IMPROVING EFFICIENCY IN FORESTRY OPERATIONS AND FOREST PRODUCT PROCESSING IN KENYA:

A VIABLE REDD+ POLICY AND MEASURE

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ABBREVIATIONS

BAU	Business-as-usual
BEF	Biomass expansion factor
Bsavings	Biomass savings
CDM	Clean Development Mechanism
Cf	Carbon fraction
CPA	Charcoal producers associations
EMCA	Environmental Management and Coordination Act
ER	Emission reductions
EU	European Union
FAO	Food and Agriculture Organization
fNRB	Non-renewable biomass fraction
FOSA	Forestry Outlook Study for Africa
FRA	Global Forest Resources Assessments (of FAO)
FRL	Forest Reference Level
FREL	Forest Reference Emission Level
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoK	Government of Kenya
ha	Hectares
ICS	Improved cook stoves
IPCC	Intergovernmental Panel on Climate Change
KAFU	Kenya Association of Forest Users
KCJ	Kenya Ceramic Jiko
KEFRI	Kenya Forestry Research Institute
KES	Kenyan Shilling
KFMP	Kenya Forest Master Plan
KFS	Kenya Forest Service
KWS	Kenya Wildlife Service
KTDA	Kenya Tea Development Agency
LPG	Liquid petroleum gas
m3	cubic meters
MEWNR	Ministry of Environment, Water and Natural Resources
MOE	Ministry of Energy
MRV	Measuring, Reporting and Verification
NWFP	Non-wood forest products
OWL	Other wooded land
PAMs	Policies and measures for REDD+
REDD+	Reducing Emissions from Deforestation and forest Degradation, and the role of conservation, sustainable management of forests and enhancement of carbon stocks in developing countries
REL	Reference emission level
R-PP	Readiness Preparation Proposal
RSR	Root-shoot ratio
RWE	Round wood equivalent
SME	Small and medium enterprises
SNA	System of National Accounts
tC	tons of carbon
tCO_2e	tons of carbon dioxide equivalent
UNEP	United Nations Environment Programme
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
UNFCCC	United Nations Framework Convention on Climate Change

SUMMARY FOR POLICYMAKERS

KEY MESSAGES

Kenya's constitution has set a minimum national tree cover target of 10%. Additionally, the country has demonstrated sustained commitment to anchoring REDD+[1] in its national policy framework and development strategy. In this context, Kenya is in the process of identifying the best ways to address the direct and indirect drivers of deforestation and forest degradation.

Both timber and fuelwood demand are increasing and the challenge ahead is to help public and private plantations to meet future demand in a sustainable way, by reducing the quantity of non-renewable biomass used to bridge the demand shortfall. According to the Kenyan Readiness Preparation Proposal (R-PP), the lack of security of timber supply to the sawmilling industry (i.e. low investment in timber processing technology, poor timber conversion ratios) is a key indirect driver of deforestation and forest degradation (KFS, 2010) as it may contribute to encroachment in forests not destined for timber production. Sustainable utilization of wood resources, including but not limited to enhanced efficiency in processing, is one way for Kenya to potentially achieve a reduction or removal of emissions and hence REDD+ results.

This report analyses whether increased efficiency in forestry operations and forest product processing and utilization are interesting REDD+ policies and measures (PAMs) for the Government of Kenya (GoK) to pursue, with the potential to attract public and/or private investments to enable REDD+ implementation. In particular, the report focuses on the extent to which efficiency improvements could address supply deficiency in the forest sector, thereby reducing pressures on existing forests and related emissions.

To this end, cost estimates and emissions reduction potential were undertaken in the following sectors:

1. Forestry operations (commercial logging)
2. Timber conversion (sawmills)
3. Charcoal production
4. Charcoal and firewood use in cooking stove technology (households)
5. Wood usage in industrial processes

Although wood is a renewable material, it becomes non-renewable when the harvesting rates exceed the ecosystem's production capacity. Thus, for each sector, the fraction of non-renewable biomass (fNRB), which indicates the proportion of biomass used that is not renewable, was a key parameter to estimate the potential emission reductions from deforestation and forest degradation of each of the five sectors. The United Nations Framework Convention on Climate Change (UNFCCC) defines this as the "proportion of total annual (woody) biomass removals that is demonstrably not renewable".

With regards to forestry operations and timber processing from forest plantations in Kenya, while strong socio-economic benefits may be derived from efficiency improvements, there is no evidence that increasing efficiency will help alleviate illegal harvesting pressure on natural forests. According to Kenya Forest Service (KFS), most of the timber produced at national level comes from forest plantations. Small, illegal saw-millers rely mostly on timber from private farms and illegally accessed timber from forest reserves, especially through indiscriminate and uncontrolled selective cutting in forests. Plantation forest products such as pine, cypress and eucalyptus are hardly substitutable with the precious woods illegally harvested in natural forests. Moreover, rare commercial species such as camphor and sandalwood are not only exploited for their precious wood but also for other products (such as bark used in the perfume industry or for medicinal use) and therefore are not affected by increasing the efficiency of forestry operations in pine, cypress and eucalyptus plantations.

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1 Reducing Emissions from Deforestation and Forest Degradation (REDD) is a concept to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. "REDD+" goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks.

Emission reductions or removals are only expected when investing in enhancing efficiency in charcoal production and fuelwood consumption at household and industrial levels. Investments to improve efficiency in charcoal production (increased supply) and fuelwood consumption (reduced demand) at household and industrial levels are both economically-attractive and have the highest potential to generate REDD+ results, with an estimated emission reduction potential of more than 20 million tons of carbon dioxide equivalent (tCO_2e) per year.

The assessment results support the mitigation activities proposed by the GoK in its Intended Nationally Determined Contribution (INDC) submitted to the UNFCCC in July 2015, including: "Enhancement of energy and resource efficiency across the different sectors" and "Making progress towards achieving a tree cover of at least 10% of the land area of Kenya". The INDC states that Kenya's total greenhouse gas (GHG) emissions were around 73 million tCO_2e in 2010, of which 75% were from the land use, land-use change and forestry (LULUCF) and agriculture sectors. **If Kenya were to implement the measures proposed in this report, the potential reduction of 20 million tCO_2e identified in this study could lead to a reduction of 27% of total GHG emissions** against 2010 numbers.

The assessment, therefore, supports the GoK by shedding light on how stimulating investments in the forest sector can create economic benefits while also reducing pressures on remaining forests. This is particularly the case for dry forests, where 75% of charcoal is sourced and the risk of over-harvesting of non-renewable biomass is higher.

FORESTS: MORE THAN TIMBER

Forests are an important feature of Kenya's landscape, ranging from montane forests (also called 'water towers') in the mountainous areas, to western rainforests, dry forests, and coastal and riverine forests. Forests also have an understated importance to Kenya's economy. While the system of national accounts (SNA), a set of rules that determine a country's Gross Domestic Product (GDP), put the total annual contribution of forests at 1.1% of GDP in 2010, this is a gross underestimation (UNEP, 2012).

Aside from timber and other wood products, forests also provide a range of services that directly or indirectly support other key productive sectors such as energy (water regulation and soil retention for hydroelectric power generation), agriculture (enhancing soil quality, reducing soil erosion) and tourism. A report by the KFS, the Kenya Bureau of Statistics and international partners (UNEP, 2012) revealed that the economic contribution of forests is considerably undervalued. Instead of 1.1% of GDP, the contribution would rise to at least 3.6% of GDP if a broader range of ecosystem services provided by Kenya's montane forests were included. Even this is an underestimate, because this work did not include the other types of forest in the analysis.

There is, therefore, a clearer domestic economic rationale to reduce deforestation rates and increase efforts to rehabilitate degraded forest areas. **The underlying idea behind this study is to assess if efficiency improvements can address the supply deficiency, reduce subsequent pressure on forests and**

therefore be an interesting REDD+ policy or measure to pursue by the Government of Kenya in order to reduce or remove forest carbon emissions.

OPPORTUNITIES FOR EFFICIENCY IMPROVEMENTS

1. **Forestry operations (commercial logging).** There is great potential to improve the quality and quantity of plantation resources in Kenya, both in the public and private realms. In order to ensure adequate wood supply, improved management practices are needed to address the current poor performances of public plantations, while increased investments will be necessary to increase the stocked plantation areas. Improved sawn log quality from appropriately managed plantations is a precondition for investments in more efficient equipment in the timber processing sector to increase the timber processing average recovery rate. Afforestation and reforestation as well as improving plantation management by appropriate silvicultural practices such as thinning, pruning and extension of rotation age, can reduce forest carbon emissions from both public and private plantations. Improving harvesting techniques has the potential to cut logging waste from harvesting volumes by 5%. However, given that there is no evidence that increased rate of recovery from harvesting in forest plantations will decrease the pressure on natural forests for timber production, and given that the non-renewable biomass fraction (fNRB) in public and private plantations is close to zero, these measures are unlikely to generate emission reductions from deforestation and forest degradation. The efficiency measures to enhance forestry operations might have positive socio-economic impacts, though, such as increasing the safety of harvesting operations and harvested timber quality.

2. **Timber conversion (sawmills).** Greater efficiency in timber processing could increase national timber production by about 238,000 m^3 round wood equivalent (RWE) per year. To reach this goal, investments in sawing and drying technologies as well as in vocational training are required. The timber and wood industry is closely linked to the construction sector and the Government of Kenya's 2030 Vision places sawmills, as small and medium enterprises (SMEs), at the heart of the country's development plan. The sector has rebounded from the effects of a 1999-2011 countrywide ban on logging in public forests and developed steadily in recent years, with almost three times the volume of sawn wood produced compared to the level of 1999. However, for the same reasons described

above, most of these measures are unlikely to generate emission reductions or removals from deforestation and forest degradation. Promoting the substitution of fuelwood from non-renewable forest sources with briquettes made of recycled sawn wood can lead to a small amount of biomass savings per year (36,000 m^3_{RWE}). Around 111,000 tCO_2e per year of emission reductions from deforestation and degradation are generated. It is reasonable to assume that improved timber production will increase safety and healthcare on working sites, create more value added and jobs in the wood supply chain and contribute to sustainable development of the country.

3. **Charcoal production.** The proposed measures range from basic improvements, such as the training of 100,000 charcoal producers to apply best practices to improve earth kilns, and the construction of 50,000 Casamance kilns (with metal chimneys, as promoted by the Kenya Forestry Research Institute (KEFRI) for several years), to technological substitution such as the use of retort kilns instead of traditional direct-combustion earth kilns. Increasing efficiency in charcoal production can reduce the pressure on forests: instead of using 10 kg of wood to produce 1 kg of charcoal, improved technologies can cut the use of wood down to 3 to 6 kg according to the technology used and best practices applied. Considering the high proportion of non-renewable biomass used to produce charcoal (between 90% and 95%), these measures could lead to 5.7 million m^3_{RWE} of non-renewable biomass savings per year from dry forests, generating about 16.5 million tCO_2e per year of emission reductions from deforestation and forest degradation. Moreover, charcoal production efficiency measures can generate other positive impacts such as the reduction of accidental burning and respiratory problems amongst charcoal producers. These measures can also generate more qualified jobs in the sector. Therefore, improving charcoal production could be an attractive measure for the Kenyan government as part of its National REDD+ Strategy and implementation plan.

4. **Use of charcoal and firewood in cooking stove technology.** The proposed measures target the large-scale adoption of 5 million improved cook stoves in urban and rural areas to replace the current inefficient cooking devices and reduce the demand for fuelwood (firewood and charcoal). Increasing efficiency in the consumption of fuelwood, mainly sourced from natural forests where high levels of non-renewable biomass are estimated, could lead to 960,100 m^3_{RWE} of non-renewable biomass savings per year from natural
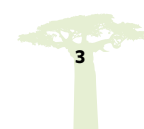
FIGURE 1: Investment opportunities to enhance efficiency in the forest sector

Charcoal production
- On-site production through training (earth kilns)
- Availability fixed/semi-mobile high yield processing units (retorts)

Firewood/charcoal consumption by households
- Firewood-based improved cook stoves in rural areas
- Charcoal-based improved cook stoves in urban areas

Options for efficiency improvements in forestry operations and forest product processing

Firewood/charcoal consumption in industrial processes
- Furnaces/boilers with improved yields

Forestry operations (commercial logging):
- Improve harvest planning
- Improve efficiency harvest operations
- Improve skidding and hauling

Timber processing (sawmills)
- Enhance recovery rate through better saws
- Use residues (sawdust) for e.g. briquettes
- Create value added timber (e.g. drying)
- Training: sawmill personnel and operators

forests, generating about 2.4 million tCO_2e per year in terms of emission reductions from deforestation and forest degradation. Moreover, these measures will generate positive impacts such as the reduction of respiratory problems among fuelwood consumers, especially women and children, and can create additional jobs in the cook stove manufacturing sector. These measures are therefore potentially attractive for the Kenyan government as part of its National REDD+ Strategy, generating both emission reductions from deforestation and degradation and positive co-benefits.

5. **Increasing efficiency in wood usage in industrial processes** may represent nearly 1.2 million m^3_{RWE} of non-renewable biomass savings per year, generating more than 2.0 million tCO_2e per year in terms of emission reductions from deforestation and forest degradation. However, more data on fuelwood origin by sector (tea, tobacco, restaurants and kiosks, etc.) is necessary to refine this conclusion. It is yet not clear whether a significant amount of non-renewable biomass from natural forests is used in these industrial processes, or if they rely only on renewable biomass harvested in forest plantations. In the latter case, the potential emission reductions from deforestation and degradation would be much less.

An overview of investment opportunities in the forest product and processing sector is shown in Figure 1.

CONCLUSION

Kenya submitted its INDC to the UNFCCC in July 2015. In the INDC, Kenya pledges to cut its carbon emissions to 30% below business-as-usual (BAU) levels by 2030. The Kenyan government has indicated that, to meet this ambitious target, a number of measures will be required including expanding solar, wind and geothermal power, and bringing national forest cover up to 10% while reducing reliance on wood fuel. The analysis carried out in this project is therefore very relevant in the context of Kenya's INDC, but also to its National Climate Change Response Strategy (2010) and National Climate Change Action Plan (2013).

Table 1 provides an overview of the costs (in terms of annual investment) and benefits (in terms of potential biomass savings and carbon benefits) of efficiency improvements in the five forestry sub-sectors that were analysed given a certain amount of upfront investment. However, only efficiency improvements in charcoal production and fuelwood consumption at household and industrial levels are expected to generate REDD+ results.

These results are relevant as they show that investments in efficiency measures in charcoal production as well as fuelwood consumption at household and industrial levels are: i) viable REDD+ policies to reduce or eliminate net carbon emissions; and ii) could significantly contribute to Kenya's

TABLE 1: Summary cost-efficiency analysis

	Potential biomass savings (m³$_{RWE}$ per year)	Emission reductions from deforestation and degradation (tCO$_2$e per year)	Investment* ($/year)
Forestry operations (harvesting)	10,000	n/a	375,000
Timber processing (including briquette production)	238,000	110,838	1,340,000
Charcoal production	5,658,810	16,476,000	15,642,000
Fuelwood consumption at household level	960,100	2,386,000	10,000,000
Fuelwood consumption at industrial level	1,191,000	2,040,000	11,430,000
Total	**8,057,910**	**21,012,838**	**38,787,000**

* For details see Tables 6, 8, 13 and 18.

GHG emission reduction targets; iii) can be cost efficient. In terms of abatement costs, these range from 0.95 $/tCO$_2$-e for efficiency improvements in charcoal production, 4.2-5.6 $/tCO$_2$-e for fuelwood consumption at household and industrial level, to 12.1 $/tCO$_2$-e for efficiency improvement to process timber.

Based on Kenya's 2010 GHG emission level of 73 million tCO$_2$e per year as stated in the INDC, reducing emissions by 21 million tCO$_2$e per year, as identified in this report, would go a long way to meeting Kenya's climate goals. Given that the policy options identified in this study are viable from a REDD+ perspective, they offer preliminary reflections that may be strategically relevant to the design of Kenya's National REDD+ Strategy and future REDD+ investment plan.

However, estimated investments needed to increase efficiency and reduce or remove carbon emissions are significant at about $38 million per annum. There is an opportunity for the GoK to identify how to incentivize the private forestry sector to (co-)finance improvements in the way charcoal and fuelwood is used for energy provisioning i.e. what financial (and other economic) incentives need to be provided in order to stimulate private actors to finance such efficiency improvements?

From a regulatory perspective, it is important to understand that productivity improvements could have the unintended consequence of actually enhancing pressures on forests as efficiency improvements can lead to higher incomes, which can perversely incentivize additional encroachment on forests. It is therefore important to identify how financial incentives to stimulate efficiency improvements can be made conditional on private users adhering to relevant social and environmental criteria so that such stimulus measures actually lead to emission reductions or removals.

ASSUMPTIONS AND METHODOLOGY

The following underlying assumptions and targets for the proposed improvement measures have to be carefully considered when analysing the overall findings.

1. **Timing in scenario analysis:** A 10-year period was used to for efficiency improvements across these five sub-sectors to allow for comparison. This can be an appropriate timeframe for firewood and charcoal consumption at household level where cooking devices have to be replaced regularly in order to sustain the efficiency improvement outcomes. However, this is not applicable for timber processing and firewood consumption at industrial level where the equipment has a write-off or amortization period that is substantially longer.

2. **Number of stakeholders:** There are large differences in the five sub-sectors in terms of number of operators targeted by the proposed efficiency improvement measures. The 10-year timeframe of vocational training to bring about more efficiency in harvesting operations could target almost 100% of forest workers in the country. Investments in new sawing equipment and training in the timber-processing sector was based on reaching 20% of the total number of saw millers. Similarly, the number of producers taken into account to set up the estimation of improved charcoal production scenario was not more than 20%. The population targeted by the action aimed at improving the cooking devices was between 80 and 100% depending on the type of device and location (wood vs. charcoal cook stoves, urban vs. rural areas). Moreover, the improvement of energy conversion in the agricultural and cottage industries targeted 30% of the total number of businesses. It is evident that if the number of people or businesses targeted by the improvement measures increases, the prospective biomass savings will increase accordingly. Indeed, proper goals have to be set according to political willingness and available resources.

3. **Abatement costs:** These have been estimated in terms of $/tCO$_2$e in order to allow meaningful comparisons between the results of each sector. The lowest abatement cost was found in the charcoal production sector ($0.9/tCO$_2$e) and the highest in the sector of firewood and charcoal consumption at industrial level ($5.6/tCO$_2$e). The estimated abatement costs from the production of briquettes made of recycled saw-dust is $4.9/tCO$_2$e, and $4.2/tCO$_2$e for the use of improved cook stoves at household level. In the charcoal production sector, efficiency can be strongly improved at a relatively low cost, as compared to the other sectors.

4. **Biomass saving:** The maximum potential biomass savings from the alternative scenarios is more than 85 million m$^3_{RWE}$ over 10 years. This outcome is almost six times higher than the potential biomass production from increasing the growing stock of public plantations from afforestation-reforestation and improving management techniques, which was estimated in this report at 15 million m$^3_{RWE}$. Moreover, it has to be noted that the potential outcome from growing stock increase in public plantations can be achieved over a much longer timeframe because the expected effect of improved management techniques take place during the whole rotation period, which for pine and cypress species is around 30 years. Afforestation and reforestation have to be progressive in order to properly integrate new establishments with the ages of previous plantation stands. In contrast, the other options discussed in this report may potentially lead to immediate, short-term results.

   Biomass savings can be more easily achieved in the agriculture, charcoal production and firewood/charcoal consumption sectors. These activities involve both large wood supply volumes as well as great efficiency improvement potential from technological innovation ranging from 10% to 50%. In the field of harvesting and timber processing efficiency improvement, no more than 5% to 20% increase can be expected from the current recovery rates levels, which is limiting the potential of total biomass savings.

   It is straightforward to assume that if the number of people or businesses targeted by the improvement measures

increases, the prospective biomass savings will increase accordingly. However so would the estimated costs of the actions.

