Yale-UNAM Project

Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and beyond

Research grant provided by the Global Alliance for Clean Cookstoves

Tier II :
Kenya

WISDOM Kenya

Analysis of woodfuel supply, demand and sustainability in Kenya

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Abstract

The spatial analysis of Kenya's consumption and supply potential of fuelwood and charcoal, carried out as part of a pan-tropical study of woodfuel sustainability, reveals that 35 to 41% of the annual consumption is unsustainable, corresponding to 9.5 - 11.2 million tons of woody biomass. By excluding the fraction of deforestation by-products used as fuel, the unsustainable share of the wood specifically harvested for energy uses is estimated between 31 and 38 % (or 7.8- 9.5 Mt), which indicates the non-renewable biomass fuel that may be reduced, at least in part, through adoption of fuel-efficient stoves.

The range of values is due to different assumptions made regarding the type of woody material used and regarding the role of commercial supply in wood-scarce rural areas: If the demand in these areas is satisfied by commercial extraction from more distant sources, the forests and rangelands of the southern portions of the Rift Valley, Eastern and Coast Provinces are at greatest risk. If, diversely, the rural deficit is partially satisfied by "marginal" wood products and local harvesting, then the pressure on these areas reduces slightly and are the populated areas of Central and Western Provinces under greater risk of degradation.

The study spatializes and integrates most relevant and recent information available from forestry and energy sectors and from socioeconomic surveys. The Kenya analysis followed the Woodfuel Integrated Supply Demand Overview Mapping (WISDOM) model, and is used to validate the pan-tropical analysis of woodfuel sustainability recently completed by the Yale-UNAM research project. Results indicate that the pan-tropical model, in spite of a moderate over-estimated the non-renewable harvesting fraction (14.8 vs 11.2 Mt), well represented the geographic variability of NRB values among the provinces, thus efficiently supporting sub national priority zoning.

This study provides the first spatial-explicit assessment of non-renewable woodfuel consumption and the resulting forest degradation of Kenya, which has considerable policy relevance for the national fuel-efficient stove program as well as for the Kenya's REDD+ Readiness Preparation process. The results of this study can contribute to the definition of national strategy objectives and, given its spatial character, can support the County-level tailoring of policy options and interventions.

Contents

Acronyms and abbreviations

A (Md) FM	Scenario "Total demand (Medium variant consumption) - Full market"
ACZ	Agro Climatic Zones
ad	Air-dry, assuming 12 % moisture content
AGB	Aboveground Biomass
B (Md) PM	Scenario "Conventional demand (Medium variant consumption) - Partial market"
DEB	DendroEnergy Biomass (aboveground biomass less leaves, twigs and stumps)
DRSRS	Kenya Department of Resource Surveys and Remote Sensing
DTM	Digital Terrain Model
ESA	European Space Agency
FAO	Food and Agriculture Organization of the United Nations
fNRB	fraction of Non Renewable Biomass (in this study taken as % of total harvesting)
Fw	Fuelwood
GACC	Global Alliance for Clean Cookstoves
GDB	Geodatabase
GIS	Geographic Information System
HH	Household
KBS	Kenya Bureau of Statistics
KFS	Kenya Forest Service
KIHBS	Kenya Integrated Household Budget Survey
kt	kilo tons ('000 metric tons)
LC	Land Cover
LCC	Land Cover Change
LCCS	Land Cover Classification System developed by FAO
MAI	Mean Annual Increment
MoE	Ministry of Energy
Mt	Million tons
NRB	Non Renewable Biomass (in this study taken as t od of non-sustainable harvesting)
od	Oven-dry, at 0% moisture content
SRTM	Shuttle Radar Topography Mission
t	metric ton
TOF	Trees outside forest
WCMC-IUCN	World Conservation Monitoring Centre - International Union for the Conservation of Nature
WDPA	World Database of Protected Areas
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping

1. INTRODUCTION

The study "Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and beyond", commissioned by the Global Alliance for Clean Cookstoves (GACC) and supported by UN Foundation, is implemented by the Yale School of Forestry and Environmental Studies (FES) in partnership with the Centro de Investigaciones en Geografía Ambiental (CIGA) and the Centro de Investigaciones en Ecosistemas (CIEco) of the National Autonomous University of Mexico (UNAM).

Scope of the project is to develop and, in select cases, validate multi-scalar geospatial estimates of the fraction of non-renewable biomass (fNRB) harvested for woodfuel, including firewood and charcoal, at national and sub-national levels in Sub-Saharan Africa, Tropical Asia and Latin America. This will enable clean cookstove and fuel substitution programs to better understand their impact on land use/land cover change (LU/LCC) and allow for more accurate and consistent accounting of carbon offsets.

At the national and regional level, there are large variations in location, method, and volume of biomass harvesting. Country-level estimates based on national statistics cannot capture the geographic specificity of biomass harvesting and may result in incorrect assumptions about the impact of fuelwood on land cover change. In contrast, spatially explicit estimates of fNRB reflect the variability that characterizes woodfuel demand, supply potential and harvesting intensity, but require more complex analyses. Geospatial approaches like the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology support strategic planning and prioritize areas for project implementation.[1]

The project follows a 3-tiers approach to draw comparisons between three different geographic scales of analysis:

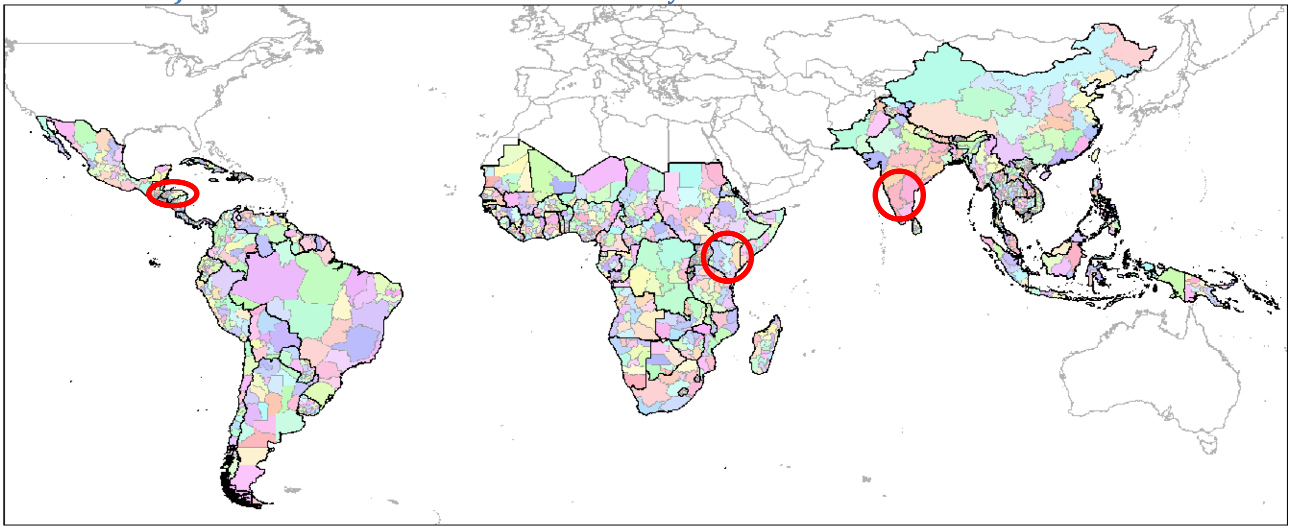
- Tier 1 - Pan-tropical (90 countries). Approach: WISDOM analysis based on existing global data (1, 2)
- Tier 2 – National/State level in Africa (Kenya), Asia (Karnataka (3)) and Latin America (Honduras). Approach: WISDOM analysis based on existing national data
- Tier 3 – Local level (selected sites within the Tier 2 study areas). Approach: Dynamic spatial and temporal aspects of woodfuel harvesting based on new field data

Tier 1 coverage and selected Tier 2 study sites are shown in Figure 1.

Kenya has been selected for Tier 2 and Tier 3 analyses. Tier 2 analysis, object of the present report, is based on the national level analysis of woodfuels supply and demand through the application of the WISDOM model. Tier III analysis, object of a separate report, is based on detailed field-based research currently in progress.

[1] For an overview of WISDOM methodology and over twenty studies from around the world, see http://www.wisdomprojects.net/global/.

Figure 1: Map showing countries included in Tier I analysis (includes 90 countries divided into 1480 sub-national units) and selection of Tier II and Tier III analyses locations.



1.1 SCOPE OF TIER II ANALYSIS - WISDOM KENYA

The scope of this activity, carried out in the framework of the GACC NRB Project as Tier II case study, is to analyze woodfuels consumption and supply potential, to estimate the intensity, locations and Non Renewable fraction (fNRB) of woodfuels harvesting.

The objectives of this study are to (i) analyze the sustainable supply potential and the demand for woodfuels in Kenya, and produce spatially explicit results on supply/demand balance for local and commercial woodfuels use and identify surplus and deficit areas through the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) model, (ii) provide estimates of the sustainable /unsustainable harvesting related to wood energy demand (i.e."fraction of Non-Renewable Biomass" -fNRB), and (iii) compare state-level results with Tier I results (2) in order to identify main discrepancies and the underlying data or analytical factors.

At the same time, WISDOM Kenya may serve to strengthen wood energy planning and enhance inter-sectoral and interdisciplinary decision making processes, strategic planning and policy formulation.

The analysis is intended as interdisciplinary and cross-sectoral, including forestry, energy, territorial and socio-economic components, as is typical for WISDOM analyses. Given the large variety of data sources and the limited resources available, the analysis is based primarily on existing information.

1.2.1 Main features of the WISDOM method

WISDOM is the fruit of a collaborative effort between the Wood Energy Programme of FAO and the Centro de Investigaciones en Ecosistemas (CIECO) of the National Autonomous University of Mexico (UNAM) (4, 5) and has been implemented in over 25 countries worldwide in a variety development and research programmes (see www.wisdomprojects.net for a review of WISDOM case studies).

The WISDOM methodology may be divided into two sequential stages of analysis:

1 - **WISDOM Base**. This stage includes the analysis over the entire territory of the study area.

2 - **Woodshed[2] analysis**. This second stage of the analysis uses the result of the WISDOM Base to delineate the sustainable supply zone of selected consumption sites (6). Depending on the scale and objectives of analysis, the selected sites could be all major deficit areas (those that depend on commercial supply chains) or specific urban centers, rural villages and existing/planned biomass plants.

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[2] The term "woodshed" is a neologism inspired by the familiar geographic concept of *water*shed. It is used to indicate the portion of the territory necessary to supply on a sustainable basis the woody biomass needed by a specific consumption site (existing or hypothetical) (6).

The specific steps of analysis are summarized below while a graphic overview is shown in Figure **2**.

WISDOM Base

The application of the standard WISDOM analysis producing supply and demand balance mapping at the local level involves five main steps (4):

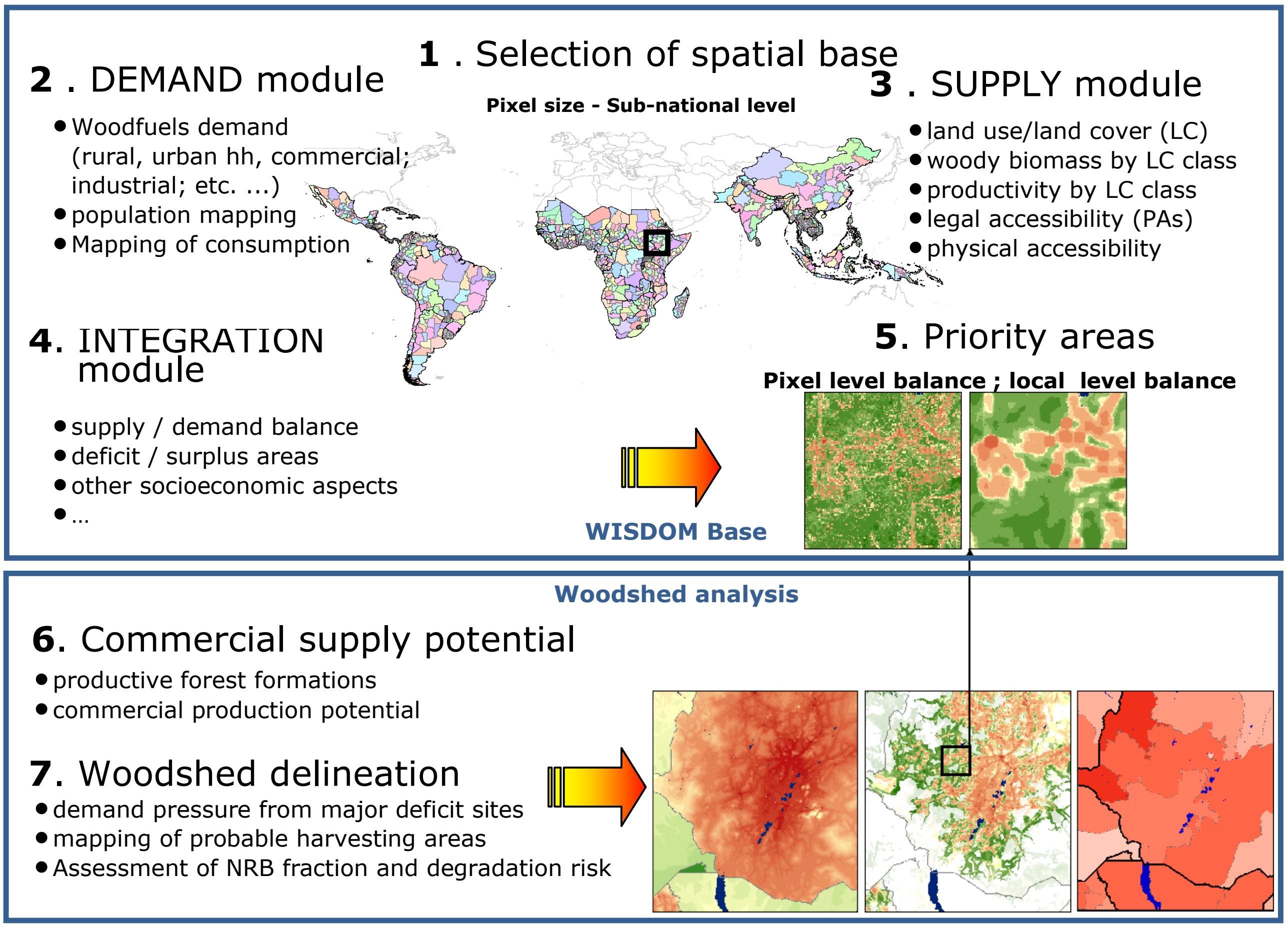
1. Definition of the minimum administrative *spatial* unit of analysis.
2. Development of the *demand* module.
3. Development of the *supply* module.
4. Development of the *integration* module.
5. Selection of the *priority* areas or woodfuel "hot spots" under different scenarios.

Woodshed analysis

The analysis for the delineation of woodsheds, i.e. supply zones of specific consumption sites requires additional analytical steps that may be summarized as follows.

6. Mapping of potential "commercial" woodfuel supplies suitable for urban, peri-urban and rural markets.
7. Definition of woodshed, or probable harvesting area, based on the level of demand, woodfuels production potentials and physical accessibility parameters.

Figure 2: WISDOM analytical steps. WISDOM Base (steps 1 to 5) and Woodshed analysis (steps 6, 7)



2.
WISDOM ANALYSIS

2.1 SELECTION OF SPATIAL BASE OF ANALYSIS

Mapping details:

Projection: Preferred/common projection for Kenya: Arc 1060 UTM 37S;

Cell size of raster layers: 100 meters (1-ha cells)

Administrative units used for population mapping:

Districts (158 units), as per Census 2009 with rural/urban distinction. Census statistics are available at sub-location level (7150 units, approx.) but the corresponding shapefile with matching census codes could not be obtained from KBS. Counties (47 units) are used as reporting level.

Census results related to cooking fuels saturation (percent of households by primary fuel) were available at District level. Quantitative fuel consumption estimates were produced by consumption zones ("cons_z", 10 units), which were derived from map of Provinces (8 units).

Reference years of WISDOM analysis

To construct the Supply Module, KFS map of 2010 (34) is used as reference, complemented by the 2008 Land Cover Classification System (LCCS) (7). To construct the Demand Module, the reference year is set by the last demographic census, i.e. 2009 (8), which represents the reference year of WISDOM analysis.

2.2 DEMAND MODULE

The goal of the Demand Module is to estimate the current consumption of woody biomass for energy in the various sectors (residential, commercial, industrial and public) and to represent as accurately as possible its spatial distribution.

The main thematic layers and processing steps of the Demand Module are presented in the flowchart in

Figure 3 and described in the following Sections.

2.2.1 Reference data

Household sector

The references that were used for the estimation of the current consumption of woodfuels in the residential sectors included the following:

(i) Census 2009 results at District level on the fraction of households using fuelwood or charcoal as primary cooking fuel in rural and urban areas.

(ii) Kenya Integrated Household Budget Survey (KIHBS) (9), 2004/05 providing fuel quantities and relevant expenditures met by households from a representative sample of over 13,000 households distributed throughout Kenya. The raw dataset presented numerous data recording/entry errors that required considerable "cleaning" based on identification of outliers and cross-referencing quantities and expenditures. A dataset of some 11,500 households was finally used to estimate the mix of fuels consumed annually by the household using primarily fuelwood, charcoal, farm residues and other non-biomass fuels. Such mix of fuels was estimated for rural and urban households from 10 "consumption zones" of Kenya[3].

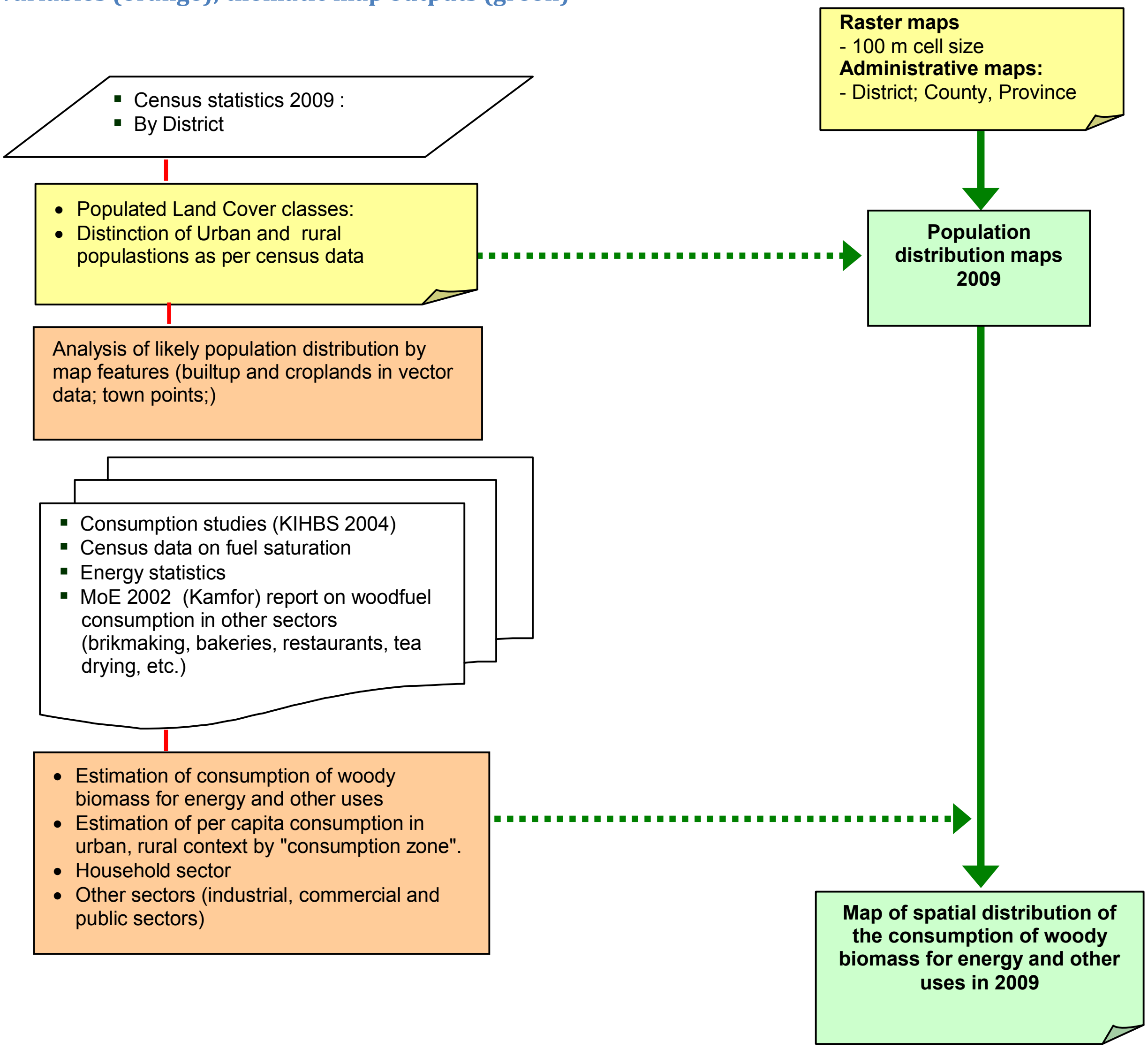
(iii) In converting charcoal consumption in DendroEnergy Biomass (DEB) equivalent, three charcoal yield rates were considered: a medium rate of 24% (charcoal output as % of od wood weight) with 17% and 31% as low and high yield, respectively. Charcoal yield values are based on 10 direct kiln measurements (10), which align well with other regional studies on traditional earth mound

[3] The map of consumption zones was based on that of Kenya Provinces with additional subdivision of Rift Valley and Eastern Provinces into Northern and Southern portions.

kilns (11-13). Mean, low and high yields were defined as mean ± 2SD of observed yields. These values were used to define Minimum (Mn), Medium (Md) and Maximum (Mx) demand scenarios, described in more detail below.

Detailed District level saturation values, per capita consumption parameters by consumption zones and by user category are reported in Annex 1 (Tables A1.1 and A1.2).

Figure 3: Demand Module Flowchart - Input data: cartographic (yellow); statistical (white); estimated variables (orange); thematic map outputs (green)



Construction material

In the absence of adequate references, the use of construction material[4] used by rural and urban households was estimated, tentatively, on the basis of estimates used in Rwanda (14), Sudan (15) and Mozambique (16), in the context previous WISDOM analyses. The values applied are 19.2 od kg of wood person^{-1} year^{-1} in rural areas and 5.6 od kg of wood person^{-1} year^{-1} in urban areas.

