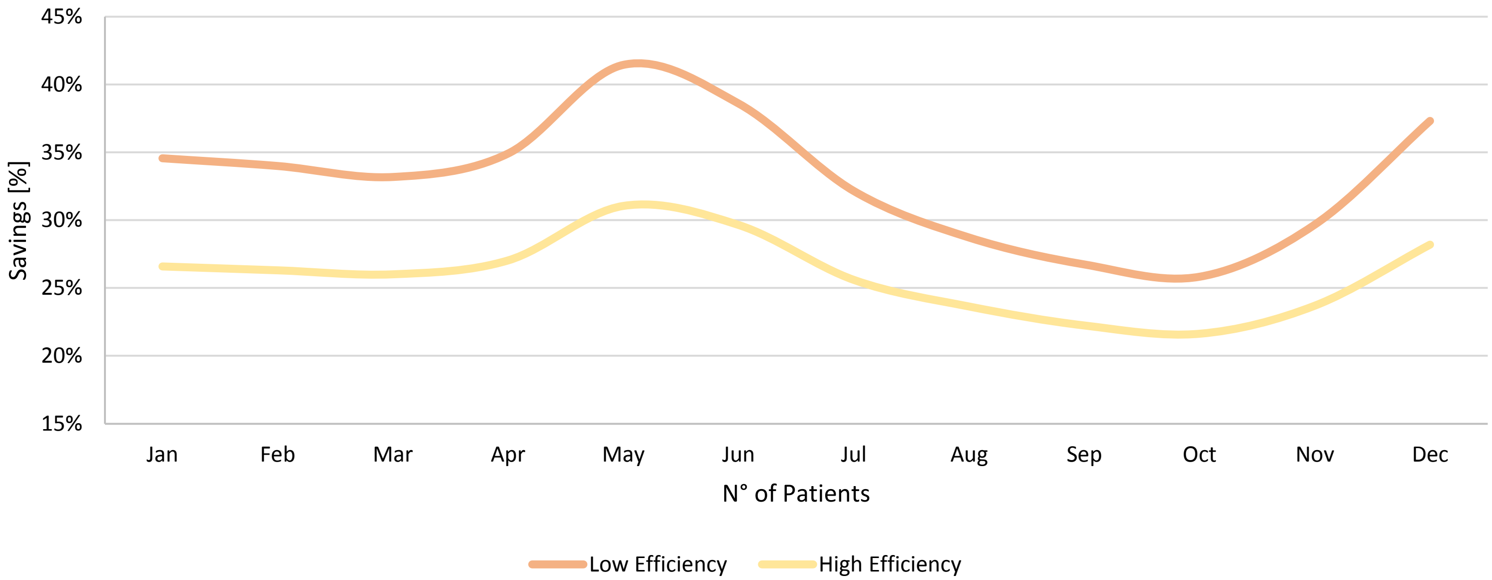


Figure A.13 - Trend of wood savings for the Hospital during the year with electrical water heater and solar integration.

Table A.45 - Operating cost for the Hospital with electrical water heater and solar integration.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	386.7	312.0	307.0	283.0	207.1	153.8	199.9	190.0	254.8	307.4	397.2	408.0	3406.8
TOTAL [EUR]	-35.56	-28.69	-28.23	-26.02	-19.04	-14.14	-18.38	-17.47	-23.43	-28.27	-36.53	-37.51	-313.3

Table A.46 - CO_2 savings at the Hospital with electrical water heater and solar integration..

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	386.7	312.0	307.0	283.0	207.1	153.8	199.9	190.0	254.8	307.4	397.2	408.0	3406.8
CO_2 from Hydroplants [kg]	5.3	4.3	4.2	3.9	2.8	2.1	2.7	2.6	3.5	4.2	5.4	5.6	46.5
Savings of CO_2 because of lees wood [kg]	-957	-828	-882	-927	-1214	-980	-765	-642	-576	-594	-739	-1116	-10221
	-737	-641	-691	-718	-910	-753	-609	-529	-479	-498	-591	-843	-7997
TOTAL BALANCE [kg]	-952	-824	-878	-923	-1211	-978	-762	-640	-572	-590	-734	-1110	-10175
	-731	-636	-687	-714	-907	-751	-606	-526	-475	-493	-585	-838	-7950

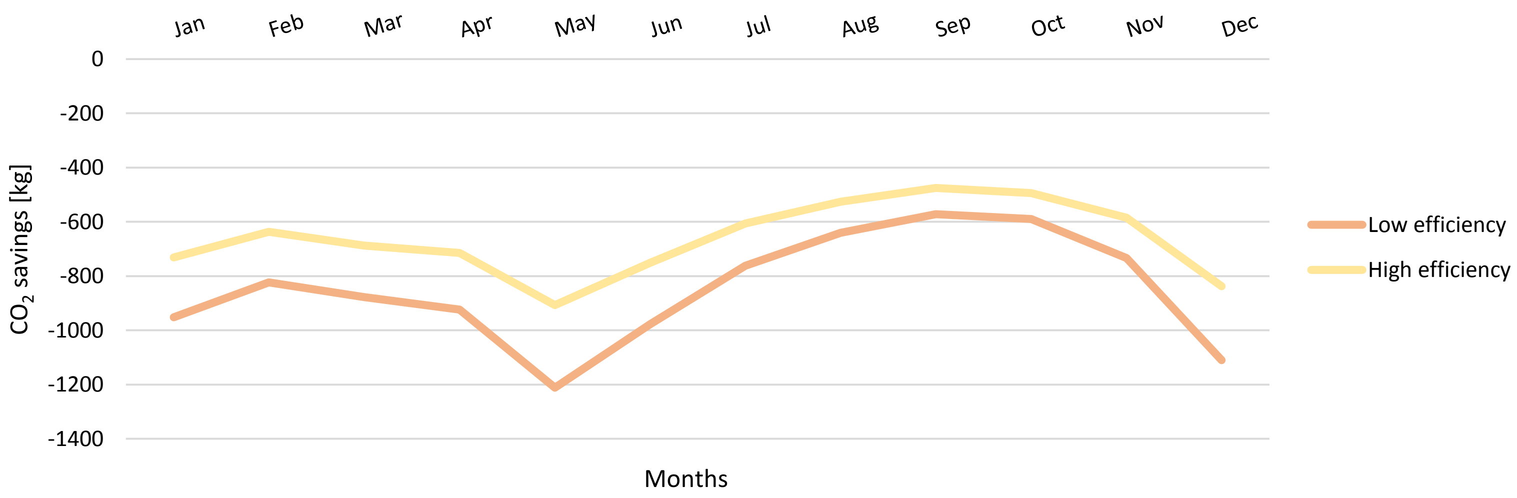


Figure A.14 - CO_2 savings for the Hospital during the years with electrical water heater and solar integration.