5. **Emissions reduction:** the following general equation (adapted from IPCC, 2006) is used to calculate the emissions reduction associated with a given REDD+ measure, including this section's focus on improving the efficiency of forestry operations and increasing wood production by reducing wastage:

$$ER = Bsavings \times fNRB \times BEF \times (1+RSR) \times Cf \times 44/12$$

Where:

ER = emission reductions (tCO_2e per year in the five REDD+ scenarios analysed)
B savings = quantity of biomass saved per year (in tons – wood density 0.6 ton/m^3) in the REDD+ scenario
fNRB = non-renewable biomass fraction
BEF = Biomass expansion factor (default IPCC values)
RSR= Root-shoot ratio (default IPCC values = 0.37)
Cf = carbon fraction (default IPCC values = 0.5)
Conversion factor from C to CO_2 = 44/12

The proportion of non-renewable biomass (also called non-renewable biomass fraction or fNRB) is an essential parameter to assess the emissions reduction potential. It is calculated as follows:

$$fNRB = \frac{(Total\ biomass\ harvested\ per\ year - Sustainable\ yield\ per\ year)}{(Total\ biomass\ harvested\ per\ year)}$$

The fNRB can be calculated for each type of forest (natural vs. planted) and wood product (in this case, logs for timber processing). When fNRB is equal to 0, the annual harvested biomass is equal to the sustainable yield: in this case, there is no carbon stocks degradation. However, when the fNRB is between 0 and 1, it indicates a decrease in carbon stocks over time, e.g. due to deforestation or forest degradation.

It has to be noted that the above parameters vary across the different sectors considered. The parameters used for each sector of activity come from UNFCCC guidelines (GOFC-GOLD, 2013). The parameters used in this study are shown in the following table.

	Report section	RSR	BEF	fNRB
Commercial forestry operations	3.1	0,37	1,9	0
Timber processng	3.2	0,37	1,3	0,25
Charcoal production	3.3	0,56	1,9	0,95
Charcoal consumption at household level	3.4	0,37	1,3	0,92
Fuelwood consumption at household level	3.4	0,37	1,3	0,92
Fuelwood consumption at industrial level	3.5	0,37	1,3	0,92

1. INTRODUCTION

There is considerable potential to improve efficiency in wood and biomass utilization which may lead to improved profitability of the timber and forest products industries, reduced demand for raw wood materials for household energy needs, and increased contribution of the forest sector to climate change mitigation.

However, at present wood conversion efficiency in Kenya is poor and the quality of final products has declined. Due to obsolete machinery, the timber industry suffers from low recovery rates and high levels of residues both in harvesting and processing operations. Rural and urban households are highly dependent on fuelwood (firewood and/or charcoal), especially for cooking. Inefficiencies in the charcoal production sector raise important concerns in Kenya, where arid and semi-arid lands are subject to forest degradation.

The Kenyan R-PP assumes that wider use of already existing best practices and technologies may significantly help the forest sector reduce emissions from deforestation and forest degradation. In this context, the present report details the feasibility and cost-benefit analysis of five areas within the broader forest sector where an improvement in efficiency might provide a viable option for decreasing deforestation and forest degradation rates in the country, while increasing the forest sector's value added. The five areas are: i) forestry operations (commercial logging); ii) timber processing (saw mills); iii) charcoal production; iv) consumption of fuelwood at household level; and v) usage of fuelwood in agricultural and cottage industries (tea, tobacco, etc.).

The objective of this study is to assess the feasibility and the socio-economic and environmental implications of increased efficiency in forestry operations and forest product processing and utilization as potential options for REDD+ implementation in Kenya. For each of the above-mentioned sectors, research on current efficiency rates and recovery rates and on tested and readily available efficient technologies has been carried out. Moreover, the potential carbon benefits have been estimated. Final results indicate policies and measures that may be suitable for REDD+ in the country.

This report focuses on harvesting operations and subsequent processing and consumption of timber and fuelwood (e.g. firewood and charcoal) in Kenya. It must be noted that not all aspects of timber production have been captured. Neither increasing carbon stocks through improved management of natural and plantation forests, nor the enhancement of carbon stocks through afforestation and reforestation, are within the scope of this study. Lastly, gender dynamics are also important to consider when designing REDD+ policies and measures. Whereas women are in charge of finding firewood and charcoal for household consumption, men are usually in charge of charcoal production, firewood/charcoal in industrial process, timber processing and forestry operations.

2. SCOPE AND DEFINITIONS

2.1 SCOPE

In 2013, the Ministry of Environment, Water and Natural Resources (MEWRN) reported a wood supply deficit of 10.3 million m³ per year in Kenya (MEWNR, 2013). Low levels of supply are explained by inefficiencies in forestry operations and wood processing and utilization, among other factors.

Forests in Kenya covered 4,138,000 ha in 2010 (KFS, 2013), divided into natural forests (93%), plantations (4.6%), bamboo forests (2.1%) and mangrove forests (0.2%). Ownership is divided between public, community and private forests. The government target is to increase the forest cover to 10% by the year 2030 (KFS, 2010) against 7.0% in 2010 (see Table 2 and Figure 2).

Public forests: public natural forests are managed for the provision of environmental services and firewood, whereas public plantation forests are used for timber products, poles, and wood energy production. These forests are also used for grazing and providing non-wood forest products.

Community forests: community forest operations are regulated by county governments. They provide both goods and services, especially building poles and fuelwood (MEWRN, 2013). Management of these forests is not always effective, and many harvests occur without consideration for sustainable management.

Private plantations: forest plantations that are privately owned and managed account for an important part of the total wood supply in Kenya. In most cases, the genus chosen is Eucalyptus, and the targeted products are electricity poles, fuelwood and sometimes sawn wood. Some tea and tobacco companies have established such plantations to secure part of their fuelwood supply (they also sell the surplus as poles).

Farms and agroforestry systems: farmlands – often scattered trees – also account for a significant amount of raw material. Nevertheless, log quality is less suitable for sawn wood and most of it is transformed into charcoal.

Kenya's national potential wood supply has been recently estimated at 31.4 million m³ (of which 67% is represented by fuelwood, 23% by timber and 10% by poles). However, only 9% of the potential wood supply comes from natural forests. According to MEWNR, farmlands represent 70% of potential wood supply and plantations 21%. Since 1990, a boom in the planting of private forest area has been observed in Kenya (+3,000 ha per year on average) whereas the area of public plantations has fallen (-1,750 ha per year on average). However, according to the Food and Agriculture Organization of the United Nations (FAO, 2015), plantations in public forests increased between 2005 and 2010 (+2,400 ha per year on average). Wood waste (sawdust, timber rejects, off-cuts) represents an additional potential source of biomass (MEWNR, 2013).

TABLE 2: Forest ownership by broad category

Type of forest	Public (gazetted)	Private/community-owned	Total (ha)
Natural forests	905,000	2,945,000	3,850,000
Plantations	120,000	72,000	192,000
Bamboo forests	71,000	15,000	86,000
Mangrove forests	1,000	9,000	10,000
Total	**1,097,000**	**3,041,000**	**4,138,000**

Source: GIS analysis of KFS forest cover dataset (KFS, 2013).
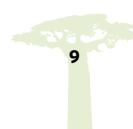
FIGURE 2: Forest cover map, Kenya 2010 (KFS, 2013)
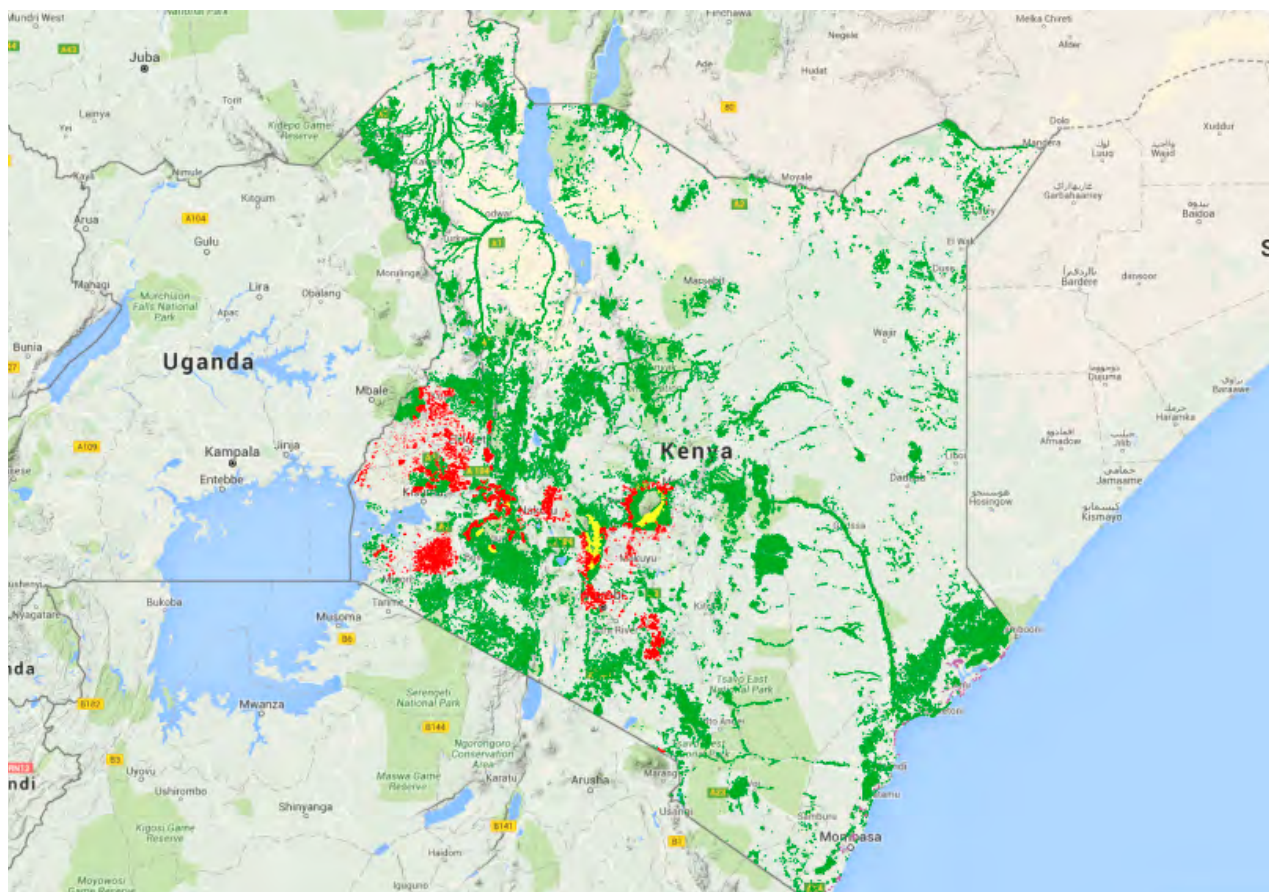
Legend: Green shows natural forests, red shows plantations, yellow shows bamboo forests, and purple shows mangrove forests.

National wood demand has been estimated at 41.7 million m^3 in 2013, showing a national deficit of more than 10.3 million m^3. According to MEWNR, the main factors explaining this deficit include relatively small forest areas, low average yields, and poor processing methods resulting from inefficient approaches and technologies. This deficit is expected to increase by almost 26.5% by 2032 (MEWNR, 2013). Total wood supply in Kenya is highly limited by particularly low recovery rates. This inefficiency is partly attributed to the use of old, inappropriate and inefficient machinery for sawmilling. Best management practices and more efficient technologies in the forest and wood products sector are thus expected to influence both the supply and demand for wood products (KFS, 2010).

According to the Kenyan R-PP, unsustainable practices such as slash and burn agriculture, overexploitation of timber, and charcoal production are direct drivers of deforestation and forest degradation (KFS, 2010).

Both public and private forestry have potential for improvement. Actions needed to improve public and private forestry have been established by KFS in its Strategic Plan (KFS, 2011) and further recommendations to foster commercial sustainable forestry were put forward by several authors (ILEG, 2011 and PWC, 2014).

Both timber and fuelwood demand are increasing and the challenge ahead is to help public and private plantations to meet future demand in a sustainable way, by reducing the quantity of non-renewable biomass used to bridge the demand shortfall.

This study assessed biomass saving options (in m$^3_{RWE}$ per year) in five areas compared to a BAU scenario for: i) forestry operations (commercial logging); ii) timber processing (saw mills); iii) charcoal production; iv) consumption of fuelwood at household level; and v) usage of fuelwood in agricultural and cottage industries (tea, tobacco, etc.). The annual investment in these five areas has been estimated by looking at capital expenditure to implement efficiency improvements. Biomass savings are also expressed in terms of potential carbon benefits. The GHG absorption/

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emissions balance represents the difference between emissions and absorption in BAU and an alternative scenario. The latter has been estimated with the support of specific methodologies (Clean Development Mechanism (CDM), Gold Standard, etc.) and IPCC guidelines and expressed in tCO_2e per year.

2.2 THE DEFINITION OF FOREST

Estimates of the forest area in Kenya vary depending on the data source used. According to KFS data (2013), Kenyan forests covered 4,138,000 ha in 2010, whereas the FAO's Global Forest Resources Assessments report (FAO, 2015) indicates an area of 4,230,000 ha in the same year. The difference can be explained by the fact that the two institutions use different cover thresholds to define forest.

The definition of forests used by KFS to carry out a wall-to-wall mapping at national scale in 2013 is based on the following characteristics: "Land spanning more than 0.5 ha with trees higher than 5 meters and canopy cover of more than 15%". In its 2015 Forest Resources Assessment country report for Kenya, FAO uses the following definition: *"Land spanning more than 0.5 ha with trees higher than 5 meters and canopy cover of more than 10% – or trees able to reach these thresholds in situ"*. It does not include land that is predominantly under agricultural or urban land use". The KFS forest definition has been used in this study.

Deforestation is defined in the IPCC's guidelines on national GHG inventories as the "long term or permanent conversion of land from forest use to non-forest use". The UNFCCC has defined deforestation as "the indirect, human-induced conversion of forested land to non-forest land" (UNFCCC, 2005 – Decision 16/CMP.1). Deforestation induces a change in land-use, and usually also in land cover towards agriculture (cropland, pastures, perennial plants, etc.) or other forms of land use.

According to the Global Observation for Forest Cover and Land Dynamics (GOFC-GOLD, 2013), although there is no official, clear definition, forest degradation can be defined as a decrease in carbon stocks that does not qualify as deforestation, resulting in anthropogenic GHG emissions.

Given these definitions, farmlands with trees may not necessarily be considered as forests from a strictly REDD+ perspective. According to MEWNR (2013), they are qualified as "agroforests". The analysis made in this report shows the impacts of the proposed measures at national level, distinguishing where possible the forest types on which they occur. The results are expressed as the potential to generate REDD+ results in terms of a reduction in forest carbon emissions sensu stricto, according to the forest cover area reported by KFS in 2013 for year 2010 (KFS, 2013).

Hence, **from a REDD+ perspective, the national definition of forest is a key parameter to calculate emission reductions or removals**. Indeed, Measurement, Reporting and Verification (MRV) systems are built on a forest benchmark, on which the estimations of GHG absorptions and emissions in the forestry sector over time are based. They are compared to the forest reference emission levels (FRELs) or forest reference level (FRL).

2.3 RANGE OF WOOD PRODUCTS PRODUCED IN KENYA

Timber: Timber is produced from public plantations (mainly for urban markets, especially the construction sector), community/private forests and farms (mainly for local use). In 1999, Kenya had 450 sawmills with transformation capacities ranging from less than 500 m^3 per year to more than 30,000 m^3 per year, employing around 20,000 people in total. As of today, registered sawmill companies number about 700 (in August 2015, according to KFS Registry) and there are 32 producers of treated transmission poles, in addition to about 400 producers of firewood. Another 300 small unregistered businesses are estimated (KTMA, informal report), together with around 3,000 individual operators working with chainsaws (Muthike, 2015,

ACCORDING TO THE KENYAN READINESS PREPARATION PROPOSAL (R-PP), THE LACK OF SECURITY FOR TIMBER SUPPLY TO THE SAWMILLING INDUSTRY (LOW INVESTMENT IN TIMBER PROCESSING TECHNOLOGY, POOR TIMBER CONVERSION RATIOS) IS A KEY INDIRECT FACTOR OF DEFORESTATION AND FOREST DEGRADATION. REDD+ IN KENYA MUST ENSURE SUSTAINABLE UTILIZATION OF WOOD RESOURCES (KFS, 2010)

informal report). Sawn wood production from these mills targets almost exclusively the domestic market.

There are three different types of operators: (i) large industrial wood processors operating in public plantations under license, (ii) poorly equipped small and medium scale processors operating in public plantations and in community/private forests and (iii) individuals using bench-saw or mobile saws operating mainly in farmlands. Efficiency in timber processing decreases from the industrial operators to the individuals. By-products are usually used for energy production.

Because of poor harvesting conditions, which could not ensure sustainable management of public forests (both natural and planted), the GoK imposed a ban on timber harvesting in public forests in 1999 (KFS, 2007). Some large companies with relatively high processing capacities were exempted from the ban and have since then accounted for almost all Kenyan sawn wood production from public forests. Furthermore, the ban gave rise to a well-developed illegal timber market (often consisting of low quality wood as a result of poor harvesting and processing practices). The ban was lifted in November 2011.

Poles: poles can be harvested from any forest type. They are used for construction, power transmission and local farming use (as fences). Many Eucalyptus have been planted, especially on private land, to meet growing domestic demand for poles. By-products are usually used for energy production.
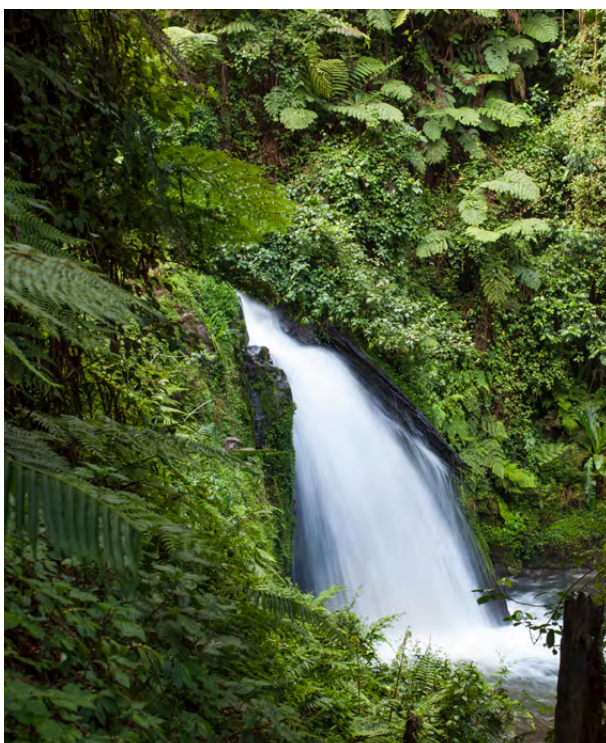
Firewood: firewood from public forests is extracted by licensed operators. In community/private forests and farmlands, firewood is extracted by the owners, who typically consume a certain quantity and sell the surplus. Firewood is mainly used in rural areas for domestic and agro-industrial use (e.g. tea, tobacco production), because of the prohibitive cost of transporting it over long distances.

Charcoal: charcoal is mainly produced in rural areas to generate incomes and is consumed in urban areas. Most of the charcoal is produced in community/private forests and farmlands, especially from natural (dry) forests and savannahs. Charcoal production is a strong driver of degradation and deforestation. Artisanal processing of wood to produce charcoal (carbonization) employs earth kilns. Such kilns have a very low recovery rate estimated at 16% according to MEWNR (2013) but it can be as low as 10% (SalvaTerra, 2014). Local producers often lack the skills, raw material and investment capacities to adopt more efficient technologies. Few producers invest in sustainable plantations for charcoal production, and the quantity of charcoal produced from sustainable sources is not yet significant. Use of charcoal in urban areas at household level is highly inefficient, despite significant efforts to disseminate charcoal efficient stoves since the 1980s.

2.4 FOREST CLASSIFICATION BY ECOLOGICAL TYPE IN KENYA

According to Peltorinne (2004), Kenyan forests can be classified among six main ecotypes:

- The high volcanic mountain and high range forests (commonly referred to as montane forests or 'water towers'): Mt. Elgon, Mt. Kenya, Aberdare Range, Cherangani Hills and Mau, which are seasonal and evergreen forests. A recent publication on forest-produced economic values focuses on these forests (UNEP, 2012). According to this publication, montane forests covered 1,240,000 ha in 2000 and 1,140,000 ha in 2010. The Kenya Water Towers Agency estimates the current area of the five main water towers at 1,083,493 ha.
- Western plateau forests (also called **western rainforests**): Kabarnet, Kakamega, Nandi, Trans-Mara. Kakamega is considered the only tropical forest left in Kenya. KFS estimates that the western plateau forests contain the richest biodiversity in Kenya (Ireri, 2012).
- Northern mountain forests (also called **dry forests**): Ndoto, Mathews Range, Leroghi, Kulal, Marsabit. According to Prime Africa and LTS International (2009), more than 20% of dryland forests are woodlands and over 73% are shrublands.