Other sectors of consumption

The use of woodfuels in industrial and commercial sectors (brick making, tobacco curing, tea processing, fish smoking, jaggary production, bakeries, kiosks and restaurants) is included in the analysis and estimated/mapped using available references. In the absence of recent information, reference is made to the MoE report produced by Kamfor in 2002 (17). In each case, consumption values were updated to 2009 on

[4] Construction material, used for fencing, stables, house repairs, etc., belong to the same supply chain as woodfuels and for this reason is added to woodfuels in the Demand Module. On the contrary, industrial roundwood and timber, that follow a separate supply chain are accounted for separately and deducted from the supply potential in Supply Module.

the basis of production statistics (i.e. FAOstat) or demographic trends.

The consumption in the public sectors, including schools, prisons and hospitals, was estimated with reference to the consumption reported by Ghithiomi (18, 19) for Central Kenya, expanded to the whole Country based on demographic statistics.

The County level consumption of fuelwood (and construction material) and charcoal in all sectors are reported in Annex 1 (Tables A1.3 and A1.4). The total County level consumption of DendroEnergy Biomass (DEB) assuming the three charcoal yield rates is presented in Annex 1 (Table A1.5).

2.2.4 Mapping population distribution and woodfuels consumption

Urban and rural population mapping: Statistical and cartographic information relative to the distribution of **the population at the level of Administrative Unit are from Census 2009.** Figure 4 **shows the main** cartographic layers used to map the distribution of rural and urban population.

Location of Rural population:

The mapping of rural population (as defined by 2009 census) respects the values reported at admin unit level (District) (8). Within such units, the spatial distribution of the population is based on additional cartographic elements/attributes from the map of land cover that indicate population presence, such as built-up areas, farming areas, etc. Distance from main roads was also used as proxy for the probable presence of human population, especially in the northern and eastern provinces where other indicators are absent. These features are used to distribute census population where it's more probable to be found. It should be emphasized that the map of Census Sub-locations and settlements produced by the National Bureau of Statistics, if available, would have permitted a far more accurate mapping of the population distribution and, most relevant, of woodfuel consumption.

Location of Urban population:

The mapping of urban population (as defined by 2009 census) is done respecting the definitions and values reported by the census (8). Within urban admin units, the spatial distribution of the population is based on additional cartographic elements or spatial proxies, such as urban boundaries.

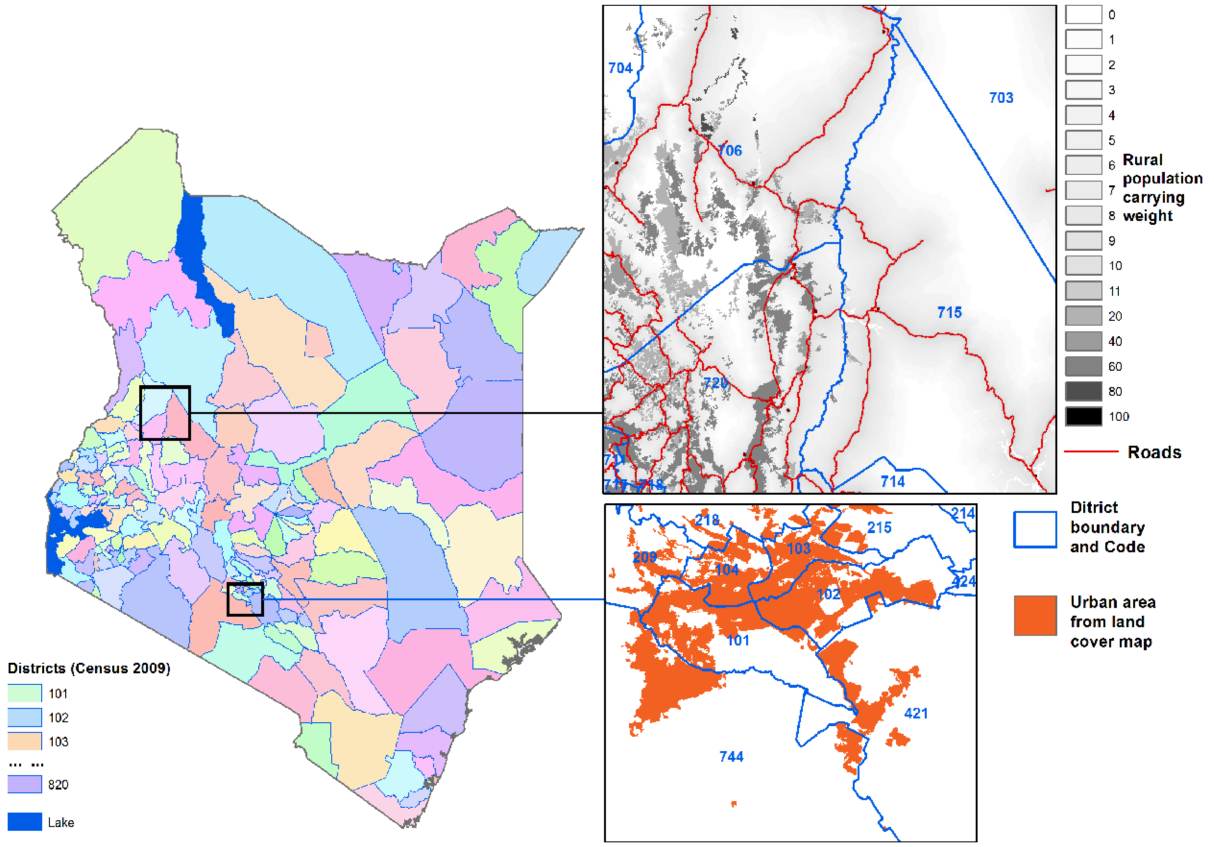
Mapping woodfuel consumption

In the case of Kenya, the household sector dominates woodfuel consumption, and the population map is instrumental to mapping the relative consumption.

No data is available on the spatial distribution of the consumption by the public sector, cottage industries and commercial food producers or the use of wood as construction material. We assume these are spatially correlated to population concentrations.

Woodfuel consumption for tobacco curing, tea processing and jaggary (sugarcane processing) were approximated in the specific regions reported in (17) and spatially distributed according to the relative crop classes shown by LCCS land cover data (7). Concerning fish smoking, the consumption was distributed along Lake Victoria shoreline.

Figure 4: Main layers used for mapping rural and urban population distribution including census administrative units (left), rural population density (upper right), and urban populations (lower right).



2.2.5 *Conventional* vs *non-conventional* fuelwood sources and assortments

Woodfuels consist of a wide variety of woody biomass assortments ranging from stem wood or branch wood to twigs, smaller branches, and shrub wood (Figure **5**). Stems and large branches are typically well documented in forest inventories. In contrast, twigs, small branches and shrubs are marginal forms of woodfuel that are often excluded from forest inventories and thus not accounted for among the conventional supply sources.

Consumption data among rural households is based on survey data that does not distinguish between conventional and marginal fuelwood. It would be misleading to consider consumption reported in these surveys to consist entirely of conventional fuelwood. Because we are comparing consumption volumes to forest inventory data, we must be careful to account for marginal forms of woodfuel that may not be accounted for in forest inventories and mean annual increment estimates. In rural areas where forest cover is thin or non-existent, but wood is still a common household fuel, it is very likely that rural households rely on a high proportion of non-conventional wood resources such as twigs and small branches from prosopis juliflora or other wild shrubs and from annual pruning of farm trees and shrubs[5].

Woodfuel consumption surveys do not differentiate between conventional and marginal resources. Therefore, we have no data indicating the quantity of marginal wood products used in rural households.

The key issue is to understand what happens in the rural areas where people use fuelwood (as per consumption surveys), but supply is scarce. In one of our scenarios we consider that in such conditions the coping strategies of fuelwood users may include a combination of the following:

- Reverting to marginal fuelwood (not included in the "conventional" supply potential)
- Overexploiting local fuelwood sources (up to stock exhaustion)
- Purchasing fuelwood from the market

[5] Annual or periodic pruning of farm trees may contribute significantly to woodfuel supply. For instance, pruning of coffee trees in El Salvador and pruning of vine trees in Argentina provide large amounts of fuelwood for residential and industrial use (20, 21). The key factor for the analysis is that the productivity of these non-conventional sources is not represented by conventional MAI data.

Figure 5: Conventional fuelwood and marginal fuelwood composed by twigs and small branches

In the absence of reference data we considered that in rural areas the three options are equivalent, each one covering an equal part of the fuelwood gap.

Hence, we consider two scenarios to account for different combinations of conventional and marginal wood resources:

Scenario A. **Total Demand**	**Scenario B.** **Conventional demand**
The demand is considered entirely, without distinction between conventional and marginal fuelwood	Only the demand for "conventional" fuelwood, is considered, excluding an estimated fraction of "marginal" fuelwood in rural deficit areas,

In scenario A we make no distinction between conventional and marginal woodfuel. The entire demand is considered in each phase of analysis.

In scenario B we assume that urban consumption is taken entirely conventional (as in scenario A), but in rural areas, where the local supply is insufficient, we assume that 1/3 of the fuelwood gap (i.e. the difference between the demand and locally available supply) is satisfied by "marginal" fuelwood.

Rural deficit areas are identified by calculating local supply/demand balance assuming full fuelwood demand (as per scenario A) accessible within a 6km radius. In deficit areas, we assume 1/3 of the deficit is satisfied by "marginal" woody biomass.

In the Medium Demand variant, the total annual consumption according to Scenario A is 27.4 Mt od, and lowers to 25.2 Mt In Scenario B. In other words, our assumptions lead us to estimate that 2.2 Mt/year are obtained from marginal sources of woody biomass that are not included in forest inventories and conventional productivity estimates [County-level consumption for both Scenarios is shown in Table 2, Results Section].

The exclusion of marginal non-commercial wood products from the supply/demand balance of conventional woody biomass is probably more realistic, but the fraction of these products in the rural fuel consumption is here only tentatively estimated. This particular component of rural households' consumption should be studied in greater detail as it plays an important role in the overall supply/demand balance as well as in soil nutrient cycling.

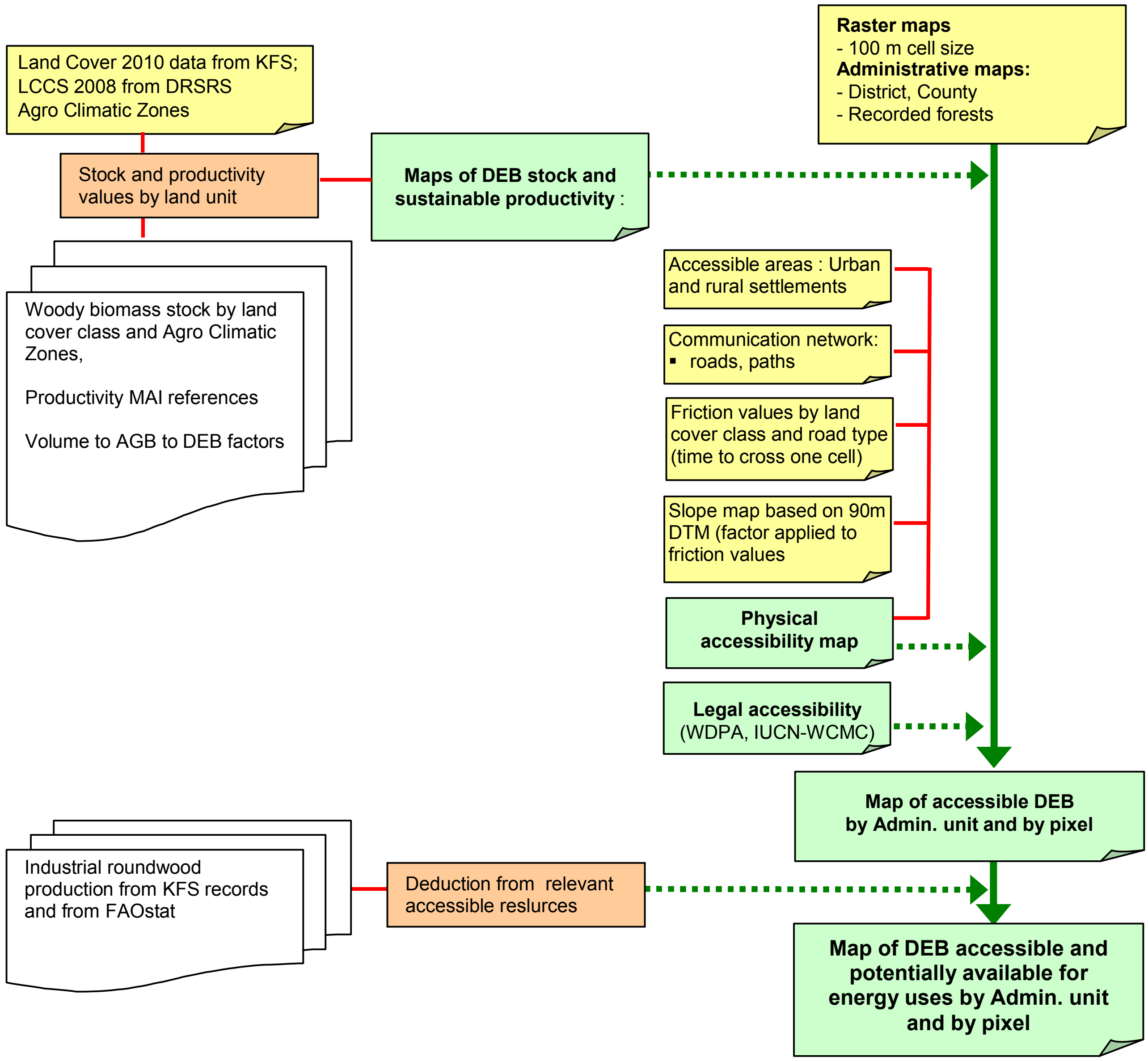
2.3 SUPPLY MODULE

The scope of the WISDOM Supply Module is to produce a spatial representation of the sustainable woodfuels supply potential from natural and man-made sources. More specifically, it analyze the stock and production potential of DendroEnergy Biomass (DEB), i.e. the fraction of aboveground biomass that is conventional source of fuelwood and for charcoal production[6]. The analysis includes components that may serve other non-energy uses such as industrial roundwood.

The estimation and mapping of the DEB supply potential is based on land cover information, describing the vegetation types and their location, and on field observations quantifying the stock and productivity, such as forest inventory data.

The flowchart in Figure 6 shows the source data and the main analytical steps of the Supply Module.

Figure 6: Flowchart of the main analytical elements of the Supply Module. Input data: cartographic (yellow); statistical (white); estimated variables (orange); thematic map outputs (green)



[6] DEB is defined as the total aboveground biomass less leaves, twigs and stumps.

2.3.1 Cartographic layers

Land cover

The Supply Module was based on the integration of **two Land Cover datasets:**

1. **KFS 2010** , produced with assistance from PASCO Corporation and based mainly on ALOS VNIR-2 imagery with 10 m resolution. The three original vector layers (Land Use, Forest Type, Forest Density) were converted to raster (1 ha cell size) and merged into a single raster dataset, as shown in Annex 2, Figure A2.1.
2. **Land Cover Classification System (LCCS) 2008,** produced by the Kenya Department of Resource Surveys and Remote Sensing (DRSRS) and based on Landsat with 30 m resolution. This dataset presents 74 land cover classes that form 370 unique map units. From these, two raster layers (1 ha cell size) were derived: one of tree density and one of shrub density (see Annex 2, Figure A2.1)

The KFS 2010 presents a good detail in the Land Use class "Forestland", for which it provides forest type and density details but remains generic for the other land use classes Cropland, Grass/shrub and Otherlands that cover the vast majority of Kenya landscapes and that contribute significantly to woodfuel production.

In order to create a comprehensive vision of the supply potential, the integrated dataset include KFS 2010 details for the class Forestland and LCCS 2008 details for all other land use classes.

Agro Climatic Zones

In order to represent the gradient of stock and productivity determined by rainfall and other ecological factors, the integrated land cover data described above was combined with the map of Agro Climatic Zones (ACZ) (22), as shown in Annex 2 Figure A2.2.

2.3.2 Stock and productivity data

Woody biomass stock

The stock of DEB per hectare by land cover class, density and ACZ was based on the combination of numerous references, each one relative to a certain formation, density and/or ACZ (23-36). The resulting range of stock values are shown in Annex 2, Table A2.1. The values for natural forests, mangroves and bamboo formations, shrublands and croplands should be considered as preliminary until a country-wide inventory of woody biomass resources will provide more robust estimates. DEB stock values for forest plantations are more reliable since they are based on recent plantation inventory results (35).

Productivity

As usual, the sustainable productivity, or Mean Annual Increment (MAI) of natural formations is a far less known parameter than the stock due to the scarcity of permanent sample plots, which are the only reliable sources of MAI data.

Concerning forest plantations, MAI values by density and ACZ were derived from plantation inventory data reporting plantations' volumes and age (35). Plantations MAI values are shown in Annex 2, Table A2.2.

To accommodate the lack of data, MAI values for all other land cover classes were estimated with a simple equation relating stock and MAI (as percent of stock) for broadleaved formations from a set of field observations in similar ecological conditions (5, 37, 38) as was done in Tier1 analysis (1, 2). See Figure A2.3 in Annex 2.

$$\mathbf{MAI\% = 37.06 \times DEB^{-0.588}} \qquad \text{[eq. 1]}$$

The maps of DEB stock and MAI are shown in Annex 2, Figure A2.4.

2.3.3 Accessibility

2.3.3.1 Physical accessibility

The estimation of the physical accessibility of biomass resources is based on estimated round-trip transport time to the nearest village or motorable road. This is done following and adapting the procedure adopted for Tier I (2, 39). The transport time map is the result of an accessibility model that considers the cost, or friction surface, based on terrain and land cover data. The analysis and results are described in Annex 3.

The result of this analysis shows that, given the uneven density of roads and of populated places, approximately 30% of Kenya's woody biomass resources are inaccessible. Some 35% of DEB MAI lies within two hours from the nearest road or village. Thus, with a 14-hour limit, only 69.7% of Kenya's resources are accessible.

2.3.3.2 Legal accessibility

The legal accessibility to woody biomass resources is determined on the basis of protection status by which forest exploitation is prohibited or limited and assuming that outside such areas the sustainable and regulated production of woodfuels and timber is allowed.

The Protected Areas considered include those shown in the World Database of Protected Areas (WDPA) published by WCMC-IUCN (40). See Annex 3 for a description of IUCN Protected Area Management Categories and the resulting Legal Accessibility map.

2.3.3 Available resources

Deduction of industrial roundwood

Some accessible MAI is unavailable for fuelwood or construction material due to competition from other uses such as wood processing industries. We account for these competing uses by taking annual production statistics of merchantable wood from natural forests and from plantations based on KFS statistics (41), which matches reasonably well the industrial roundwood production reported by FAO . The production statistics considered cover the years 2011-2013, just after lifting the harvesting ban and hence more representative of "normal" production regime than years 2009-2011.

Not knowing the location of future harvesting areas, and assuming that harvesting will rotate over all accessible resources, the estimated annual industrial roundwood production was deducted from accessible natural forest and from plantations.

Sawmill residues available as woodfuels

Part of the residues produced in processing industrial roundwood is available for energy uses. The total sawmill residues are calculated as 45% of industrial roundwood of which 15% is in form of sawdust and thus not immediately usable as fuel[7]. The quantity of residues potentially available for energy is tentatively estimated as 50% of the residues remaining. Finally, the residues potentially available are estimated as 19.1% of industrial roundwood. In absence of sawmill locations, the residues potentially are spatially distributed on harvesting areas.

The products of the Supply Module for each phase of analysis are presented in Section 3.2.

2.4 INTEGRATION MODULE

The Integration Module combines the parameters developed in the demand and supply modules by discrete land units (pixel-level and sub-national unit-level) in order to discriminate areas of deficit and surplus according to estimated consumption levels and sustainable production potentials.

The first and most important result of the integration module is the balance between the accessible potential productivity and the total consumption of woody biomass for energy generation and other uses.

In order to describe the various planning dimensions of wood energy, the supply/demand balance analysis is carried out at the following three levels:

(i) Cell-level balance, combining supply and demand within single pixels,

(ii) Balance in a local context, few km around consumption sites, representing the informal self-supply horizon of rural and peri-urban households and,

(iii) Balance based on the surplus remaining after local demand is satisfied. This is assumed to serve as the source of commercial woodfuels production systems serving distant consumption sites.

[7] Pellet production from sawdust is fast developing in Kenya but still too limited quantitatively to be considered in this analysis.

2.4.1 Pixel-level balance

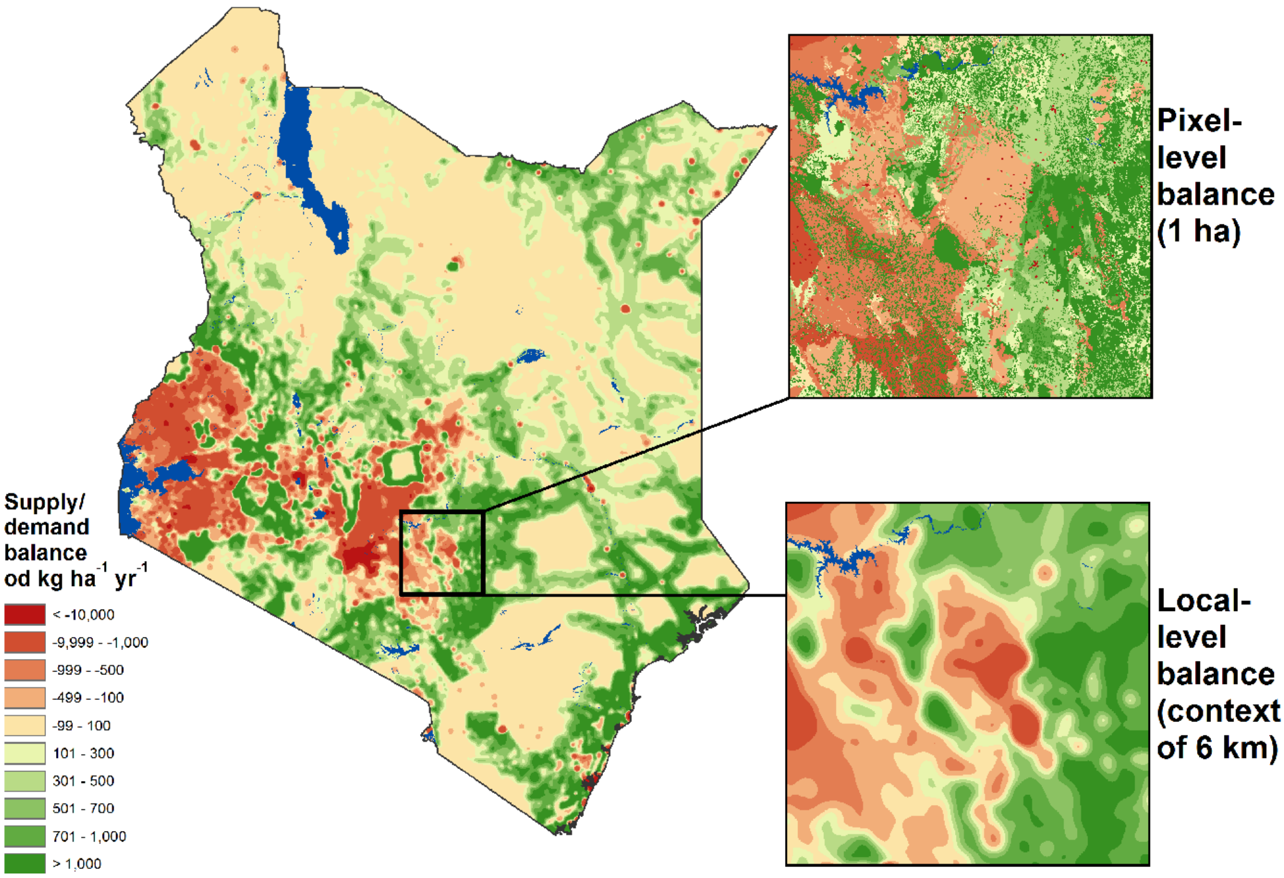
At the pixel-level, supply/demand balance is calculated by subtracting demand from available DEB MAI. The balance in each 1-hectare cell has an useful accounting function but it represents a somewhat virtual balance since individual pixels are usually either a production or a consumption site. An example of pixel-level balance is shown in Figure 7 (top-right inset).