Heat pump with solar integration

PaMu

Table A.47 - Results for PaMu with *Water constant and wood proportion to the number of patient during the year* with heat pump and solar integration.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} [°C]	63.3	64.4	66.9	66.6	69.4	73.4	70.7	71.6	68.4	67.4	62.8	62.2
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{hot\ water_{Plancha}}$ [l]	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770
$m_{boil\ water_{Plancha}}$ [l]	267	267	267	267	267	267	267	267	267	267	267	267
$E_{II_{Plancha}}$ [MJ]	438	440	442	442	445	450	447	448	444	443	438	437
$\Delta m_{Plancha}$ [kg]	353	351	360	360	345	342	337	338	339	353	360	358
	235	234	240	240	230	228	225	225	226	235	240	239
$m_{hot\ water_{Rocket}}$ [l]	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082
$m_{boil\ water_{Rocket}}$ [l]	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581
$E_{II_{Rocket}}$ [MJ]	257	269	296	293	323	366	337	347	312	301	252	245
Δm_{Rocket} [kg]	55	57	64	64	67	74	68	70	64	64	55	54
	47	49	55	54	57	64	58	60	54	55	47	46
$m_{wood_{PaMu}}$ [kg]	2177	2117	2080	2154	2321	2065	1855	1733	1720	1778	2007	2362
S_{PaMu} [%]	18.8%	19.3%	20.4%	19.7%	17.8%	20.2%	21.9%	23.5%	23.4%	23.5%	20.7%	17.4%
	13.0%	13.4%	14.2%	13.7%	12.4%	14.1%	15.3%	16.5%	16.3%	16.3%	14.3%	12.0%

Table A.48 - Results for PaMu with *Water and wood constant during the year* with heat pump and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$m_{wood_{PaMu}}$ $[kg]$	1855	1837	1873	1873	1786	1750	1739	1733	1757	1836	1895	1885
S_{PaMu} [%]	22.0%	22.2%	22.7%	22.6%	23.1%	23.8%	23.3%	23.5%	22.9%	22.7%	21.9%	21.8%
	15.3%	15.4%	15.8%	15.7%	16.1%	16.7%	16.3%	16.4%	16.0%	15.8%	15.2%	15.1%

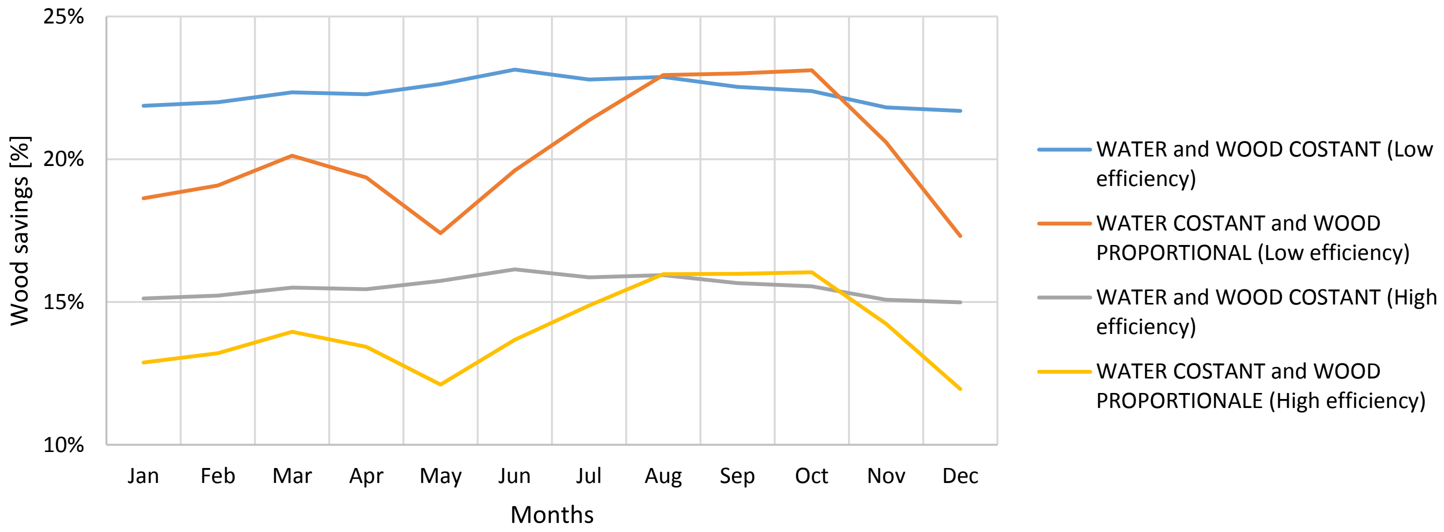


Figure A.15 - Trend of wood savings for PaMu during the year with heat pump and solar integration.

Table A.49 - Results for PaMu for meals of the restaurant with heat pump and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{tech} [°C]	63.3	64.4	66.9	66.6	69.4	73.4	70.7	71.6	68.4	67.4	62.8	62.2
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{Plancha}$ [l]	4960	4480	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960
$E_{II_{Plancha}}$ [MJ]	941	870	1015	977	1067	1113	1094	1113	1013	1026	900	918
$\Delta m_{Plancha}$ [kg]	758	695	826	795	828	846	827	840	773	818	741	752
	505	463	551	530	552	564	551	560	515	545	494	501
$m_{wood_{PaMu}}$ [kg]	2101	1880	2122	2053	2023	1918	1970	1969	1926	2079	2077	2135
S_{PaMu} [%]	36.08%	36.95%	38.95%	38.71%	40.94%	44.12%	41.97%	42.69%	40.14%	39.34%	35.68%	35.20%
	24.05%	24.64%	25.96%	25.80%	27.29%	29.41%	27.98%	28.46%	26.76%	26.23%	23.79%	23.47%

Table A.50 - Mean yearly wood savings at PaMu only for meals preparation with heat pump and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
S_{PaMu} [%]	28.4%	28.6%	30.5%	30.0%	30.6%	33.1%	32.7%	33.7%	32.1%	31.8%	28.7%	27.4%	30.5%
	19.2%	19.4%	20.7%	20.3%	20.7%	22.4%	22.2%	22.8%	21.7%	21.5%	19.4%	18.5%	20.7%

Table A.51 - Global mean yearly wood savings at PaMu considering all the activities with heat pump and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
S_{PaMu} [%]	14.1%	14.4%	15.1%	15.0%	15.0%	15.8%	15.5%	15.8%	15.2%	15.3%	14.3%	13.8%	14.9%
	9.5%	9.8%	10.2%	10.2%	10.2%	10.7%	10.5%	10.7%	10.3%	10.4%	9.7%	9.3%	10.1%

Table A.52 - Operating cost for PaMu considering all the activities with heat pump and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	91.2	74.3	72.4	63.6	42.9	31.7	44.2	40.9	58.6	70.4	97.8	96.5	784.45
Monthly Cost of Electricity [EUR]	8.4	6.8	6.7	5.8	3.9	2.9	4.1	3.8	5.4	6.5	9.0	8.9	72.13
Savings of Wood [EUR]	21.83	22.43	23.45	23.31	23.34	24.48	24.06	24.57	23.67	23.77	22.24	21.41	278.55
	14.75	15.18	15.86	15.77	15.80	16.60	16.29	16.64	16.02	16.08	15.03	14.46	188.35
TOTAL [EUR]	13.44	15.60	16.79	17.46	19.40	21.57	20.00	20.80	18.27	17.30	13.25	12.54	206.41
	6.36	8.34	9.21	9.93	11.86	13.68	12.23	12.88	10.63	9.61	6.04	5.59	116.22