- **Coastal forests** and **mangrove areas**: Arabuko-Sokoke, Tana, Kayas. These forests shelter rare and endangered species. Kaya forests are traditional, sacred sites but the decline of traditional beliefs and rising demand for forest products has eroded their traditional protection.
- **Southern hills** (including Eastern Arc Mountains forests): Taita Hills, Kasigau, Shimba Hills, Chyulu Hills, Nguruman. The Taita Hills forests, part of the Eastern Arc Mountains, have high rates of endemism and constitute one of the world's 25 biodiversity hot-spots (Myers *et al.*, 2000). They also serve as catchment areas supplying fresh water to over 200,000 people.
- **Riverine forests**: Tana and tributaries, Ewaso-Ngiro, Kerio, Turkwel, Galana. These forests extend 1-3 km on either side of the rivers.

KFS also distinguishes urban forests (Karura, Ngong Road, Dagoretti, Oloolua, Kabiruini, Menengai, etc.). For the purpose of this study, natural dry forests are defined as natural forests present in semi-arid, arid and very arid areas (moisture content zone V to VII, see Figure 3). A GIS analysis has been carried out on KFS's forest cover dataset (2013) to determine the natural dry forests cover area, estimated at 2,268,000 ha in 2010.

The KFS dataset from 2013 does not distinguish indigenous montane forests from other types of natural forests but UNEP (2012) provides an estimation of 1,140,000 ha in 2010. As a consequence, the area covered by "other natural forests" is estimated at 442,000 ha in 2010.

2.5 SOCIO-ECONOMIC ASPECTS

Socio-economic aspects may be treated under two categories:

- **Efficiency improvement.** This refers to, for example, the additional added-value or revenue resulting from the use of an alternative process. For example, in theory, households spend less income to buy charcoal when using an ICS. Producers generate more charcoal and thus achieve more added-value with better control of the carbonization process.
- **Job creation, health and safety.** These aspects are only treated in this study on a qualitative basis, rather than on a quantitative basis. Measures might have adverse impacts on "poor jobs" such as traditional charcoal making, but have positive impacts on health and safety – especially in the fuelwood production and consumption sector. Gender aspects also are discussed.

FIGURE 3: Dry forests in Kenya, 2010 (KFS data, 2013)
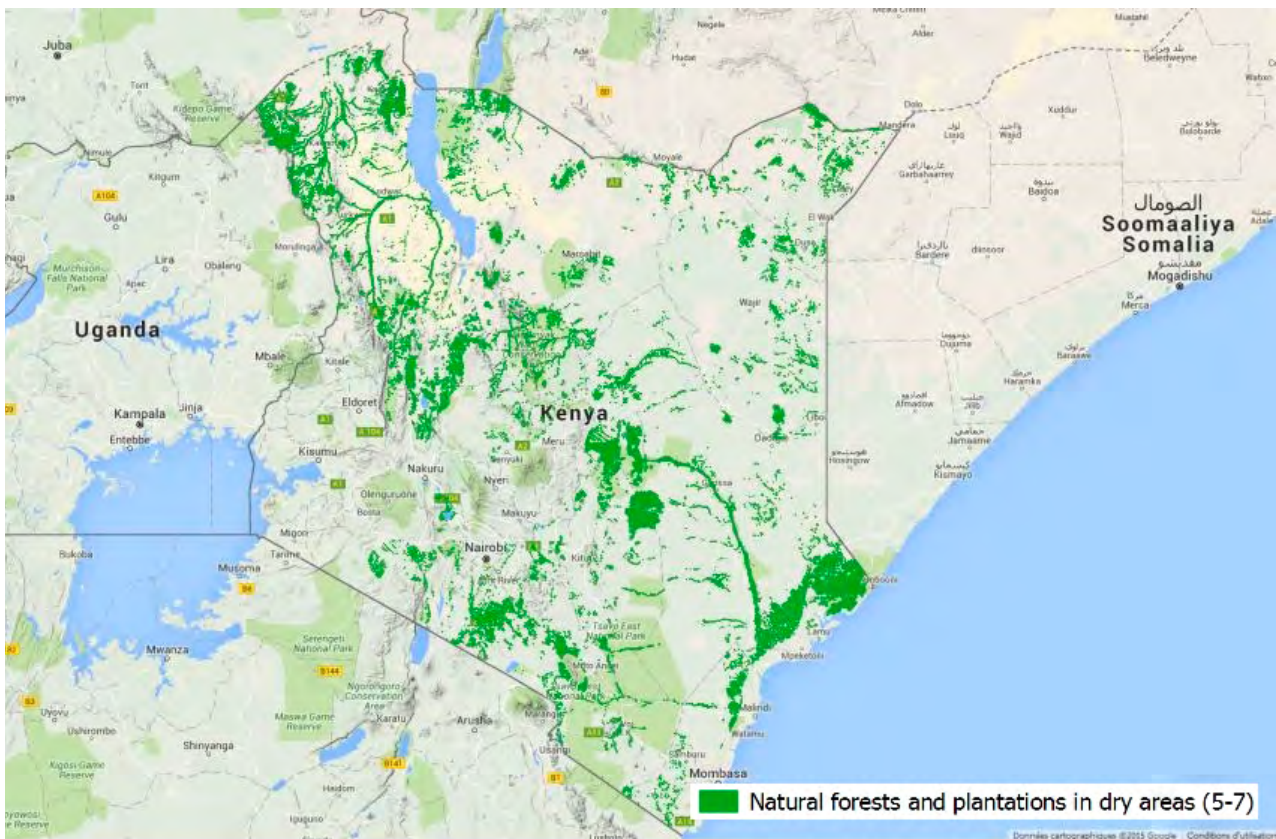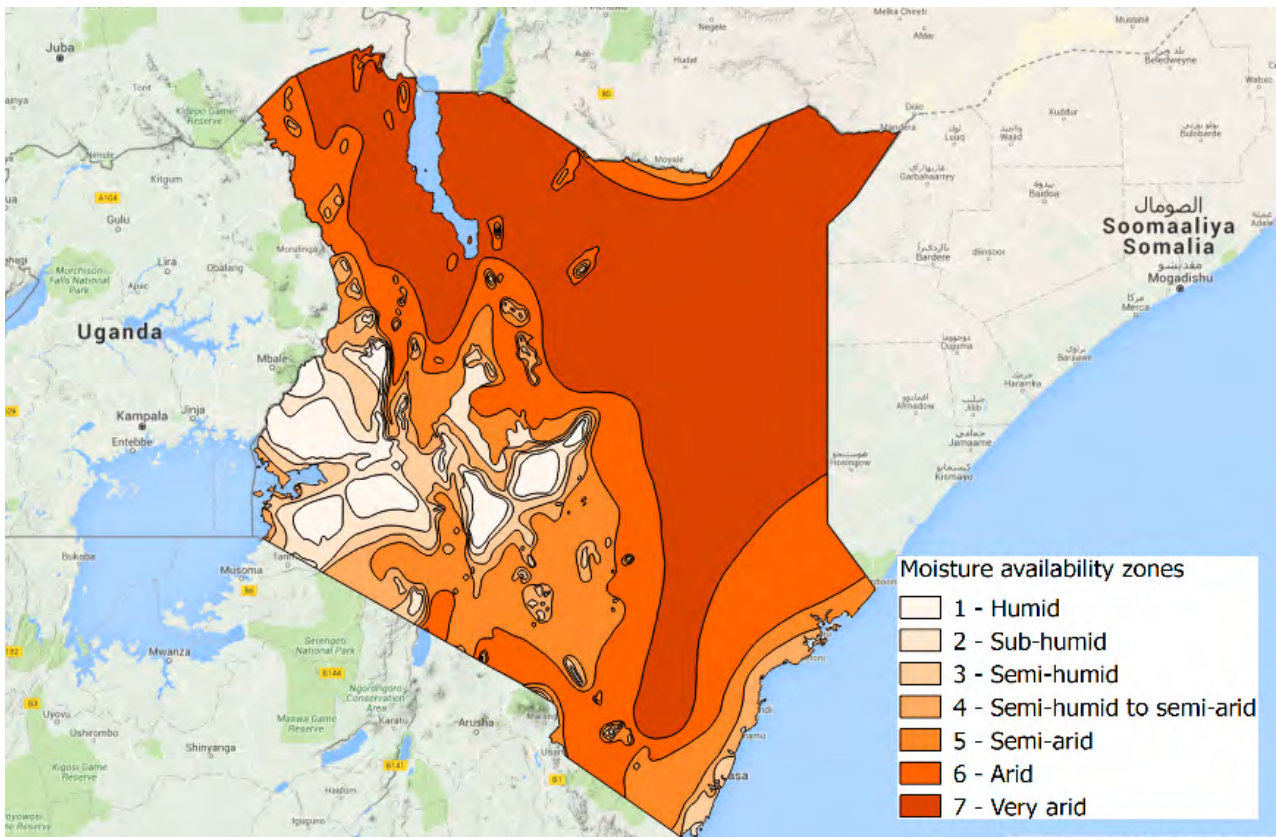
Legend: (above) Moisture availability zone in Kenya (data from ILRI GIS portal); (below) natural forests and plantations in dry areas (moisture availability zones 5, 6 and 7).

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3. OPPORTUNITIES FOR EFFICIENCY IMPROVEMENTS AND CARBON BENEFITS

This section describes potential biomass savings and subsequent emission reductions for five sectors: commercial forestry operations (commercial logging), timber processing industry (sawmills), charcoal production, firewood and charcoal consumption at household level; and wood usage in industrial processes. Each of the five sections introduces a sector after which a description is provided of technologies and measures for improving efficiency, the ability to generate biomass savings, and subsequent carbon benefits.

3.1 COMMERCIAL FORESTRY OPERATIONS

In Kenya there are two types of production forests: woodlands supplying fuelwood, and plantations supplying fuelwood, timber and industrial wood. In 1999 the GoK suspended timber harvesting in all government and indigenous forests (public forests). This logging ban was lifted in 2011 but it was effective until 2012-2013. During this time timber supply from public plantations was heavily reduced. The impact on the timber industry and on public and private plantations will be discussed in the following sub-sections along with related issues and prospects.

3.1.1 Natural forests

Indigenous closed canopy, mangrove and bamboo forests[2] are gazetted as forest reserves falling mainly under the jurisdiction of the KFS, and managed by national park bodies or Kenya Wildlife Service (KWS). A smaller proportion falls under the authority of local governments (PWC, 2014).

No commercial extraction of wood products is allowed, except the collection of firewood from windfalls and

dead trees by adjacent communities. While some authors (ILEG, 2011) have reported illegal harvesting practices in gazetted forests, particularly in densely populated areas, there are no data available about the resulting log volumes.

Some authors have suggested that allowing commercial forestry in gazetted forests could help address the current wood supply deficit in Kenya and reduce forest loss and degradation. They point to the limited ability of the authorities and the regulatory framework to halt illegal logging (PWC, 2014). Woodlands[3] are found predominantly in arid and semi-arid lands. As well as providing various environmental services, they provide habitat for a large proportion of Kenya's wildlife, which is essential for the country's eco-tourism interests (PWC, 2014). Woodlands are managed by a combination of KFS, KWS, county governments, private landowners, and community-based associations with goals including sustainable forest management and charcoal supply. It is estimated that at least 75% of wood used in charcoal production comes from woodland areas (KFS, undated).

3.1.2 Plantations (public and private)

For this assessment plantations were divided into three categories:

- **Public plantations:** managed by KFS to supply timber, industrial wood and fuelwood
- **Private plantations:** intensively managed, either owned by large companies or small landowners, under various forms of partnerships and agreements with industrial companies to supply fuelwood for industrial processes

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2   KFS definition of indigenous forest: a forest, which has come about by natural regeneration of trees primarily native, and includes mangrove and bamboo forests.

3   KFS definition of woodland: an open stand of trees of 10 to 30% of tree canopy cover and trees growing to 2m tall, which has come about by natural regeneration.
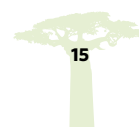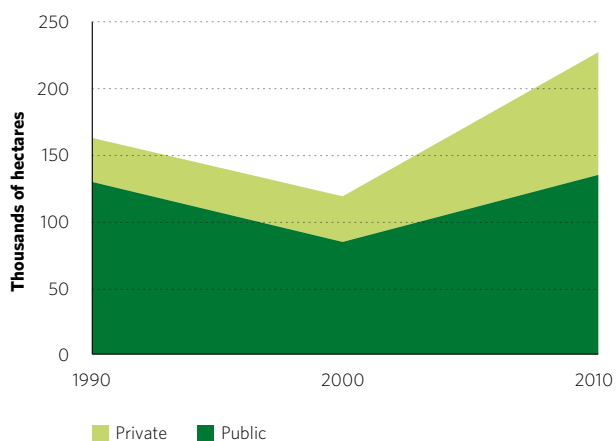
Source: 1990 and 2000 data from FAO, 2010 data from KFS and PWC
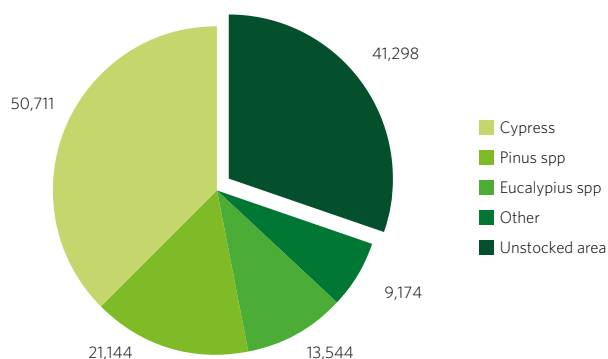
Source: KFS 2010 data

- **Private agroforestry:** trees planted and inter-cropped as small woodlots, along field boundaries and as windbreaks.

As shown in Figure 4, following the logging ban, both the area and size of private and public plantation increased. Within private plantations, this outcome is likely to be related to the diversion of timber supply from public to private plantations which in turn brought about incentives to landowners to invest in new plantations. Within public plantations, KFS increased planting during the logging ban by more than 4,000 ha per year from 2000 onwards (PwC, 2014).

Public plantations

According to 2010 inventory data from KFS, there are 94,572 ha of stocked public plantations comprising mainly cypress and pine species and to a lesser extent Eucalyptus and others, as shown in Figure 5

In its Strategic Plan 2009/2010 – 2013/2014, KFS reported an unstocked area of about 41,298 ha (KFS, 2011). This area is to be planted under the KFS national plantation development programme, which aims to maintain and enhance the productivity of large-scale forest plantations and increase efficiency in wood utilization for wealth and employment creation. This should allow the extension of public plantation area up to 135,871 ha. By 2012, 5,219 ha of industrial forest plantations were already established (KFS, 2012).

Log volumes harvested from public plantations from 2010 to 2014 are shown in Table 3, broken down by main species and wood categories (timber, firewood).

Given that, from 1999 to 2009, harvested volumes from public plantations ranged from 0.2 to 1.0 million m^3, averaging about 0.5 million m^3 (ILEG 2011), following the lifting of the logging ban, public plantations

TABLE 3: **Main wood harvesting parameters from public plantations (2010-2014)**

Species	Volume harvested in 5 years (m³)	Area harvested (ha)	Average stand volume at felling (m³)	Annual average harvested volume (m³)	Timber (*)	Fuelwood (*)
Cypress	2,268,001	14,367	158	453,600	426,384	27,216
Pinus spp	1,471,532	8,643	170	294,306	270,762	23,545
Eucalyptus spp	450,527	4,867	93	90,105	6,307	83,798
Other	483,661	881	549	96,732	87,059	9,673
Total	**4,673,721**	**28,757**		**934,744**	**790,512**	**144,232**

Source: KFS (2015)
(*) Broken down by category according to MEWNR (2013) average yield categorization for cypress, Pinus and Eucalyptus plantations. Wood categorization applied to 'other' log volumes were 90% of timber and 10% of fuelwood.

TABLE 4: Growing stock and harvested volumes and related parameters (plantation inventory data 2010-2014)

Species	Growing stock volume (m³)	Annual average harvested volume from 2010 to 2014 (m³)	Average rotation cycle	Annual allowable cut presumed from average rotation (m³)	Volumes exceeding the presumed allowable cut (m³)
Cypress	11,222,282	453,600	30	374,076	79,524
Pinus spp	5,532,889	294,306	30	184,430	109,877
Eucalyptus spp	1,699,179	90,105	10	169,918	-79,812
Other	1,231,108	96,732	40	30,778	65,954
Totals	**19,685,458**	**934,744**		**759,201**	**175,543**

Source: KFS (2015)

experienced an increased rate of harvesting which, from 2010 to 2014, averaged 0.9 million m³.

Sustainable yield parameters are not available to assess whether this rate of harvesting is sustainable. However, a proxy of annual sustainable yield was calculated per plantation species by dividing the growing stock volumes (i.e. tree growth) by the average rotation period, including the inter-rotation number of years. This parameter called 'presumed allowable cut volume' is compared in Table 4 with average harvested volumes from 2010-2014.

From 2010-2014, harvested volumes for cypress, pine and 'other' plantation species exceeded the presumed allowable cut. However, this overharvesting cannot be considered unsustainable, at least in the short term. This is because, in the period following the logging ban, there is likely a need to harvest over-mature stands. This can justify a rate of harvesting above the annual allowable cut. Nevertheless, this data shows that in the near future sustainable harvesting may not bring about higher timber volumes than those harvested over the period 2010-2014.

As a consequence, the following cost-benefit analysis of opportunities arising from improved harvesting practices was based on the assumption that the whole current harvesting yield from public plantation is sustainable.

Private plantations
In 1990, the area planted in community and private forests was less than 20,000 ha and is now reaching more than 94,000 ha as a result of the country's policy favouring new plantations for the provision of wood. Private forest plantations account for an important part of the total wood supply in Kenya. In 2009 the total productivity of private plantation forests was estimated at 1 million m³$_{RWE}$ (PWC, 2014).

The following analysis divides private plantations into: plantations intensively managed; and planted trees on agroforestry systems.

Intensively managed plantations
Privately owned plantations usually supply poles and fuelwood for agricultural and industrial uses. Eucalyptus is the main genus used, with other exotic genuses, including Cupressus, Grevillea, Robusta and Pinus, typically grown for sawn wood production. The tea and tobacco industries have some fuelwood plantations to secure their own supply. They also run out-grower plantation schemes, where tree seedlings are distributed to local communities to stimulate the future supply of firewood.

There are no official statistics and little information was found on privately owned plantations, consequently this assessment was mainly informed by case studies focused on:

- Finlays Kericho, a tea estate which manages 3,000 ha of forest plantation to supply fuelwood for five tea factories
- Kenya Tea Development Agency (KTDA), a tea management company supplied by small-scale producers, relying on an out-growers plantation scheme as well as own plantations to supply fuelwood for 65 tea factories

Finlays case study
Finlays Kericho produces more than 23,000 tons of tea every year with five tea factories supplied by a 6,000 ha tea estate. The estate is self-sufficient for thermal energy, supplied by boilers fed with firewood extracted from a 3,000 ha industrially managed Eucalyptus plantation (illustrated in Figure 6).

FIGURE 6: Intensively managed Eucalyptus plantation stand and logs at Finlays' estate (Kericho)

Particularly favourable conditions in conjunction with intensive management practices result in Finlays Eucalyptus plantations reporting an average mean annual increment between 20 and 30 m^3 per ha. Tree planting is done by machine and stems, all branches and stumps are used for firewood (almost 95% recovery). Finlays has invested in heavy wood cutting machines and greenhouse sheds for drying (personal interview).

KTDA case study

KTDA sources some of its wood fuel for tea processing from an out-growers plantation scheme, ensuring that it does not indirectly contribute to forest degradation, while small tea producers rely on firewood to meet energy requirements for tea processing.

Between 2009 and 2014, KTDA supported the expansion of its tea business by releasing more than 20 million seedlings to communities in tea growing areas in order to meet an increase in demand for firewood of an estimated 4.5 million m^3 over the same period. KTDA also aims to acquire more than 16,000 ha of land to increase its forest plantation area (Business Daily, 2015).

Planted trees on agroforestry systems

As with intensively managed private plantations, official statistics on planted trees in agroforestry systems are not available. Consequently, the assessment was carried out on the basis of information gathered from a literature review.

Tree planting on farms for commercial purposes in Kenya dates back to the 1970s. Late in the 1990s,

following the logging ban and subsequent timber shortage, farmers saw the potential for income from timber and investments in commercial tree planting on their land. However, at that time many trees harvested in agroforestry systems were not planted for timber. They were mostly intended to provide animal fodder, firewood, or other wood requirements. Since they were not planted for timber, silvicultural practices such as spacing, pruning and thinning were not carried out resulting in mature trees with poor stem form and knotty and reaction wood not suitable for sawn logs.