2.4.2 Local balance

Local balance is calculated by assuming a small horizon of fuelwood collection on foot or other non-mechanized transportation that is typical for rural areas like bicycles or oxcarts. This horizon may vary with environmental and socio-economic conditions. Travel distance for subsistence woodfuel collection is typically below 3 km in biomass rich areas (42, 43), but may be farther in biomass-poor areas (15). In this study we use a single supply horizon radius of 6 km to define the likely upper limit of subsistence harvesting. Results (Figure 7) show areas of local surplus, where woodfuels harvesting is less than supply (defined by available DEB MAI), and local deficit, where the supply within a 6-km radius is insufficient to meet demand.[8]

Comparing the local balance to the pixel-level balance (the two insets in Figure 7), it is interesting to see how the local context renders deficit areas more visibly, giving a more realistic perception of deficit and surplus zones.

Figure 7: Local balance calculated on a 6-km context with details of local-level vs pixel-level. Scenario B: considering only "conventional" fuelwood, excluding "marginal" fuelwood in wood-scarce rural areas



[8] Note both pixel- and local-balances assume optimal harvesting. The non-optimal exploitation is introduced in a subsequent phase of analysis.

2.4.3 "Commercial" balance

Our assessment of commercial balance is based on the assumption that woodfuel provision for urban and high-deficit rural areas is accomplished through a woodfuel market. Market actors exploit *legally and physically accessible* rural areas (defined above). They utilize the surplus DEB that remains after local demand is satisfied. However, they limit exploitation to accessible resources that are economically viable given their transport and management costs. To simulate these operating principles, we define two quantitative thresholds:

- **Minimum stock required for profitable commercial exploitation**: This assumes that DEB stock below a certain threshold would not be economically viable to exploit given transportation costs. In case of Kenya, in consideration of the strong demand and large areas of sparse resources that are used for woodfuel production (44), we opted for a low threshold and tentatively set this value at 6 t/ha oven-dry DEB/ha, which is lower than that previously applied (i.e. 12 t) based on (45).
- **Minimum MAI**: This assumes that only the areas with sufficient productivity to permit rotation lengths less than 30 years will be commercially exploited. This implies MAI $\geq$ 0.205 odt/ha-yr.
- **Exclusion of all surplus resources from IUCN Protected Areas.**

These thresholds are theoretical because they imply that resources are exploited rationally, without leading to long-term depletion of forest stocks. Thus, these thresholds are useful for defining theoretical limits of sustainable forest management, but do not necessarily represent existing processes. Current exploitation is often unregulated, leading to exploitation that exceeds sustainable limits in some areas and exploitation below sustainable limits in others. We address this below. The products of the Integration Module for local and commercial balance for both demand scenarios are presented in Section 3.3.

2.5 WOODSHED ANALYSIS

Woodshed analysis is used to develop a spatial projection of commercial demand of major woodfuel consumption sites (urban and high-deficit rural areas) in order to outline the harvesting areas and/or the potential sustainable supply zones, accounting for consumption of other surrounding consumers. We define these zones as "woodsheds" in analogy with the geographic concept of watersheds (6). For a given center of demand, the sustainable woodshed is the minimum area in which the woodfuel balance is nearly zero. When a single consumption site is considered, the woodshed is determined by the physical accessibility of the available surplus resources. However, when multiple sites are considered simultaneously, the woodshed is determined by the combined effect of physical accessibility of available resources and the aggregated demand of all sites. In order to combine these components, the analysis is carried out using an inverse distance weighted (IDW) interpolation in the Dinamica EGO processing environment (46), where the variable is woodfuel demand and distance is replaced by the transport time relative to any given pixel using a friction map (expressing in minutes per meter the transport time needed to cross each cell twice, unloaded and loaded), (Figure 8.b). The woodfuel demand is represented by a map of deficit peaks, defined in a lookup table. For this, we defined local deficits within a 15 km radius (Figure 8.a). This radius is chosen to represent the cumulative demand of even the largest urban and peri-urban areas in a single point. We defined 41 such points in Kenya.

The resulting map is a cumulative "pressure" determined by the intensity and location of major deficit areas (Figure 8.c).

For analytical purposes, the continuous map resulting from the weighted interpolation analysis is segmented into buffers; cities with high demand produce wide woodshed buffers and cities with low demand produce narrow buffers, which simulates the territory under pressure from urban and high-deficit rural areas. Woodsheds are defined using zonal statistics to calculate the supply/demand balance of each buffer, progressively expanding the area until the commercial balance, initially negative, achieves a positive value, which indicates that supply potential has met demand. But positive values are not always achieved, depending on the commercial balance of the study area (see balance results in Table 4). For Scenario A (Total Demand), the commercial balance of Kenya is negative by 2.2 Mt and therefore there is no sustainable woodshed, and also for Scenario B (Conventional demand) the commercial balance is negative, by 0.07 Mt preventing the delineation of a finite "theoretically sustainable" woodshed within the Country.

Note this approach assumes optimal harvesting of DEB. It does not reveal actual harvesting patterns. Nevertheless, it provides a sense of the area that is likely to come under urban influence. In addition, it defines the areas in which overlap of local, rural demand and non-local, commercial demand are likely to occur and could be useful for developing policy interventions.

Transport time threshold

The woodshed zone is determined by the availability of local surplus resources and commercial demand, which may include resources that are distant from the market. For commercial supply, we adopted a threshold of 12-hour transport time between point of harvest and market. To define the territory within such threshold we conduct a cost-distance analysis on the same major deficit points used for woodshed analysis and using transport time as cost factor.

Figure 9.a shows the map of transport time from the 41 major deficit sites and the territory within 12 hours. Figure 9.b shows the balance resulting from commercial harvesting pressure assuming commercial harvesters target accessible resources within 12 hours of travel time. The resources within the time thresholds are likely to undergo the greatest harvesting pressure.

Figure 8: Major deficit sites calculated on a 15-km context (a); friction map with transport time in minutes per meter (b); pressure zone map resulting from weighted IDW interpolation with transport time (c).

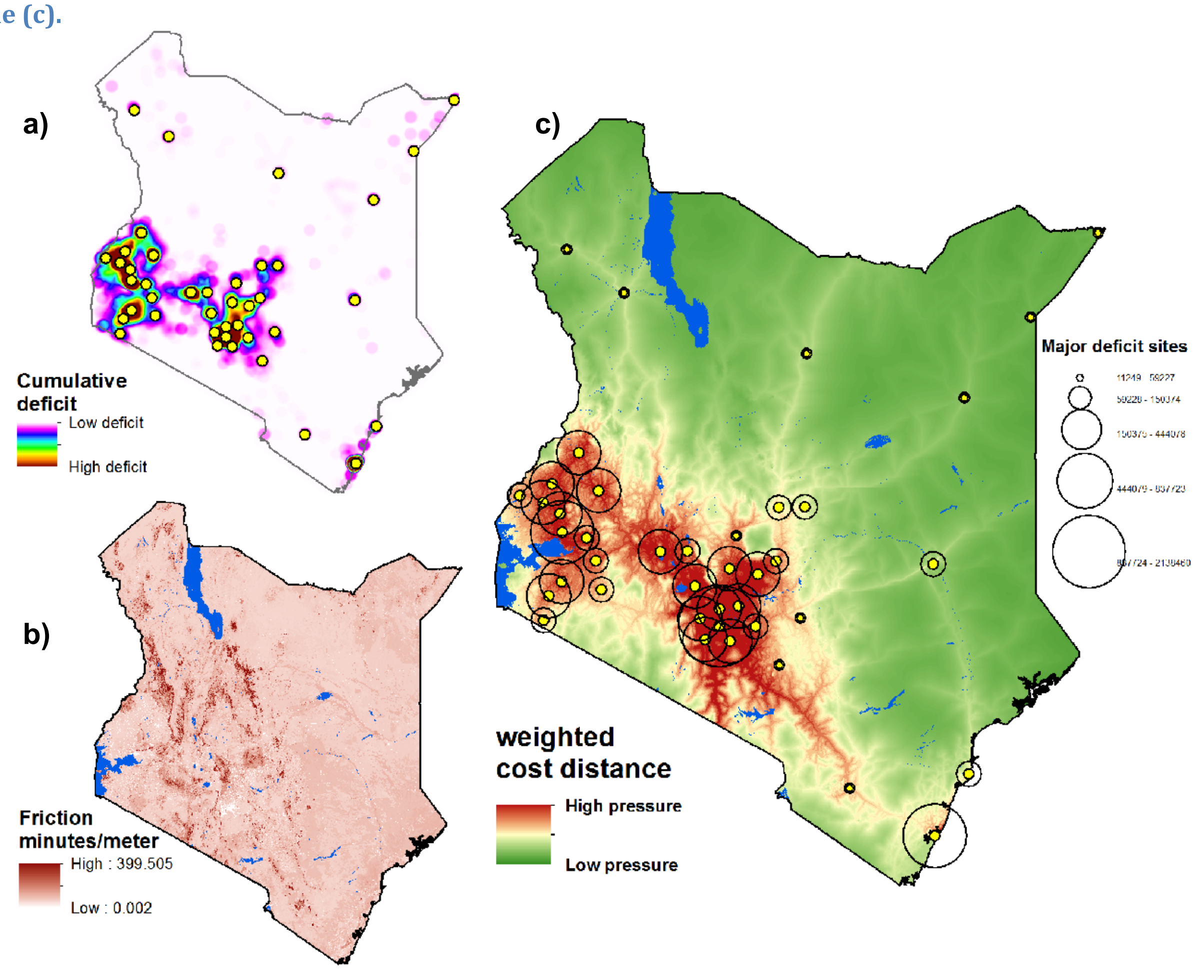
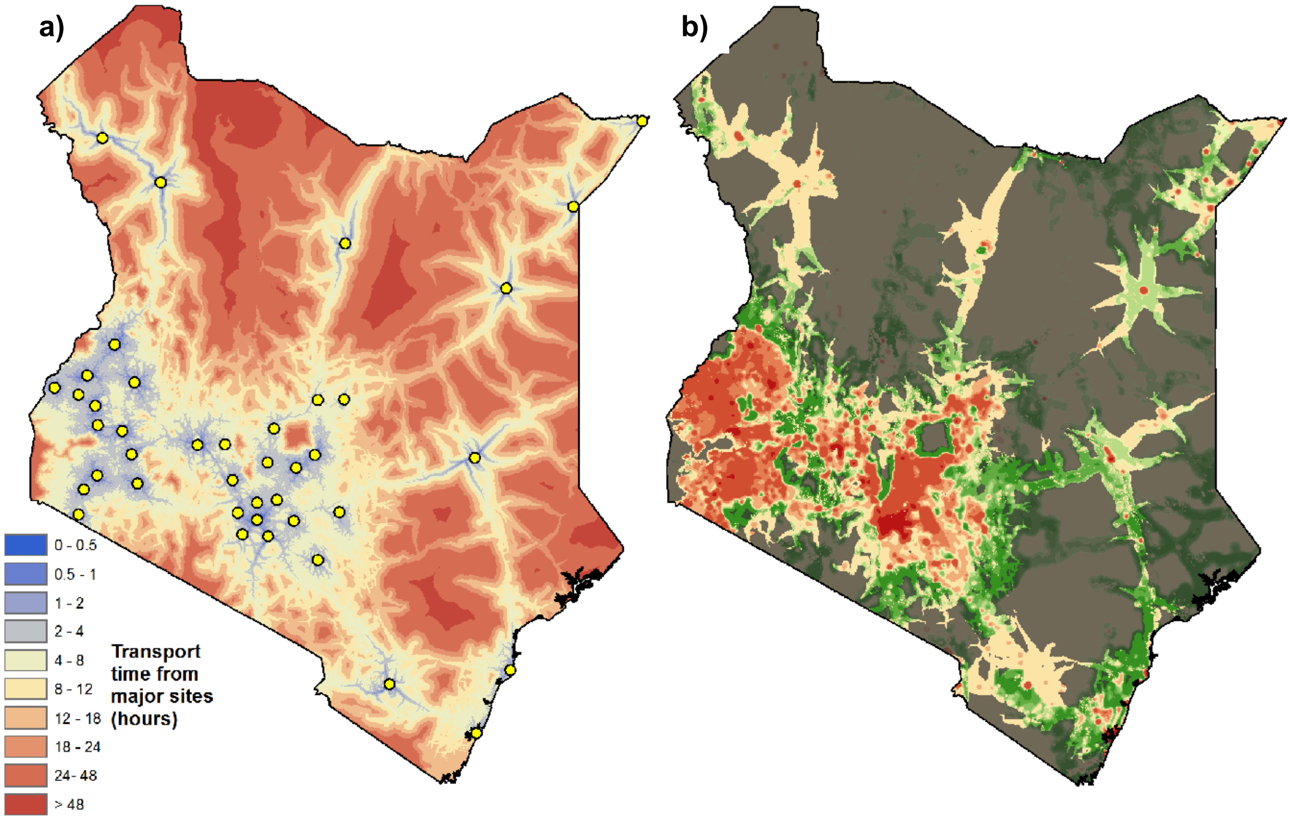


Figure 9: Transport time from major deficit sites (a); Commercial balance within 12-hours transport time (b)



Note: The map of commercial balance (b) is relative to demand scenario B, Medium consumption variant (see Figure 7 for legend). The dark grey shade covers areas above 12-hours transport time from the major deficit sites.

Converting local deficit in commercial harvesting

What fraction of the local deficit converts to commercial harvesting?

The demand for woodfuels in urban areas always create a local deficit; thus, it is safe to assume that they depend entirely on the commercial supply of fuelwood and charcoal. The situation in rural areas is less straightforward because the supply is primarily local and informal. Rural areas that are densely populated or that simply lack adequate accessible wood resources also expereince deficit conditions, but these may induce different responses. For example, people may respond by:

- (i) shifting towards non-conventional fuelwood assortments (annual pruning, twigs, etc.) and crop residues,
- (ii) excessive harvesting of the limited resources locally available, or
- (iii) depend on commercial supply.

Shifting to marginal wood assortments is already considered in demand scenario B, the two remaining responses to rural deficit are used as basis for three alternative commercial harvesting scenarios:

1. **"Full Market"** scenario: All local deficits, (urban or rural) gives origin to commercial harvesting.
2. **"Urban Market"** scenario: Only major deficit areas (urban areas, mainly) give origin to commercial harvesting, while deficit in rural areas remains local and produces a strong impact on surrounding biomass resources.
3. **"Partial Market"** scenario: Part of the rural deficit originates overexploitation of local resources and part is covered by market supply. In this scenario, all deficit in urban areas give rise to commercial harvesting; in rural areas, half of the deficit induce local harvesting (up to stock exhaustion) and the remaining fraction of the deficit (half or more) originates commercial harvesting.

In case of Kenya we decided to carry out the analysis following the "Full Market" and "Partial Market" scenarios. The first one because it reflects the assumptions made in Tier 1 analysis and the second one because it appears more probable than the "Urban Market" scenario[9],.

Combined with the Scenarios A and B, which distinguish between the use of "marginal" fuelwood, we present four scenarios in total, described in Table 1.

Table 1: Scenarios of NRB estimates and relative assumptions

Woodfuels market scenarios	Demand scenarios: **A. Total Demand** The demand is considered entirely, without distinction between conventional and marginal fuelwood	Demand scenarios: **B. Conventional demand** Only the demand for "conventional" fuelwood, is considered, excluding "marginal" fuelwood in rural deficit areas
1. Full market (FM): all conditions of local deficit, including urban and rural areas, originate commercial harvesting of distant resources	**Scenario A** (Mn, **Md**, Mx) **FM**	**Scenario B** (Mn, **Md**, Mx) **FM**
2. Partial market (PM): all urban deficit originates commercial harvesting while ½ rural deficit remains "local" and ½ originates commercial harvesting	**Scenario A** (Mn, **Md**, Mx) **PM**	**Scenario B** (Mn, **Md**, Mx) **PM**

Spatial distribution of commercial harvesting

Harvesting intensity within the commercial harvesting areas defined through woodshed analysis is not evenly distributed; thus, we assume that the expected amount of harvesting in any given pixel depends on the commercial demand pressure (Figure 8.c) and on the commercial surplus available, as per the Equation 2:

$$Har_i = w\_s_i * (\sum c\_d / (\sum w\_s) \quad \text{[eq. 2]}$$

where:

- Har_i = commercial harvesting in pixel $_i$
- w_s_i = weighted surplus = commercial surplus in pixel $_i$ * pressure level in pixel $_i$)
- $\sum c\_d$ = Total commercial deficit within woodshed
- $\sum w\_s$ = Total w_s within woodshed

With this algorithm, commercial harvesting is proportional to demand pressure and commercial surplus.

2.6 ESTIMATING NON RENEWABLE FRACTION OF WOODFUEL HARVESTING

The nonrenewable fraction of woodfuel harvesting is estimated for any given area by subtracting the harvesting from the sustainable supply potential, which is the available commercial surplus of DEB MAI. When harvesting is smaller than the sustainable supply, then that harvesting is renewable (or sustainable); when the harvesting is greater than the sustainable supply, the quantity exceeding the supply represents non-renewable component of harvesting (NRB), and fNRB is then estimated as the non-renewable percent of total harvesting (NRB / total harvesting *100).

However, if, when estimating the sustainability of commercial harvesting we consider the commercial surplus entirely, we implicitly assume that the resources are optimally exploited, maximizing the renewable capacity of supply sources. We consider this the <u>minimum NRB</u> (mNRB) resulting from optimal management, but this is not a realistic estimation of the actual exploitation practices.

[9] Previous surveys show that a substantial minority of rural households purchase fuelwood (17% according to the KAMFOR report (17) and 22% according to KIHBS data (9).

In Tier 1 analysis, we estimated the expected NRB (eNRB) by applying a reduction factor representing sub-optimal resource management. Lacking reliable parameters describing actual exploitation, we used FAO country statistics on the fraction of forest resources under management plans and/or planted (6). This "Sustainable Increment Exploitation Factor" (SIEF) ranges between 0 and 1, where 1 represents optimal management (optimal rotation) and 0 represents worst-case exploitation (stock depletion without rotations). For Kenya, the SIEF applied to commercial harvesting is 0.76. In the absence of other information about "management parameters", we applied the same value of SIEF for commercial harvesting in Tier 2 analysis.

2.6.1 Accounting for Land Cover Change by-products

As reported by Hansen et al. (47), many parts of Kenya are characterized by high rates of land cover change,(LCC) including loss and, to a lower extent, gain of forest areas. Using changes detected between 2000 and 2010, we estimate average annual loss and gain of forest area in each county and quantities of DEB generated in the process (Annex 4). On average, the annual change includes a forest area loss of some 30,000 ha and a gain of 10,000 ha.

Though not directly linked to woodfuel demand, these LCC processes impact woodfuel supplies. Deforestation releases large volumes of woody biomass, and afforestation augments renewable woodfuel supplies by adding to the existing growing stock. When deforestation occurs in regions accessible to woodfuel users, as is the case of Kenya, the cleared woody biomass may be utilized as timber and woodfuel. Similarly, afforestation adds DEB equivalent to the mean annual increment (MAI) of the surrounding land class. However, the degree to which LCC by-products are actually used as woodfuel is unknown. To accommodate this uncertainty, we explore two additional scenarios. In the first scenario we assume LCC by-products are not used and that all demand originates woodfuel harvesting. In the second scenario, we assume that 70% of the DEB by-products are used as woodfuel, yielding two NRB components: NRB of by-products, that in case of deforestation are considered entirely non-renewable (NRB_{bp}) and NRB of the wood harvested directly to meet whatever demand remains after LCC by-products are utilized (NRB_{dh}).

3. RESULTS

3.1 Woodfuels demand

According to Scenario A-"Total Demand", the estimated total woodfuels consumption in Kenya in 2009 was 27.4 Mt od of woody biomass, assuming Medium charcoal yield factor of 24%. Minimum and Maximum consumption of 24.5 and 32.5 Mt od, respectively, applying high and low charcoal yields. In Scenario B, "Conventional Demand", which excludes the consumption of "marginal" fuelwood in wood-scarce rural deficit areas, the total consumption - Medium variant - was 25.2 Mt od, with a Min-Max range of 22.6 - 30 Mt od.

Figure 10 shows population distribution in 2011 (left) and woodfuel consumption in Scenario A Med variant (right). County-level estimates of both scenarios and relative variants are shown in Table 2Table 2. Consumption by sector and rural/urban areas is reported in Annex 1.