Table A.53 - CO_2 savings at PaMu considering all the activities with heat pump and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	91.2	74.3	72.4	63.6	42.9	31.7	44.2	40.9	58.6	70.4	97.8	96.5	784.5
CO_2 from Hydroplants [kg]	1.2	1.0	1.0	0.9	0.6	0.4	0.6	0.6	0.8	1.0	1.3	1.3	10.7
Savings of CO_2 because of lees wood [kg]	-1912.3	-1806.0	-2036.0	-1992.7	-2060.6	-2070.5	-1995.3	-2006.1	-1885.7	-1979.0	-1872.7	-1924.5	-23541
	-1292.2	-1221.9	-1377.3	-1348.3	-1394.9	-1403.5	-1351.1	-1358.8	-1276.6	-1338.9	-1265.5	-1299.9	-15929
TOTAL BALANCE [kg]	-1911.1	-1805.0	-2035.0	-1991.8	-2060.0	-2070.0	-1994.6	-2005.5	-1884.9	-1978.0	-1871.3	-1923.2	-23531
	-1290.9	-1220.9	-1376.3	-1347.4	-1394.3	-1403.1	-1350.5	-1358.2	-1275.8	-1337.9	-1264.2	-1298.6	-15918

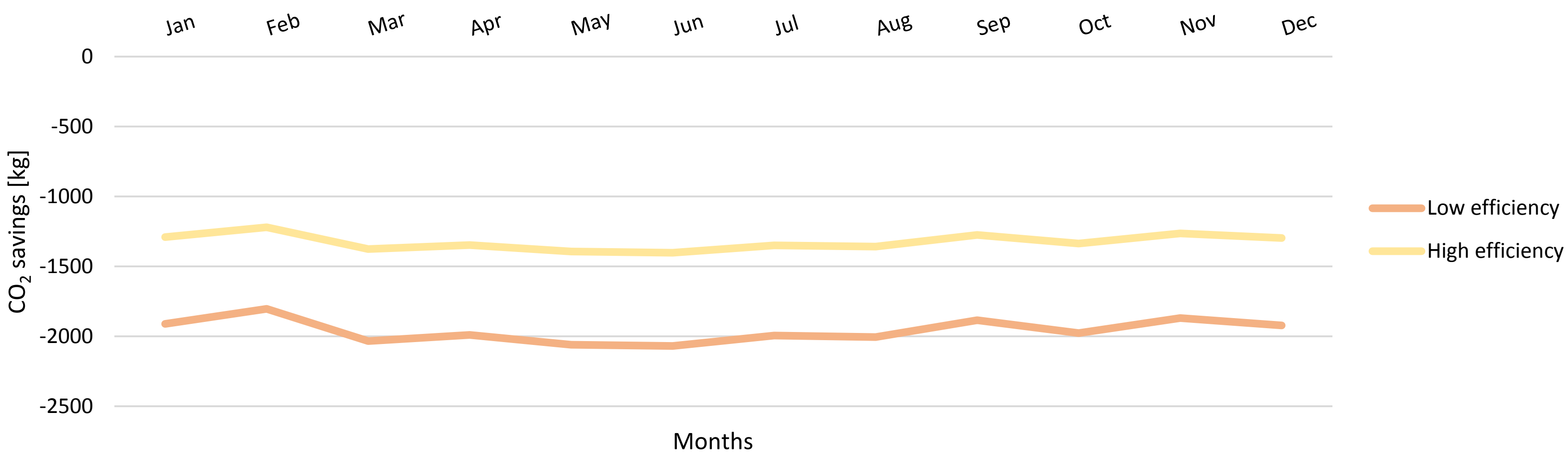


Figure A.46 - CO_2 savings for PaMu during the years with heat pump and solar integration.

Hospital

Table A.54 – Results for the Hospital with heat pump and solar integration.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} [°C]	64.4	65.7	69.3	69.6	73.2	78.1	74.7	75.8	71.7	71.1	64.2	62.7
LHV $[MJ/kg]$	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{boil\ water_{Plancha}}$ $[l]$	1415	1161	1036	1231	2165	1404	777	362	246	192	708	1888
$E_{II_{Plancha}}$ $[MJ]$	275	232	222	266	500	353	184	87	55	43	137	353
$\Delta m_{Plancha}$ $[kg]$	221	185	181	216	388	269	139	66	42	34	113	289
	181	147	134	159	267	170	93	43	30	24	93	246
$m_{boil\ water_{Rocket}}$ $[l]$	6200	5600	6200	6000	6200	6000	6200	6200	6000	6200	6000	6200
$E_{II_{Rocket}}$ $[MJ]$	1204	1118	1331	1296	1433	1509	1472	1500	1349	1378	1160	1160
Δm_{Rocket} $[kg]$	259	238	289	281	296	306	296	302	275	293	255	253
	222	204	248	241	254	262	254	259	235	251	218	217
$m_{wood_{Hospital}}$ $[kg]$	1723	1515	1653	1652	1822	1580	1480	1391	1339	1431	1550	1860
$S_{Hospital}$ [%]	27.9%	27.9%	28.4%	30.1%	37.6%	36.4%	29.4%	26.5%	23.7%	22.9%	23.7%	29.2%
	21.4%	21.6%	22.3%	23.3%	28.1%	27.9%	23.4%	21.8%	19.7%	19.1%	18.9%	22.1%

YEAR	
28.6%	22.5%

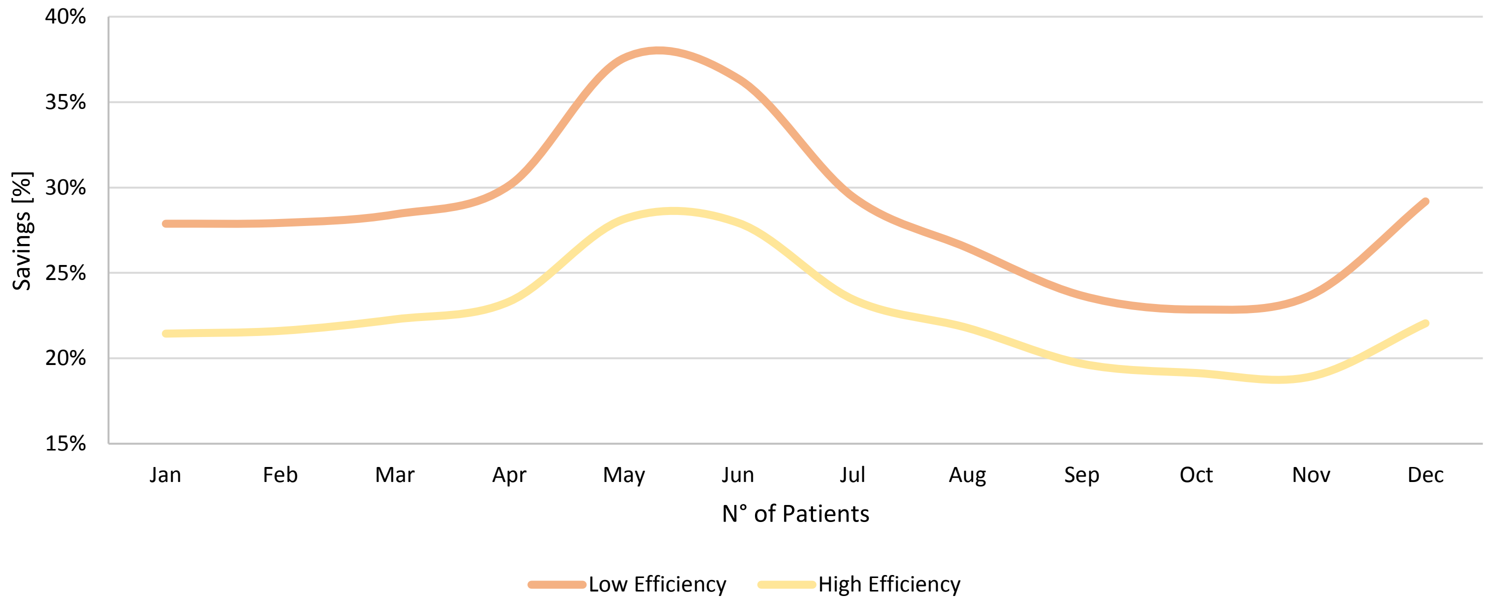


Figure A.17 - Trend of wood savings for the Hospital during the year with heat pump and solar integration.