Nevertheless, the perceived declining ability of public forests and plantations to meet demand for wood products has encouraged agroforestry to fill the supply gap including for sawn logs and other timber. To promote tree planting on farms, the Government has drawn up favourable policies.

3.1.3 Opportunities for biomass savings in commercial forestry operations

There is scope for new public and private plantations to reduce the imbalance between wood demand and supply.

There are several actions that can be undertaken for example to increase the growing stock in public plantations, including planting unstocked areas, improving plantation management in order to maximize the yield potential or expanding plantations. This last option is also beyond the scope of this study.

The estimations provided in the following two sections for existing public and private plantations are based on

FIGURE 7: Poor quality sawn logs at a log yard in Nakuru

the assumption that the goals of improving plantation management and afforestation within them can be achieved without any detrimental impact on the sustainability of plantations.

Indeed, increasing the growing stock needs to be accompanied by an improvement in the quality of the timber supplied from plantation resources. One of the major factors impeding higher efficiency in timber processing is the poor quality of sawn logs supplied from private and public plantations (see Figure 7 as an illustration). Afforestation techniques and silvicultural operations such a pruning and thinning have to be appropriately and punctually implemented to allow future plantation resources to supply quality sawn logs, thus enabling higher recovery rates in timber processing and maximising the return of investments made both in forestry and timber processing.

Public plantations

Unstocked area in public plantations amounts to 41,298 ha. Assuming that investments focus on cypress and pine plantations performing according to the potential yield reported by Wanleys (2013), this area could allow an increase of the current public plantation growing stock of more than 9 million m³. KFS is incurring planting cost of around $174 per ha and consequently the investment needed to restock the 41,298 ha is more than $7 million. Operating costs to be incurred during rotation and related to pruning, thinning, re-spacing,

coppice reduction, road maintenance, and fire management activities are not included.

The above result might only be attainable in the long term, after planting the whole area and fully integrating the new areas into the rotation cycle. This investment would result in an increased wood harvesting potential of about 350,000 m³ per year.

Data are not available to assess the efficiency of public plantation management. However, among stakeholders there is a widespread perception that public plantation management can be improved. The logging ban heavily disrupted KFS management, mainly because of the lack of resources for silvicultural operations (ILEG, 2011). Backlogs, which are likely to disrupt future timber supply, are also well known and need to be considered when planning harvesting and new establishments (personal interview). Mean annual Increment per plantation species is not known. However, the comparison of average volume at felling calculated from KFS inventory data from 2010 and 2014 with the potential volumes reported by Wanleys (2013) for cypress and pine plantations reported in Table 5 shows that the current yield potential of plantations is not fully exploited.

Given that environmental conditions such as soil fertility and climate are reasonably favourable for cypress and pine species, it is likely that the problems disrupting

TABLE 5: Comparison of current and potential public plantation average volumes at felling and expected outcome from the improvement of public plantations management

Species	Land cover (ha)	Current average stand volume at felling (m³/ha)	Potential average stand volume at felling reported by Wanleys 2013 (m³/ha)	Potential increase in growing stock from improved management of public plantations (m³)
Cypress sp.	50,711	157	250	4,672,455
Pinus sp.	21,144	170	250	1,685,951
Total	**71,855**			**6,358,406**

Source: KFS inventory data (2010-2014)

the full potential come from inadequate management practices resulting in poor yields. Assuming that improved plantation management can increase the yield potential to their average level, the total increase of the public plantations growing stock would be more than 6 million m³, which is an increase of 30% from the current level.

From the combined additional growing stock from afforestation-reforestation on unstocked public lands and improvement of public plantations management, an increase of the current growing stock of about 15 million m³ can be achieved, which is a 77% increase from the current level.

Potential additional volumes are compared with the current level of growing stock in Figure 8.

FIGURE 8: Potential additional growing stock from afforestation on public unstocked areas and improvement of public plantations management

Potential additional growing stock from afforestation (Pinus and Cypress sp)

Potential increased growing stockimproved management practices

Current grwing stock
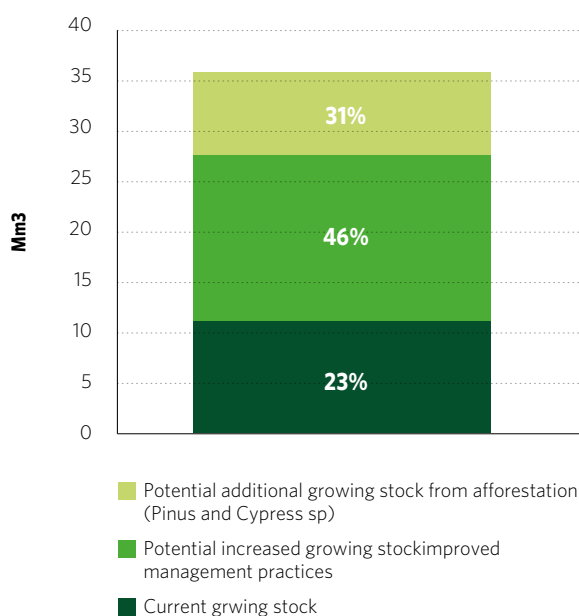
Private plantations
Opportunities in terms of afforestation-reforestation and/or improved management of growing stock could also be realized on private plantations.

However, plantations which are intensively managed and owned by large corporations have largely already achieved the optimum yield rate, reducing the potential for further increase. Land availability and tenure were mentioned by the stakeholders as factors limiting the expansion of private plantations. Consequently, it seems that there is little room to increase the private intensively managed plantation area, although these fall outside the scope of this study.

Small scale plantations and particularly trees in agroforestry systems have more promising prospects in terms of efficiency gains. It was mentioned above that there is a favourable policy environment for tree planting on farmlands. The Kenya Forests Master Plan, for example, estimated that trees on farms could be increased by 526,000 ha. Currently the average biomass of trees on farms is about 9.3 m³/ha and this could be increased up to 27 m³/ha without adversely affecting agricultural production. Promoting investments in tree planting in order to have an average biomass of 20 m³ per ha on additional 525,000 ha of farmland could result in an increase in growing stock of 10.5 million m³.

3.1.4 Measures for improving efficiency in harvesting operations and potential outcomes

In Kenya, harvesting is usually done by chainsaw, with varying levels of mechanization used in timber extraction depending on the scale of the operation, ranging from carrying timber by hand to use of machinery such as skidders and tractors.

Information on forest harvesting is very limited and neither statistics nor data allow benchmarking of harvesting techniques or a quantitative analysis of issue related to forestry operations. Consequently, this study

was informed by a literature review from which the following main problems were identified:

- Inadequate or ineffective planning of harvesting and other forestry operations;
- Poor infrastructure and low-performing machinery and equipment;
- Unskilled chainsaw operators and/or inadequate supervision; and
- Poor maintenance of equipment and machinery.

The issues above are a source of inefficiencies and can result in log damage and/or difficulties in meeting product specifications, causing wastage or downgrading of timber.

While opportunities for improving the efficiency of forest harvesting fall within the realm of policy, training and technology, some areas with potential REDD+ opportunities are outlined below.

Improved harvest planning

Kenya has regulations in place that govern timber harvesting in public forests (overseen by KFS) and community forests (overseen by County Governments). However, there is a need to refine harvesting systems and techniques so that they become fully compatible with the objectives of sustainable forest management. Moreover, appropriate harvesting techniques could be defined in a code of good logging practices, or a similar framework for outlining best practices and oversight of timber harvesting. Developing such a code could be an opportunity to improve harvesting efficiency and utilisation rates through support for technicians and managers involved in wood harvesting as well as forest contractors. For examples of best practices relevant to the Kenyan and regional context, see FAO (2004).

Improved efficiency of harvest operations

Vocational training in chainsaw use, tree felling and harvesting operations would help to ensure that skilled operators carry out harvesting and thereby reduce wastage and ensure optimum quality and value of logs. With correct supervision, improvements in forest sawing practices would help to ensure product specifications are met when cutting trees into logs and help to increase production rates of harvesting crews[4].

Training can avoid loss of material in felling. Damage can arise because of errors in felling as logs crash or wood splits due to improper felling techniques. Some loss could normally be caused by errors in dividing stems into logs of appropriate length and quality (log grading) according to processing specifications.

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4 See: Silayo (2015); Pasiecznik and Carsan (2006).

Many authors have studied felling losses and calculated it 8-10% of cut volume, depending on species and site conditions (AAvv, 2013). Training is estimated to be capable of reducing those losses significantly. When a decision is made not to clear cut, training in felling is important too for saving any remaining trees. Also for safety reasons, training should be mandatory for fellers.

Planning and managing log skidding and in-forest transport is a potential area for improvement in relation to both forest management and fuel usage. Identification of efficient skidding and haulage approaches could improve recovery and lower the cost of operations.

An example of opportunities for efficiency improvements is the use of winches and synthetic rope to minimise the movement of skidders during extraction, and/or the use of tractors with trailers to move full tree lengths (or the longest possible sections) to a central processing point. In this scenario, the effective use of tractors minimizes the number of people making key decisions on what products are cut and puts all products and residue in one spot for effective recovery (Melemez et al, 2014).

These types of actions can improve efficiency by reducing waste during logging and log processing and thus allow higher recovery rates. This means that higher volumes of wood could be extracted from plantation resources and less waste will be left after harvesting.

Investment in a code of harvesting practices and vocational training for about 250 workers per year could increase the efficiency rate of logging operations by 5%. Hence, wood volume recovery from logging can be increased by 5% (FAO, 1986; Nikooy *et al.*, 2013).

A program to build capacity through vocational training would have to move forward gradually. The number of forest workers operating in Kenya is not known. Given that there are between 700 and 1,000 saw millers, it is reasonable to estimate the number of forest workers at 2,000-3,000 (without workers involved in manual debarking). Assuming training of between 250 forest workers per year, it would take 10 years to train the whole workforce. Table 6 shows the potential outcomes from improved harvesting practices, which is based on the above-mentioned assumptions.

The training courses needed for loggers could have a structure and features similar to those for saw operators described in Section 3.2.2. Based on similar courses in Europe, the overall cost for courses on harvesting techniques involving 10 trainees and a duration of 10 days is around $15,000. Accordingly, the training of 2,500 forest operators would have a cost of about $3,750,000.

TABLE 6: Potential outcomes from improved efficiency brought about by training measures

Harvested timber volumes from public and private plantations (m³/year)*	2,000,000
Average harvested volume per operator (m³/year)	800
Expected recovery rates increase (%)	5
Average increase of revolted logs volume (or decrease of wood losses) per operator (m³/year)	40
Number of forest operators trained per year	250
Reduction in wood waste from improved forest operations (m³) over 10 years and assuming 2,500 operators	100,000

(*) based on estimations presented in Section 3

3.1.5 Analysing carbon benefits

Emission reductions

As explained above, improving harvesting operations through appropriate techniques could reduce wood waste from logging by about 5%. This would help increase the production capacity in public and private plantations by reducing wastage. The objective of this section is to determinate the REDD+ potential associated with these savings.

Improving the efficiency of harvesting operations is a relevant REDD+ measure if it reduces GHG emissions from deforestation and/or degradation in comparison to a BAU scenario. The BAU scenario must include current national trends to remain consistent with UNFCCC guidelines (GOFC-GOLD, 2013).

From a REDD+ perspective, emissions reductions from improving the efficiency of harvesting operations in forest plantations may come from two sources: first, alleviation of the pressure on natural forests due to an increase in total production from plantations, and second, savings of non-renewable biomass in plantations.

Alleviation of pressure on natural forests to produce timber

The measures proposed above are addressed to formal operators harvesting in public and private plantations. Hence, these measures are not expected to affect illegal logging operators in natural forests.

There is no evidence that increasing wood supply from plantation harvesting will decrease the pressure on natural forests for timber production. From a

REDD+ perspective, this is crucial, because it affects the potential emission reductions of the proposed measures.

If such a link could be demonstrated, the biomass savings generated by the proposed measures might be converted into emission reductions using the equation above. Hereafter, some key elements for further discussion are presented:

- According to KFS (2007), since the 1999 ban, most of the timber produced at national level comes from plantations with most of the timber used in Kenya sourced from across the border. Timber trade between Kenya, Tanzania, Uganda, DR Congo, etc. remains informal and unregulated. Small, illegal saw millers rely mostly on timber from private farms and illegally accessed timber from forest reserves.
- Illegal logging for timber production is still occurring in forest reserves, especially through indiscriminate and uncontrolled selective cutting of rare species (KFS, 2007). However, construction material is not the only driver of illegal timber harvesting. Sandalwood (*Osyris lanceolata*), mainly use in the perfume industry and for its medicinal properties, is one of those rare species, exported to Tanzania, India, Europe and South Africa. Camphor (*Cinnamomum camphora*), is also illegally harvested with the bark used to produce oil.

At the moment, it is not possible to conclude based on evidence that increasing timber supply from harvesting in plantations will decrease the pressure on natural forests for timber production. In this case, improving the efficiency of forestry operations is therefore not likely to generate additional emission reductions in terms of REDD+.

The Kenyan R-PP (KFS, 2010) suggests to *"Undertake a comprehensive study to assess and analyse the existing information on the scope and extent of illegal logging and other forest crimes to provide a basis for regular monitoring and up-dating of information"*. This recommendation remains valid.

Savings of non-renewable biomass in plantations

Increasing afforestation-reforestation on public and private lands is a notable trend within the BAU scenario[5]. Public and private plantations are the main providers of timber for users among Kenya's small and medium enterprises (SME) and the total planted area increased following the logging ban in natural forests.

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5   +5,400 ha/year between 2005 and 2010 and +1,400 ha/year between 2010 and 2015 according to FRA (2015).

As described above, it is assumed that the annual harvest is close to the sustainable yield (or mean annual increment) in public and private plantations. Therefore, the fNRB in the BAU scenario is close to zero. Improving the efficiency of forest operations such as harvesting will therefore not generate additional emission reductions from non-renewable biomass savings. As such, increasing recovery rates might not have an impact on growing carbon stocks but rather on the overall wood supply (more production, less wastage – 10,000 m³$_{RWE}$ per year).

Conclusion

To conclude on REDD+ opportunities in forestry operations, it is expected that several measures that are out of the scope of this study might have significant impacts in terms of emission reductions, such as:

- Carbon sequestration by increasing the forest area through afforestation/reforestation. However, the annual rate of afforestation/reforestation must exceed the current trend as a result of REDD+ measures to be considered as additional.
- Carbon stocks enhancement in forest plantations by improving silvicultural practices such as thinning, pruning, extension of rotation age might be a potential source of emission reductions, by increasing the mean carbon stock per ha.

3.1.6 Efficiency improvement

Biomass savings are the quantity of wood biomass saved per year through the implementation of the proposed measures. Biomass savings correspond to an increase of the total production from harvesting operations.

Considering the savings of 10,000 m³$_{RWE}$ per year from plantations, this would represent a total value of $140,000 based on KES1,400/m³ (the price paid by a company for harvesting in plantation forests (Vermeulen and Walubengo, 2006)).

3.1.7 Job creation, health and safety

In general, forest harvesting techniques are improved through training, including in safety procedures. Operators are trained in aspects including controlling tree-felling direction, delineating safety tracks on-site, team alerts and first aid. Thus, operator safety is a major co-benefit of training measures.

3.2 TIMBER PROCESSING INDUSTRY

Introduction
Industrial timber sawing in Kenya started early in the last century (1913), and progressively developed

through World War II, when timber sawing activity grew as it supplied the arms industry through its 60 sawmills (Muthike et al, 2011).

Following Kenyan independence in 1963, and the implementation of numerous development plans, the number of sawmills had increased to 450 by the 1990s, with an overall production capability of 200,000 m³ of sawn timber products per year. The industry had about 20,000 full-time employees, and additional seasonal workers (Muthike et al., 2011).

The first restrictions on the use and export of local timber were introduced in the 1980s, and in 1999 a specific ban officially prohibited timber harvesting in public forests. Only a few large companies were able to obtain derogation and were authorized to continue their activities, while 90% of small and medium businesses had to stop or considerably reduce their operations. Some companies started to supply agricultural businesses or community forests, and timber was harvested in small private parcels.

The Forests Act passed in 2005 marked a turning point as it provided much more support to the timber sector. In 2011/2012 timber harvesting in public plantations resumed, while natural forests remained exclusively devoted to nature conservation.

Registered sawmill companies currently number about 700, according to the KFS Registry, with 32 producers of treated transmission poles, in addition to about 400 producers of firewood. One study estimates the existence of another 300 unregistered small businesses, together with 3,000 individual operators harvesting by chainsaw (Muthike 2015, informal report).

The 2030 Vision (Republic of Kenya, 2007) places sawmills, together with other SME, at the heart of the country's development plan. However, small sawmills have to face a range of economic difficulties and structural deficiencies and weaknesses which put them at a disadvantage compared to larger organisations (adapted from Wamukoia & Associates, 2007). These include:

- Difficulty/uncertainty in finding raw material
- Difficulty accessing credit and high interest rates
- Obsolete and inefficient equipment and machinery (over 75% of registered sawmills are equipped with circular saw, with a performance/yield ranging between 18% and 30%)
- High equipment purchase costs due to taxation on imported equipment/machinery
- Difficulty in setting up production facilities due to barriers to authorizations and utilities

- Unclear relationships and rights vis-à-vis different local communities
- Presence of irregular operators and unfair competition

The timber processing business
Even though a registry of authorized companies exists, statistical data on this sector are incomplete.

With regards to equipment/machinery, KFS reports the following breakdown:

- 75% circular saws
- 15% wood mizer mobile saws
- 10% other band saws

For this study, sawmills were classified according to the type of equipment and personnel they have into the following three groups:

- Industrial sawmills featuring varied wood product outputs, efficient sawing equipment and infrastructure, usually employing more than 100 employees (there are less than 5 in the entire country)
- Small and medium-size sawmills featuring inefficient equipment and infrastructure and usually employing less than 100 employees
- Individuals harvesting and processing timber with mobile equipment.

The volumes of sawn logs produced in Kenya can only be estimated using the productivity potential of sawmills assessed among selected samples during the field study for this report in July 2015, and the volume of round timber sold from public plantations (KFS, interviews).

Using this method, the annual volume of logs processed by sawmills was estimated at 1.8-2.0 million m³. Average sawn timber volume processed per individual operator was estimated at 100,000 m³ annually, indicating a total volume of sawn logs processed of around 300,000 m^3_{RWE} per year (assuming a recovery rate of 33%). Consequently, for the purpose of this study, we estimated that 2.2 to 2.4 million m^3_{RWE} are currently processed by the timber industry and individual operators combined. This can be broken down as follows:

- 0.9 million m³ supplied from public forest (see Table 3 – KFS)
- 1 million m³ supplied from private plantations forests (PWC, 2014)
- About 0.3-0.5 million m³ of wood supplied from community forest and farmlands (World Agroforestry Center, 2011).

In total 2.2-2.5 million m³ could be logged from the Kenyan forests for sawing purposes. It also has to be noted that illegal logging, notably from public natural forests, are other possible sources of timber supply. Combining the two means of supply we arrive at a value **of 2.4 million m³ sawn logs produced**.

Several authors estimate that 70% of sawn logs and other timber products (timber-based panels and poles) rely on timber harvested in public plantations, while the remaining 30% come from private plantations and from the widespread "timber farming" business (Muthike et al 2011). But as shown above, it is considered likely that the proportion of timber coming from private landowners and/or other sources is actually higher, perhaps reaching **more than a half of total supply**.

By looking at these figures, it would appear that the sector, despite its challenges, has steadily developed. Applying the average recovery rate from wood sawing of 37.5%[6] to the sawn log volume of 2.4 million m^3_{RWE}, the annual sawn wood production may be estimated at 900,000 m^3_{RWE}, which is more than three times the figure for the 1990s (200,000 m³).

It should be noted that national supply covers about half of national demand in this sector (MEWNR, 2013) and that small and medium sawmills are located close to forest resources (a range of 70-100 km) and often close to cities or roads leading towards urban agglomerations (Nairobi and Mombasa) where the bulk of the demand for sawn timber comes from.

Timber sawing is also carried out in forest and rural areas by individuals using chainsaws or portable sawing equipment on an occasional basis. This kind of activity is relatively widespread in agroforestry fields and has increased since 1999. These operators are able to fulfil specific requirements, even for small quantities, and they supply local market demand which would not be met by industrial sawmills.

Sawmill processing
There are few industrial sawmills in Kenya and each one represents a case of its own (see Figure 9). Tim Sales, one example examined during the preparation of this report, is a sawmill facility carrying out several production processes (timber treatment, drying, sawing, panel production, production of finished door and window frames) that use the raw material and offcuts in an integrated way, maximizing recovery rates.