Figure 10: Population distribution and total consumption of woodfuels and construction material (Scenario A: Total Demand, Medium variant)

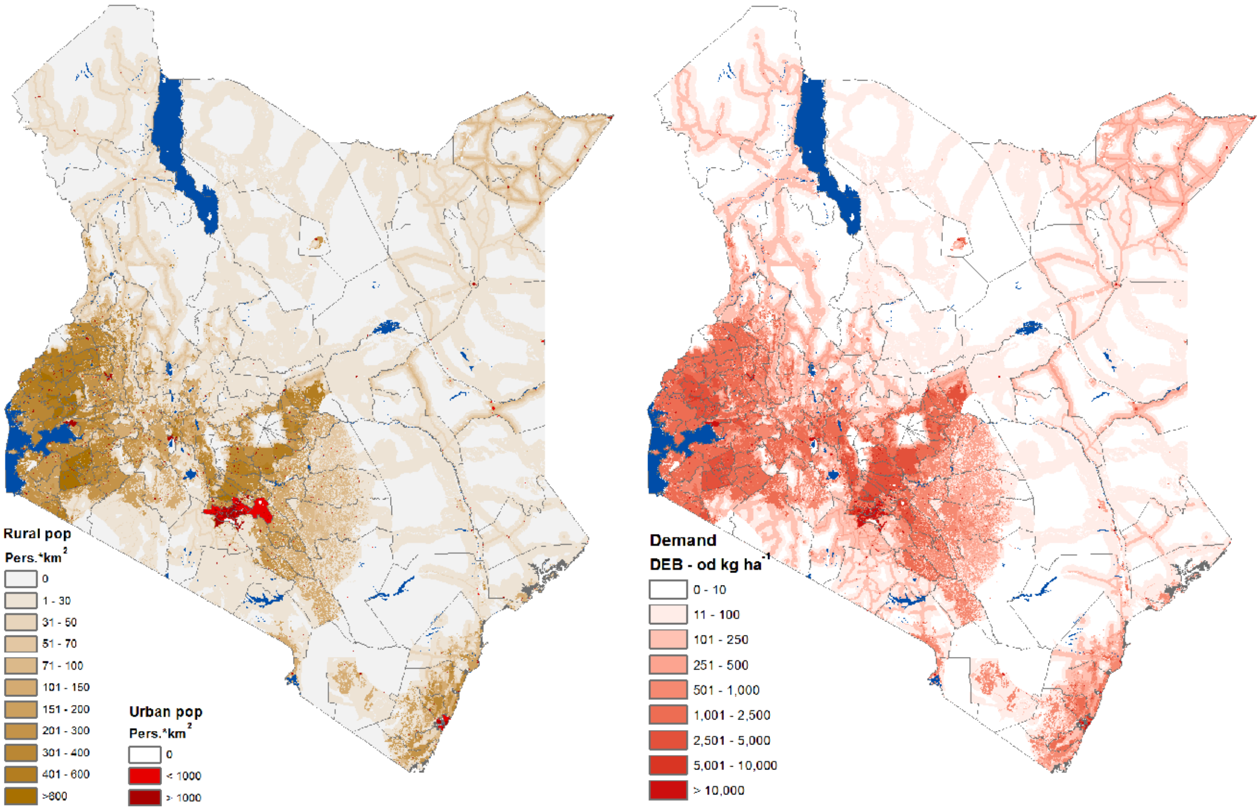


Table 2: County-level woodfuel consumption scenarios

kt od (wood eq.)	Scenario A: Total demand (conventional + marginal woodfuels)			Scenario B: Conventional demand (excluding marginal assortments)		
County	**Mn**	**Md**	**Mx**	**Mn**	**Md**	**Mx**
Nairobi	1,927	**2,308**	3,003	1,927	**2,308**	3,003
Nyandarua	500	**554**	654	437	**483**	566
Nyeri	558	**619**	729	494	**546**	641
Kirinyaga	414	**454**	529	332	**365**	424
Murang'a	587	**631**	711	488	**524**	590
Kiambu	1,469	**1,704**	2,131	1,362	**1,580**	1,979
Mombasa	723	**878**	1,162	723	**878**	1,162
Kwale	311	**334**	376	309	**332**	373
Kilifi	579	**640**	751	568	**626**	734
Tana River	120	**130**	150	120	**130**	149
Lamu	53	**59**	70	53	**59**	70
Taita Taveta	153	**171**	205	151	**169**	203
Marsabit	153	**162**	179	145	**154**	170
Isiolo	92	**104**	125	91	**102**	124
Meru	770	**827**	933	669	**717**	804
Tharaka	232	**251**	285	221	**238**	269
Embu	309	**337**	387	280	**305**	350
Kitui	600	**643**	723	588	**631**	708
Machakos	825	**938**	1,145	787	**897**	1,095
Makueni	511	**550**	623	490	**525**	591
Garissa	290	**314**	356	287	**310**	352
Wajir	273	**281**	298	265	**274**	291
Mandera	441	**460**	494	436	**454**	488
Siaya	505	**549**	631	424	**460**	527
Kisumu	814	**946**	1,185	741	**867**	1,098
Homa Bay	595	**650**	749	524	**570**	653
Migori	642	**720**	863	590	**662**	792
Kisii	711	**774**	888	595	**649**	748
Nyamira	359	**389**	443	303	**327**	373
Turkana	398	**419**	459	382	**402**	441
West Pokot	232	**242**	259	230	**239**	256
Samburu	109	**118**	134	109	**118**	133
Trans Nzoia	524	**584**	693	449	**502**	598
Baringo	317	**340**	384	314	**337**	379
Uasin Gishu	659	**763**	952	590	**687**	864
Keiyo-Marakwet	215	**232**	263	211	**227**	257
Nandi	462	**497**	562	428	**458**	512
Laikipia	274	**313**	382	264	**300**	365
Nakuru	1,292	**1,524**	1,947	1,213	**1,429**	1,822
Narok	505	**551**	635	476	**517**	592
Kajiado	483	**562**	706	471	**547**	686
Kericho	412	**462**	555	388	**435**	522
Bomet	535	**575**	649	483	**516**	578
Kakamega	1,031	**1,098**	1,220	835	**895**	1,004
Vihiga	323	**346**	389	277	**299**	338
Bungoma	820	**890**	1,017	686	**749**	865
Busia	446	**484**	554	364	**399**	462
Kenya	24,552	**27,380**	32,540	22,568	**25,199**	29,999

3.2 Woodfuels supply potential

The total estimated MAI of DEB is 42.9 Mt od/yr, which represents the "gross" supply potential. Due to the uneven distribution of human settlements and road network as well as the presence of large protected areas 35% of these resources are considered non accessible. Leaving 65% of the DEB MAI, i.e. 28.1 Mt od/yr as physically and legally accessible (Table 3).

Deducting 0.7 Mt that is used as industrial roundwood for the timber industry, but adding 19% of such amount on account of the sawmills residues usable as woodfuel, we find approximately 27.5 Mt od/yr resources potentially available for energy use. This resource is spatially distributed as shown in Figure 11; County-level values are shown in Table 3.

Figure 11: MAI of legally and physically accessible Dendro-energy Biomass (DEB) potentially available for energy use.

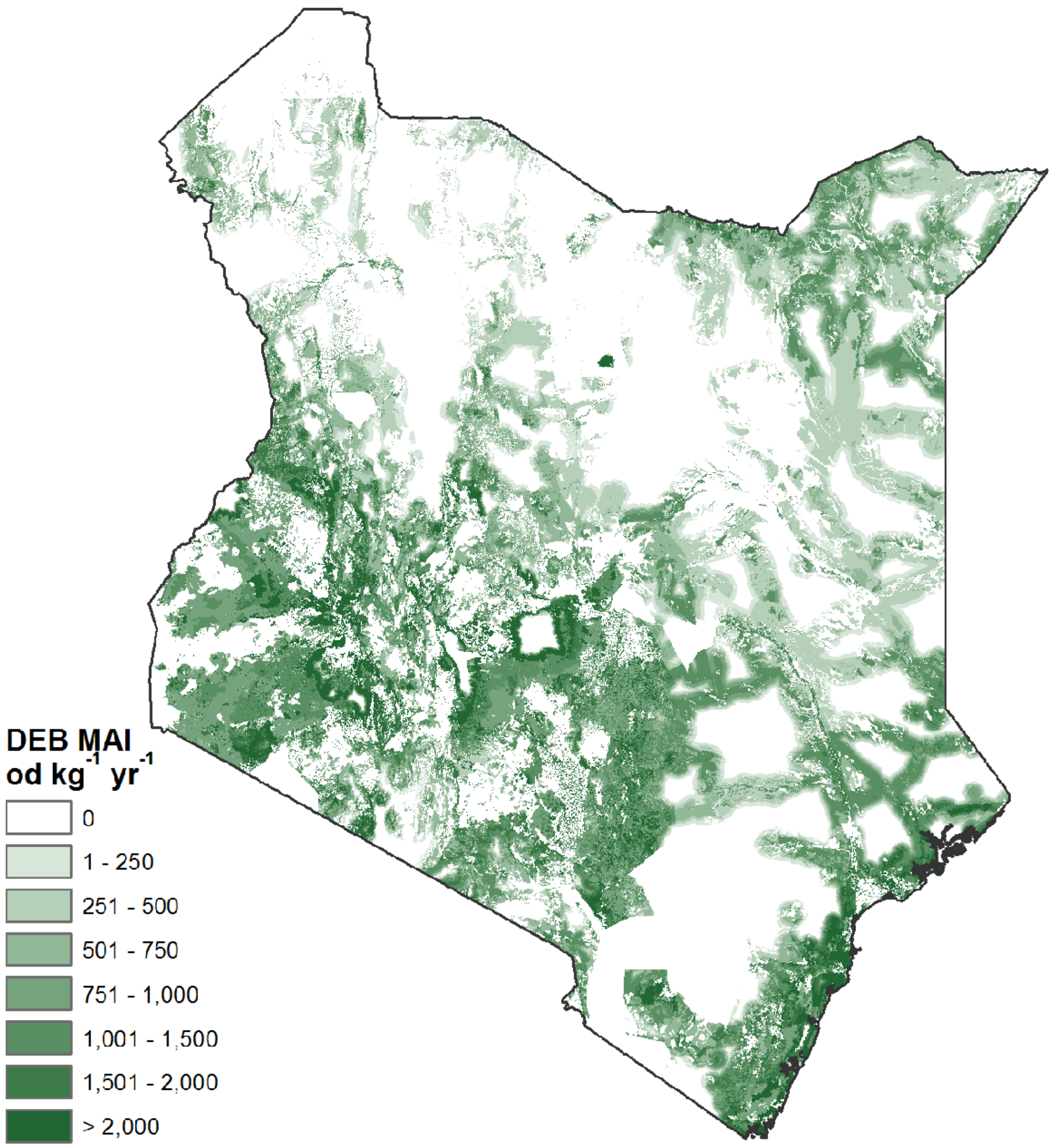


Table 3: County-level supply potential

kt od (wood eq.)	DEB Stock	Tot MAI	Physically & Legally accessible MAI	Available MAI
County	kt od	kt od	kt od	kt od
Nairobi	830	44	40	35
Nyandarua	14,910	380	308	282
Nyeri	25,048	574	422	380
Kirinyaga	6,166	180	138	134
Murang'a	6,758	247	216	212
Kiambu	13,779	435	427	396
Mombasa	781	28	26	26
Kwale	28,906	1,106	871	869
Kilifi	53,174	1,769	1,297	1,293
Tana River	46,729	3,182	1,337	1,332
Lamu	34,551	1,123	644	639
Taita Taveta	18,857	1,112	550	548
Marsabit	18,278	1,824	851	849
Isiolo	12,700	1,114	671	669
Meru	25,045	738	545	518
Tharaka	11,741	320	245	243
Embu	8,376	307	278	273
Kitui	66,353	3,459	2,201	2,196
Machakos	7,134	334	322	317
Makueni	19,845	852	731	717
Garissa	59,160	3,618	1,573	1,570
Wajir	26,664	2,926	1,681	1,679
Mandera	19,560	1,838	1,231	1,230
Siaya	2,916	182	182	181
Kisumu	1,683	91	91	91
Homa Bay	6,335	330	295	292
Migori	3,119	237	235	234
Kisii	3,567	185	184	173
Nyamira	3,029	128	127	106
Turkana	25,607	2,074	911	907
West Pokot	30,561	1,120	767	764
Samburu	34,215	1,632	925	920
Trans Nzoia	8,824	255	191	165
Baringo	37,462	1,308	1,054	1,007
Uasin Gishu	7,782	198	188	170
Keiyo-Marakwet	22,589	537	486	444
Nandi	18,257	489	468	427
Laikipia	18,658	698	586	582
Nakuru	22,477	670	587	539
Narok	82,521	2,145	1,568	1,555
Kajiado	27,681	1,510	1,176	1,170
Kericho	13,977	371	359	315
Bomet	16,556	456	404	395
Kakamega	9,200	294	286	263
Vihiga	1,595	70	70	67
Bungoma	11,831	343	236	227
Busia	1,527	88	88	84
Kenya	**937,313**	**42,921**	**28,069**	**27,481**

3.3 Supply / demand balance

Balance analysis shows the distribution of deficit and surplus areas (Figure 12) and supports the calculation of summary values. Table 4 presents the "simple" pixel-level balance by County combining the available supply potential with minimum, medium and maximum demand values for both Total and Conventional demand scenarios. Depending on the assumption taken, the simple balance at national level varies between minus 5 and plus 4.9 Mt. Considering only medium demand values, which are more likely, scenario A (Total demand) shows a small surplus of + 0.1 Mt while Scenario B (Conventional demand) shows a more consistent surplus of + 2.3 Mt.

Local and Commercial balance values (for medium demand values) are shown in Table 5: the summary of **Local balance** is positive for both demand scenarios (+0.35 in A and +2.5 Mt od in B), which may induce some initial optimism, but over half of the Counties show negative values in both scenarios. For **Commercial balance**, which provides a more realistic perception of the resources potentially available, the national summary becomes negative in both scenarios: strongly negative (-2.2 Mt) in Scenario A and slightly negative (-0.05 Mt) in Scenario B.

But summary values may be misleading because, in the analysis of NRB, the spatial distributions of supply and demand are more important than the respective quantities. For NRB estimates, some further analysis is needed in order to assess the amount and probable distribution of commercial harvesting, as discussed below. Nevertheless, the Balance map is useful in ranking the communities according to local balance conditions, which is particularly relevant for poor rural communities that depend primarily on local resources.

Figure 12: Local supply demand balance maps according to Scenario A -Total Demand (a) and to Scenario B -Conventional Demand (b).

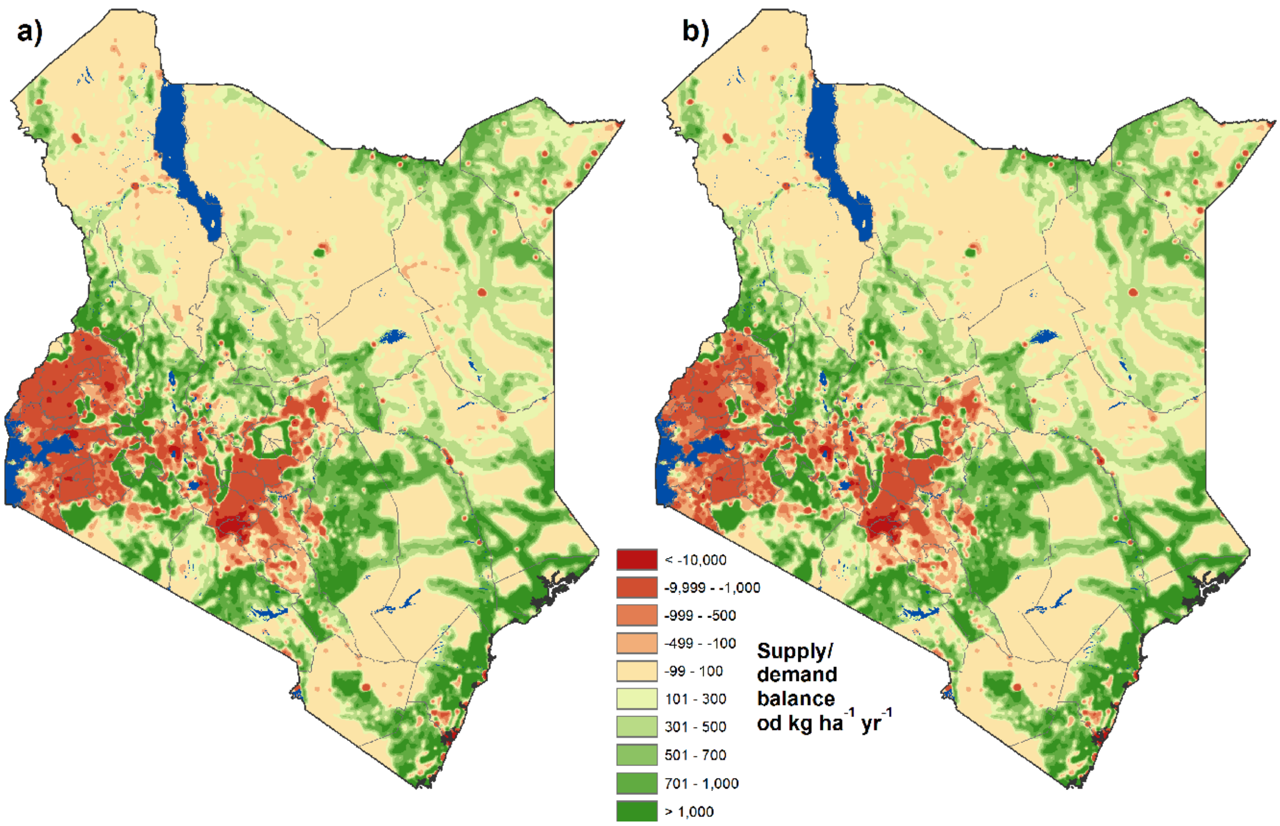


Table 4: County-level simple Supply / demand balance

	Balance Sc. A: Total demand (conventional + marginal woodfuels)			Balance Sc. B: Conventional demand (excluding marginal assortments)		
	Mn	**Md**	**Mx**	**Mn**	**Md**	**Mx**
County	kt od	kt od	kt od	kt od	kt od	kt od
Nairobi	-1,893	**-2,274**	-2,968	-1,893	**-2,274**	-2,968
Nyandarua	-218	**-272**	-373	-155	**-201**	-284
Nyeri	-178	**-239**	-349	-114	**-166**	-261
Kirinyaga	-280	**-321**	-395	-199	**-231**	-291
Murang'a	-375	**-419**	-499	-277	**-312**	-378
Kiambu	-1,073	**-1,308**	-1,735	-965	**-1,184**	-1,582
Mombasa	-697	**-852**	-1,136	-697	**-852**	-1,136
Kwale	558	**535**	492	560	**537**	496
Kilifi	714	**653**	542	725	**666**	559
Tana River	1,212	**1,201**	1,182	1,212	**1,202**	1,182
Lamu	586	**580**	569	586	**580**	569
Taita Taveta	395	**376**	342	396	**378**	345
Marsabit	696	**686**	670	704	**695**	678
Isiolo	577	**565**	543	578	**566**	545
Meru	-252	**-309**	-415	-151	**-199**	-286
Tharaka	11	**-8**	-42	22	**5**	-26
Embu	-36	**-63**	-114	-7	**-31**	-77
Kitui	1,597	**1,554**	1,473	1,608	**1,566**	1,488
Machakos	-508	**-622**	-828	-471	**-580**	-778
Makueni	206	**166**	93	227	**191**	126
Garissa	1,279	**1,256**	1,214	1,283	**1,260**	1,218
Wajir	1,406	**1,398**	1,381	1,414	**1,405**	1,389
Mandera	789	**770**	736	794	**775**	742
Siaya	-324	**-368**	-449	-243	**-279**	-345
Kisumu	-724	**-855**	-1,095	-651	**-777**	-1,007
Homa Bay	-303	**-358**	-457	-233	**-278**	-361
Migori	-408	**-486**	-628	-356	**-427**	-557
Kisii	-539	**-602**	-716	-422	**-477**	-575
Nyamira	-253	**-283**	-336	-196	**-221**	-267
Turkana	509	**488**	448	525	**505**	466
West Pokot	532	**523**	505	534	**525**	508
Samburu	811	**802**	787	811	**803**	787
Trans Nzoia	-360	**-420**	-529	-285	**-337**	-434
Baringo	691	**667**	623	694	**671**	629
Uasin Gishu	-488	**-592**	-782	-420	**-517**	-693
Keiyo-Marakwet	229	**212**	180	232	**216**	187
Nandi	-35	**-70**	-135	-1	**-31**	-85
Laikipia	308	**269**	199	318	**282**	216
Nakuru	-753	**-984**	-1,408	-674	**-889**	-1,282
Narok	1,050	**1,004**	920	1,079	**1,038**	963
Kajiado	687	**608**	464	699	**622**	484
Kericho	-97	**-148**	-240	-73	**-121**	-207
Bomet	-140	**-180**	-254	-88	**-121**	-182
Kakamega	-768	**-835**	-957	-572	**-632**	-741
Vihiga	-256	**-279**	-322	-210	**-232**	-271
Bungoma	-593	**-663**	-790	-459	**-522**	-638
Busia	-362	**-400**	-470	-280	**-315**	-378
Kenya	**2,929**	**102**	**-5,058**	**4,913**	**2,282**	**-2,517**

Table 5: County-level Local and Commercial Supply / demand balance

	Scenario A		Scenario B	
	Local balance	Commercial balance	Local balance	Commercial balance
County	kt od	kt od	kt od	kt od
Nairobi	-2,156	-2,156	-2,155	-2,155
Nyandarua	-266	-278	-197	-209
Nyeri	-232	-248	-160	-177
Kirinyaga	-324	-326	-237	-239
Murang'a	-411	-414	-305	-309
Kiambu	-1,354	-1,355	-1,233	-1,234
Mombasa	-804	-804	-804	-804
Kwale	512	467	515	469
Kilifi	649	592	662	605
Tana River	1,163	983	1,163	983
Lamu	583	539	583	540
Taita Taveta	381	322	383	323
Marsabit	686	454	694	462
Isiolo	558	440	561	442
Meru	-302	-320	-193	-212
Tharaka	-14	-27	0	-14
Embu	-50	-59	-16	-26
Kitui	1,535	1,445	1,548	1,457
Machakos	-642	-653	-599	-611
Makueni	176	150	200	173
Garissa	1,300	1,087	1,304	1,091
Wajir	1,392	1,166	1,400	1,173
Mandera	773	654	778	659
Siaya	-317	-317	-232	-233
Kisumu	-779	-779	-702	-702
Homa Bay	-328	-329	-251	-253
Migori	-462	-462	-402	-403
Kisii	-568	-568	-449	-449
Nyamira	-287	-287	-226	-226
Turkana	487	243	504	258
West Pokot	513	451	516	454
Samburu	802	639	802	639
Trans Nzoia	-410	-414	-329	-333
Baringo	654	568	658	572
Uasin Gishu	-591	-598	-515	-522
Keiyo-Marakwet	205	183	210	188
Nandi	-88	-93	-46	-52
Laikipia	252	154	266	167
Nakuru	-927	-951	-833	-858
Narok	955	793	993	829
Kajiado	557	402	571	416
Kericho	-157	-165	-128	-137
Bomet	-174	-175	-115	-116
Kakamega	-848	-849	-646	-646
Vihiga	-253	-253	-209	-209
Bungoma	-656	-659	-516	-519
Busia	-385	-385	-303	-303
Kenya	349	-2,193	2,509	-53

Note: Local balances differ from the arithmetic result of Available MAI <minus> Demand (as per pixel-level balance) due to the 6 Km context of analysis.