Table A.55 - Operating cost for the Hospital with heat pump and solar integration.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	57.3	44.6	45.5	38.9	21.2	18.9	23.1	21.3	35.5	46.7	64.0	62.3	479.3
TOTAL [EUR]	-5.27	-4.10	-4.19	-3.58	-1.95	-1.73	-2.12	-1.96	-3.26	-4.30	-5.88	-5.73	-44.1

Table A.56 - CO_2 savings at the Hospital with heat pump and solar integration.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	57.3	44.6	45.5	38.9	21.2	18.9	23.1	21.3	35.5	46.7	64.0	62.3	479.3
CO_2 from Hydroplants [kg]	0.8	0.6	0.6	0.5	0.3	0.3	0.3	0.3	0.5	0.6	0.9	0.9	6.5
Savings of CO_2 because of lees wood [kg]	-772	-680	-756	-800	-1101	-924	-701	-592	-510	-526	-591	-873	-8824
	-594	-526	-592	-620	-825	-709	-558	-487	-424	-440	-472	-659	-6907
TOTAL BALANCE [kg]	-772	-680	-755	-800	-1100	-923	-700	-592	-509	-525	-590	-872	-8818
	-593	-526	-592	-619	-824	-709	-558	-487	-423	-440	-471	-659	-6900

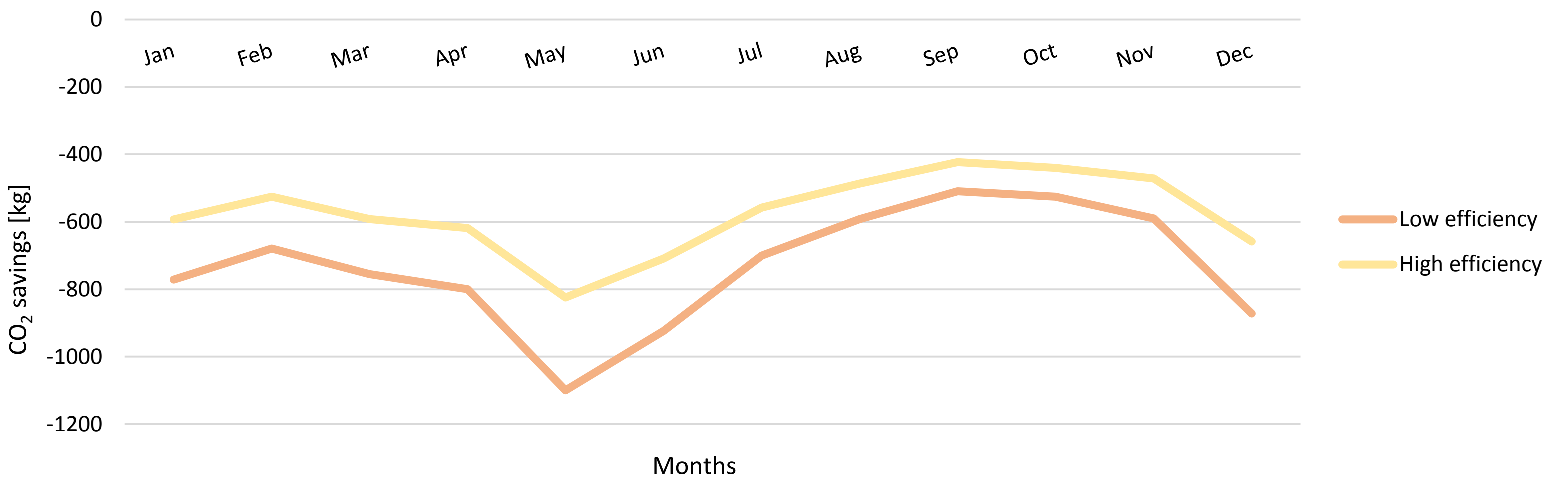


Figure A.18 - CO_2 savings for the Hospital during the years with heat pump and solar integration.

Solar collectors and storage

PaMu

Table A.57 - Results for PaMu with *Water constant and wood proportion to the number of patient during the year* with solar collectors and storage.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} [°C]	47.9	50.1	54.2	54.8	60.2	65.4	61.7	62.5	56.7	54.6	45.9	45.8
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{hot\ water_{Plancha}}$ [l]	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770
$m_{boil\ water_{Plancha}}$ [l]	267	267	267	267	267	267	267	267	267	267	267	267
$E_{II_{Plancha}}$ [MJ]	347	372	420	427	435	441	437	437	431	424	324	322
$\Delta m_{Plancha}$ [kg]	279	297	342	347	337	335	330	330	329	338	266	264
	186	198	228	232	225	223	220	220	219	226	178	176
$m_{hot\ water_{Rocket}}$ [l]	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082	1082
$m_{boil\ water_{Rocket}}$ [l]	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581	2581
$E_{II_{Rocket}}$ [MJ]	135	145	164	167	224	280	240	249	186	166	126	126
Δm_{Rocket} [kg]	23	25	28	29	32	37	32	33	29	28	22	22
	20	21	24	25	27	32	27	28	25	24	19	19
$m_{wood_{PaMu}}$ [kg]	2177	2117	2080	2154	2321	2065	1855	1733	1720	1778	2007	2362
S_{PaMu} [%]	14.2%	15.5%	18.1%	17.8%	16.5%	19.0%	20.4%	21.9%	21.3%	21.0%	14.7%	12.3%
	9.7%	10.6%	12.4%	12.2%	11.4%	13.2%	14.1%	15.2%	14.6%	14.4%	10.0%	8.4%

Table A.58 - Results for PaMu with *Water and wood constant during the year* with solar collectors and storage.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
$m_{wood_{PaMu}}[kg]$	1855	1837	1873	1873	1786	1750	1739	1733	1757	1836	1895	1885
S_{PaMu} [%]	16.6%	17.9%	20.1%	20.5%	21.5%	22.4%	21.7%	21.9%	20.9%	20.4%	15.5%	15.5%
	11.4%	12.2%	13.8%	14.0%	14.8%	15.5%	15.0%	15.1%	14.3%	13.9%	10.6%	10.6%