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6   This recovery rate is estimated by authors combining data issued from literature, direct observations on Kenyan sawmills and data collected in professional expertise.

Infrastructure and equipment are considerable, efficient, and reasonably modern.

However, this study is focused on small-to-medium sawmills, because they offer more opportunities for improvement and because they are quite widespread. Despite poor infrastructure and equipment, these sawmills are very dynamic. Log and sawn timber yards and storage areas for offcuts and cull wood are often insufficient as well as the area dedicated to sawmilling *per se*. These deficiencies influence the possibility of rationalizing processes, particularly incoming and outgoing material handling and its division by quality classes.

Logs are not sorted according to quality in the sawmills. Apart from non-commercial species, all the supplied logs are sawed. In most mills, sawing is carried out using old-style band saws (equipment dating back to the 1960s and 1970s) or newer mobile wood mizer type saws (15% of cases) (TMA, interviews). The latter equipment is relatively cheap, and has narrower blades that allow higher recovery rates, and is highly flexible as it can cut large and small diameter logs. Productivity is not comparable to that of a fixed trolley-based saw.

Logs are fed into the sawing machine by conveyor belts or by hand. Subsequent handling (e.g. unloading of sawn wood, stacking) is carried out manually. In some cases, there are pit saw lines or other belt saws mounted on a bench designed to trim sawn wood into smaller thickness.

Sawn wood is sold after only limited sorting: usually final products are not classified according to quality and/or size. Sales are made in bulk to resellers or to timber yards. Interviews given for this study indicate that sawmillers know little about the attributes required for the final use of their products, which is usually in the construction sector.

Mill wastes, such as offcuts and slabs, are limited as sawing is performed in order to optimize the use of a log regardless of the machine and labour time involved. Mill wastes are in the range of 30-40% and they are sold as firewood (see Figure 10). No recycling or other internal valorisation of mill cull was observed. Chipping is performed by industrial sawmills but not in the medium and small sized sawmills. Saw dust is removed manually in the sawing area, stocked on the yard, and sold in the market as biomass energy at a very low price.

The performance of sawmills using circular saws is poorer, with the recovery rate being around 18-30% (Wamukoya and associated, 2007).

Sawing by chainsaw also has low recovery rates in Kenya. This is primarily due to the low skills or experience of the operators. Otherwise, recovery rates could exceed 50%, especially for thick products (Muthike, 2011). The use of a frame can considerably ameliorate the recovery rate and the quality of the sawn timber.

Table 7 contains data from field interviews and estimates of the economic margins of sawmilling in a standard medium-size business processing around 2,000 m^3 of logs annually.

FIGURE 9: Band saw and wood mizer saw at Bufflo and Kelkos sawmills (Nakuru)

FIGURE 10: Sawdust and offcuts at Lanet sawmill and timber yards at Bufflo sawmill (Nakuru)

3.2.1 Available technologies and measures to increase efficiency in timber processing

The actions suggested below include several intended to have a direct impact on efficiency at the processing site, as well as others concerning the sustainable development of the sector as a whole. In the final section, the outcomes from the potential efficiency improvement will be assessed in terms of potential raw material savings and hence reduced or removed emissions.

Available efficient technologies
A range of technologies that could deliver efficiency improvements is described below:

- **Chainsaw milling**. Inefficiencies arise from the wide kerf of a chainsaw and in inaccurate sawing when done free-hand. KEFRI has developed an improved chainsaw mill attachment that guides the chainsaw as it cuts, thus helping to reduce waste and improve the quality (straightness and dimensional accuracy) of the timber produced.

TABLE 7: Economic margins of the current BAU medium-size sawmilling businesses

Item	Value
Cost of standing raw material	$25-30/m³
Tree cull in the forest	(5-10% volume of the tree)
Mill cull (off cuts)	(30-40% volume of the trunk)
Mill cull (sawdust)	(10-15% volume of the trunk)
Value of sold sawn wood	$220-250/m³ sawn wood
Value of off cuts and briquettes	$10-15/ton
Value of saw dust	$5-6/ton

- **Sawmill**. Portable and semi-portable sawmill systems are available in Kenya for a variety of scales of operation, ranging from portable in-forest sawmills to medium-sized operations. Some medium-sized sawmills in Kenya have recently adopted wood mizer equipment which cuts with band saws. Other options, particularly for smaller operations, include Lucas Mills which are portable mills that cut with 'swing-blade' circular saws.
- **Multi-blade saws**. The logs sourced from Kenyan plantations (mainly Eucalyptus) are generally of small diameter and are difficult to efficiently process. Multi-blade circular saws are available that cut multiple boards in a single pass by the sawmill operator. Using such equipment could help maximize production yield from small logs.
- **Utilization of processing residues for energy**. There is potential to utilize mill cull, such as timber offcuts and sawdust, to generate heat and electricity for sawmill and processing equipment such as kiln dryers. Wood fired electricity generation systems exist that can be used in sawmill operations as well as in other industries such as tea production. Energy costs are then reduced for the sawmill.
- **Adding value to timber**. Drying is an important production step to ensure the stability of timber during use and therefore its quality and durability. Kiln drying systems could be used by small-medium producers or perhaps groups of producers. Such technology could help to improve the wood quality and financial returns to small producers. Relatively simple systems can be constructed with a capacity of 15-20 m³ using a shipping container and solar power.
- **Training**. Instruction in framed chainsaw techniques as well as awareness-raising among local enterprises could encourage investments in producing the frames to make them cheaper and readily available to chainsaw operators.

Policy measures

Structural actions, such as improvements in the road network and access to the supply of electric power, are important for timber processing as well as for other craft-related sectors.

Considering the situation of forests in the country, the most important measure to ensure a prosperous future for the sector is to provide a constant and secure supply of raw material, both by improving the management of public plantations, and by promoting timber farming in private farms. Otherwise, investments that would significantly improve efficiency in sawmills are unlikely to materialize, since there will be no certainty that such investments will generate sufficient returns.

Insecure supply of raw material forces local sawmills to close or to become second-tier businesses dealing with imported sawn wood. Timber import seems bound to increase, but import of round wood faces increasing export limitations imposed by many African countries, to the advantage of processors in those countries.

Policy could also support the industry by establishing:

- Supply continuity for multi-annual purchasing contracts (at least three years),
- Transparent trading procedures, including full information on volumes, timber quality and accessibility of forest stands
- Regulatory mechanisms to avoid the concentration of resources and to grant incentives to the best players and avoid privileged positions.

Technical improvements

Recommended technical improvements for the sector mainly comprise measures at processing installations and training for operators. These measures can improve efficiency rates, including better use of equipment and machinery. They include:

- Better company infrastructure (yards, warehouses) to promote the quality of the product and improve working conditions, including health and safety
- Replacing circular saws with portable belt saws and/or high-productivity sash gang saws to boost recovery rates
- Improvements in the valorisation of offcuts and sawdust, for example by installing systems to make briquettes from saw dust
- Improvements in the value of processing products by for example drying timber or developing secondary processing lines for products such as panels, floors, etc.

The values shown in Table 8 refer to a typical medium-size sawmill, processing 1,000-1,500 m³ of round wood per year with about 15 employees, and suitable for investments in improved saws and briquette-making equipment. Investment in drying equipment would only be feasible for sawmills processing at least 4,000 m³ of round wood per year.

Government financial support for such investments can be delivered in various forms, including through grants, subsidies, or in terms of tax relief. Public contributions are calculated as an average amount of 30% of the investment. This is comparable to the level of support to develop forest industries in the European Union.

Table 8 also shows the average investments needed to support the suggested technical improvements as well as the potential outcomes in terms of wood volume savings over 10 years. The calculations are based on the average expected increase of recovery rates and the number of industry participants willing to make this kind of investment. The estimated number of industry participants is based on the feedback received by local stakeholders during the field study and a workshop organised in July 2015 in the context of this study.

Training for sawmill personnel

Training courses are important to realize the benefits of technical improvements by allowing the efficient utilization of new technologies. Based on the experience of sawmill operators in Europe, three types of courses could be put forward:

- business management for sawmill owners
- wood technology and timber marketing for sawmill owners and production managers
- training for saw operators and maintenance staff

Table 8 shows the costs of the various training options.

Currently sawmills tend to perform basic processing work, rather than adding value to a raw material. It appears that higher margins are left to resellers and wholesalers who are in direct contact with final customers and who have the best knowledge of the market, products, and relevant needs.

An example is the limited ability of small and medium sawmills to add value to best quality forest stands. These mills are not able to diversify their products on a qualitative basis and according to the end use. In order to add value to primary production and transformation, managers and marketing personnel as well as technical staff working in sawmills have to receive training.

Vocational training for individual operators

For operators of portable chainsaws, it is possible to envisage short courses (2-3 days) mainly focused on
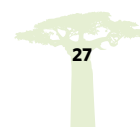
safety issues, chain sharpening and the use of bar-guide devices to be attached to the chainsaw.

The cost of importing a chainsaw frame would be about $350-400, while producing it locally currently costs $120-130. This should create incentives to produce the frame locally. Awareness-raising for local metalworkers could allow local businesses to seize this opportunity.

3.2.2 Estimated potential outcomes from the improved alternative scenario

This study considered only raw material savings. However, it should be noted that the proposed measures will also increase the quality and quantity of sawn wood, and so improve the entire wood supply chain from the forest resource to the carpentry sector.

Table 8 shows the potential outcomes of the recommended efficiency measures in timber processing. Each measure has a specific target in term

of number of operators involved ranging from 10 to 400 enterprises or individuals. Unit costs are based on the real costs of the investment and do not take into account transaction costs. Sawn wood and sawdust production figures are based on a typical small-to-medium size enterprise.

Concerning vocational training, experience from European countries shows that, initially, training must be delivered free of charge because it is not perceived as a real benefit by operators. Only in a secondary stage will operators understand the advantages and become willing to invest their own money. To the extent possible, training initiatives should target both men and women.

The introduction of adequate supporting policies, infrastructure improvements, equipment investments and human resource training can contribute to increased recovery rates and allow raw material savings ranging between 5% and 10%.

TABLE 8: Summary of efficiency measures in timber processing

	Investments in infrastructure	Saw Equipment	Briquettes making equipment	Timber drying	Vocational training (business management, wood technology, markets)	Vocational training (operators)	Vocational training (individual chainsaw splitters)
Unit cost ($)	25,000	25,000	7,500	200,000	2,000	3,000	500
Current round wood consumption (m³ per year)*	2,000	2,000	2,000	4,000	2,000	2,000	100
Current sawn wood production (m³ per year)	1,000	1,000					30
Current sawdust production (m³$_{RWE}$ per year)			240				
Potential sawn wood processed (m³ per year)				2,000			
Expected increase of recovery rates (+%)	+5%	+15%		+5%	+5%	+5%	+20%
Production increase from higher recovery rates (sawn wood – m³ per year)	100	300		100	100	100	20
Raw material savings from higher recovery rates in 10 years (m³$_{RWE}$)	1,000	3,000	1,200**	2,000	2,000	2,000	200
N° of relevant companies/operators	100	200	300	10	400	200	500
Overall savings calculated over 10 years of activity (m³$_{RWE}$)	100,000	600,000	360,000	20,000	800,000	400,000	100,000
Total raw material saving = Sum overall savings calculated over 10 years activity (m³$_{RWE}$)	**2,380,000**						

* Estimates are based on the average size sawmill consuming around 2,000 m³ of round wood per year. Statistics are not available to break down estimates according to industrial, medium-size and small sawmilling. The average recovery rate of sawmill processing is estimated at 50%. Board drying technologies are assumed to be viable only for sawmills consuming more than 4,000 m³ per year.

** assuming saw dust utilization of 50%, 120 out of 240 m³$_{RWE}$ per year are transformed and sold as briquettes. Over 10 years, this saves the equivalent of around 1,200 m³$_{RWE}$ of fuelwood per sawmill.

Improving efficiency in forestry operations and forest product processing in Kenya: A viable REDD+ policy and measure

Taking into account the current output of processed sawn logs in Kenya, the potential improved recovery rate would result in about 238,000 m^3_{RWE} savings per year and 2,380,000 m^3_{RWE} savings over 10 years.

3.2.3 Analysing carbon benefits

Emission reductions
From a REDD+ perspective, emission reductions from improving the efficiency of timber processing operations in forest plantations may come from two sources: first, savings of non-renewable biomass in plantations, and second, alleviation of the pressure on natural forests due to an increase in total production from plantations.

Savings of non-renewable biomass in plantations:
The fNRB is an essential parameter to assess the emission reductions potential in this sector. It represents the proportion of wood biomass harvested per year that exceeds the sustainable yield. As described above, we may assume that the annual harvest in public plantations is close to the sustainable yield. Therefore, in absence of degradation in plantations in the BAU scenario, the fNRB and emission reductions could be close to zero. We may also assume that private plantations are in a similar situation, being even slightly better managed than public plantations.

However, as it cannot be excluded that a part of sawn timber is coming from non-renewable sources in the next ten years, it is considered that 25% of saved timber can generate emission reductions.

The biomass savings could have two types of impact on saw millers.

First, these savings may indicate a reduction in the volume of raw material required to produce the same amount of wood products per year. However, given the growth of the construction industry, the development of the first processing sector, and the subsequent demand increase in wood and timber from plantations (KFS, 2007; MEWNR, 2013), it seems difficult to adopt this assumption for all SMEs targeted by the measure.

Second, the savings may correspond to an increase in the saw mills' total annual production with the same amount of raw material used. In view of the above, this hypothesis is more realistic in the Kenyan context.

Savings of non-renewable biomass in natural forests by substitution of firewood with recycled saw dust:
As stated earlier, saw dust may be used for cogeneration of heat and power at the mill, or transformed to briquettes to be sold on the market. If briquettes sold on the market replace firewood or charcoal from non-renewable forest sources, this may generate a REDD+ potential.

Assuming that, for a single saw mill, the saw dust will be used at 50% for cogeneration, 120 out of 240 m^3_{RWE} of saw dust per year may be used as briquettes, substituting around 120 m^3_{RWE} of fuelwood per saw mill per year, e.g. 36,000 m^3_{RWE} per year considering 300 sawmills (see Table 8).

Based on considerations in the ER formula (see the section on Assumptions and methodology) and using an fNRB of 50%, the estimated emission reductions are close to 111,000 tCO_2e per year.

Alleviation of pressure on natural forests to produce timber
It is not possible to demonstrate or exclude clearly that increased wood supply from harvesting in plantations for wood processing will decrease the pressure on natural forests for timber production. In this case, improving the efficiency of timber processing is therefore likely to generate limited additional emission reductions in terms of REDD+.

3.2.4 Efficiency improvement

Savings of around 238,000 m^3_{RWE} per year as a result of efficiency improvements in wood processing would represent a total value for the whole sector of $3.3 million based on a price of KES 1,400/m^3. Moreover, if briquettes are sold on the market at $12.5/ton (compared to the $5.5/ton for sawdust), this would generate additional annual revenues of $151,200 (36,000 m^3_{RWE} x 0.6t/ m^3_{RWE} x $(12.5-5.5)/ton).

3.2.5 Job creation, health and safety

According to the Kenya Timber Manufactures Association (KTMA), between 30,000 and 150,000 people lost jobs directly or indirectly as a result of the logging ban (KFS, 2007). Hence, it is reasonable to assume that increasing wood production will generate more employment. However, according to PWC (2014), it should be noted that the potential job creation in the forestry sector depends more on increasing plantation area and forest maintenance.

3.3 CHARCOAL PRODUCTION

Charcoal is a key source of energy in Kenya. The charcoal supply chain involves about 2.5 million people in transportation and marketing. About 700,000 charcoal producers are involved and most of the Kenyan population are consumers (2011, PAC pisces project).

TABLE 9: Annual charcoal potential supply (m³$_{RWE}$) in Kenya

Forest ownership	Forest type	Charcoal (m³)	% by category
Public forests	Natural forests	285,187	6%
	Plantations	174,071	
Community and private forests	Natural forests	1,040,935	18%
	Plantations	280,116	
Trees on farms	n/a	5,578,407	76%
Total		**7,358,716**	

TABLE 10: Annual charcoal consumption (m³$_{RWE}$) in Kenya

	Value	Unit	Source
Charcoal consumption per capita	0.3915	M³$_{RWE}$/year	MEWNR (2013)
Population (2014)	45,545,980	Inhabitants	World Bank online database
Population using charcoal	90%	-	Githiomi et al.(2002)
Total annual demand	**16,048,126**	**M³$_{RWE}$/year**	**Calculated**

From an economic point of view, the charcoal sector generates an annual market value of KES 32 billion ($31 million) (Camco, 2013). From a fiscal point of view, the revenue generated for the government is quite low due to low tax compliance, but it has significant potential (2013, KFS NRCO).

The annual potential supply of charcoal from forests and farmlands in Kenya is estimated at 7.4 million m³$_{RWE}$ whereas demand in 2014 was estimated at 16.0 million m³$_{RWE}$ (Table 9 and Table 10), leaving a production gap of around 8.7 million m³$_{RWE}$ per year. We assume the gap is filled mostly through non-renewable wood harvesting, plus small imported volumes.

As presented in Table 9, trees on farms account in theory for 76% of the potential charcoal supply. Forest

plantations account only for 6% of the potential charcoal supply, whereas natural forests account for 18%. In the absence of concrete data on fuelwood origin, these figures are assumptions mainly based on a literature review.

The identification of viable efficiency options for the charcoal sector is urgently needed, as the combination of unsustainable harvesting of trees for charcoal production, increased charcoal consumption, and the use of inefficient traditional kilns, form a key threat to forest resources in Kenya (KEFRI, 2014). Conversely, charcoal supply chain improvement could have a tremendous REDD+ impact, because of the amount of biomass involved.

Often considered an industry of the poor, one of the challenges with regards to introducing new technologies into the sector is to make it both affordable and able to offer optimal recovery of the wood used to make it (Monica et al, undated).

3.3.1 Regulatory and legislative aspects

Charcoal production and transportation is subject to legal authorization. Marketing of charcoal and transportation of more than five bags of charcoal requires a permit from KFS. The Traffic Act outlines the laws that need to be observed during transportation of charcoal and the verification of charcoal movement permits.

Improving efficiency in forestry operations and forest product processing in Kenya: A viable REDD+ policy and measure

Retailers need a business permit from county Governments to sell charcoal. Under the Charcoal Rules (2009) a person engaged in wholesale or retail trade in charcoal is expected to record the sources of charcoal, and keep copies of relevant certificates. For charcoal imports and exports, customs authorities provide permits.

However, problems including complicated and unevenly interpreted procedures and overlapping jurisdictions, together with historical and cultural motivations, result in poor enforcement (KFS and Miti Mingi Maisha Bora, 2013). Today few producers are compliant with the law, while only a portion of the goods is transported with a permit (MEWNR, 2013).

Thus, those producing charcoal in compliance with good practices and environmental sustainability operate in the same context as those who are totally or partially resorting to illegal and abusive methods to exploit forest resources. The latter can obviously produce at lower costs.

Simpler regulations and stricter controls on the ground, in production sites and in selling centres, could bring advantages when addressing illegality in charcoal production.

The strengthening of charcoal producers' associations (CPAs), which were launched with the Charcoal Rules in 2009, would help the sector to equip itself with a structure designed to disseminate good practices and raise awareness among operators. The cost of illegal practices accounts today for at least 20% of the finished product.

Also, the implementation of product-related technical standards could contribute to market growth by allowing some players to stand out for their product's purity, heating power and origin. These characteristics depend mainly on the carbonization process and the original wood species.

3.3.2 Current efficiency rates

Most charcoal production is small scale and informal with little involvement of entrepreneurs, and is often a subsistence activity. Approaches vary across the country, depending on the vegetation, and the agricultural, social, and economic context.

In highly productive rural areas, charcoal is a by-product or a secondary output of more profitable agriculture and forestry, with tree branches or wood residue used as a raw material. In poorer areas, animal husbandry is often supplemented by charcoal production for consumption and sale.

Following the entry into force of new laws after 2009, many CPAs have been formed and today control 40% of charcoal production, with 60% still managed according to traditional methods and outside of any formal structures.

Some CPAs operate in full compliance with the law. Despite bureaucratic difficulties, and the fact that in some cases illegal production or imports are involved, it is believed that the further promotion of CPAs is key to improvement measures in the sector.

Given the poor roads in rural areas where charcoal is typically produced, the high cost of transporting heavy firewood, and the higher value of charcoal (up to 20 times more expensive than firewood), charcoal is usually produced near forested areas where the raw material is sourced and trucked to storages areas and on to mostly urban markets.

Most production is carried out on the ground near the felling area using traditional kilns. These have a very low recovery rate, ranging between 10% and 15%[7] (SalvaTerra, 2014) and produce low quality charcoal contaminated with dirt and soil.