3.4 Distribution and intensity of woodfuel harvesting

The spatial distribution of woodfuel harvesting induced by local deficit conditions is critical in the analysis of NRB. In this respect we have assumed two main scenarios:

"Full Market" scenario : Under the "Full Market" scenarios, we assume that demand in rural deficit sites, like urban sites, is met by commercial harvesting rather than overexploitation of rural resources. This assumption shifts pressure toward accessible forest resources and other areas with surplus biomass.

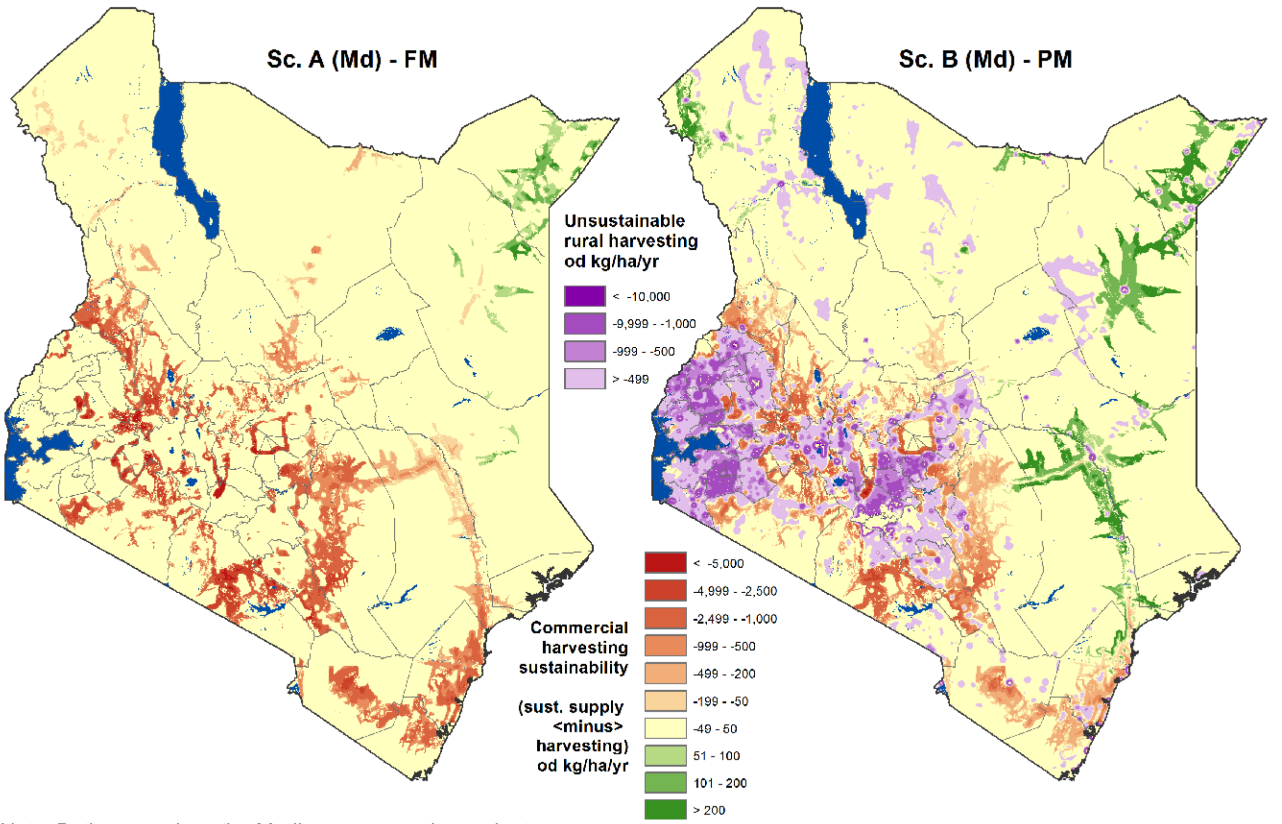
"Partial Market" scenario : Under the "Partial Market" scenario, we assume that urban demand is satisfied by commercial harvesting, but demand in rural deficit sites is met by a combination of local overexploitation and commercial supplies. Lacking specific data, we assume these two sources contribute equally to meeting local rural demand so that half of the excess demand is met by overexploitation of local rural biomass resources and half is met by commercial harvesting. This assumption reduces commercial harvesting pressure in comparison to the Full Market scenario and increases the overexploitation of woody biomass in farmlands and woodlands close to sources of rural demand.

In both scenarios, the resulting commercial harvesting is distributed according to the demand pressure (see Section 2.5) and the availability and distribution of suitable wood resources.

Figure 13 shows harvesting sustainability relative to the two market scenarios in combination with the two demand scenarios, thus presenting the spatial effect of the range of assumptions considered: In Scenario A(Md)-FM, the impact of commercial harvesting is higher and is located entirely on accessible forests and woodlands; in contrast, in Scenario B(Md)-PM the impact is lower and more homogeneously distributed over accessible forests, woodlands and rural areas.

The harvesting sustainability is calculated by subtracting the harvesting from the available local surplus. Where the commercial harvesting is greater than the sustainable commercial surplus the result is negative representing areas of unsustainable exploitation and likely degradation (shades of red in maps); where the harvesting is less than the sustainable surplus, the result is positive, representing areas of sustainable exploitation (shades of green in maps). The purple shades of scenario B (Md)-PM represent areas of unsustainable harvesting in rural deficit areas.

Figure 13: Harvesting sustainability according to the Total Demand- Full Market (A Md - FM) scenario and to the Conventional Demand - Partial Market (B Md - PM) scenario.



Note: Both maps show the Medium consumption variant.

3.5 NRB estimates

The spatial distribution of non-renewable harvesting NRB values for scenarios A(Md)-FM and B(Md)-PM are shown in Figure 14 and summarized by County in Table 6, where Counties experiencing fNRB greater than the national average are highlighted. Figure 15 shows County-level NRB and fNRB estimates for both scenarios. From these maps and table it is evident that Market scenarios influence the spatial distribution of excessive harvesting.

At national level, fNRB is 41.3%, or 11.2 Mt for Scenario A(Md)-FM and 38.3%, or 9.5 Mt for Scenario B(Md)-PM.

By excluding the woody biomass becoming annually available as by-products of land cover change, and thus referring to direct woodfuel harvesting only, fNRB rates 35%, or 9.5 Mt for Scenario A(Md)-FM and 31.2% or 7.8 Mt for Scenario B(Md)-PM. Thus, the by-products of annual deforestation, although non-renewable in their own right, avoid 1.7 Mt of direct NRB harvesting. The NRB fraction of direct woodfuel harvesting is important as it allows to quantify the maximum amount of CO_2 emissions that a program aiming at the reduction of the consumption, such as improved cookstoves or fuel switching, may potentially offset. On the contrary, the adoption of fuel-efficient stoves (notwithstanding all other important benefits) would have little impact on the emissions related to deforestation caused by farming expansion since it is likely that, if not used as woodfuel, these byproducts would be burned on site.

There is a wide variability among Counties, with some experiencing fNRB significantly higher than the national average. In Sc. A(Md)-FM, above-average fNRB values occur in (listed by decreasing NRB values): Kajiado, Kitui, Narok, Baringo, Kilifi, Taita Taveta, Makueni, Laikipia, Embu, Nyeri, Kericho, Samburu, and Uasin Gishu.

In Sc. B(Md)-PM, above-average fNRB values occur in (listed by decreasing NRB values): Kajiado, Nakuru, Kiambu, Baringo, Kakamega, Taita Taveta, Bungoma, Nyeri, Uasin Gishu, Kisii, Kericho, Nyandarua, Migori, Embu, Trans Nzoia, Murang'a, Kisumu, Kirinyaga, Mombasa, Busia, Nyamira and Vihiga.

The Counties with above-average fNRB and NRB values in most or all scenarios are subject to pressure from commercial harvesting and are more likely to be affected by progressive processes of degradation. These include Kajiado, Baringo, Makueni, Taita Taveta, Nyeri, Kericho and Kiambu.

Figure 14: Non Renewable harvesting (NRB) according to the Total Demand- Full Market (A Md - FM) scenario and to the Conventional Demand - Partial Market (B Md - PM) scenario.

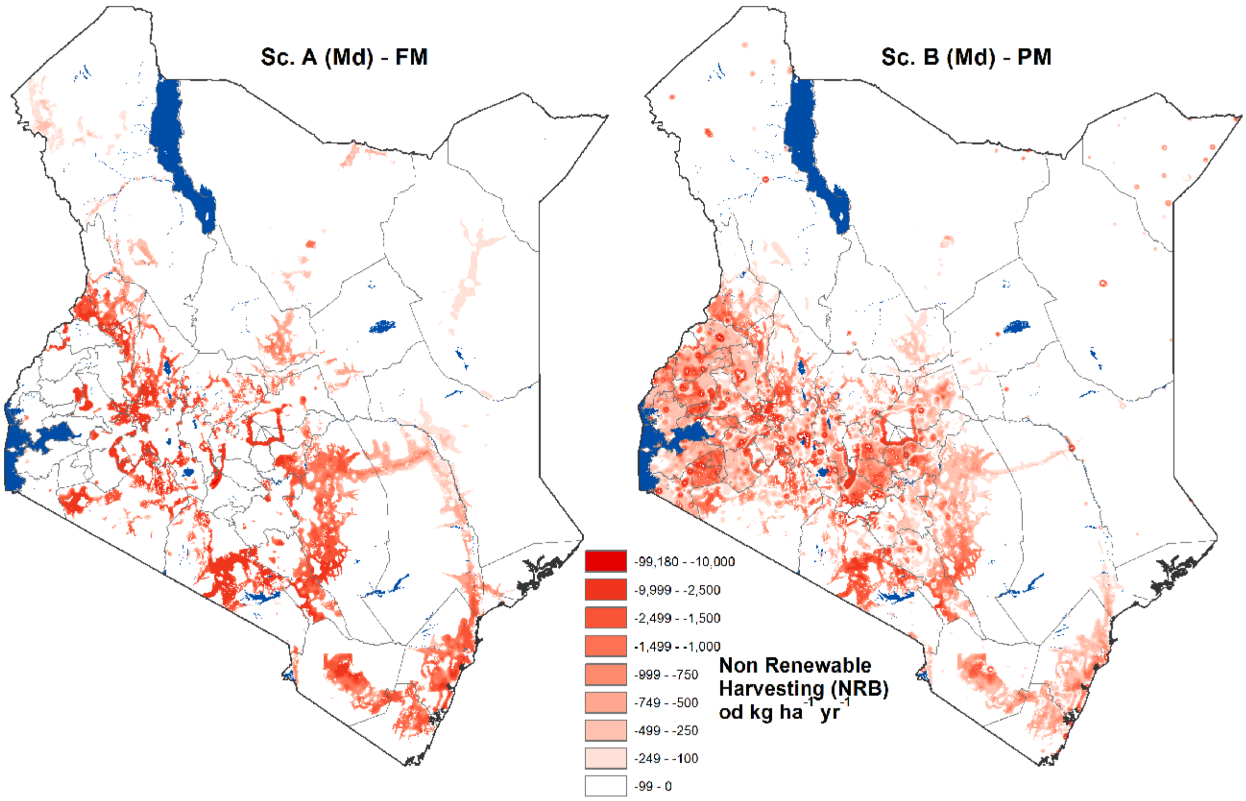
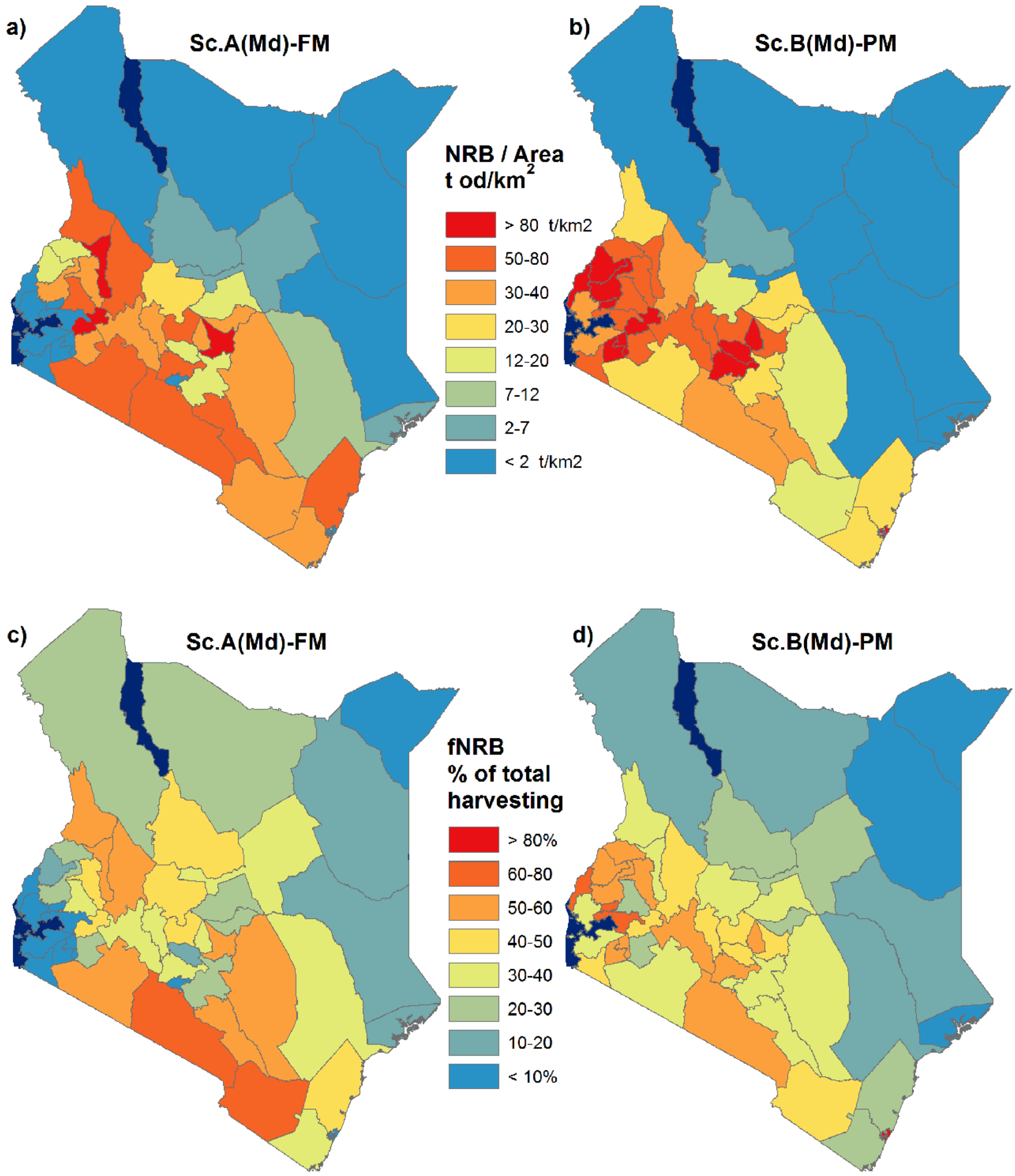


Table 6: County level NRB values according to A (Md) Full Market Scenario and to B (Md) Partial market-scenario.

	Scenario A (Md) FM "Total demand - Full market"				Scenario B (Md) PM "Conventional demand - Partial market"			
	NRB Total Direct harv. + LCC byprod.		NRB$_{dh}$ Direct harvesting only (less LCC byprod.)		NRB Total Direct harv. + LCC byprod.		NRB$_{dh}$ Direct harvesting only (less LCC byprod.)	
County	kt od	fNRB %	kt od	fNRB %	kt od	fNRB %	kt od	fNRB %
Nairobi	0	0.0	0	0.0	22	38.3	20	35.9
Nyandarua	125	33.3	121	32.1	193	43.7	189	42.7
Nyeri	220	40.5	219	40.4	243	43.0	243	42.9
Kirinyaga	60	32.9	60	32.8	140	53.3	140	53.3
Murang'a	32	13.5	32	13.5	177	46.6	176	46.6
Kiambu	206	35.4	205	35.2	430	53.4	429	53.3
Mombasa	0	0.0	0	0.0	138	88.7	130	83.4
Kwale	311	38.3	156	19.2	171	26.9	15	2.4
Kilifi	693	43.1	528	32.8	312	25.4	146	12.0
Tana River	363	38.2	341	35.9	67	10.4	45	7.0
Lamu	20	18.8	0	0.0	3	2.9	0	0.0
Taita Taveta	577	61.3	575	61.1	276	43.2	274	42.9
Marsabit	58	22.0	58	22.0	35	16.3	35	16.3
Isiolo	78	38.9	78	38.9	40	25.9	40	25.9
Meru	129	21.6	128	21.5	199	30.0	199	29.9
Tharaka	81	28.0	7	2.4	72	25.8	0	0.0
Embu	250	51.4	189	38.8	180	43.3	119	28.6
Kitui	1,372	53.0	1,275	49.2	610	33.4	513	28.1
Machakos	98	24.7	91	22.7	170	36.2	162	34.5
Makueni	577	50.2	544	47.3	346	37.7	313	34.1
Garissa	46	12.5	41	11.1	37	11.2	31	9.5
Wajir	52	10.0	52	10.0	26	6.2	26	6.2
Mandera	3	0.5	3	0.5	34	7.0	34	7.0
Siaya	4	2.2	0	0.0	106	38.0	96	34.3
Kisumu	2	1.8	0	0.0	156	62.8	135	54.6
Homa Bay	3	1.1	0	0.0	125	31.3	119	29.8
Migori	2	0.8	0	0.0	189	44.8	185	43.9
Kisii	0	0.0	0	0.0	218	56.2	217	55.9
Nyamira	0	0.0	0	0.0	111	51.1	110	50.4
Turkana	118	20.3	117	20.1	88	17.3	86	17.1
West Pokot	509	53.0	414	43.1	220	32.9	125	18.6
Samburu	141	41.3	141	41.3	58	23.0	57	22.9
Trans Nzoia	45	23.0	8	4.1	179	54.3	142	43.0
Baringo	819	59.0	783	56.4	408	41.8	372	38.1
Uasin Gishu	113	41.9	64	23.7	218	58.1	169	45.0
Keiyo-Marakwet	349	51.4	248	36.6	169	33.9	68	13.7
Nandi	183	31.8	154	26.8	153	28.1	124	22.8
Laikipia	277	47.1	233	39.6	180	37.0	136	28.0
Nakuru	320	39.8	135	16.8	529	52.4	344	34.1
Narok	1,013	54.3	614	33.0	501	37.2	102	7.6
Kajiado	1,473	69.5	1,470	69.3	841	57.0	837	56.7
Kericho	210	42.9	175	35.8	204	42.2	169	35.0
Bomet	103	22.3	103	22.2	142	28.3	141	28.1
Kakamega	99	28.0	94	26.4	309	54.8	304	53.8
Vihiga	0	0.0	0	0.0	102	60.3	102	60.3
Bungoma	43	17.5	13	5.5	258	56.1	229	49.7
Busia	0	0.0	0	0.0	136	62.7	121	55.7
Kenya	**11,179**	**41.3**	**9,470**	**35.0**	**9,516**	**38.3**	**7,770**	**31.2**

Figure 15: County level NRB, represented as tons per km² (a, b) and fNRB, as % of total harvesting (c, d) according to the Total Demand- Full Market scenario (a, c) and to the Conventional Demand - Partial Market scenario (b, d).



Summary of scenarios

National level NRB estimates according to the scenarios considered are presented in Table 7.

Table 7: Overview of NRB estimates and relative assumptions

Woodfuels market scenarios	Demand scenarios: A. Total Demand (without distinction between conventional and marginal): **27.4 Mt** (24.5-32.5)	Demand scenarios: B. Conventional demand (demand for "conventional" fuelwood only, excluding "marginal" fuelwood): **25.2 Mt** (22.6-30)
1. Full market (FM): all conditions of local deficit, including urban and rural areas, originate commercial harvesting of distant resources	**Scenario A** (**Md**)-**FM**: **11.2 Mt = 41.3 %** **NRB of Direct harvesting only: 9.5 Mt = 35 %** Highest impact in forest areas	Not implemented - Expected NRB would be close to the values below but concentrated on forest areas
2. Partial market (PM): all urban deficit originates commercial harvesting while ½ rural deficit remains "local" and ½ originates commercial harvesting	Not implemented - Expected NRB would be close to the values above but distributed on forest and rural areas	**Scenario B** (Mn, **Md**, Mx)-**PM** **9.5 Mt** (7.2-13.9) **= 38.3 %** (33–47) **NRB of Direct harvesting only: 7.8 Mt** (5.6-12.1) **= 31.2 %** (25-41) Impact in forests and rural areas

The spatial distribution of unsustainable harvesting for each scenario are shown in

Figure 13 and Figure 14 above.

In

Figure 13, the sustainability of harvesting is shown disaggregated into its rural/local and urban/commercial components. Figure 14 combines the non-renewable component of both subsistence and commercial demand. Commercial harvesting is influenced by assumptions about how rural supply deficits are accommodated, If the rural supply deficit is accommodated with commercial harvesting on forest areas (as in scenarios A(Md)-FM), then commercial harvesting significantly exceeds sustainable levels, with clear impacts throughout accessible forested areas. However, if the rural supply deficit is (partially) accommodated by overexploitation of local resources and partially by commercial supply (as in scenario B(Md)-PM), then the unsustainable commercial harvesting on forest areas is reduced and pressure is shifted to rural farmlands and woodlands throughout Central and Western Kenya.

3.6 Degradation of biomass stock from excessive woodfuel harvesting

Figure 16 and Figure 17 show alternate perspectives, with NRB harvesting shown as a percentage of the stock of DEB. This indicates the expected rate of degradation induced by excessive woodfuel exploitation in each scenario.

In A(Md)-FM, unsustainable harvesting occurs in forest areas where DEB stock is relatively high and degradation rates generally remain below 10%. In contrast, in scenario B(Md)-PM, unsustainable harvesting occurs in poorly stocked rural areas, with degradation rates ranging from 10 to 50%.

In Figure 17, all areas classified in KFS 2010 as non-forested are masked (gray areas) in order to allow comparison of the expected degradation of forest stock according to the two scenarios considered. In A(Md)-FM, the forest degradation rate in most accessible forest areas is 3-5 % with peak values of 10%. In scenario B(Md)-PM, the expected forest degradation is significantly lower, with rates of 1-3 % in most accessible forest areas and with peak values of 6%.