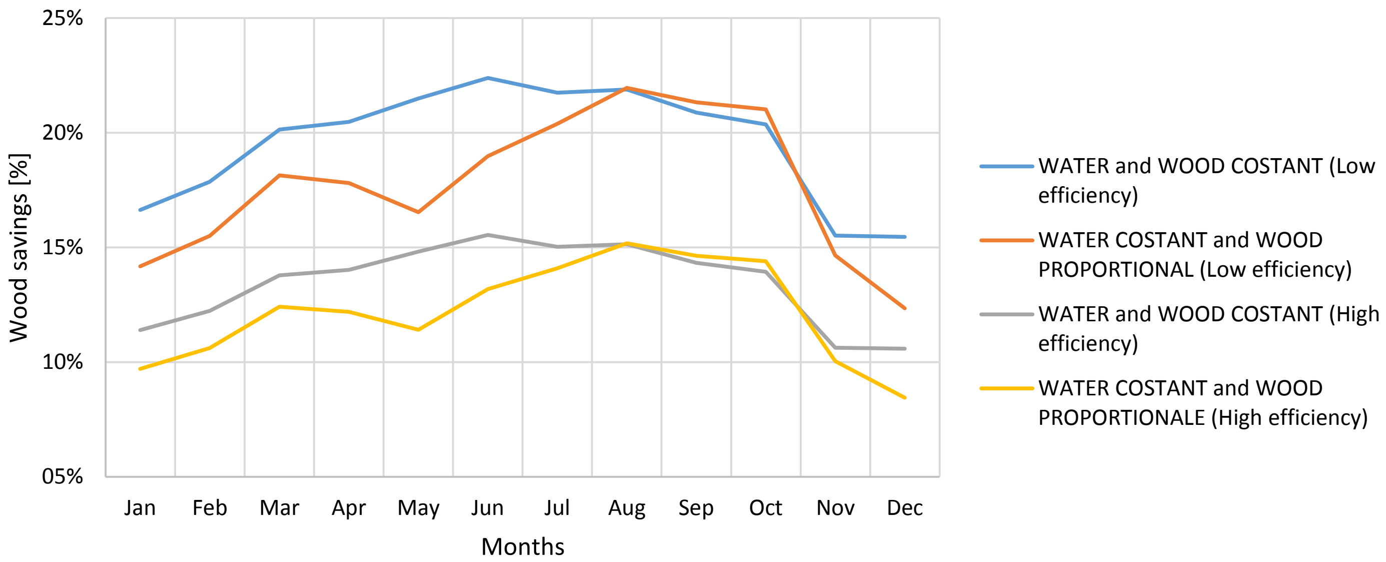


Figure A.19 - Trend of wood savings for PaMu during the year with solar collectors and storage.

Table A.59 - Results for PaMu for meals of the restaurant with solar collectors and storage.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{tech} [°C]	47.9	50.1	54.2	54.8	60.2	65.4	61.7	62.5	56.7	54.6	45.9	45.8
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{Plancha}$ [l]	4960	4480	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960
$E_{II_{Plancha}}$ [MJ]	621	602	752	739	876	952	907	924	778	760	561	577
$\Delta m_{Plancha}$ [kg]	500	481	612	602	680	724	685	698	594	606	461	473
	333	320	408	401	453	483	457	465	396	404	308	315
$m_{wood_{PaMu}}$ [kg]	2101	1880	2122	2053	2023	1918	1970	1969	1926	2079	2077	2135
S_{PaMu} [%]	23.81%	25.57%	28.83%	29.31%	33.61%	37.75%	34.80%	35.44%	30.82%	29.15%	22.22%	22.14%
	15.88%	17.04%	19.22%	19.54%	22.41%	25.17%	23.20%	23.63%	20.55%	19.43%	14.81%	14.76%

Table A.60 - Mean yearly wood savings at PaMu only for meals preparation with solar collectors and storage.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
S_{PaMu} [%]	17.2%	18.4%	22.9%	22.6%	25.1%	27.3%	27.0%	27.9%	24.5%	24.2%	17.6%	17.4%	22.5%
	11.6%	12.4%	15.5%	15.2%	16.9%	18.5%	18.2%	18.8%	16.5%	16.3%	11.9%	11.8%	15.2%

Table A.61 - Global mean yearly wood savings at PaMu considering all the activities with solar collectors and storage.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
S_{PaMu} [%]	8.5%	9.3%	11.3%	11.3%	12.3%	13.0%	12.8%	13.1%	11.6%	11.6%	8.8%	8.8%	11.0%
	5.7%	6.3%	7.6%	7.6%	8.3%	8.8%	8.6%	8.8%	7.8%	7.8%	5.9%	5.9%	7.4%

Table A.62 - Operating cost for PaMu considering all the activities with solar collectors and storage.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	3.1	2.7	3	2.9	3	2.9	3	3	2.9	3	2.9	3	35.40
Monthly Cost of Electricity [EUR]	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	3.26
Savings of Wood [EUR]	13.22	14.44	17.62	17.54	19.16	20.22	19.82	20.32	18.07	18.09	13.63	13.63	205.77
	8.92	9.75	11.88	11.82	12.94	13.69	13.39	13.74	12.19	12.19	9.19	9.18	138.69
TOTAL [EUR]	12.94	14.19	17.35	17.27	18.89	19.95	19.55	20.05	17.80	17.81	13.37	13.35	202.51
	8.63	9.50	11.60	11.56	12.66	13.42	13.12	13.46	11.92	11.91	8.92	8.91	135.44

Table A.63 - CO_2 savings at PaMu considering all the activities with solar collectors and storage.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	3.1	2.7	3	2.9	3	2.9	3	3	2.9	3	2.9	3	35.4
CO_2 from Hydroplants [kg]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.48
Savings of CO_2 because of lees wood [kg]	-1159	-1162	-1530	-1499	-1692	-1710	-1644	-1659	-1440	-1506	-1148	-1225	-17374
	-781	-785	-1031	-1011	-1143	-1158	-1111	-1122	-971	-1015	-774	-825	-11726
TOTAL BALANCE [kg]	-1159	-1162	-1530	-1499	-1692	-1710	-1644	-1659	-1440	-1506	-1148	-1225	-17374
	-781	-785	-1031	-1011	-1143	-1158	-1111	-1122	-971	-1015	-774	-825	-11726

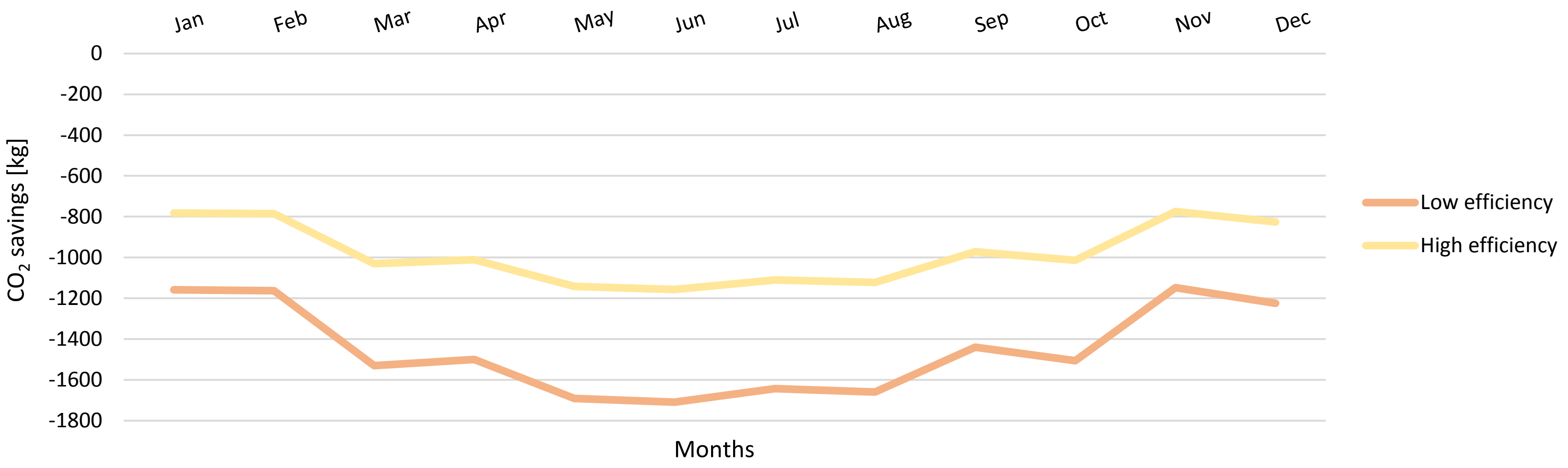


Figure A.20 - CO_2 savings for PaMu during the years with solar collectors and storage.