3.3.3 Available efficient technologies

While each charcoal production technology available for consideration has positive and negative attributes, a common set of rules can be adopted to improve the production of charcoal. These include:

- **Wood drying:** Wood should be dried for at least one month before carbonization. This is difficult for small producers who cannot wait that long
- **Homogenizing wood diameters:** If necessary, the largest wood logs must be split first or put in the middle of the wood pile
- **Avoid mixing wood species:** different wood species have different pyrolysis times
- **Optimize other factors:** air exclusion, temperature and humidity must be controlled to optimize charcoal production

An opportunity exists across the sector to train charcoal producers in basic good practices. In addition, a number of technologies are available for charcoal production ranging from simple traditional kilns for domestic production to advanced technologies that could be considered for industrial production.

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7   Mass efficiency ratio: charcoal (output) / dry wood (input).
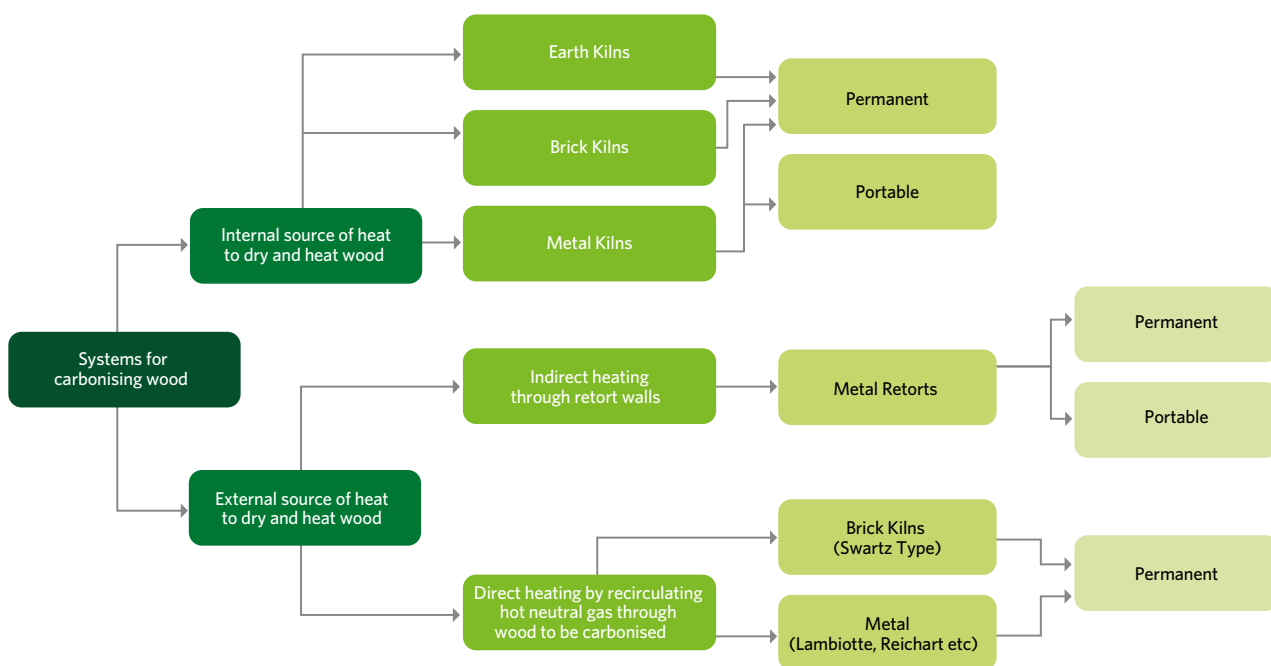
Figure 11 illustrates the main groups of technologies available for charcoal production.

Kilns with internal heating – improved earth kilns

The easiest way to improve traditional earth kilns (see Figure 12 below for an illustrative example) is to introduce rigorous construction rules in order to better control the quantity of air penetrating the kiln. This ensures a more even inner temperature and generates less ash. An air corridor around and beneath the wood pile improves the circulation of air. Kilns should not be too high, to reduce the risk of burns and facilitate surveillance. Surveillance time is reduced

from 2 to 3 weeks to a few days because pyrolysis is much faster.

While traditional earth kilns achieve a mass-efficiency ratio (the volume of charcoal produced as a percentage of the volume of wood used) of around 10-15%, a ratio of 15-20% may be obtained with improved kilns (SalvaTerra, 2014). There are no additional costs for the producer.

Metal chimneys and air outlets could also be added (see Casamance kiln), though small producers are generally reluctant to make such investments. They

FIGURE 12: Improved traditional earth kilns in western Democratic Republic of Congo

Source: SalvaTerra

Source: Projet Makala

would also need training to construct kilns with these features.

The Casamance kiln is an improved earth kiln with special features, well described by KEFRI. The fuelwood is cut into lengths of 0.5 m and stacked in a circular form with an air channel built across the centre. A chimney made of galvanised iron sheet is placed at the opposite end from the lighting point, connected to the air channel. According to KEFRI, this design can achieve a mass efficiency ratio of up to 30%.

Kilns with internal heating – brick or metal kilns, transportable or permanent

Controlling parameters such as air temperature and moisture in the kiln is key to producing charcoal more efficiently. Improved earth kilns are limited in this respect, especially because some of the wood is partially burnt to release enough energy to start pyrolysis. Brick and metal ("Magnien") kilns (see Figure 13) are slightly more efficient. However, the gains are outweighed by the cost of transporting wood to the kiln. Hence, technologies using partial load combustion such as brick or metallic kilns should be avoided, and are not considered in the following evaluation.

Kilns with external, indirect heating – retorts

Retort kilns use indirect heating instead of partial combustion to initiate pyrolysis. The mass-efficiency ratio of some designs can reach up to 35-40% (Adam, personal communication) although other experts put this figure at 30-35%. There are many designs, including the "Adam retort" (see Figure 14), a brick and metal based kiln for use in developing countries. Each component can be built on-site with local materials.

Retorts are typically composed of two chambers. Biomass and waste are burnt in the combustion chamber to heat the load in the second chamber. Gases emitted during pyrolysis are returned to the combustion chamber and burnt to increase the temperature and accelerate pyrolysis. This process reduces GHG emissions and air pollution compared to other kiln types.

However, there are additional costs for wood transport because the retort kiln is permanent. It is sometimes necessary to build several kilns because a single kiln can handle a maximum of 188 m^3_{RWE} of wood per year. This is probably not suitable for production from large-scale plantations but is well adapted for farmlands with small woodlots.

The Adam retort type of kiln is protected by patent and costs approximately $1,700/unit (construction and patent included). It operates with a small load of 1,875 m^3_{RWE} per production cycle (two days per cycle) and has a lifespan of five years. It has been tested successfully in Kenya, with a three-month return on investment (Adam, personal communication).

FIGURE 14: Adam retort kiln

Source: Chris Adam

Kilns with external, direct heating – metal kilns

A number of technologies have been developed to produce high-grade industrial charcoal that are more efficient and less labour intensive and polluting than the above techniques. These include the Lambiotte and Reichert retorts (FAO, 1987) and are described below.

Lambiotte retorts

Continuous carbonising systems such as the Lambiotte retort provide a higher yield than the more simple technologies as well as providing savings in the fuel required for heating. Production of charcoal using the Lambiotte process involves placing pre-dried wood into the top of the retort and then moving it slowly down through the retort where it will encounter a countercurrent of inert hot gas which dried the wood and raises it to carbonising temperature. The process takes about eleven hours (FAO, 1987).

An important variable in the efficiency of the system is the moisture content of the timber entering the retort, with an increase in energy use required as the moisture content increases. Corrosion is the other main problem with such steel-made systems. This can be overcome by using stainless steel, but at a high cost.

Reichert retorts

The Reichert retort recirculates inert heated gas through the load inside the retort. While this system has been used for many years, its efficiency and cost-effectiveness rely on mechanization of the wood and charcoal loading system. In addition, as the investment costs are high, it has not been considered appropriate in the Kenyan situation (FAO, 1987).

There is currently no industrial charcoal production in Kenya, given the high investment costs of systems such as the Lambiotte and Reichert retorts. Industrial operations also cannot compete with local charcoal producers who have low labour costs and typically no cost for the wood resource.

Kilns with external, direct heating – brick kilns
Schwartz kiln

The Schwartz kiln is a brick and metal kiln that passes hot flue gas from an external fire grate through the kiln to dry and heat the wood and bring about carbonization. The overall yield of the Schwartz kiln, when firewood is included in the accounting, is inferior to other kilns (FAO 1987). Hence this type of kiln is also not considered applicable to the Kenyan scenario.

Technologies for analysis

Seven kiln types have been reviewed in this analysis of potential technologies suitable for charcoal production. For the reasons explained above, only two – improved earth kilns and retorts – are considered relevant to the Kenyan situation and hence merit further analysis. They are also the most affordable solutions. Table 11 below summarises their key features.

TABLE 11: Outline of opportunities for improved carbonization

	Improved traditional earth kilns	Retort (e.g. Adam Retort)
Cost/unit (approximate)	0 – without chimneys $30 – with chimneys, 3 years lifespan (Casamance kiln)	$1,700 including patent Five year lifespan
Operating costs (labour and others)	$1-6/m$^3_{RWE}$ (mean value: 3.5) – same as traditional earth kilns	$2-3/m$^3_{RWE}$ (mean value: 2.5) – lower than earth kilns
Maintenance costs	Zero – kilns are temporary	15% of operational costs
Training through CPAs	$45-100 per capita (mean value: 64)	$400 per unit
Efficiency in conversion	15-20% without chimney (17.5% for subsequent analysis) 30% for Casamance (KEFRI)	30-35% (32.5% for subsequent analysis)
Skill set required for operation	Construction rules are easy to learn but training is required.	Training required for masonry work and operations. A construction manual has been developed.
Adoption challenges	Producers need to be convinced with demonstration. Construction rules are rigorous and affect directly the quantity of charcoal produced.	Relatively high investment costs for small producers and potentially high transport costs (permanent kiln). Small load per cycle.
Viability assessment and approaches to enable adoption	Easiest way to improve charcoal production at no cost (except training costs) or low-cost (with chimneys)	Not adapted to large-scale plantations, but well adapted to small-scale plantations and farmlands.

3.3.4 Proposed improvement measures

As with any technology, efficiency gains will be realized when equipment is used appropriately and consistent procedures are followed. Charcoal production technologies are no different. As such, the implementation of training for the Kenyan charcoal production sector has the potential to impact its efficiency and effectiveness. Typical improvements that can easily be implemented include changing the stacking of the wood and managing air control to help the carbonisation process (KEFRI 2014).

The adoption of enhanced versions of traditional charcoal kilns would allow yield improvement from +5% up to +25% according to the type of technology involved. In view of concentrating production in fixed facilities, there are many construction solutions available for charcoal burners of various sizes, capable of increasing the yield to the point of even tripling (from 10% to 30-35%) efficiency and thus reducing the corresponding need for wood.

However, improved kilns are still rarely adopted. Apart from with improved traditional earth kilns, a major constraint is the high cost in the light of the financial situation of the average operator. There are also difficulties in changing the supply chain organization, which implies re-allocating costs and revenues among wood owners, charcoal makers, freight carriers and wholesalers. As such, along with the promotion of new charcoal technologies, it is important to set up organizational, planning and training measures to ensure improvements are sustainable.

Three lines of action have been identified (and are listed below). The first two have a direct impact on efficiency having to do with production improvement. The third one has to do with the social and regulatory context and thus has an indirect impact on recovery rates from charcoal production processing. The third kind of action, however, is related to the reduction of the transaction cost of charcoal production and thus is not considered in the following cost-benefit analysis. Given that 75% of charcoal production takes place in dry areas (KFS, undated), dry forests are the focus of these interventions, in line with the Kenyan R-PP (KFS, 2010).

The results expected from the improvements should first of all impact the environment – especially dryland forests – by providing savings in terms of wood biomass and, as a consequence, a reduction of the area annually subjected to deforestation or forest degradation, together with better adherence to laws and regulations, and improved economic and social conditions for people working in this sector.

Action 1 (direct impacts): improvement of on-site production practices by providing vocational training, especially through CPAs, as well as the promotion of Casamance kilns. These are considered the most suitable solution for charcoal makers.

Action 2 (direct impacts): enhance availability of fixed and semi-mobile high-yield processing units (retorts) for the purpose of achieving raw material savings in dryland forests. This option is less affordable but provides higher performance and co-benefits.

Action 3 (indirect impacts): review and revision of the charcoal regulatory framework with the goal of facilitating producers willing to operate within legal boundaries. This would include:

- Introduction of a system of licenses for professional and non-professional charcoal production, with five-year duration and a system for the payment of annual taxes; multi-level controls and inspections (national and local); issue of titles for wood extraction; sustainable management plans; registration system for production control (simplified procedures for non-professional licenses)
- Introduction of professional licenses for the wholesale sector (and for import)
- Measures to encourage the establishment of CPAs with the aim of de-fragmenting the market and aggregating the supply chain, and facilitating the adoption and enforcement of rules and regulations;
- General policy measures to increase production quality (product standards, incentives for sustainable charcoal, communication campaigns on reducing fuel/charcoal consumption).

3.3.5 Analysing carbon benefits

As mentioned above, the potential supply of wood from renewable sources for charcoal production is lower than the national demand with an estimated shortage of 8.7 million m^3_{RWE} per year (adapted from MEWNR, 2013). The proposed actions aim to reduce the production of charcoal from non-renewable sources by increasing production efficiency (see the key-results summarised in Table 27).

With these improvements, the overall production of charcoal remains equal to the BAU scenario, but fewer raw materials are consumed, which generates an opportunity to achieve REDD+ results. This contrasts with the forestry and timber processing sectors, where overall production would likely increase due to the measures proposed.

The emission reduction estimates are calculated as the difference between the biomass used in the BAU scenario and the biomass used in the REDD+ scenario, multiplied by the fNRB. The same equation used in previous scenarios is used to convert non-renewable biomass savings into tCO_2e.

As explained in the section on 'Assumptions and methodology', it is necessary to determine the fNRB of the biomass used to produce charcoal in order to estimate the potential emission reductions resulting from the proposed REDD+ measures. The biomass produced in forest plantations may not be qualified as non-renewable, given that the harvesting volumes are close to the annual yields (see Sections 3.1 and 3.2). Moreover, the illegal production of charcoal in gazetted forests must be excluded from these estimations because the measures are not targeted towards these activities, but rather towards dry forest areas.

It is estimated that 75% of the charcoal produced in Kenya comes from dry forests (KFS, undated), representing an estimated 2,268,000 ha in 2010 (based on KFS data, 2013). The total charcoal demand is estimated at 963,000 tons per year, from which 722,000 tons are produced in dry forests (75%, equivalent to 12.0 million m^3_{RWE}). According to Mbugua (2000), sustainable production is estimated at 0.28 m^3/ha/year in dry forests.

Action 1: Improvement of production practices on site (improved traditional earth kilns) through CPAs
These estimates are based on the following scenario:

- 100,000 charcoal producers trained in good practices out of the estimated over 700,000 countrywide and 280,000 working in dry forests.
- An additional 50,000 charcoal producers trained to build Casamance kilns. This reflects the fact that many producers cannot afford to pay the $30 cost of metal chimneys.
- Increased mass efficiency ratio from 10% to 17.5% for traditional earth kilns without chimneys and to 30% with Casamance kilns.

- Parameters for calculations: RSR = 0.56 (IPCC 2006 default value for Tropical dry forests, aerial biomass < 20 tms/ha); Biomass expansion factor = 1.9 (IPCC 2006 – Tropical dry forests, broadleaved, growing stock between 21 and 40 m^3/ha); Carbon fraction = 0.5 tC/t of dry wood ; C/CO_2e ratio = 44/12 = 3.67.

The quantity of biomass used in the BAU scenario by 150,000 charcoal producers in dry forests may be estimated at 3.4 million m^3_{RWE}, whereas the biomass consumed in the REDD+ scenario to produce the same amount of charcoal is about 1.7 million m^3_{RWE} – a reduction of 50%. The emission reductions are close to 4.8 million tCO_2e per year as illustrated in Table 12 below.

The costs of implementing Action 1 are mainly training costs because the technology used is fundamentally the same. Vocational training of this type is typically carried out using field demonstrations. The most efficient way to deliver this is to train representatives of CPAs who in turn train the members. This approach would work well in Kenya where the Forests Charcoal Rules (2009) require commercial charcoal producers to be in a registered CPA (KEFRI 2014).

The cost of such training may be estimated at $10,000 for 10-15 charcoal makers, who would then teach the techniques to 10-15 members of their association (estimates based on vocational training in similar conditions in DR Congo).

For Casamance kilns, there is an additional $30/kiln corresponding to the cost of chimneys (around KES3,000 according to KEFRI), with an estimated lifespan of 3 years (i.e. $10/year/producer).

Under this scenario, the cost of training 100,000 producers is estimated at $6.4 million and the cost of Casamance kiln chimneys at $500,000 per year i.e. $2.1/$tCO_2e$ saved.

TABLE 12: Non-renewable biomass savings and emission reductions of Action 1 (charcoal production)

	Biomass consumed (m^3_{RWE} per year)	Non-renewable biomass savings (m^3_{RWE} per year)	Emission reductions (tCO_2e/year)
BAU scenario – 150 000 producers	3,438,900		
REDD+ scenario – 100 000 producers trained in good practices	1,316,600	935,400	2,723,300
REDD+ scenario – 50 000 producers trained to build Casamance kilns	378,300	716,600	2,086,500

TABLE 13: Summary of findings – Charcoal production

Hypotheses	per year
Number of charcoal producers	700.000
Number of charcoal producers working in dry forests	525.000
Population (2014) - Worldbank database	45.545.980
% of the population using firewood and/ or charcoal	90%
Annual consumption of charcoal per capita (m³ RWE per year)	0,3915
Annual demand of charcoal at national level (m³ RWE per year)	16.048.126
Wood density	0,6
Proportion of fuelwood produced in dryland of forests	75%
fNRB (non renewable biomass fraction)	95%
Root-Shoot ratio (no dimension)	0,56
Biomass expansion factor (no dimension)	1,90
Carbon fraction (tC/ton of dry wood)	0,5
tC to tCO_2 ratio	3,67
Annual demand at national level (tons of charcoal)	962.888
Efficiency (output/input mass ratio)	10%
Annual potential sustainable supply from dry forests (m³ RWE per year)	635.040
Total charcoal production from dry forests (m³ RWE per year)	12.036.095
Total charcoal production from dry forests (tons)	722.166
Fuelwood - farmgate price (USD/m³)	3,7
TEV-Dry forests (USD/ha)	171
Growing stock - Other wooded land (m³/ha)	32
Action 1: Improved traditional earth kilns + Casamance kilns	**per year**
Efficiency (output/input mass ratio) - improved traditional earth kilns	17,50%
Efficiency (output/input mass ratio) - Casamance kilns	30%
Nb of producers in dry forests	525.000
Target (Nb of producers trained : improved earth kilns + Casamance)	150.000
Target Casamance kilns (Nb of producers trained)	33%
Biomass consumed by trained producers (m³ RWE) - BAU	3.438.884
Charcoal produced by trained producers (tons) - BAU and Action 1	206.333
Biomass consumed by trained producers (m³ RWE) - Action 1, improved earth kilns	1.316.601
Biomass consumed by trained producers (m³ RWE) - Action 1, Casamance kilns	378.277
Biomass savings (m³ RWE) - improved earth kilns	987.451
Biomass savings (m³ RWE) - Casamance kilns	756.555
Biomass savings (m³ RWE) - non renewable fraction - improved earth kilns	935.352
Biomass savings (m³ RWE) - non renewable fraction - Casamance kilns	716.638
Emission reductions (tCO_2e/year) - assuming 5% keakages - improved earth kilns	2.723.312
Emission reductions (tCO_2e/year) - assuming 5% keakages - Casamance kilns	2.086.517
Cost of one vocational training (USD/capita)	64
Cost of chimneys (Casamance kilns) - USD per year per kiln	10
Cost of chimneys (Casamance kilns) - USD per year	495.000
Total training costs (USD)	9.600.000
Cost per tCO_2e (USD/tCO_2e)	2,1
Beneficiary margin	6.535.852
TEV preserved (USD)	8.827.819
Action 2: Introducing more efficient carbonisation technologies	**per year**
Efficiency	32,50%
Dissemination target (number of units countrywide)	10.000
Annual biomass capacity per unit (m³ RWE)	188
Annual biomass capacity in total (m³ RWE)	1.880.000
Charcoal production with new technology (tons)	366.600
Biomass production from BAU scenario to produce the same amount of charcoal (m³ RWE)	6.110.000
Biomass savings (m³ RWE)	4.230.000
Biomass savings (m³ RWE) – non renewable fraction	4.006.820
Emission reductions (tCO_2e/year) – assuming 5% leakages	11.666.005
Purchase and maintenance – duration: 5 years (USD/unit)	343
Cost of one vocational training (USD/capita)	400,0
Total costs (purchase, maintenance, vocational training) (USD)	7.426.550
Labour costs correction (USD) – 1 UDS/m³ RWE inferior as compared to traditional earth kilns	1.880.000
Total costs (USD)	5.546.550
Cost per tCO_2e (USD/tCO_2e)	0,48
Beneficiary margin	15.852.390
TEV preserved (USD)	21.441.443
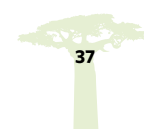
Action 2: Disseminating fixed or semi-mobile processing units (retorts)
These estimates are based on the following hypotheses:

- 10,000 fixed or semi-mobile processing units (retorts), each with a capacity of 188 m^3_{RWE} per year, disseminated countrywide
- Mass efficiency ratio increases from 10% to 32.5%
- Parameters for calculations as in Action 1.