Probably, none of the options considered is entirely accurate. Nevertheless, they are useful in that they demonstrate the range of NRB values and different locations where excessive harvesting could take place depending whether supply deficits are satisfied by local overexploitation or market-oriented suppliers exploiting resources from further afield. The factors leading to the intensity and location of woodfuel harvesting are strongly interrelated and influenced by land use patterns and economic factors. In particular, economic factors are key to determine the proportions of the responses to rural deficit (i.e. market vs local overexploitation) and may serve as weighting factor in future analyses.

Figure 16: Annual degradation of biomass resources as percent of stock resulting from unsustainable harvesting according to the Total Demand- Full Market (A-Md-FM) scenario (left) and the Conventional Demand - Partial Market (B-Md--PM) scenario (right).

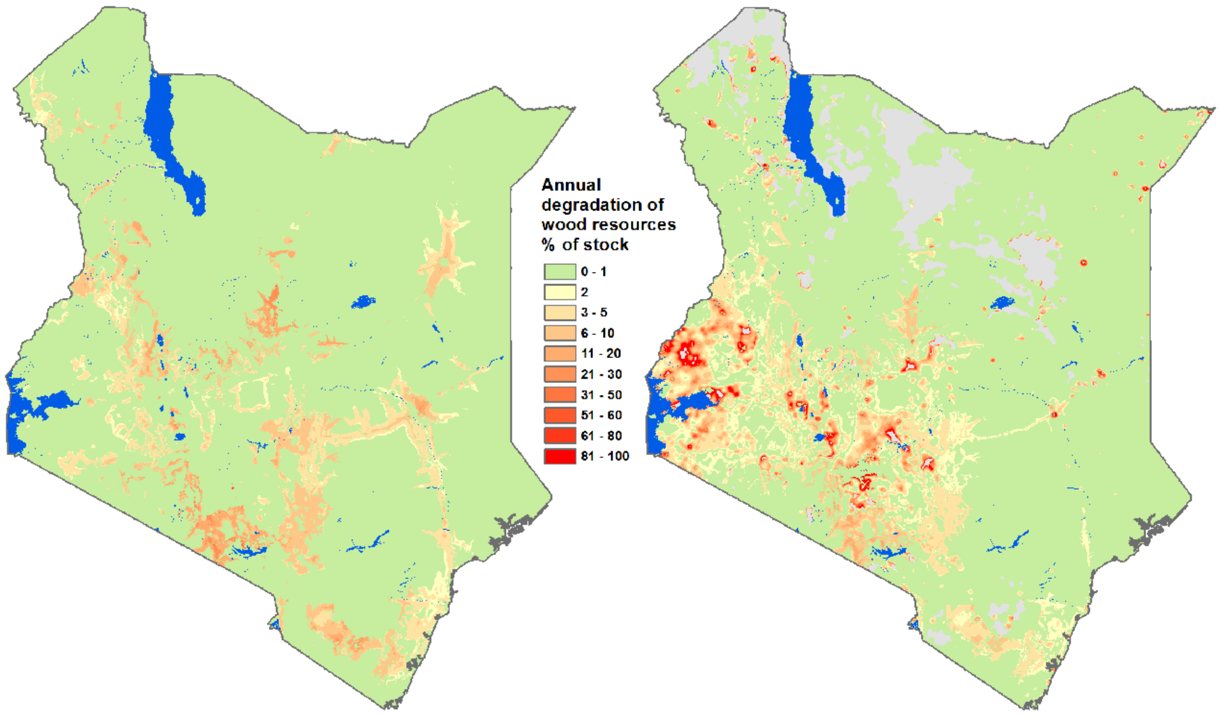
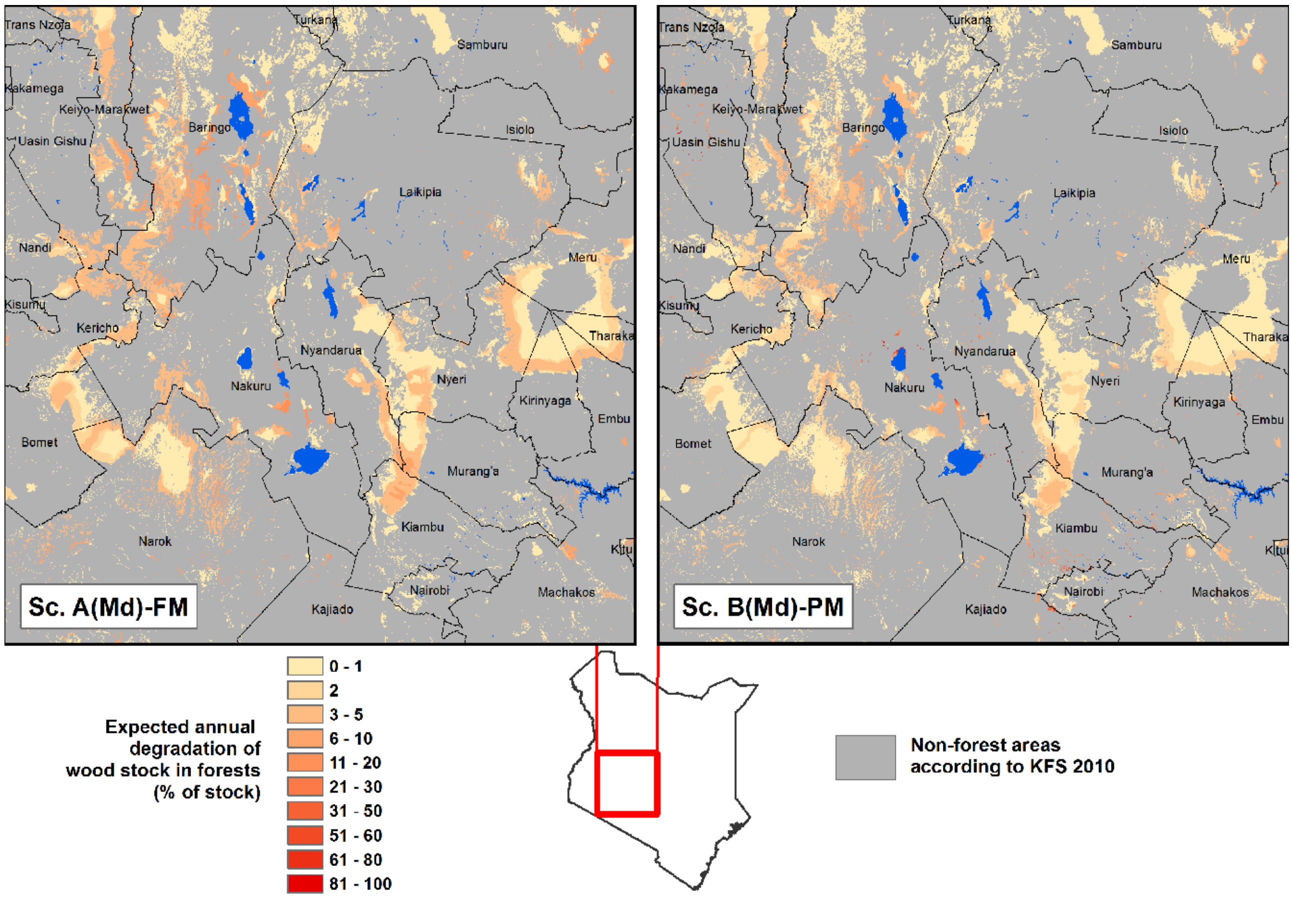


Figure 17: Expected degradation of forest areas due to unsustainable harvesting according to the two main scenarios considered.



4. COMPARING TIER 1 AND TIER 2 RESULTS FOR KENYA

In Tier 1 analysis, NRB estimates are produced at first subnational level according to UN Global Administrative Unit Layers (GAUL) data and for Kenya this corresponds to 8 Provinces. The different supply and demand values applied in Tier 1 and Tier 2 and relative NRB estimates are shown in Table 8. The Tier 2 values shown in the table are relative to the "full market full demand scenario" (Sc.A1) which matches the assumptions made in Tier 1.

The most relevant difference is in the estimated supply potential, with apparent Tier 1 underestimation of 24%. Demand estimates are closer, but still on the lower side in Tier 1, with 15 % less. These induce a Tier 1 "simple" balance of 2.3 Mt, versus the +0.1 Mt of Tier 2.

Table 8: Comparing Tier 1 and Tier 2 estimates for Kenya

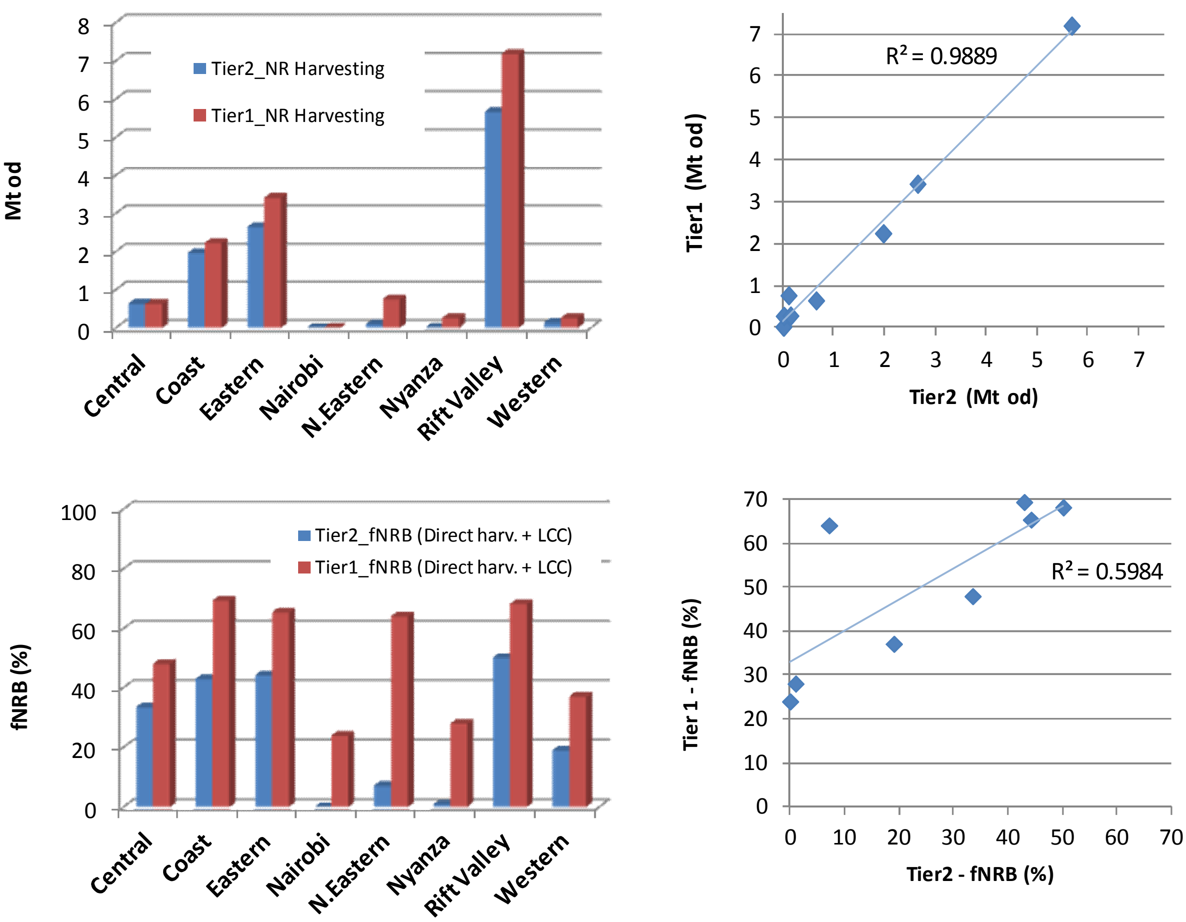
	Available supply potential		DEB Demand		NRB Total (direct+LCC)			
	Tier2	**Tier1**	**Tier2**	**Tier1**	**Tier2 NRB**	**Tier1 NRB**	**Tier2 fNRB**	**Tier1 fNRB**
Province	Kt od	Kt od	Kt od	Kt od	Kt od	Kt od	%	%
Central	1,404	995	3,962	3,116	643	633	34	48
Coast	4,706	2,731	2,213	2,367	1,965	2,233	45	69
Eastern	5,781	4,582	3,812	3,015	2,643	3,414	45	65
Nairobi	35	27	2,308	3,362	0	7	0	24
North Eastern	4,479	3,713	1,055	631	101	757	7	64
Nyanza	1,077	850	4,028	3,052	11	264	1	28
Rift Valley	9,360	7,276	7,183	5,340	5,675	7,182	50	68
Western	641	630	2,818	2,271	142	272	19	37
KENYA	**27,481**	**20,804**	**27,380**	**23,154**	**11,179**	**14,761**	**42**	**64**
% Difference between Tier 1 and Tier 2		**24%**		**15%**		**+32%**		**+53%**

The absolute values of NRB harvesting are reasonably close, with Tier 1 estimate 32% greater than Tier 2. When comparing the NRB estimates expressed as *fractions* of total harvesting, the difference appear more relevant (+53% for the expected fNRB) since total harvesting in Tier 1 is significantly smaller than in Tier2.

Although the national level supply and demand values and NRB results differ, provincial NRB results are highly comparable (Figure 18), with Tier1 values correlating well with the geographic variability of the Country (R^2 0.99 for NRB in tons and 0.60 for fNRB) and thus efficiently supporting subnational priority zoning.

Besides the comparison of Tier 1 and Tier 2, the Kenya study provides useful elements on the adoption of different assumptions on the compositions of woodfuels used (conventional vs marginal) and on commercial harvesting mechanisms in rural deficit areas (full market vs partial market) that should be considered in the next version of the pantropical model.

Figure 18: Provincial level Non Renewable Harvesting. Tier1 vs Tier2 estimates



5. CONCLUSIONS

Supply/demand balance

- From simple accounting of demand and accessible supply potential, Kenya shows a slight positive balance for the Total Demand scenario (Sc. A) and a more consistent surplus for the Conventional Demand scenario in which marginal fuelwood types are excluded (Sc. B) … however:
- When considering the "commercial" supply potential (excluding sparse resources clearly not suitable to commercial woodfuel production), the balance becomes markedly negative (-2.2 Mt) for Scenario A and slightly negative (-0.05 Mt) for Scenario B.

Analysis of the probable commercial harvesting and NRB estimates

- Kenya presents nonrenewable harvesting fractions (fNRB) even when more optimistic assumptions are made.
- The fNRB values of woodfuel harvesting range between 38 and 41 % of total harvesting (9.5 – 11.2 Mt of unsustainable DEB harvesting), depending on the assumptions made.
- These fNRB values are rather high and indicate the risk of progressive degradation.

Assumptions made and NRB estimates

- Different assumptions about the magniture of Demand lead to variation in fNRB estimates:
    - 41.3 % for Scenario A Med, in which total woodfuel demand is considered, without distinction of type and sources
    - 38.3 (*33-47*) % for Scenario B Med (*Min-Max*), in which marginal woodfuels in wood-scarce rural areas are excluded because they may not be accounted for in inventories of biomass stocks and/or growth.
    - The use of marginal wood products reduces the pressure on forests, but their extraction may negatively affect soil fertility, because of reduced reintegration of twigs, leaves and residues' nutrients into the soil of forests, plantations and agricultural fields. Over time, this can result in a progressive loss of soil fertility, with a reduction of productivity, increased vulnerability among communities depending on that productivity, and decreased living standards.
- Assumptions on which part of the local deficit is served by commercial harvesting make little change on national NRB values, but induce significant differences in the areas that are likely to be overexploited:
    - In the **Full Market Scenario** we assume that all local deficits in both rural and urban areas are met by commercial harvesting. .We also assume that commercial harvesting occurs within 12 hours transport time from woodfuel markets.

        With these assumptions, rural areas put little pressure on their scarce local resources and all rural demand that is locally unsustainable joins urban demand to generate commercial harvesting pressure that impacts forest areas and woodlands.

        - The Counties that are most heavily exploited, resulting in fNRB values over the national average are (listed by decreasing NRB values): Kajiado, Kitui, Narok, Baringo, Kilifi, Taita Taveta, Makueni, Laikipia, Embu, Nyeri, Kericho, Samburu, and Uasin Gishu.
    - In the **Partial Market Scenario** we assume that commercial harvesting is originated by urban centers and by only half of the rural deficit (the residual part of deficit remaining local with consequent overexploitation of local resources). Here also we apply the 12-hour transport threshold.
        - With these assumptions, the commercial harvesting is less than in Full Market Scenario, since part of the rural deficit remains local, and unsustainable harvesting is more evenly distributed over forests, woodlands and non-forest rural areas.
        - The Counties that are most heavily exploited, resulting in fNRB values over the national average occur in (listed by decreasing NRB values): Kajiado, Nakuru, Kiambu, Baringo, Kakamega, Taita Taveta, Bungoma, Nyeri, Uasin Gishu, Kisii, Kericho, Nyandarua, Migori, Embu, Trans Nzoia, Murang'a, Kisumu, Kirinyaga, Mombasa, Busia, Nyamira and Vihiga.

- The Counties that present high fNRB and NRB values in all or most scenarios are those where forest resources are under greatest pressure for commercial harvesting and are more likely affected by progressive degradation. These include, by decreasing NRB Total values: Kajiado, Baringo, Makueni, Taita Taveta, Nyeri, Kericho and Kiambu. Together, these counties account for 29-42% of the country's total volume of unsustainably harvested wood.

Critical assumptions affecting the scenarios:

There are numerous factors that affect the level and location of NRB harvesting. the most relevant include:

a) The extent to which consumers utilize "marginal" wood in rural areas

b) The extent to which consumers in rural deficit areas rely on commercial sources of woodfuels or overexploitation of locally available resources.

c) The Management factor, which defines the extent to which woodfuel users stray from optimal harvesting practices

Alternative scenarios were produced making alternative assumptions for the first two factors, in order to simulate what happens in rural areas where woodfuel use is high but wood resources are scarce. None of the assumptions can accurately reflect reality, but each one is useful in demonstrating the range of NRB values and the different locations where excessive harvesting could take place. Additional empirical research is needed to determine which of these scenarios most accurately captures actual practices of woodfuel users.

The Management factor, intended to represent how rationally the resources are exploited, is important but difficult to determine. In this study we assumed, based on broad forest management parameters, that some 24% of the potential sustainable supply goes untapped, with consequent increased pressure on exploited resources. This is tentative and more accurate information on formal and informal resource management practices should be collected in order to define robust local and/or national management factors.

Data gaps and weaknesses

In addition to the assumptions described above, WISDOM Kenya utilized numerous sources of data that need further validation. The most relevant information gaps to be filled in with priority include the following:

Woody biomass supply data

- **Stock**: we used two land cover datasets, LCCS 2008 and KFS 2010, which are both reasonably up-to-date and based on high-resolution data. For this study we integrated them in order to best map DEB stock. For a wider use of land cover information in the forestry and other sectors, we recommend that Kenya encourage interagency cooperation between KFS and DRSRS with the scope of harmonizing and integrating the two datasets.
- **Productivity**: we found little data on productivity of natural forests and no data on productivity in farmlands and shrublands. These are important sources of fuelwood, which must be well understood in order to accurately assess the impact of extraction on forest cover. For instance, *prosopis juliflora* is becoming more and more relevant in rural fuelwood mix and its current role and real potential should be further investigated.

Demand data

- Lack of consistent and detailed administrative maps has been a major constraint in the analysis. Access to the map of Sub-locations used in Census 2009 and of the map of settlements, both produced and held by the KBS, would have allowed a far more accurate map of woodfuel consumption.
- Lack of information about the quantity, species preference, and harvest location of woodfuel resources can result in poorly designed policies. In order to foster better decision-making, we recommend that periodic surveys be conducted that include questions designed to accurately assess the magnitude, source, and type of wood harvested for fuel, specifically differentiating between "conventional" fuelwood (stem wood and branches) and "marginal" fuelwood (twigs and fine branches), which are not accounted for in conventional MAI values.
- In addition, we have very little understanding of the coping strategies that households put in place

when woody biomass is scarce. We suspect that people periodically prune trees and shrubs in and around farmlands, and utilize crop residues when they are available. However, such responses may vary seasonally and geographically, and may also be different among different socioeconomic groups. Detailed survey data would also help to reveal these patterns of variation and assist with the design of better policies.

POLICY RELEVANCE

Besides its contribution to the pan-tropical study, the analysis of Kenya has considerable national-level policy relevance. The WISDOM methodology, here applied to estimate NRB values, was in fact, originally conceived as a tool for strategic planning and policy formulation[10].

The estimation of woodfuel-related NRB contributes to the identification of priority areas of intervention for improved stoves projects. NRB values related to direct woodfuel harvesting quantify current emissions and, as such, indicate the mitigation potential of improved stoves programs. Local balance maps help to identify the rural areas suffering from scarcity of local wood resources and thus primary target for subsistence energy programs.

With reference to Kenya's REDD+ Readiness Preparation Proposal (Government of Kenya 2010c), which includes a number of strategy options for addressing the unsustainable use of forest for woodfuel harvesting, the results of this study on the amount of unsustainable exploitations can contribute greatly to the overall definition of national strategy objectives. Moreover, the spatial character of this study can support the tailoring of policy options and interventions per County (or any other administrative layer) by defining County-level policy objectives and the optimal combination of lines of intervention.

The REDD+ RPP identifies a series of lines of interventions that range from sustainable and more efficient charcoal making to sustainable fuelwood production, from promotion of fuel-efficient stoves in households and institutions to increased communities' use of biofuels for cooking and lighting, from establishment of fast growing fuelwood plantations to promotion of agroforestry practices and improved management of woodlands. Each County qualifies differently for these lines of intervention and the current WISDOM geo-database, with the integration of limited additional data, can support the definition of quantitative targets for each County and the definition of the County-specific optimal "blend" of interventions.

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[10] See case studies at www.wisdomprojects.net . Of particular relevance are the studies in Rwanda (update 2012), Sudan, Nepal, Argentina, among others .