Hospital

Table A.64 – Results for the Hospital with solar collectors and storage.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
N. of patients	313	308	296	307	347	315	285	266	261	259	283	335
T_{tech} [°C]	47.9	50.1	53.2	54.8	60.2	65.4	61.7	62.5	56.7	54.6	45.9	45.8
LHV [MJ/kg]	15.5	15.7	15.4	15.4	16.1	16.4	16.5	16.6	16.4	15.7	15.2	15.3
$m_{boil\ water_{Plancha}}$ [l]	1415	1161	1036	1231	2165	1404	777	362	246	192	708	1888
$E_{II_{Plancha}}$[MJ]	177	156	153	190	382	279	142	67	40	29	83	220
$\Delta m_{Plancha}$[kg]	143	125	124	154	297	212	107	51	30	23	68	180
	181	147	134	159	267	170	93	43	30	24	93	246
$m_{boil\ water_{Rocket}}$[l]	6200	5600	6200	6000	6200	6000	6200	6200	6000	6200	6000	6200
$E_{II_{Rocket}}$[MJ]	776	752	914	924	1095	1190	1134	1155	972	950	701	721
Δm_{Rocket}[kg]	167	160	198	201	227	241	228	233	198	202	154	158
	143	137	170	172	194	207	196	199	170	173	132	135
$m_{wood_{Hospital}}$[kg]	1723	1515	1653	1652	1822	1580	1480	1391	1339	1431	1550	1860
$S_{Hospital}$ [%]	18.0%	18.8%	19.5%	21.5%	28.7%	28.7%	22.7%	20.4%	17.1%	15.8%	14.3%	18.2%
	13.8%	14.5%	15.3%	16.6%	21.5%	22.0%	18.1%	16.8%	14.2%	13.2%	11.4%	13.7%

YEAR	
20.3%	15.9%

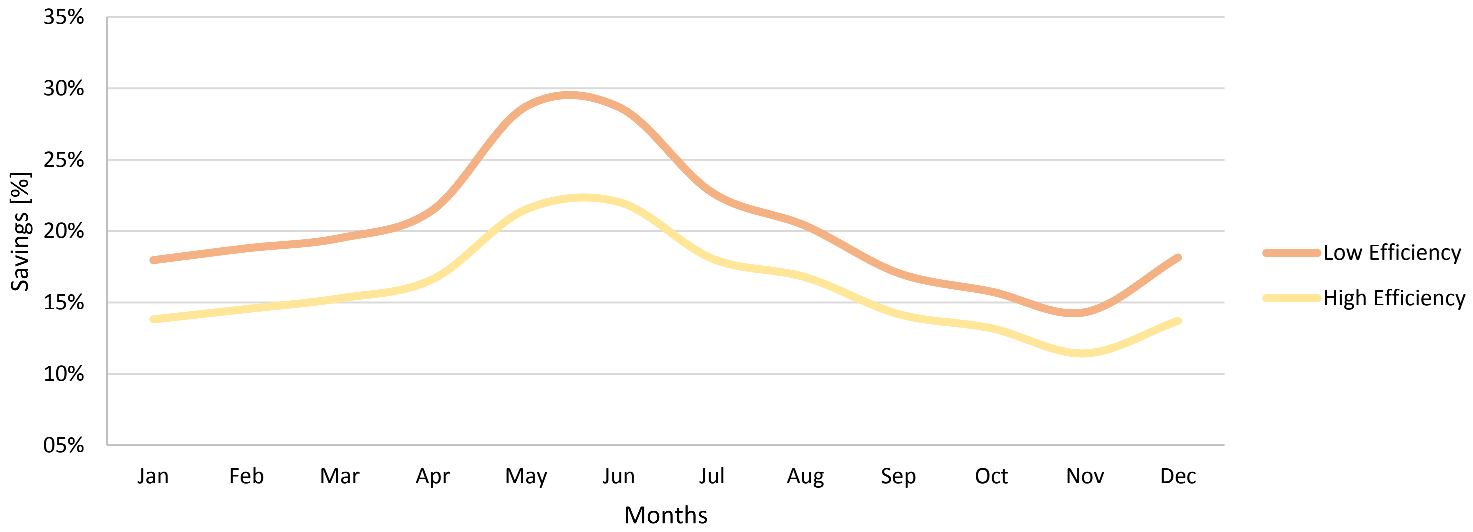


Figure A.21 - Trend of wood savings for the Hospital during the year with solar collectors and storage.

Table A.65 - Operating cost for the Hospital with solar collectors and storage.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*YEAR*
Electrical Energy [kWh]	3.1	2.8	3.1	2.9	3	3	3	3	3	3.1	2.9	3	35.9
TOTAL [EUR]	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-3.3

Table A.66 - CO_2 savings at the Hospital with solar collectors and storage.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Electrical Energy [kWh]	3.1	2.8	3.1	2.9	3	3	3	3	3	3.1	2.9	3	35.9
CO_2 from Hydroplants [kg]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.5
Savings of CO_2 because of lees wood [kg]	-498	-458	-518	-571	-841	-728	-540	-456	-367	-362	-357	-543	-6239
	-383	-354	-406	-442	-630	-560	-430	-375	-305	-304	-285	-410	-4884
TOTAL BALANCE [kg]	-498	-458	-518	-571	-841	-728	-540	-456	-367	-362	-357	-543	-6239
	-383	-354	-406	-442	-630	-560	-430	-375	-305	-303	-285	-410	-4884

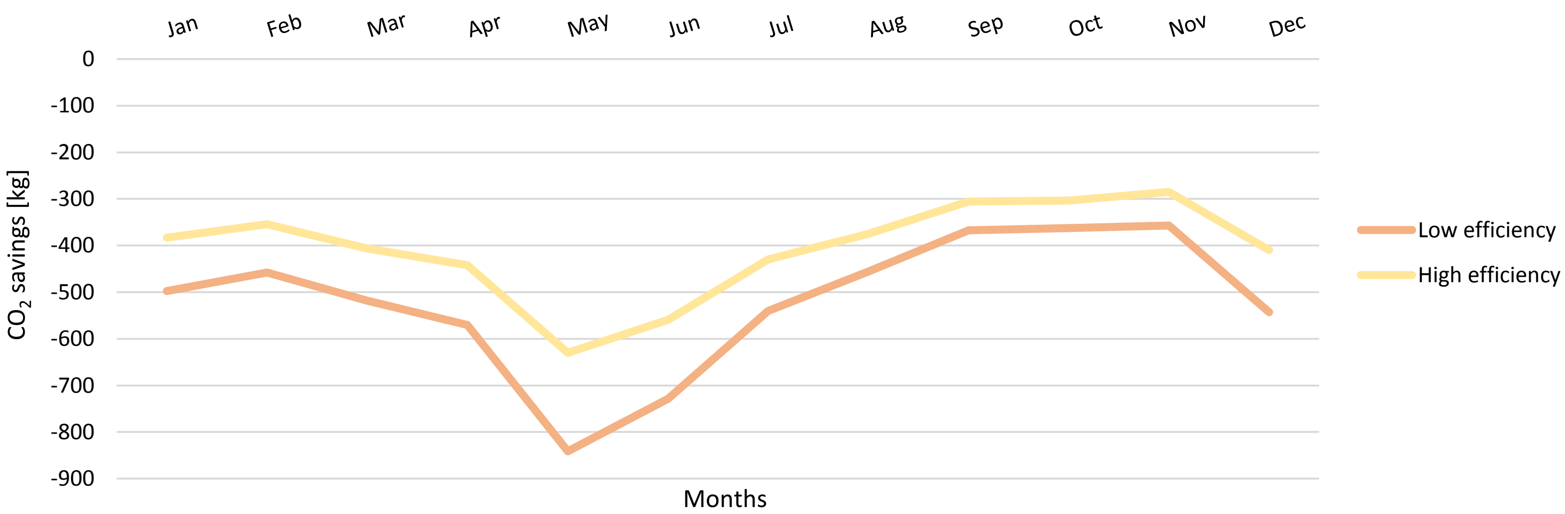


Figure A.22 - CO_2 savings for the Hospital during the years with solar collectors and storage.