In this scenario, the fixed and/or semi-mobile units have the capacity to produce 366,600 tons of charcoal annually with only 1.9 million m^3_{RWE} of biomass. The same amount of charcoal would be produced with traditional methods in the BAU scenario using 6.1 million m^3_{RWE} of biomass. By using a fNRB equal to 95% for dry forests and 5% leakages (conservative default value), the emission reductions are close to 11.7 million tCO_2e per year.

The cost of implementing Action 2 is composed of operational costs of $343/unit/year, including purchase and maintenance costs for retorts with a five-year lifespan, and training costs estimated at $400/unit[8]. Labour costs for these processing units are $1/$m^3_{RWE}$, less than for earth kilns in the BAU scenario (see Table 13). Total costs may be estimated at $5.5 million, e.g. $0.5/$tCO_2e$.

3.3.6 Efficiency improvement

The overall beneficiary margin in the sector will increase due to the reduction in the use of raw material as a result of efficiency improvement, estimated at KES 392/m^3 (based on farm gate prices), or $22.4 million in total, for both actions combined and considering the overall biomass savings from dry forests.

3.3.7 Job creation, health and safety

In the scenario used here, the number of charcoal producers would remain equal over time for Action 1 and would decrease for Action 2 because fewer producers are needed to produce the same amount of charcoal in comparison with the BAU scenario. However, Action 2 will generate the need for more qualified workers.

From a health and safety perspective, these actions will generate positive impacts such as the reduction of accidents resulting in burn injuries from the collapse of traditional earth kilns. Moreover, Action 2 will lower emissions of carbon monoxides and other toxic gases by recycling and combustion of pyrolysis gases.

Respiratory problems are widespread amongst charcoal producers.

3.4 FIREWOOD AND CHARCOAL CONSUMPTION AT HOUSEHOLD LEVEL

Firewood is the main source of energy for cooking and heating for almost all households in rural areas in Kenya. Firewood is also used for lighting and operating home businesses. A study by the Kenya National Bureau of Statistics indicated that 87.7% of households – both urban and rural – in Kenya use firewood (Ministry of Planning and National Development, 2007). Rural families' preference for both space heating and cooking from the same source and the high cost of alternative fuel sources such as charcoal, electricity, liquid petroleum gas (LPG) and kerosene often makes firewood the only viable choice.

According to a 2013 Ministry of Environment, Water and Natural Resources study on wood demand and supply, the annual potential supply of firewood is 13.7 million m^3_{RWE} while current demand is 18.4 million m^3_{RWE}, leading to a sustainable production gap of 4.7 million m^3_{RWE} per year (see Table 14 and Table 15).

Encouraging farmers to plant more trees could increase the supply of fuelwood from farmlands (Vermeulen and Walubengo, 2006). However, scarcity of land and competing land uses limit the extent to which people are willing to put land under trees for fuelwood.

Charcoal consumption at household level
The urban population represents 25% of Kenya's total population according to the World Bank database. Most of the charcoal in Kenya is consumed in urban areas: it is estimated that 82% of urban households use charcoal as a source of energy (Mugo and Gathui, 2010). Other charcoal consumers are businesses such as hotels and restaurants, institutions including schools and hospitals, and users in the informal sector.

3.4.1 Regulatory and legislative aspects

Charcoal production and consumption are regulated while the consumption of fuelwood is addressed in various regulatory frameworks related to energy and the environment. Households can produce and burn their own charcoal subject to the Charcoal Rules (2009) under the Forests Act 2005. The Environmental Management and Coordination Act of 1999 (EMCA) regulates the supply of fuelwood and charcoal indirectly from an environmental conservation perspective. For example, the Act encourages tree-planting to boost renewable energy resources and sets a national goal of 10% tree cover.

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8 $10,000 to train 25 charcoal make

TABLE 14: Firewood potential supply

Forest ownership	Forest type	Firewood (m³$_{RWE}$/year)	% by category
Public forests	Natural forests	529,634	6%
	Plantations	323,276	
Community and private forests	Natural forests	1,919,224	18%
	Plantations	520,215	
Trees on farms	n/a	10,361,673	76%
Total		**13,654,022**	

TABLE 15: Firewood consumption

	Value	Unit	Source
Firewood consumption per capita	0.4485	m³$_{RWE}$/year	MEWNR (2013)
Population (2014)	45,545,980	Inhabitants	World Bank online database
Population using firewood	90	%	Githiomi et al.(2002)
Total annual demand	**18,384,635**	**m³$_{RWE}$/year**	**Calculated**

Important policy frameworks for charcoal and firewood consumption are the Energy Policy (2004) and Energy Act (2006). Some of the objectives of the Energy Policy are:

- Increasing the rate of adoption of efficient charcoal stoves from 47% in 2004 to 80% in 2010 and to 100% by 2020 in urban areas; and to 40% by 2010 and 60% by 2020 in rural areas
- Increasing the rate of adoption of efficient firewood stoves from 4% in 2004 to 30% by 2020
- Promoting inter-fuel substitution
- Increasing the thermal efficiency of improved charcoal stoves from the 2004 level of 30-35% to 45-50% by 2020
- Offering training opportunities at the village level for the artisanal manufacture, installation and maintenance of renewable energy technologies including efficient cook stoves. Training should be offered to both men and women as women are usually tasked with domestic duties and collecting resources such as firewood and water

The Energy Act regulates the production, distribution and use of renewables and other forms of energy.

3.4.2 Current efficiency rates

Many Kenyans consume firewood in traditional ways, for instance with "three-stone" open fires. These have very low thermal efficiency of about 10% and pose health hazards, however, they are popular for most households as they are cheap and also provide heating (Githiomi et al, 2007). Some traditional cooking methods have been improved without additional cost, e.g. by surrounding the stove with wood, ash or cow dung to reduce heat loss.

The thermal efficiency of regular charcoal stoves may be estimated at 20%. Some improved cook stoves (ICS) are in use in Kenya, such as the *Kenya Ceramic Jiko* (KCJ). This stove, which incorporates an insulating clay liner to preserve heat, was developed in the 1980s and is widely produced by local artisans.

However, the majority of Kenyans still do not use ICS technology. Studies have estimated that 30-40% of the population has access to some type of ICS; however the actual number could be somewhat lower due to the potentially high numbers of broken, poor quality and unused stoves (USAID, 2011). Energising Development (2012) put the figure at just 13%. The real use of ICS may be estimated at 25% countrywide, with penetration higher in urban areas such as Mombasa and Nairobi.

3.4.3 Available efficient technologies

The key technology available for improving the efficiency of consumption of firewood and charcoal is ICS, stoves that have been modified to use less

FIGURE 15: The Kenya Ceramic Jiko

fuel, cook faster and reduce smoke (SNV 2015). For example, a traditional metal charcoal stove can be improved by adding clay as insulating material which helps conserve heat and save fuel while cooking. ICS have been developed for use with either firewood or charcoal, or even biomass briquettes. According to sources, modern stoves can save up to 70% in fuelwood in comparison to open fires.

Kenya has been at the forefront of ICS development over the last 30 years (see Figure 15). One of the first ICS to be produced on a commercial scale was the widely known KCJ, a ceramic charcoal stove. The successful local production and uptake of the KCJ led to the spread of training programs and business models for similar products in several other countries (USAID 2011), and to the continuing evolution of the ICS in Kenya.

Many donor organisations, international NGOs and local social organisations have contributed to further technological developments and awareness-raising around the use of ICSs (see for example the Global Alliance for Clean Cook Stoves). More recently, carbon finance projects have led to the development of more mass produced and imported ICS (USAID 2011).

- The bulk of stove manufacturing is still done by artisanal producers despite imported stoves increasingly entering the market. Some of the common technologies introduced in Kenya are listed in.

Table 16 and include:

- Envirofit stoves, with models for either wood or charcoal, operating on a rocket stove principle (see Figure 16 below)
- Jiko Kisasa: a fixed firewood stove promoted by GIZ. Has an insulating ceramic chamber that is 'mudded-in' allowing for better airflow around fuel
- Jiko Upesi: a fixed firewood stove promoted by Practical Action. Similar to the Maendeleo and Kisasa designs, but with a slightly different pot-stove interface and the addition of a chimney (see Figure 17 below)

TABLE 16: Examples of available ICS in Kenya

Portable		Fixed
Firewood	Charcoal	Firewood
Envirofit M5000 Kuni Mbili Jiko Poa	KCJ Envirofit CH5200	Co2balance Jiko Upesi Maendeleo Jiko Kisasa

FIGURE 16: Envirofit M5000 cook stov

(c) Envirofit

FIGURE 17: Upesi cook stove

TABLE 17: Opportunities for improved efficiency in consumption of firewood and charcoal

	KCJ	Co2balance	Envirofit household wood and charcoal stoves	Envirofit EFI 100L Institutional wood stove Suitable for cooking in e.g. schools
Purchase cost (approximate)	$4-10	$2 (cost of installation, subsidised by co2balance)	$23.5 (subsidised)	$100 (subsidised)*
Efficiency in conversion	30-40%	35%	60%	up to 80%
Maintenance costs	No maintenance cost, however the lifespan is limited (efficiency decreases over time)			
Skill set required for operation	No technical skills required			
Adoption challenges	User perceptions and awareness Availability and distribution can be limited	User perceptions and awareness Availability and distribution can be limited	User perceptions and awareness Price is dependent on subsidies. Full price is around $100#.	Price is dependent on subsidies.
Viability assessment and approaches to enable adoption	Most suited for use with charcoal or briquettes, rather than firewood.	Suitable for use with wood Continued distribution at this price dependant on funding availability	Models available for either wood or charcoal. Need to establish distribution networks.	Need to establish distribution networks.

Source: Clough (2012) and other references
*Cost is estimated based on comparative costs of smaller Envirofit cook stoves for households
Price taken from http://www.evansoutdoorstore.com/m-5000---rocket-stove.html

- Kuni Mbili: a portable firewood stove that consists of an insulating ceramic chamber (as used in Maendeleo, Kisasa and Upesi stoves) encased in metal
- Jiko Poa: a locally manufactured firewood rocket stove, similar in performance to the Envirofit
- Maendeleo Jiko: for use with firewood. A ceramic liner provides insulation while the raised fireplace allows for better airflow around burning sticks. Similar in nature to Jiko Kisasa and Jiko Upesi
- Co2balance: a fixed firewood stove made entirely of fired ceramics, operating with the rocket principle and restricting greatly the size and amount of fuel used.

There are many other ICS models that are potentially available, although only about 10 main types have been used in Kenya. Attributes that can be used to differentiate between the various models are:

- Household-level (small) or institutional level (large)
- Fixed i.e. permanently built into a kitchen, or portable
- Designed for use with firewood or charcoal, or both (most cook stoves are usually designed for use with a single fuel type).

Given the high number of ICS designs, it is important to recognise the role of a market-based approach and consumer preferences in selection of an 'appropriate' technology. In promoting further uptake of ICS, consideration should be given to factors such as: convenience, portability and affordability, as well as efficiency (Ghitiomi and Oduour 2012). Table 17 is not complete, but is intended to illustrate a variety of ICS on the market. When offering training opportunities, it is important to ensure that both men and women are targeted on an equal basis.

It is also important to recognise that cook stove efficiency is determined by the amount and quality of fuel that is used as well as the technical specifications. Bentson et al (2013) conducted tests on a number of charcoal cook stoves and found a high degree of variation in efficiency. Most stoves were more efficient when less fuel was used.

3.4.4 Proposed improvement measures

Use of ICS, especially portable models, is critical to enhancing charcoal consumption efficiency. There are many types of ICS that are more efficient than the KCJ. These include the Envirofit charcoal stove and Jiko Poa.

According to the Stockholm Environment Institute (SEI, 2014), traditional fuelwood collection and use has received limited attention from researchers, development
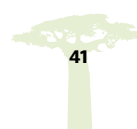
practitioners, development partners (donors) and policy makers. This has led to a general lack of knowledge on how to move to more sustainable practices such as the use of improved firewood stoves. These stoves not only improve efficiency and reduce health hazards, they also reduce the time used in fuelwood collection since they consume less. Another, sometimes overlooked issue, is the necessity to get buy-in from women for more efficient cooking methods as they are usually tasked with preparing food for the family and creating awareness and getting their support is important to ensure long-term sustainability and application.

Two actions are suggested:

Action 1: introduction of firewood-based ICS to replace traditional firewood-based methods such as the 'three-stone' open fire, mostly in rural areas

Action 2: introduction of charcoal-based ICS to replace regular charcoal stoves, mostly in urban areas

Both actions are in line with the Energy Policy (2004) and Energy Act (2006). The potential impacts of such actions are described below.

3.4.5 Analysing carbon benefits

The proposed actions are intended to reduce demand for fuelwood – both firewood and charcoal – at the household level by increasing the efficiency of cooking devices. This will help reduce the overall production of charcoal and firewood, leading in turn to a reduction in the non-renewable harvest of fuelwood.

Emission reductions estimates are based on the quantity of non-renewable biomass saved by implementing the proposed measures. The same equation deployed elsewhere in this report is used to convert the amount of non-renewable biomass savings into tCO_2e.

Action 1: introduction of firewood-based ICS at household level

These estimates are based on the following assumptions:

- 75% of the population live in rural areas (World Bank database, figures for 2014), where almost 90% of the population use firewood (author's estimate), mainly in three-stones open fires;
- The actual dissemination rate of firewood-based ICS is around 30%, while the dissemination target is 3.5 million devices, or around 80% of the total rural population;
- The number of people per household may be estimated at five;
- The efficiency of the ICS is 30% over its lifespan (5 years) compared to 20% for traditional cooking methods (default value drawn from CDM and Gold Standard methodologies);
- fNRB is estimated at 92% for natural forests in Kenya (default value given by UNFCCC, 2012). In this scenario, we consider natural forests as a whole, not only dry forests (as in the previous section) because firewood is harvested not only from dry forests;
- The proportion of firewood produced from forests is not known. According to Table 18, the potential supply of firewood from natural forests is estimated at 18% of the annual demand. This figure is used as conservative value in the following calculations. This assumption is key, because the higher this parameter, the higher the REDD+ impacts;
- Calculations are also based on: RSR = 0.37 (tropical dense forests, IPCC 2006); Biomass expansion factor = 1.3 (tropical dense forests, IPCC 2006); Carbon fraction = 0.5 tC/ton of dry wood ; C/CO_2e ratio = 44/12 = 3.67.

TABLE 18: Summary of findings – Firewood and charcoal consumption at household level

Hypotheses	per year
Population (2014) – Worldbank database	45.545.980
% of population using firewood and/or charcoal	87,70%
Rural population (2014) – Worldbank database	75%
Urban population (2014) – Worldbank database	25%
Annual consumption of charcoal per capita (m³ RWE)	0,3915
Annual consumption of firewood per capita (m³ RWE)	0,4485
Proportion of firewood from forests	18%
Wood density	0,6
Ratio: tCO_2e = x tons of dry wood	1,8
fNRB (non renewable biomass fraction)	92%
Root-Shoot ratio (no dimension)	0,37
Biomass expansion factor (no dimension)	1,3
Carbon fraction (tC/ton of dry wood)	0,5
tC to tCO_2 ratio	3,7
BAU devices thermal efficiency (BAU)	20%
BAU Charcoal-stove efficiency (BAU)	20%
Household composition (number of people per household)	5
TEV – Natural forests (USD/ha)	323
Fuelwood – farmgate price (USD/m³)	3,7
Growing stock – Natural forests (m³/ha)	180
Action 1: Introducing firewood-based efficient cookstoves (ICS) to replace 3-stones stoves	**per year**
% of firewood consumed in rural areas	90%
Quantity of ICS disseminated to reach target	3.500.000
Current dissemination rate	30%
Project dissemination rate	81%
ICS efficiency (annual mean over lifespan)	30%
Number of days stoves are used per year	365
Firewood – Non-renewable biomass savings (m³ RWE) from forests	389.926
Firewood – Emission reductions (tCO_2eq) including 5% leakages	725.709
Cost of one ICS (USD/unit)	2
Total cost of disseminating ICS under Action 1	7.000.000
Cost per tCO_2e (USD/tCO_2e)	9,6
TEV preserved (USD)	643.724
Beneficiary margin	1.588.359
Action 2: Introduction efficient cookstoves (ICS) to replace regular charcoal-based stoves	**per year**
% of charcoal consumed in rural areas	82%
Quantity of ICS disseminated to reach target	1.500.000
Current dissemination rate	30%
Project dissemination rate	96%
ICS efficiency (annual mean over lifespan)	30%
Number of days stoves are used per year	365
Charcoal – Non-renewable biomass savings (m³ RWE) from dry forests	570.173
Charcoal – Emission reductions (tCO_2eq) including 5% leakages	1.660.079
Cost of one ICS (USD/unit)	2
Total cost of disseminating ICS under Action 1	3.000.000
Cost per tCO_2e (USD/tCO_2e)	1,8
TEV preserved (USD)	2.886.103
Beneficiary margin	2.255.804

On this basis, the total non-renewable biomass savings from forests reach 390,000 m³$_{RWE}$ per year, generating 726,000 tCO_2e emission reductions per year (including 5% leakages).

The costs of implementing Action 1 are mainly linked to acquiring ICS. These costs are estimated at $10 per unit, with a lifetime of five years, e.g. $2 per year. However, the transaction costs necessary to develop a market-based approach to allow the dissemination of 3.5 million stoves, including artisan capacity building, cannot be estimated easily. As a consequence, the abatement cost may be estimated at $9.6/$tCO_2e$, but it is probably underestimated by not considering the additional transaction costs.

Action 2: introduction of charcoal-based ICS in urban areas

These estimates are based on the following assumptions:

- 25% of the population live in urban areas (World Bank database, figures for 2014) where almost 82% of them use charcoal, mainly in regular charcoal-based stoves;
- The actual dissemination rate of charcoal-based ICS is around 30% and the dissemination target is close to 100% (1.5 million ICS);
- The efficiency of the ICS is 30% compared to 20% for the regular charcoal-based stove;
- In the previous section, we estimated the proportion of fuelwood produced from dry forests at 75%; and
- The fNRB is estimated at 95% in dry forests. Hence, the constants used for Equation 2 in the previous section are also used here.

On this basis, the total non-renewable biomass savings from forests would represent 570,000 m^3_{RWE} per year, generating 1.7 million tCO_2e emission reductions per year (including 5% leakages).

The costs of implementing Action 2 are also mainly linked to ICS acquisition. With the same hypothesis as above (i.e. \$2/year) the abatement cost may be estimated at \$1.8/tCO_2e (including 5% leakages), but it is probably underestimated because transaction costs are also difficult to estimate.

3.4.6 Efficiency Improvement

Households would reduce their fuelwood expenses by reducing their consumption of raw material (firewood and charcoal). Considering the savings of 1.0 million m^3_{RWE} biomass per year from natural forests, this would represent a total value of \$3.8 million based on KES392/m^3 (farm gate prices).

3.4.7 Job creation, health and safety

Developing a market-based approach for ICS dissemination would require many competencies, from building efficient devices, to marketing, etc., unless these ICS are imported from abroad. Disseminating five million cooking devices would generate hundreds, if not thousands, of jobs.

The main health and safety benefits are linked to the reduction of the acrid smoke produced by unimproved stoves and that is responsible for many respiratory diseases and deaths, especially amongst women and children.

3.5 WOOD CONSUMPTION BY THE INDUSTRIAL SECTOR

The forestry sector contributes to value added in different industries, as shown in Figure 18 (UNEP, 2012).