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ANNEX 1: CONSUMPTION BY SECTOR

Table A1.1 : Cooking fuel saturation of Kenya households by District (Census 2009)

District	Saturation Fw		Saturation Ch		Other fuels	
	Urb	Rur	Urb	Rur	Urb	Rur
	%	%	%	%	%	%
Kenya total	**19.8**	**90.1**	**37.8**	**7.2**	**42.4**	**2.6**
NAIROBI WEST	2.4		30.2		67.4	
NAIROBI EAST	1.0		11.6		87.4	
NAIROBI NORTH	1.1		13.6		85.3	
WESTLANDS	2.2		14.7		83.1	
NYANDARUA NORTH	40.8	85.9	50.1	12.5	9.1	1.5
NYANDARUA SOUTH	29.0	81.1	53.6	16.7	17.4	2.3
NYERI NORTH	12.6	82.5	55.7	12.5	31.7	5.0
NYERI SOUTH	20.1	89.8	38.0	5.7	41.9	4.4
KIRINYAGA	18.2	84.7	43.0	10.8	38.8	4.5
MURANGA NORTH	19.3	93.0	27.2	2.9	53.5	4.0
MURANGA SOUTH	44.2	90.0	19.5	5.2	36.3	4.8
KIKUYU	16.3	53.6	42.7	34.7	41.0	11.7
LARI	0.0	74.0	0.0	19.5	100.0	6.6
GITHUNGURI	19.4	77.9	40.1	14.7	40.5	7.4
THIKA EAST	10.7	74.4	41.8	16.1	47.5	9.5
THIKA WEST	5.3	41.5	24.6	18.6	70.1	39.9
RUIRU	8.7	90.2	21.4	1.6	69.9	8.2
GATANGA	16.4	82.4	5.5	8.0	78.2	9.5
GATUNDU	18.1	87.1	13.2	7.5	68.7	5.4
KIAMBU & LIMURU	16.7	60.0	39.1	26.3	44.1	13.7
MOMBASA	5.0	81.8	39.9	11.9	55.1	6.3
KILINDINI	6.8	79.6	42.7	14.8	50.6	5.6
KWALE	48.2	91.8	34.5	5.9	17.3	2.4
KINANGO	44.8	92.0	42.4	6.4	12.8	1.6
MSAMBWENI	31.3	93.2	32.3	5.2	36.4	1.6
KILIFI	21.5	92.6	42.6	4.6	35.8	2.7
KALOLENI	17.3	90.6	58.4	5.9	24.3	3.6
MALINDI	17.8	89.0	55.0	7.1	27.2	3.8
TANA RIVER	29.8	88.6	65.2	10.1	5.0	1.3
TANA DELTA	26.2	90.5	63.1	7.9	10.8	1.5
LAMU	16.7	83.4	62.4	13.0	20.9	3.5
TAITA	20.0	76.7	57.7	17.0	22.3	6.3
TAVETA	24.2	87.0	64.4	11.3	11.3	1.7
MARSABIT	58.7	97.1	26.6	2.0	14.7	0.9
CHALBI	0.0	98.5	0.0	0.9	100.0	0.6
LAISAMIS	87.1	97.2	11.0	2.4	1.8	0.5
MOYALE	62.7	98.3	31.3	0.8	6.0	1.0
ISIOLO	25.7	90.2	64.1	6.7	10.2	3.1
GARBATULA	84.9	96.3	11.7	2.8	3.4	0.8
MERU CENTRAL	0.0	90.5	0.0	6.6	100.0	2.9
IMENTI NORTH	17.7	80.0	50.4	15.3	31.8	4.7
IMENTI SOUTH	14.1	89.6	63.6	7.9	22.3	2.5
MERU SOUTH	44.4	91.9	33.8	5.4	21.8	2.6
MAARA	62.2	93.0	19.2	4.7	18.6	2.4
IGEMBE	13.5	88.2	55.1	8.6	31.4	3.1
TIGANIA	41.7	94.3	44.8	4.2	13.5	1.5
THARAKA	46.1	95.3	36.1	3.9	17.8	0.9
EMBU	21.2	87.9	42.8	7.8	36.0	4.3
MBEERE	27.1	89.9	44.8	6.5	28.1	3.6
KITUI	40.0	93.4	39.3	5.1	20.8	1.5
MUTOMO	10.6	94.9	68.1	3.9	21.3	1.2
MWINGI	3.7	94.9	65.3	4.2	31.1	1.0
KYUSO	11.4	95.4	71.4	3.7	17.1	0.9
MACHAKOS	12.6	83.2	34.4	11.4	53.0	5.4
MWALA	9.0	91.6	60.0	6.0	31.0	2.4
YATTA	31.9	91.0	35.9	6.0	32.3	3.0
KANGUNDO	66.6	87.8	20.6	8.9	12.7	3.4
MAKUENI	40.7	92.5	39.3	5.7	19.9	1.8
MBOONI	9.3	92.4	70.4	6.0	20.4	1.7
KIBWEZI	11.7	88.1	64.2	9.0	24.2	2.9
NZAUI	1.1	91.0	60.5	6.4	38.4	2.5
GARISSA	18.4	95.6	73.1	3.3	8.5	1.1

District	Saturation Fw		Saturation Ch		Other fuels	
	Urb	Rur	Urb	Rur	Urb	Rur
	%	%	%	%	%	%
LAGDERA	77.3	96.5	15.9	1.9	6.8	1.6
FAFI	80.7	96.1	19.3	2.2	0.0	1.7
IJARA	44.0	96.2	51.6	2.9	4.4	0.9
WAJIR SOUTH	83.7	97.8	10.2	1.1	6.1	1.1
WAJIR NORTH	0.0	97.4	0.0	1.6	100.0	1.0
WAJIR EAST	65.2	95.1	26.3	3.5	8.5	1.4
WAJIR WEST	0.0	97.3	0.0	1.4	100.0	1.3
MANDERA CENTRAL	92.1	98.6	5.3	1.0	2.6	0.4
MANDERA EAST	42.4	95.4	53.8	3.2	3.8	1.4
MANDERA WEST	94.7	97.7	1.8	1.4	3.5	0.9
SIAYA	28.0	89.9	62.7	8.2	9.3	1.8
BONDO	30.0	80.1	59.0	17.3	11.0	2.6
RARIEDA	25.9	88.2	55.5	9.0	18.5	2.7
KISUMU EAST	11.0	79.7	60.1	14.9	29.0	5.4
KISUMU WEST	10.4	90.1	63.1	7.4	26.5	2.5
NYANDO	33.7	89.3	52.3	8.3	13.9	2.4
HOMABAY	25.0	92.1	65.7	6.3	9.3	1.6
SUBA	11.5	85.1	75.1	12.7	13.4	2.2
RACHUONYO	49.4	90.1	45.1	8.0	5.5	1.8
MIGORI	29.3	92.0	60.3	6.6	10.4	1.4
RONGO	51.2	91.1	38.0	7.1	10.8	1.8
KURIA WEST	17.2	89.1	70.8	9.0	11.9	1.9
KURIA EAST	0.0	91.8	0.0	6.7	100.0	1.6
KISII CENTRAL	22.7	91.6	52.5	5.7	24.7	2.7
KISII SOUTH	72.4	92.4	19.9	4.7	7.7	2.9
MASABA	62.2	93.2	30.3	4.9	7.4	1.9
GUCHA	25.4	93.1	52.4	4.7	22.2	2.2
GUCHA SOUTH	76.8	94.0	17.5	3.4	5.7	2.7
NYAMIRA	60.1	93.8	27.8	4.1	12.1	2.1
MANGA	0.0	92.3	0.0	4.9	100.0	2.7
BORABU	39.2	92.8	45.1	5.1	15.7	2.1
TURKANA CENTRAL	38.0	94.6	57.1	4.7	4.9	0.7
TURKANA NORTH	57.7	94.2	36.3	4.6	5.9	1.2
TURKANA SOUTH	0.0	90.6	0.0	8.4	100.0	0.9
WEST POKOT	31.8	94.6	61.7	3.5	6.5	1.9
POKOT NORTH	0.0	97.4	0.0	2.0	100.0	0.5
POKOT CENTRAL	0.0	96.3	0.0	3.2	100.0	0.5
SAMBURU CENTRAL	11.5	87.9	82.2	10.8	6.3	1.3
SAMBURU EAST	28.3	93.5	65.7	5.2	6.1	1.3
SAMBURU NORTH	37.3	95.0	58.7	4.4	4.1	0.5
TRANS NZOIA WEST	18.4	87.0	66.2	9.4	15.4	3.6
TRANS NZOIA EAST	0.0	90.2	0.0	7.8	100.0	2.0
KWANZA	73.5	90.1	23.6	7.1	2.9	2.8
BARINGO	32.9	93.3	58.3	5.1	8.8	1.6
BARINGO NORTH	45.5	94.9	54.5	4.2	0.0	0.9
EAST POKOT	0.0	97.0	0.0	2.4	100.0	0.6
KOIBATEK	40.0	92.2	53.9	6.6	6.1	1.2
ELDORET WEST	8.3	87.6	61.1	9.3	30.5	3.1
ELDORET EAST	11.4	87.5	59.0	9.9	29.6	2.6
WARENG	10.6	83.8	63.3	12.7	26.1	3.5
MARAKWET	37.5	94.5	54.7	4.7	7.8	0.8
KEIYO	50.3	93.2	42.4	5.3	7.3	1.5
NANDI NORTH	37.5	93.8	50.9	4.8	11.5	1.4
NANDI CENTRAL	44.2	91.6	46.2	6.4	9.6	2.0
NANDI EAST	31.6	92.5	51.2	5.4	17.1	2.1
NANDI SOUTH	0.0	94.1	0.0	4.5	100.0	1.4
TINDERET	0.0	94.3	0.0	4.6	100.0	1.0
LAIKIPIA NORTH	0.0	85.1	0.0	11.7	100.0	3.1
LAIKIPIA EAST	9.5	78.8	56.0	16.5	34.5	4.7
LAIKIPIA WEST	11.4	85.8	69.4	13.0	19.2	1.2
NAKURU	3.9	74.3	63.7	20.8	32.4	4.9
NAKURU NORTH	22.4	73.2	60.1	23.1	17.5	3.7
NAIVASHA	8.5	60.2	61.4	31.1	30.0	8.7
MOLO	25.8	85.3	66.8	12.7	7.3	2.0

District	Saturation Fw Urb	Saturation Fw Rur	Saturation Ch Urb	Saturation Ch Rur	Other fuels Urb	Other fuels Rur
	%	%	%	%	%	%
NAROK NORTH	4.6	78.5	80.3	19.3	15.1	2.2
NAROK SOUTH	0.0	88.5	0.0	7.7	100.0	3.8
TRANS MARA	11.0	93.1	76.6	4.8	12.4	2.1
KAJIADO CENTRAL	7.9	86.7	70.0	10.4	22.1	2.9
LOITOKITOK	29.3	85.9	54.6	11.8	16.1	2.3
KERICHO	28.7	92.1	54.8	5.1	16.6	2.8
KIPKELION	69.2	95.0	27.3	3.9	3.4	1.1
BURET	25.1	92.1	53.9	5.5	20.9	2.4
SOTIK	17.2	93.7	55.5	4.0	27.2	2.3
BOMET	58.7	94.2	33.2	4.2	8.1	1.6
KAJIADO NORTH	4.9	56.8	29.9	21.0	65.3	22.1
KAKAMEGA CENTRAL	20.1	93.8	54.6	3.9	25.3	2.3
KAKAMEGA SOUTH	0.0	96.2	0.0	1.6	100.0	2.2
KAKAMEGA NORTH	49.0	93.1	41.0	5.2	10.0	1.7
KAKAMEGA EAST	67.6	91.4	27.0	5.2	5.4	3.4
LUGARI	46.1	91.5	39.2	6.2	14.7	2.3
VIHIGA	77.9	93.1	13.4	3.9	8.7	2.9
EMUHAYA	73.0	94.5	19.0	3.3	7.9	2.3
HAMISI	0.0	92.2	0.0	5.0	100.0	2.9
MUMIAS	36.2	93.9	42.1	4.1	21.7	2.0
BUTERE	52.5	95.0	29.0	3.3	18.6	1.8
BUNGOMA SOUTH	17.0	92.1	63.7	5.9	19.3	2.0
BUNGOMA NORTH	70.9	93.5	22.3	4.4	6.8	2.0
BUNGOMA EAST	29.6	91.6	54.1	6.4	16.3	2.0
BUNGOMA WEST	0.0	90.7	0.0	7.0	100.0	2.3
MT ELGON	34.6	93.6	54.2	4.5	11.2	1.9
BUSIA	13.5	92.1	74.7	6.2	11.8	1.7
TESO NORTH	23.7	92.9	60.2	5.4	16.2	1.7
SAMIA	0.0	91.4	0.0	6.9	100.0	1.7
BUNYALA	32.6	88.7	61.6	9.2	5.8	2.1
TESO SOUTH	20.0	92.3	65.4	6.2	14.5	1.5
BUNGOMA SOUTH	16.3	53.6	42.7	34.7	41.0	11.7
BUNGOMA NORTH	0.0	74.0	0.0	19.5	100.0	6.6
BUNGOMA EAST	19.4	77.9	40.1	14.7	40.5	7.4
BUNGOMA WEST	10.7	74.4	41.8	16.1	47.5	9.5
MT ELGON	5.3	41.5	24.6	18.6	70.1	39.9
BUSIA	8.7	90.2	21.4	1.6	69.9	8.2
TESO NORTH	16.4	82.4	5.5	8.0	78.2	9.5
SAMIA	18.1	87.1	13.2	7.5	68.7	5.4
BUNYALA	16.7	60.0	39.1	26.3	44.1	13.7
TESO SOUTH	5.0	81.8	39.9	11.9	55.1	6.3

Table A1.2 : Per capita fuel consumption of woodfuels users in the residential sector

Use of Fuelwood (od kg/person/year)

Area	Fuelwood users		Charcoal users		Farm residues users		Other users	
	avg	±@95%	avg	±@95%	avg	±@95%	avg	±@95%
Rural Avg	**467**	***11***	**93**	***13***	**201**	***73***	**74**	***22***
Central	653	*39*	110	*31*	107	*210*	69	*37*
Coast	387	*34*	45	*33*			22	*24*
East_N	450	*41*	60	*39*			74	*27*
East_S	460	*28*	114	*46*	852	*932*	86	*49*
NorthE	371	*60*	0					
Nyanza	448	*28*	84	*15*	257	*166*	110	*59*
Rift_V_N	411	*51*	5	*7*				
Rift_V_S	464	*23*	98	*30*	102	*62*	76	*53*
West	452	*32*	62	*30*	204	*104*	52	*41*
Urban Avg	**431**	***42***	**14**	***2***	**31**	***47***	**7**	***3***
Nairobi	858	*492*	16	*16*			11	*7*
Central	697	*248*	9	*7*			9	*6*
Coast	393	*133*	11	*5*			1	*1*
East_N	304	*111*	22	*13*	48		0	
East_S	577	*161*	14	*8*			3	*3*
NorthE	321	*98*	1	*2*			0	
Nyanza	537	*168*	18	*6*	0		3	*4*
Rift_V_N	346	*185*	4	*5*			0	
Rift_V_S	385	*68*	14	*4*	0		12	*11*
West	395	*69*	17	*6*	65	*110*	2	*3*
Tot Kenya	**464**	***11***	**36**	***4***	**176**	***64***	**15**	***4***

Use of Charcoal (kg/person/year)

Area	Fuelwood users		Charcoal users		Farm residues users		Other users	
	avg	±@95%	avg	±@95%	avg	±@95%	avg	±@95%
Rural Avg	**11**	***1***	**238**	***16***	**3**	***2***	**94**	***21***
Central	24	*5*	290	*31*	25	*19*	81	*24*
Coast	3	*2*	171	*35*			31	*26*
East_N	6	*3*	122	*50*			0	
East_S	11	*2*	194	*59*	0		40	*29*
NorthE	0	*0*	40					
Nyanza	16	*3*	192	*27*	3	*5*	98	*68*
Rift_V_N	4	*4*	61	*27*				
Rift_V_S	9	*2*	297	*34*	3	*3*	156	*54*
West	8	*2*	147	*37*	0		37	*46*
Urban Avg	**20**	*4*	**269**	*10*	**14**	*12*	**71**	*6*
Nairobi	5	*9*	261	*43*			42	*7*
Central	49	*37*	329	*39*			53	*12*
Coast	9	*6*	231	*35*			57	*11*
East_N	14	*13*	227	*60*	63		13	*25*
East_S	27	*20*	303	*34*			107	*23*
NorthE	4	*4*	172	*23*			0	
Nyanza	40	*16*	268	*21*	12		121	*30*
Rift_V_N	7	*9*	194	*57*			21	*28*
Rift_V_S	29	*12*	281	*18*	0		96	*17*
West	19	*7*	265	*27*	19	*17*	116	*33*
Tot Kenya	**12**	*1*	**260**	*8*	**5**	*3*	**74**	*6*

Use of DendroEnergy Biomass (od kg/person/year) **Medium variant [Ch Yield: 24%]**

Area	Fuelwood users		Charcoal users		Farm residues users		Other users	
	avg	±@95%	avg	±@95%	avg	±@95%	avg	±@95%
Rural Avg	**442**	***11***	**1072**	***71***	**184**	***62***	**456**	***90***
Central	656	*44*	1304	*138*	197	*183*	396	*105*
Coast	343	*31*	752	*157*			149	*105*
East_N	407	*36*	561	*213*			63	*23*
East_S	435	*26*	906	*273*	724	*792*	242	*117*
NorthE	317	*51*	167					
Nyanza	449	*28*	869	*113*	230	*139*	500	*286*
Rift_V_N	368	*49*	258	*112*				
Rift_V_S	431	*22*	1319	*148*	98	*55*	713	*231*
West	417	*30*	663	*158*	173	*88*	200	*188*
Urban Avg	**452**	***44***	**1131**	***41***	**86**	***71***	**300**	***25***
Nairobi	748	*416*	1100	*181*			186	*31*
Central	797	*289*	1379	*161*			227	*50*
Coast	373	*121*	970	*147*			236	*47*
East_N	318	*106*	967	*249*	303		53	*105*
East_S	603	*169*	1276	*143*			449	*96*
NorthE	288	*86*	717	*95*			0	
Nyanza	622	*186*	1133	*88*	50		505	*126*
Rift_V_N	324	*161*	813	*236*			89	*116*
Rift_V_S	446	*94*	1182	*74*	0		412	*72*
West	413	*70*	1119	*110*	136	*120*	487	*139*
Tot Kenya	**443**	***11***	**1115**	***35***	**169**	***54***	**319**	***24***

Table A1.3 : Total fuelwood and charcoal consumption

	Fuelwood consumption			Charcoal consumption		
	Urban HH	Rural HH	Other uses	Urban HH	Rural HH	Other uses
County	kt od	kt od	kt od	Ch. kt	Ch. kt	Ch. kt
Nairobi	63	0	559	245	0	159
Nyandarua	26	232	54	21	32	6
Nyeri	19	256	75	29	27	9
Kirinyaga	10	215	50	14	25	4
Murang'a	33	327	75	16	24	7
Kiambu	82	341	242	146	52	52
Mombasa	22	0	167	118	0	48
Kwale	14	163	54	12	7	6
Kilifi	20	249	102	39	11	14
Tana River	4	61	19	6	4	2
Lamu	1	23	9	3	2	1
Taita Taveta	5	59	25	10	7	3
Marsabit	11	85	25	5	2	3
Isiolo	6	29	16	8	1	3
Meru	10	446	115	23	33	6
Tharaka	21	105	41	10	5	4
Embu	9	156	49	14	11	4
Kitui	25	327	97	23	17	7
Machakos	101	190	145	78	13	29
Makueni	16	285	74	18	19	5
Garissa	11	145	55	17	1	7
Wajir	17	173	52	4	1	5
Mandera	35	259	85	9	1	9
Siaya	13	260	79	17	26	5
Kisumu	42	159	163	98	16	26
Homa Bay	23	289	96	25	26	7
Migori	61	215	99	49	18	16
Kisii	63	357	125	36	26	14
Nyamira	19	151	41	8	11	3
Turkana	18	239	66	11	6	6
West Pokot	4	158	36	5	3	2
Samburu	3	59	18	6	2	2
Trans Nzoia	15	234	70	32	23	8
Baringo	8	186	41	11	11	3
Uasin Gishu	15	193	95	70	23	18
KeiyoMarakwet	9	119	29	8	8	3
Nandi	15	243	84	16	16	5
Laikipia	4	103	36	20	16	5
Nakuru	32	280	185	151	58	37
Narok	2	281	65	14	32	3
Kajiado	9	127	76	45	25	14
Kericho	35	135	68	33	9	12
Bomet	22	283	91	18	19	7
Kakamega	29	512	260	38	20	13
Vihiga	45	138	58	11	5	9
Bungoma	38	387	155	42	17	15
Busia	9	223	82	24	11	6
Kenya	**1095**	**9454**	**4302**	**1655**	**718**	**634**

Table A1.4 : DEB consumption other than residential cooking: construction material and woodfuel consumption by public, commercial and industrial sectors.

	Construction material		Public sector	Commercial and cottage industries Medium variant
	Urban HH	Rural HH	Schools, Hospitals, prisons)	Restaurants, Brick making, Tobacco Curing, fish smoking, jaggary, tea drying
County	kt od	kt od	kt od	kt od
Nairobi	18	0	126	1,079
Nyandarua	1	9	24	43
Nyeri	1	10	28	72
Kirinyaga	0	9	21	37
Murang'a	1	12	31	61
Kiambu	6	15	72	365
Mombasa	5	0	38	323
Kwale	1	10	26	41
Kilifi	2	16	45	100
Tana River	0	4	10	13
Lamu	0	2	4	7
Taita Taveta	0	4	11	22
Marsabit	0	4	12	22
Isiolo	0	2	6	22
Meru	1	24	55	60
Tharaka	0	5	15	38
Embu	0	8	21	37
Kitui	1	17	41	68
Machakos	3	10	44	208
Makueni	1	15	36	44
Garissa	1	9	25	51
Wajir	1	11	27	34
Mandera	1	16	41	65
Siaya	1	14	34	50
Kisumu	3	9	39	219
Homa Bay	1	16	39	69
Migori	2	12	37	114
Kisii	2	19	51	111
Nyamira	0	8	20	27
Turkana	1	14	34	43
West Pokot	0	9	21	16
Samburu	0	4	9	14
Trans Nzoia	1	13	33	59
Baringo	0	9	22	22
Uasin Gishu	2	11	36	120
KeiyoMarakwet	0	6	15	19
Nandi	1	12	30	63
Laikipia	1	6	16	35
Nakuru	4	17	64	255
Narok	0	15	34	28
Kajiado	2	8	28	99
Kericho	1	7	24	84
Bomet	1	15	36	68
Kakamega	1	27	67	218
Vihiga	1	7	22	64
Bungoma	2	21	55	141
Busia	1	12	30	66
Kenya	**70**	**502**	**1,553**	**4,816**

Table A1.5: Total DendroEnergy Biomass (DEB) consumption. Minimum, Medium and Maximum consumption variants calculated assuming 31%, 24% and 17% charcoal yield, respectively.