APPENDIX B

This section reports in detail the results summarized in Paragraph 0 concerning the test of solar cookers.

	HOURS	*T BOX [°C]*	*T PANEL [°C]*	*AIR TEMPERATURE [°C]*	*DNI [W/m2]*	*ΔT_BOX [°C]*	*Q_BOX [W]*	*Q_BOX_ADJ [W]*	*ΔT_PANEL [°C]*	*Q_PANEL [W]*	*Q_PANEL_ADJ [W]*
11/07/2014	10:20:00	28.77	29.22	23.54	894.00	5.23	-	-	5.68	-	-
	10:30:00	33.29	35.26	22.98	907.00	10.31	34.33	26.50	12.28	76.84	59.30
	10:40:00	38.04	41.67	23.61	914.00	14.43	36.14	27.68	18.06	81.60	62.49
	10:50:00	42.46	48.17	23.73	914.00	18.73	33.57	25.71	24.44	82.66	63.31
	11:00:00	46.73	54.61	23.90	884.00	22.83	32.51	25.74	30.71	82.03	64.95
	11:10:00	50.77	59.97	23.63	888.00	27.14	30.71	24.21	36.34	68.22	53.78
	11:20:00	54.33	64.69	23.44	867.00	30.89	27.09	21.87	41.25	59.97	48.42
	11:30:00	57.60	69.34	24.92	882.00	32.68	24.89	19.75	44.42	59.21	46.99
	11:40:00	60.76	74.50	24.57	911.00	36.19	24.01	18.45	49.93	65.69	50.47
	11:50:00	63.54	79.17	24.31	942.00	39.23	21.10	15.68	54.86	59.47	44.19
	12:00:00	66.32	83.29	24.37	843.00	41.95	21.15	17.56	58.92	52.43	43.54
	12:10:00	68.45	87.13	24.21	835.00	44.24	16.21	13.59	62.92	48.80	40.91
	12:20:00	70.45	89.71	24.59	872.00	45.86	15.22	12.22	65.12	32.87	26.39
	12:30:00	72.24	91.86	25.75	926.00	46.49	13.63	10.31	66.11	27.36	20.68
	12:40:00	73.58		25.96	911.00	47.62	10.16				
	12:50:00	75.17		25.98	901.00	49.19	12.08				
	13:00:00	76.79		26.47	914.00	50.32	12.31				
	13:10:00	78.00		25.76	918.00	52.24	9.19				

	HOURS	T BOX [°C]	T PANEL [°C]	AIR TEMPERATURE [°C]	DNI [W/m2]	ΔT_BOX [°C]	Q_BOX [W]	Q_BOX_ADJ [W]	ΔT_PANEL [°C]	Q_PANEL [W]	Q_PANEL_ADJ [W]
	13:20:00	79.17		26.06	929.00	53.11	8.95				
	13:30:00	80.30		26.48	935.00	53.82	8.57				
	13:40:00	81.04		26.51	922.00	54.53	5.62				
	13:50:00	82.53		26.27	914.00	56.26	11.32				
	14:00:00	83.42		26.83	825.00	56.59	6.80				
15/07/2014	10:10:00	28.81	28.67	25.40	879.00	3.41	-	-	3.27	-	-
	10:20:00	33.56	34.45	25.36	871.00	8.20	36.11	29.02	9.09	73.54	59.10
	10:30:00	38.15	40.59	26.62	875.00	11.53	34.93	27.94	13.97	78.19	62.55
	10:40:00	42.55	47.02	26.09	890.00	16.46	33.49	26.34	20.93	81.82	64.35
	10:50:00	46.50	53.27	26.66	880.00	19.84	30.03	23.89	26.61	79.58	63.30
	11:00:00	50.22	59.25	27.24	879.00	22.98	28.24	22.49	32.01	76.18	60.67
	11:10:00	53.59	65.01	26.69	891.00	26.90	25.65	20.15	38.32	73.31	57.60
	11:20:00	56.75	70.37	26.43	893.00	30.32	24.05	18.85	43.94	68.32	53.56
	11:30:00	59.72	75.46	26.16	891.00	33.56	22.54	17.71	49.30	64.77	50.89
	11:40:00	62.36	79.58	27.01	956.00	35.35	20.11	14.72	52.57	52.41	38.37
	11:50:00	64.97	83.40	26.98	890.00	37.99	19.86	15.62	56.42	48.68	38.28
	12:00:00	66.97	86.80	27.19	888.00	39.78	15.20	11.98	59.61	43.33	34.16
	12:10:00	69.61	89.23	26.88	890.00	42.73	20.11	15.81	62.35	30.95	24.34
	12:20:00	71.61	91.36	27.79	1005.00	43.82	15.16	10.56	63.57	27.11	18.88
	12:30:00	73.18		28.10	884.00	45.08	12.00	9.50			
	12:40:00	75.27		27.85	854.00	47.42	15.83	12.98			
	12:50:00	76.81		28.04	926.00	48.77	11.76	8.89			
	13:00:00	78.13		28.04	856.00	50.09	10.00	8.18			

	HOURS	T BOX [°C]	T PANEL [°C]	AIR TEMPERATURE [°C]	DNI [W/m2]	ΔT_BOX [°C]	Q_BOX [W]	Q_BOX_ADJ [W]	ΔT_PANEL [°C]	Q_PANEL [W]	Q_PANEL_ADJ [W]
	13:10:00	79.85		28.00	869.00	51.85	13.08	10.54			
	13:20:00	81.27		28.30	865.00	52.97	10.84	8.77			
	13:30:00	82.56		28.70	867.00	53.86	9.79	7.91			
	13:40:00	83.56		28.93	847.00	54.63	7.63	6.30			
	13:50:00	84.46		29.13	857.00	55.33	6.78	5.53			
	14:00:00	85.20		28.74	875.00	56.46	5.70	4.56			
16/07/2014	10:10:00	30.67	31.95	27.94	856.00	2.73	-	-	4.01	-	-
	10:20:00	35.05	37.37	28.75	859.00	6.30	33.29	27.13	8.62	68.97	56.20
	10:30:00	39.31	43.25	28.05	859.00	11.26	32.37	26.38	15.20	74.96	61.08
	10:40:00	43.44	49.21	28.75	870.00	14.69	31.41	25.27	20.46	75.82	61.01
	10:50:00	47.41	55.17	28.74	859.00	18.67	30.26	24.66	26.43	75.85	61.81
	11:00:00	51.09	60.86	29.44	863.00	21.65	27.95	22.67	31.42	72.47	58.78
	11:10:00	54.54	66.39	28.39	859.00	26.15	26.24	21.38	38.00	70.45	57.41
	11:20:00	57.72	71.61	28.54	872.00	29.18	24.14	19.38	43.07	66.46	53.35
	11:30:00	60.73	76.37	28.66	874.00	32.07	22.91	18.35	47.71	60.54	48.49
	11:40:00	63.50	80.84	29.48	859.00	34.02	21.06	17.16	51.36	56.91	46.38
	11:50:00	66.18	85.09	28.64	867.00	37.54	20.43	16.49	56.45	54.20	43.76
	12:00:00	68.47	88.30	28.51	835.00	39.96	17.41	14.60	59.79	40.83	34.23
	12:10:00	70.76		28.68	882.00	42.08	17.37	13.78			
	12:20:00	72.82		29.29	837.00	43.53	15.65	13.09			
	12:30:00	74.67		29.01	810.00	45.66	14.11	12.20			
	12:40:00	76.45		28.41	818.00	48.04	13.51	11.56			
	12:50:00	78.13		29.06	823.00	49.07	12.80	10.89			