WOOD AS RAW MATERIAL

Timber is the raw material used by the construction wood industry and in the manufacturing of poles (see section 3.2). With regards to the building construction sector, timber provides simple unfinished and finished products accounting for 25% of the added value produced in the sector (see Figure 18).

With regards to paper, only two types of imported cellulose pastes are processed in the country, but the only paper mill processing the raw material is no longer operational. No consumption of wood to produce paper is hence registered.

Of less relevance is the wattle bark extract industry, which only processes timber of a specific species of acacia. Such product is used by several chemical industries (leather, paints, etc.) (Export Processing Zones Authorities, 2005).

WOOD AS ENERGY

As energy sources, wood biomass and charcoal are very important in the agricultural sector, in the agro-food sector and in several handicraft jobs, as well as in catering.

These are different small-to-medium scale productive activities, mainly disseminated in rural areas or in secondary urban centres. In the agro-food industries

FIGURE 18: Contribution of the forestry sector to value added in different industries in Kenya, annual average 2000-2009 (as share of total value induced) (UNEP, 2012)

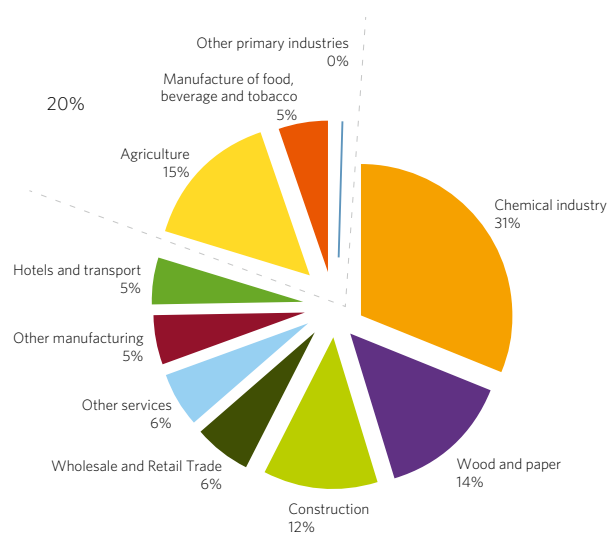

Other primary industries 0%
Manufacture of food, beverage and tobacco 5%
20%
Agriculture 15%
Hotels and transport 5%
Other manufacturing 5%
Other services 6%
Wholesale and Retail Trade 6%
Construction 12%
Wood and paper 14%
Chemical industry 31%

TABLE 19: Firewood and charcoal consumption by type of activity in the framework of agricultural industries and cottage industry.

Biomass Demand	Qty of fuelwood in tons/year	Qty of charcoal in tons/year	Qty of charcoal in tons$_{RWE}$/year	Total biomass consumption (tons$_{RWE}$/year)
Restaurant/Kiosks*	1,276,000	428,025	1,945,568	3,221,568
Tea industry**	800,000			800,000
Tobacco farmers*	140,000			140,000
Agrifood industries *(jaggary, milk, fish, etc.)	223,000	540	2,455	225,455
Bakeries*	20,000	622	2,827	22,827
Total agroindustry and cottage industry	**2,459,000**	**429,187**	**1,950,850**	**4,409,850**

*Data obtained from literature (Mugo and Gathui, 2010; Kibwage, 2012); ** data from interview.*

FIGURE 19: Wood drying before use in a boiler fed by woody biomass at Finlays estate (Kericho)

(e.g. milk, fish drying and smoking, lime processing), bakeries, and restaurants and public places where food and drinks are prepared, it is assumed that the energy need is covered at least 20-30% by wood or charcoal (Ministry of Energy, 2002).

In sugar factories, wood is used for the processing of 'bagasse' (residues), which is still a biomass of vegetable origin. In many other cases, wood or charcoal are preferred for strictly economic reasons and because they are easy to find compared to electric power, liquid petroleum gas (LPG) or fuel oil. In restaurants and luxury hotels instead of wood and charcoal they integrate LPG for reputational reasons and for the preparation of traditional dishes.

Available statistics on firewood and charcoal consumption are shown in Table 19, according to the type of user. It shows consumption in agricultural and cottage industries split between firewood and charcoal.

Focus on the tea industry

Tea is a vital industry in Kenya, with an annual production in 2014 of about 445,000 tons[9]. Tea factories are fitted with large boilers for the production of steam. Firewood is burnt in large quantities, accounting for 70% of all energy used (Finlays and KTDA interview). As presented in Section 3.2, tea companies often source firewood from their own plantations. To boost external supplies, they also support firewood production through outside grower schemes (see Figure 19).

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9 *Source:* http://www.teaboard.or.ke/statistics

Firewood demand is increasing because of rising tea production and the higher cost of fuel oil. Companies seek to boost efficiency by investing in new boiler technology, and the average fuelwood consumption per kilo of finished tea has fallen to 2.5 kg from 4 kg in recent years due to such improvements (Finlays interview). Concerns about future firewood supply are prompting some companies to reduce their reliance on firewood, for instance, by using briquettes (of bagasse, sawdust, coffee husks, rice husks) or bamboo.

Focus on the tobacco industry

Tobacco cultivation began relatively recently in Kenya and has spread rapidly. In 2011, about 50,000 small producers were growing tobacco on 23,000 ha (Kibwage, 2012). Tobacco can provide higher incomes than other crops. On the other hand, this labour-intensive crop requires great attention to cultivation techniques, fertile and irrigated soils, and use of pesticides and fungicides.

The heat necessary for the fermentation and drying of leaves is mainly obtained from firewood, with a consumption rate depending on the type of equipment used. Consumption is 10-12 kg of wood per kg of finished product in traditional barns commonly used by small farmers and 5 kg for rocket barns, which have been widely tested but not widely adopted, and 2.5-3 kg for the most modern installations (Nyer, 2008).

In terms of product, treating a ton of green tobacco leaves requires 0.5 to 2 tons of wood depending on the cycle and efficiency of the treatment plant. In Kenya, wood from 2.5 ha of Eucalyptus plantation is needed to dry the production of 1 ha of tobacco (Musoni et al, 2013).

The consumption of wood fuel in other sectors reported by the Ministry of Environment (2002) appears to have diminished sharply or even stopped, as in brick factories that have replaced wood with other biomass and fuel oil as a main source of energy.

3.5.1 Proposed improvement measures

A range of efficient combustion systems are available. The suitability of a system for a given plant depends on factors such as the end-use of the heat and the size of the wood. The final selection is made on a case-by-case basis (FAO, 1990).

The most appropriate biomass furnaces for most of the above mentioned agrofood industries in Kenya are pile burners, which burn fuel in piles on a refractory floor or grate. Combustion is enhanced by air coming from under and above the grate. While this is a simple technology and allows for flexibility in the type of fuel used, its low combustion efficiency and the need to manually remove the ash mean that it is not often used in commercial plants unless the ash content is very low (Goble and Peck 2012).

Pile burners can be divided into two main types – heaped pile burning furnaces and thin pile furnaces. In heaped pile burning furnaces, fuel is continuously fed from the top of the furnace in batches via chutes

TABLE 20: Consumption and estimated potential wood savings from efficiency improvement in agricultural and cottage industries

Sector	Total biomass consumption (tons/ year)	Part of energy consumption potentially involved in improvement measures	Increase in energy conversion	Savings per year (tons/ year)
Restaurants/kiosks*	3,221,568	25%	from 20 to 40%	402,696
Tea industry**	800,000	50%	from 20 to 50%	240,000
Tobacco farmer*	140,000	50%	from 10 to 20%	35,000
Agrofood industry (milk, fish, etc.)*	225,455	25%	from 20 to 50%	33,818
Bakeries*	22,827	25%	from 20 to 40%	2,853
Total	**4,409,850**			**714,367**

located across the grates. Thin pile furnaces burn hogged fuel as a thin bed spread across the grate (FAO, 1990).

Based on experiences from European countries, the purchase and installation of furnaces/boilers with improved yield can be promoted through incentive campaigns.

In the case of large installations, the contribution is released directly to the investing company, following a short administrative procedure aiming at verifying the feasibility of the intervention and the existence of admissibility pre-requirements.

In the case of smaller installations, a contribution to the boiler producer could be envisaged, aimed at reducing the purchase cost for the final user, similar to the incentive used in some European countries for low-emission vehicles. The amount of contribution must be of at least 20% of the purchase cost to really boost the company and of 30-40% for smaller installations bought by micro-enterprises or individuals. The level of the subsidies can be adjusted according to geographical, social or economic factors (disadvantaged areas). The overall investment needed under this scenario is estimated at $81.4 million (see Table 21 for details of the calculations).

Table 20 shows current fuelwood consumption and the potential outcome from investments in improved furnaces. The outcome is estimated in terms of tons of wood saved per year.

3.5.2 Analysing carbon benefits

The exact origin of the firewood consumed in agricultural and cottage industries is not known.

According to Vermeulen and Walubengo (2006), KTDA firewood supply depends partly on its own plantations. These authors indicate that it is not clear whether the other part is supplied by private farms, state plantations or public land. It is however an essential parameter to estimate the proportion of non-renewable biomass used.

As discussed in previous sections, we may assume that private plantations are grown to supply tea factories, and in such scenarios, no emission reductions are expected from increased recovery rates in the agricultural and cottage industries, because the fuelwood that is used in the BAU scenario is assumed to be 100% renewable (trees being replanted).

On the other hand, we assume there is no obligation to use renewable wood for the tea factories, and that the saved roundwood in tea processing can be sold thereby reducing demand anywhere (i.e. no leakage). In this case, considering fNRB is equal to 92% in natural forests in Kenya (UNFCCC, 2012), saving one ton of firewood in natural forests represents approximately 2.9 tCO_2e of emission reductions from deforestation and degradation.[10]

The measures proposed to increase efficiency in the agricultural and cottage industries are expected to reduce fuelwood consumption by up to 714,000 tons per year (equivalent to a volume of 1.2 million m^3_{RWE}), generating up to 2.0 million tCO_2e per year of emission reductions. The actual emission reductions will depend on the proportion of fuelwood sourced in natural forests.

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TABLE 21: Public investment for the purchase of improved efficiency furnaces in agricultural and cottage industries

Sector	Part of energy consumption potentially involved in improvement measures	Average consumption of wood biomass per operator (tons/year)	Number of operators	Number of operators potentially involved in the improvement measures	Average investment for more efficient furnaces ($)	Totals investments ($)	Percentage of public funding	Public funding ($)	Public funding per saved ton over 10 years' time* ($/ton)
Restaurants/ kiosks	25%	50	64,431	16,108	3,000	48,324,000	30%	14,497,200	3,60
Tea industry	50%	4,000	200	100	200,000	20,000,000	20%	4,000,000	1,67
Tobacco farmer	50%	30	4,667	2,334	3,000	7,002,000	40%	2,800,800	8,00
Agrofood industry (milk, fish, etc.)	25%	1,000	225	56	100,000	5,600,000	30%	1,680,000	4,97
Bakeries	25%	50	457	114	5,000	570,000	30%	171,000	5,99
Total			**69,980**	**18,712**		**81,496,000**		**23,149,000**	

* = 10 years is the period considered in the study. The lifetime of improved equipment is usually around 10 years.

3.5.3 Efficiency improvement

Industrial fuelwood consumers would reduce their costs by reducing their consumption of raw material. Considering the savings of around 1.2 million m^3_{RWE} biomass per year from natural forests, this will represent a total value of $4.7 million based on KES 392/m^3 (farm gate prices).

3.5.4 Job creation, health and safety

Increasing the efficiency of furnaces and boilers will reduce the total biomass consumption for the agricultural and cottage industries, thus having positive impacts on health from reduced smoke inhalation.
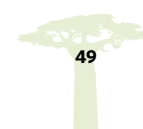
Improving efficiency in forestry operations and forest product processing in Kenya: A viable REDD+ policy and measure

KEY FINDINGS

Table 22 below summarizes the potential biomass savings and related carbon benefits in terms of tCO_2 emissions per annum for each of the five areas researched in this report. The estimated investment is also shown and provides some indication of the costs of implementing REDD+ efficiency improvements in the forestry sector in Kenya. In terms of abatement costs, these range from 0.95 $/tCO_2$-e for efficiency improvements in charcoal production to 12.1 $/tCO_2$-e for efficiency improvement to process timber.

TABLE 22: Summary cost-efficiency analysis

	Potential biomass savings (m^3_{RWE} per year)	Emission reductions from deforestation and degradation (tCO_2e per year)	Investment ($ per year)
Forestry operations (harvesting)	10,000	n/a	375,000
Timber processing (including briquette production)	238,000	110,838	1,340,000
Charcoal production	5,658,810	16,476,000	15,642,000
Fuelwood consumption at household level	960,100	2,386,000	10,000,000
Fuelwood consumption at industrial level (cottage and agroindustry)	1,191,000	2,040,000	11,430,000
Total	**8,057,910**	**21,012,838**	**38,787,000**

CONCLUSIONS

This study assessed whether increased efficiency in forestry operations and forest product processing and use in Kenya may be potentially interesting REDD+ PAMs as the government moves towards REDD+ implementation. Specifically, five types of efficiency measure were identified and compared for their economic and environmental costs and benefits. The link between REDD+ opportunities, increased efficiency and reduced pressure on forests has been discussed for each sector and wood product.

Plantations were established in Kenya to provide timber materials and offer a buffer for natural forests, with the underlying assumption that all timber materials would come from plantations instead of natural forests. At the moment, there is no clear evidence that increasing efficiency in forestry operations and timber processing will help alleviate pressure on natural forests from illegal harvestings for timber production. However, realizing any such benefits through boosting efficiency in the production chain does seem realistic.

Forestry operations (harvesting): Increased efficiency in forestry operations, such as improved harvesting techniques in public and private plantations, would increase national timber production by a limited volume (10,000 m^3_{RWE} per year). However, as there is no evidence that increasing timber supply from harvesting in forest plantations will decrease the pressure on natural forests for timber production, and the fNRB in public and private plantations is close to zero, these measures are unlikely to reduce emissions from deforestation and forest degradation. Still, they might have positive socio-economic impacts, such as increasing the safety of harvesting operations and harvested timber quality.

Timber processing (including briquette production): Increasing efficiency in timber processing would also increase national timber production, by an estimated 238,000 m^3_{RWE} per year. For the same reasons described above, these measures would have a limited impact in terms of emission reductions from deforestation and forest degradation (around 111,000
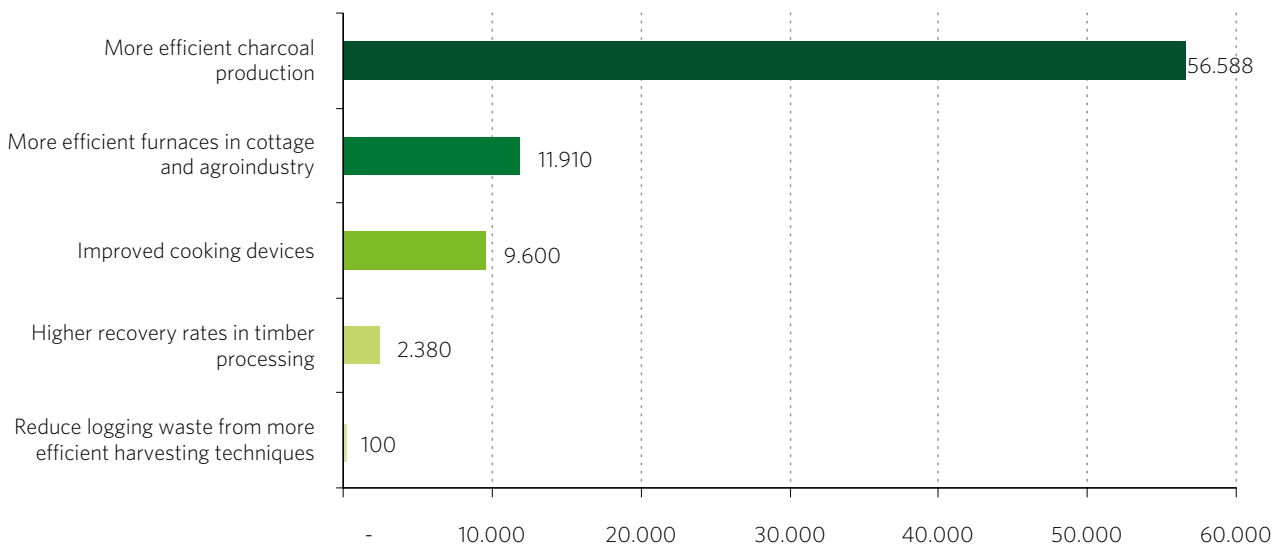
tCO$_2$e per year). Also, it is reasonable to think that increasing wood production would create more jobs in this industry and increase its profitability and reduce wood imports.

Charcoal production: Increased efficiency in charcoal production in dry forests could lead to 5.7 million m^3_{RWE} of non-renewable biomass savings per year, generating more than 16.5 million tCO$_2$e per year of emission reductions from deforestation and forest degradation. These measures would generate other positive impacts such as the reduction of accidents and respiratory problems among charcoal producers. These measures could also generate more qualified jobs in the sector. Lastly, efficiency improvements in charcoal production could go a long way towards meeting Kenya's ambitious climate targets. Therefore, considering these measures is strongly encouraged as they are directly relevant for the Kenyan REDD+ strategy, generating both emission reductions from deforestation and degradation and positive co-benefits.

Fuelwood consumption at household level: Increasing efficiency in the consumption of firewood and charcoal from natural forests could lead to 960,000 m^3_{RWE} of non-renewable biomass savings per year, generating 2.4 million tCO$_2$e per year in terms of emission reductions from deforestation and forest degradation. While the reduction potential is lower than from efficiency measures in charcoal production, these are nonetheless very relevant from the perspective of Kenya's climate change target. These measures will generate other positive impacts such as the reduction of respiratory problems amongst fuelwood consumers (affecting mainly women and children). Finally, these measures can create jobs in ICS manufacturing. Therefore, considering these measures is strongly encouraged as they are directly relevant for the Kenyan REDD+ strategy, generating both emission reductions from deforestation and degradation and positive co-benefits.

Fuelwood consumption at industrial level: Increasing efficiency in wood usage in industrial processes could represent 1.2 million m^3_{RWE} of non-renewable biomass

FIGURE 20: Potential biomass saving from improved alternative scenarios over 10 years (x 1000 m³$_{RWE}$)

Category	Value
More efficient charcoal production	56.588
More efficient furnaces in cottage and agroindustry	11.910
Improved cooking devices	9.600
Higher recovery rates in timber processing	2.380
Reduce logging waste from more efficient harvesting techniques	100

savings per year, generating more than 2.1 million tCO$_2$e per year in terms of emission reductions from deforestation and forest degradation. The overall balance of costs and benefits could also be positive. However, more data on fuelwood origin by sectors (tea, tobacco, restaurants and kiosks, etc.) is necessary to refine this conclusion. Indeed, it is yet not clear whether a significant amount of non-renewable biomass from natural forests is used in these industrial processes, or if they rely only on renewable biomass harvested in forest plantations.

It is also expected that several measures that are out of the scope of this study might have significant impacts in terms of net GHG emission removal, such as increasing the forest area through afforestation and/or reforestation. Carbon stocks enhancement in forest plantations by improving silvicultural practices such as thinning, pruning, and extension of rotation age, may also be a potential source of net GHG removal, by increasing the mean carbon stock per ha.

Potential outcomes from the improved scenarios presented in the previous sections are aggregated in Figure 22 which shows the potential biomass savings arising over a 10-year period from the efficiency improvements proposed for the five areas of research falling within the scope of this assessment.

The potential overall biomass savings reach more than 80 million m³$_{RWE}$. This outcome is almost six times higher than the potential biomass production from increasing the growing stock within public plantations from afforestation and improved management techniques. Moreover, it has to be noted that the

potential outcome from growing stock increase in public plantations can only be achieved over a much longer timeframe because the expected effect of improved management techniques take place during the whole rotation period, which for pine and cypress species is around 30 years. Afforestation has to be progressive in order to properly integrate new establishments with the ages of previous plantation stands. In contrast, the options discussed in this report may potentially lead to immediate or short-term results.

Figure 22 also shows that biomass savings can be more easily achieved in the agricultural and cottage industries, charcoal production, and firewood/charcoal consumption sectors. These activities involve both large wood supply volumes as well as potential efficiency improvements ranging from 10% to 50%. In the field of harvesting and timber processing, one cannot expect to achieve an efficiency improvement of more than 5% to 20% over current recovery rates. While efficiency measures concerning firewood and charcoal must involve a large number of people and companies to get significant results, investments in forest industries with a limited number of operators can be more easily implemented.

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