	HOURS	T BOX [°C]	T PANEL [°C]	AIR TEMPERATURE [°C]	DNI [W/m2]	ΔT_BOX [°C]	Q_BOX [W]	Q_BOX_ADJ [W]	ΔT_PANEL [°C]	Q_PANEL [W]	Q_PANEL_ADJ [W]
	13:00:00	79.63		29.14	829.00	50.49	11.41	9.64			
	13:10:00	80.86		29.38	833.00	51.48	9.31	7.82			
	13:20:00	82.10		29.50	859.00	52.60	9.45	7.70			
	13:30:00	83.13		29.83	856.00	53.30	7.80	6.38			
	13:40:00	83.96		30.53	861.00	53.43	6.33	5.14			
	13:50:00	84.73		29.78	859.00	54.95	5.88	4.79			
	14:00:00	85.36		30.76	854.00	54.60	4.78	3.91			
17/07/2014	10:10:00	29.27	28.52	28.33	773.00	0.94	-	-	0.19	-	-
	10:20:00	33.69	33.42	27.71	786.00	5.98	33.55	29.88	5.71	62.39	55.56
	10:30:00	38.02	38.99	28.09	778.00	9.93	32.93	29.63	10.90	70.92	63.81
	10:40:00	41.88	44.69	28.13	780.00	13.75	29.38	26.37	16.56	72.52	65.09
	10:50:00	45.61	50.49	28.52	788.00	17.09	28.37	25.20	21.97	73.89	65.63
	11:00:00	49.24	56.15	28.90	795.00	20.34	27.61	24.31	27.25	72.07	63.45
	11:10:00	52.65	61.72	28.51	795.00	24.14	25.91	22.81	33.21	70.87	62.40
	11:20:00	55.85	66.92	29.20	808.00	26.65	24.31	21.06	37.72	66.26	57.40
	11:30:00	58.81	71.86	29.36	808.00	29.45	22.50	19.49	42.50	62.94	54.52
	11:40:00	61.43	76.33	29.55	816.00	31.88	19.96	17.12	46.78	56.93	48.83
	11:50:00	63.89	80.43	29.18	842.00	34.71	18.71	15.55	51.25	52.10	43.31
	12:00:00	66.29	84.10	29.20	831.00	37.09	18.24	15.37	54.90	46.78	39.40
	12:10:00	68.52	87.32	29.29	882.00	39.23	16.99	13.48	58.03	41.05	32.58
	12:20:00	70.59	89.99	28.84	799.00	41.75	15.68	13.74	61.15	33.96	29.75
	12:30:00	72.66	92.14	29.76	852.00	42.90	15.77	12.96	62.38	27.36	22.48
	12:40:00	74.37		30.35	795.00	44.02	13.00	11.44			

	HOURS	T BOX [°C]	T PANEL [°C]	AIR TEMPERATURE [°C]	DNI [W/m2]	ΔT_BOX [°C]	Q_BOX [W]	Q_BOX_ADJ [W]	ΔT_PANEL [°C]	Q_PANEL [W]	Q_PANEL_ADJ [W]
	12:50:00	75.72		29.73	846.00	45.99	10.30	8.53			
	13:10:00	76.29		30.11	833.00	46.18	7.33	6.16			
	13:20:00	77.58		29.96	795.00	47.62	9.80	8.63			
	13:30:00	78.96		30.12	787.00	48.84	10.46	9.31			
	13:40:00	80.02		30.21	801.00	49.81	8.10	7.08			
	13:50:00	80.85		29.81	831.00	51.04	6.31	5.32			
	14:00:00	81.55		30.17	852.00	51.38	5.33	4.38			
18/07/2014	10:10:00	29.36	29.76	27.49	750.00	1.87	-	-	2.27	-	-
	10:20:00	33.51	34.39	27.29	754.00	6.22	31.51	29.26	7.10	58.98	54.75
	10:30:00	37.55	39.59	27.33	761.00	10.22	30.71	28.25	12.26	66.14	60.84
	10:40:00	41.48	45.33	28.07	774.00	13.41	29.92	27.06	17.26	73.07	66.09
	10:50:00	45.17	50.97	28.17	771.00	17.00	28.05	25.46	22.80	71.82	65.21
	11:00:00	48.70	56.71	28.82	793.00	19.88	26.83	23.68	27.89	73.10	64.52
	11:10:00	52.19	62.25	28.60	795.00	23.59	26.56	23.38	33.65	70.54	62.11
	11:20:00	55.24	67.39	28.60	786.00	26.64	23.19	20.66	38.79	65.44	58.28
	11:30:00	58.32	72.22	29.11	799.00	29.21	23.44	20.54	43.11	61.57	53.94
	11:40:00	60.88	76.73	29.38	808.00	31.50	19.44	16.85	47.35	57.39	49.71
	11:50:00	63.58	81.06	29.08	785.00	34.50	20.52	18.30	51.98	55.16	49.18
	12:00:00	65.95	84.64	29.68	801.00	36.27	18.08	15.80	54.96	45.58	39.83
	12:10:00	67.90	87.75	29.22	801.00	38.68	14.77	12.91	58.53	39.55	34.56
	12:20:00	70.18	90.24	28.61	805.00	41.57	17.40	15.13	61.63	31.75	27.61
	12:30:00	72.22	92.37	29.10	861.00	43.12	15.47	12.58	63.27	27.06	22.00
	12:40:00	73.90		29.25	806.00	44.65	12.75	11.08			

	HOURS	T BOX [°C]	T PANEL [°C]	AIR TEMPERATURE [°C]	DNI [W/m2]	ΔT_BOX [°C]	Q_BOX [W]	Q_BOX_ADJ [W]	ΔT_PANEL [°C]	Q_PANEL [W]	Q_PANEL_ADJ [W]
	12:50:00	75.76		29.63	801.00	46.13	14.14	12.36			
	13:00:00	77.50		30.13	801.00	47.37	13.29	11.62			
	13:10:00	78.76		30.01	816.00	48.75	9.53	8.17			
	13:20:00	80.38		30.09	816.00	50.29	12.34	10.59			
	13:30:00	81.52		30.49	801.00	51.03	8.67	7.58			
	13:40:00	82.34		30.44	808.00	51.90	6.24	5.40			
	13:50:00	83.35		29.71	808.00	53.64	7.67	6.65			
	14:00:00	84.17		30.10	797.00	54.07	6.24	5.48			

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