	Total DendroEnergy Biomass (DEB) consumption kt od (wood equivalent)		
County	Low variant (31%CY)	**Medium variant (24%CY)**	High variant (17%CY)
Nairobi	1,927	**2,308**	3,003
Nyandarua	500	**554**	654
Nyeri	558	**619**	729
Kirinyaga	414	**454**	529
Murang'a	587	**631**	711
Kiambu	1,469	**1,704**	2,131
Mombasa	723	**878**	1,162
Kwale	311	**334**	376
Kilifi	579	**640**	751
Tana River	120	**130**	150
Lamu	53	**59**	70
Taita Taveta	153	**171**	205
Marsabit	153	**162**	179
Isiolo	92	**104**	125
Meru	770	**827**	933
Tharaka	232	**251**	285
Embu	309	**337**	387
Kitui	600	**643**	723
Machakos	825	**938**	1,145
Makueni	511	**550**	623
Garissa	290	**314**	356
Wajir	273	**281**	298
Mandera	441	**460**	494
Siaya	505	**549**	631
Kisumu	814	**946**	1,185
Homa Bay	595	**650**	749
Migori	642	**720**	863
Kisii	711	**774**	888
Nyamira	359	**389**	443
Turkana	398	**419**	459
West Pokot	232	**242**	259
Samburu	109	**118**	134
Trans Nzoia	524	**584**	693
Baringo	317	**340**	384
Uasin Gishu	659	**763**	952
KeiyoMarakwet	215	**232**	263
Nandi	462	**497**	562
Laikipia	274	**313**	382
Nakuru	1,292	**1,524**	1,947
Narok	505	**551**	635
Kajiado	483	**562**	706
Kericho	412	**462**	555
Bomet	535	**575**	649
Kakamega	1,031	**1,098**	1,220
Vihiga	323	**346**	389
Bungoma	820	**890**	1,017
Busia	446	**484**	554
Kenya	**24,552**	**27,380**	**32,540**

ANNEX 2: SUPPLY PARAMETERS

Figure A2.1 shows the map combining land use, forest type and forest density layers of KFS 2010 dataset and two layers derived from LCCS 2008 (trees and shrub densities) that were used to estimate and map the supply potential.

Figure A2.1 : Land cover data: KFS 2010 Forest Map and trees and shrub density layers derived from LCCS 2008

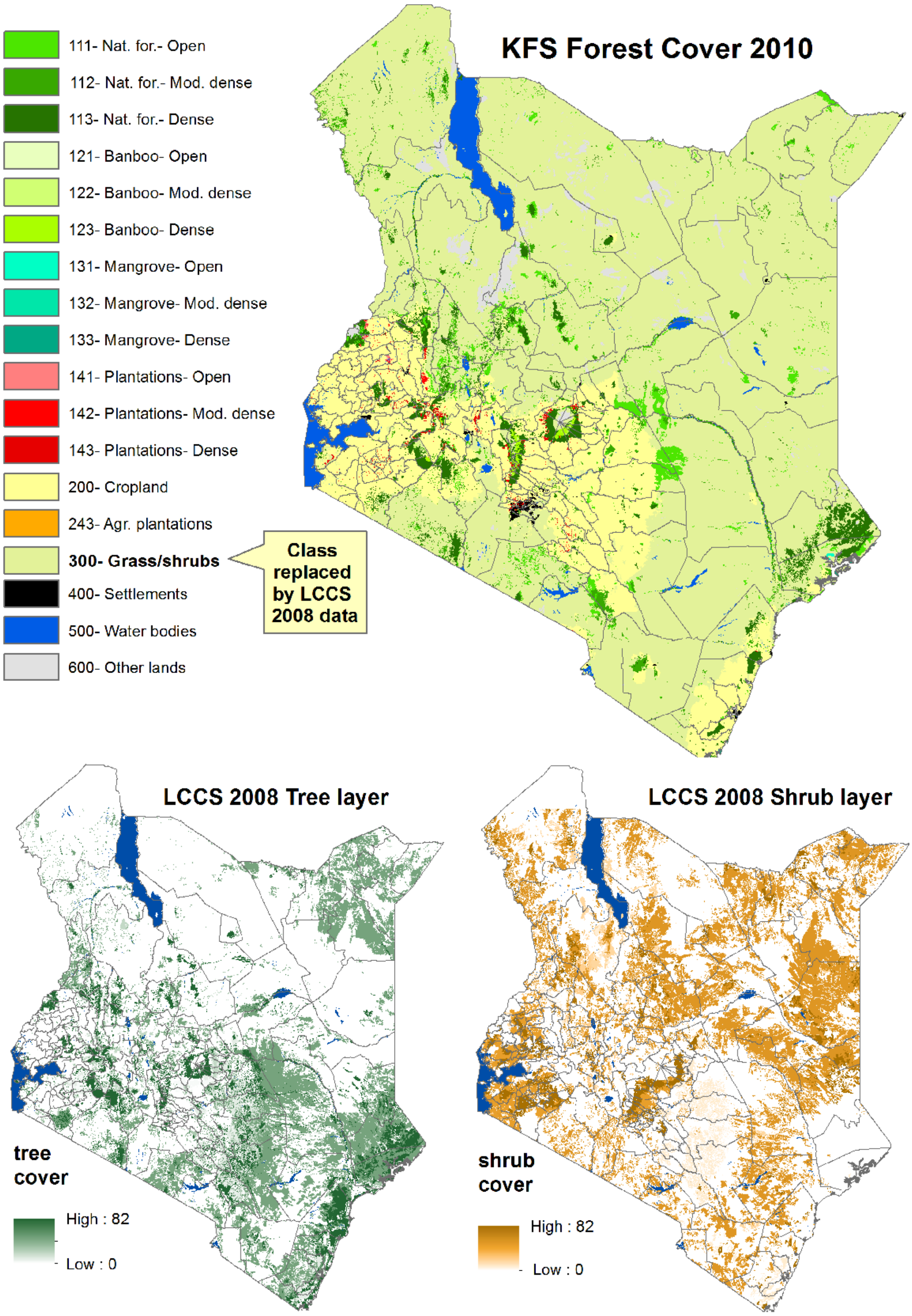


Table A2.1 : Reference stock values by Agro Climatic Zones (Values : DEB in od t / ha)

Land Use	Type	Density	Agro Climatic Zones: Humid	Subhumid	Semihumid	Semihumid to Semiarid	Semiarid	Arid	Very arid
Cropland	na	na	14	11	8	6	4	2	1
	Plantations	Very Dense > 65% CC	186	146	142	128	105		
Forestland	Nat.forest	Open 15 - 40% CC	81	68	57	45	34	22	14
		Mod.Dense 40-65% CC	155	130	108	86	64	42	27
		Very Dense > 65% CC	243	205	170	135	101	66	43
	Bamboo	Open 15 40% CC	7	7					
		Mod.Dense 4065% CC	13	13					
		Very Dense > 65% CC	21	21					
	Mangroves	Open 15 - 40% CC		46	46	46	46		
		Mod.Dense 40-65% CC		87	87	87	87		
		Very Dense > 65% CC		137	137	137	137		
	Plantations	Open 15 - 40% CC	62	49	47	43	35		
		Mod.Dense 40-65% CC	119	93	90	82	67		
		Very Dense > 65% CC	186	146	142	128	105		
Grass/ shrub	na	na	**Vegetation density from LCCS2008:** For tree cover and bamboo cover, use values above. For **shrubs**, use values below						
Otherlands	na	na							
	Shrubs	Mod.Dense 40-65% CC	18.2	15.8	13.8	12.0	10.2	8.4	3.9
Settlements	na	na	2	2	2	2	2	2	2
Water/ Wetlands	na	na	0	0	0	0	0	0	0

Table A2.2 : Reference MAI values by Agro Climatic Zones (Values : DEB in od t/ha/year)

Land Use	Type	Density	Agro Climatic Zones: Humid	Subhumid	Semihumid	Semihumid to Semiarid	Semiarid	Arid	Very arid
Cropland	na	na	**Apply the MAI-Stock Equation**						
	Plantations	Very Dense > 65% CC							
Forestland	Nat.forest	Open 15 - 40% CC							
		Mod.Dense 40-65% CC							
		Very Dense > 65% CC							
	Bamboo	Open 15 - 40% CC							
		Mod.Dense 40-65% CC							
		Very Dense > 65% CC							
	Mangroves	Open 15 - 40% CC							
		Mod.Dense 40-65% CC							
		Very Dense > 65% CC							
	Plantations	Open 15 - 40% CC	2.28	1.83	1.61	1.42	1.17	2.28	
		Mod.Dense 40-65% CC	4.35	3.49	3.07	2.71	2.23	4.35	
		Very Dense > 65% CC	6.84	5.49	4.83	4.26	3.50	6.84	
Grass/ shrub	na	na	**Apply the MAIStock Equation**						
Otherlands	na	na							
	Shrubs	Mod.Dense 40-65% CC							
Settlements	na	na							
Water/ Wetlands	na	na							

Figure A2.2 : Agro Climatic Zones

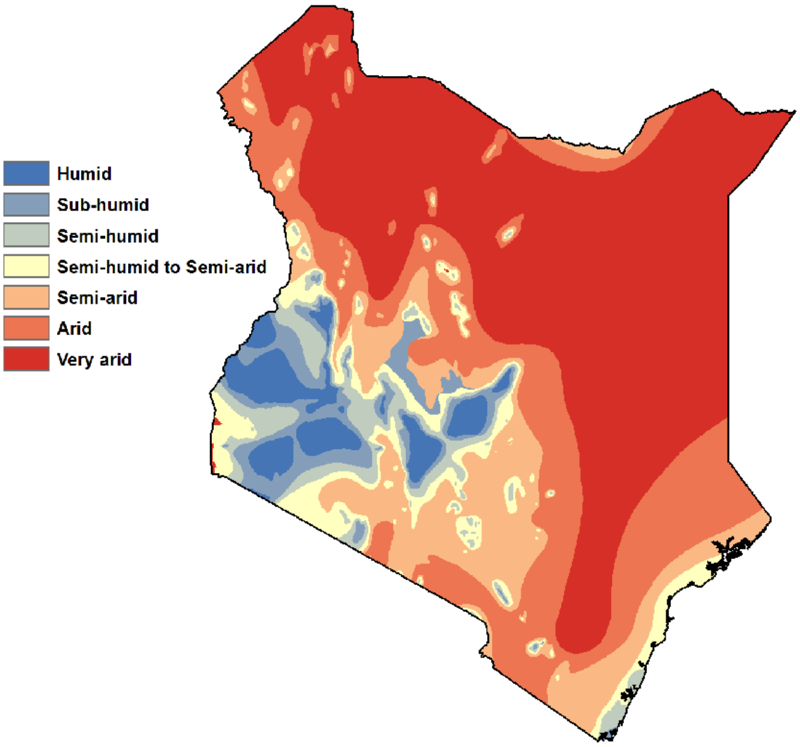


Figure A2.3 : Stock vs MAI relations for natural broadleaves and coniferous formations in tropical and subtropical zones

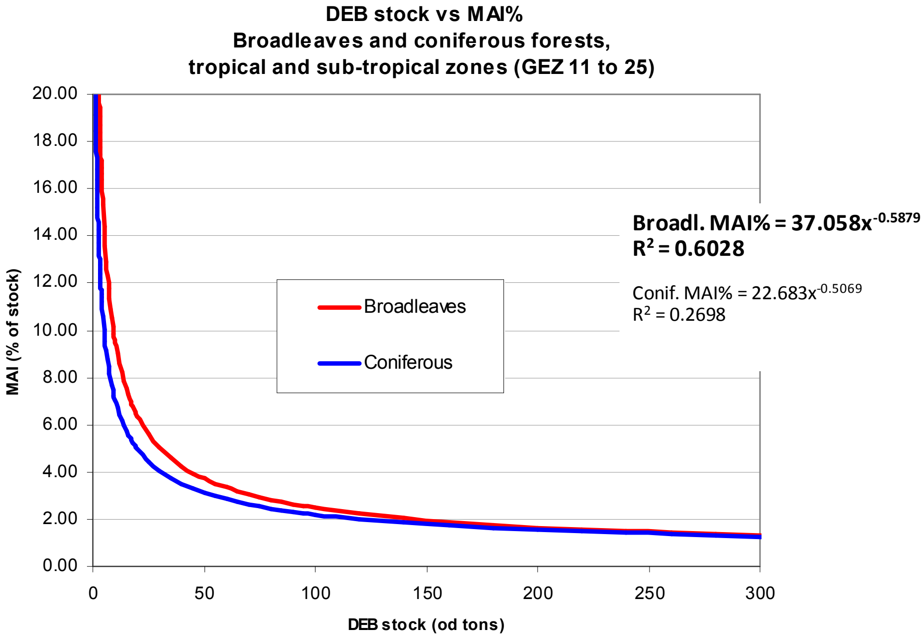
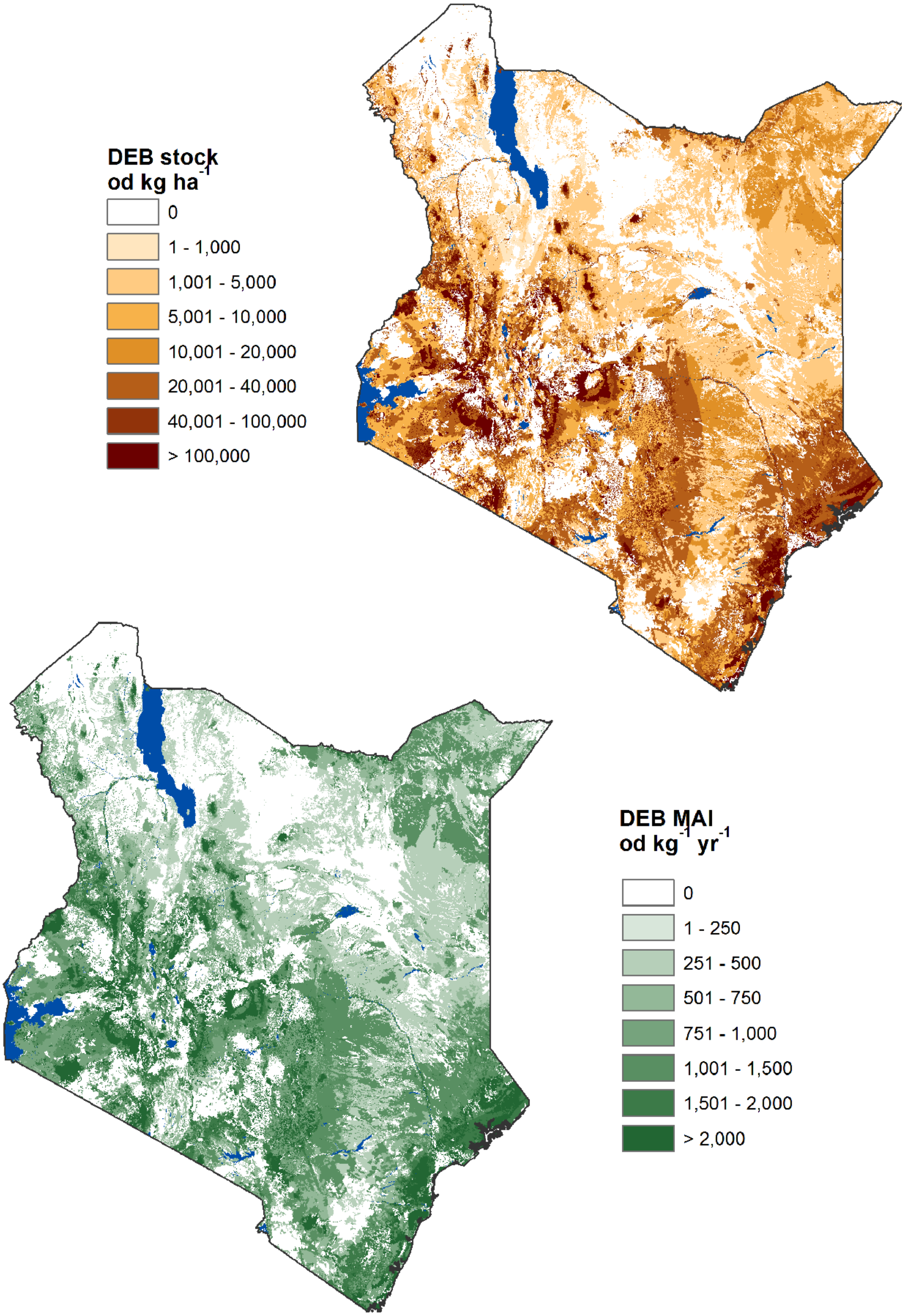


Figure A2.4 : Maps of DEB stock and MAI



ANNEX 3: ACCESSIBILITY OF BIOMASS RESOURCES

1 Physical accessibility

Offroad accessibilityTravel time to nearest access feature (city, populated area, motorable road, cart tract)

Assuming that the resources that are located along communication routes (motorable roads and cart tracts) or that are close to populated places (urban centres, villages and densely populated rural areas) have highest accessibility, it may be assumed that the accessibility of the resources located far from such features are inversely proportional to the time (or effort) necessary to reach them (considering here the time needed to go and return with fuelwood load).

In order to associate a parameter of physical accessibility to the legallyaccessible woody biomass resources, a **fuelwood transport time map** is produced following and adapting the procedure implemented in Tier 1 analysis. The specific features of the Kenya study include:

- the estimation of woodfuels transport time (rather than travel time) considering the time needed for the return trip with additional friction due to the load of fuelwood or charcoal;
- the redefinition of the target locations based on the most detailed available national maps (road, tracts, trail, footpaths, railways and builtup areas),
- the use of 90m elevation model for slope mapping and
- use of best available land cover data, and the adaptation of friction factors and slope factors to Kenya situation.

Target locations

The target locations are all accessible areas, including:

1. Populated places,:

    a. Densely populated areas (urban and villages). The mask of the densely populated rural areas is **fric_pop_mkm**, derived from the map urbrur_cl1. The value is 8 for the 8min/km (return trip; @ 15km/hr) assumed [same speed of builtup area])

2. Communication features:

    a. Road network (map: **k_rd_mn1**), derived from gROADSv1, combining Functional Class and Surface Type (see list of road types in Table A3.1).
    Railways are not used as target since the accessible entry points are the stations that are already included in populated area layer.

The target locations (or source features of costdistance analysis) is composed by the layers described above, merged into a single map (**target_mkm**) with **k_rd_mn1** over **fric_pop_mkm**.

Friction surface components

Land cover friction

The base friction values applied to land cover classes and communication features, intended as transport time in minutes per km (return trip loaded) assuming flat terrain are reported in Table A3.1.

Land cover friction map: **fric_lc_mkm**. Friction of land cover classes in minutes per km considering round trip (return trip loaded).

Table A3.1: Friction values (transport time in minutes / km return trip) applied to land cover classes and communication features, assuming flat terrain.

KFS Classes		Going m/km	loaded factor	Return loaded	tot return trip min/km
	Open 15 40% CC	26	1.5	39	**65**
Nat.forest	Mod.Dense 40 65% CC	28	1.5	42	**70**
	Very Dense > 65% CC	30	1.5	45	**75**
	Open 15 40% CC	26	1.5	39	**65**
Bamboo	Mod.Dense 40 65% CC	28	1.5	42	**70**
	Very Dense > 65% CC	30	1.5	45	**75**
	Open 15 40% CC	40	1.5	60	**100**
Mangroves	Mod.Dense 40 65% CC	40	1.5	60	**100**
	Very Dense > 65% CC	40	1.5	60	**100**
	Open 15 40% CC	16	1.5	24	**40**
Plantations	Mod.Dense 40 65% CC	18	1.5	27	**45**
	Very Dense > 65% CC	20	1.5	30	**50**
Water/Wetlands		60	1	60	**120**

LCCS2008 Classes				
Urban and associated areas, rural settlements	4	1	4	**8**
Irrigated herbaceous crop	16	1.5	24	**40**
Rainfed herbaceous crop	16	1.5	24	**40**
Rice fields	16	1.5	24	**40**
Bare areas	18	1.5	27	**45**
Open to closed herbaceous vegetation	18	1.5	27	**45**
Rainfed shrub crop	18	1.5	27	**45**
Tree crop	18	1.5	27	**45**
Forest plantation undifferentiated	20	1.5	30	**50**
Open shrubs (6540% crown cover)	20	1.5	30	**50**
Sparse shrub	20	1.5	30	**50**
Very open shrubs (4015% crown cover)	20	1.5	30	**50**
Closed shrubs	24	1.5	36	**60**
Very open trees (4015% crown cover)	26	1.5	39	**65**
Trees and shrubs savannah	27	1.5	40.5	**67.5**
Open trees (6540% crown cover)	28	1.5	42	**70**
Closed trees	30	1.5	45	**75**
Open to closed herb. veg. on temporarily flooded	30	1.5	45	**75**
Open to closed shrubs veg. on temporarily flooded	30	1.5	45	**75**
Open trees on temporarily flooded land	30	1.5	45	**75**
Closed herbaceous veg. on permanently flooded land	40	1.5	60	**100**
Mangrove (Trees)	40	1.5	60	**100**
Permanent Snow and Ice	40	1.5	60	**100**
Waterbodies	60	1	60	**120**

Communication features		Going m/km	loaded factor	Return loaded	tot return trip min/km
1=Highway	1=Paved	1	1	1	**2**
	2=Gravel	1.5	2	3	**4.5**
	3=Dirt/Sand	2	3	6	**8**
2=Primary	0=Unspecified	2	4	8	**10**
	1=Paved	1.5	5	7.5	**9**
	2=Gravel	2	6	12	**14**
	3=Dirt/Sand	3	7	21	**24**
3=Secondary	0=Unspecified	3	8	24	**27**
	1=Paved	2	9	18	**20**
	2=Gravel	3	10	30	**33**
	3=Dirt/Sand	4	11	44	**48**
4=Tertiary	0=Unspecified	3	12	36	**39**
	1=Paved	2.5	13	32.5	**35**
	2=Gravel	3	14	42	**45**
	3=Dirt/Sand	4	15	60	**64**
6=Trail	0=Unspecified	6	16	96	**102**
Railway		3	1	3	**6**

Slope factor

The slope map was produced on the basis of the Digital Elevation Model of 90m spatial resolution (source: SRTM[11] 3 arcsecond). The effect of slope on travel speed is estimated following Nelson's approach, which was based on van Wagtendonk and Benedict (1980)[12] and is computed as follows: **v = v0eks** , where:

v = off road foot based velocity over the sloping terrain,
v0 = the base speed of travel over flat terrain, 5km/hr in this case,
s = slope in gradient (metres per metre) and,
k = a factor which defines the effect of slope on travel speed

For the Kenya case study a base walking speed of 5km/hr and k = 2.0 were assumed (and constant for uphill and downhill travel). The velocities over the slope grid were computed and then converted into a friction factor by dividing the base speed by the slope speed. This was then used as a multiplier against footbased travel components (map = **slp_factor**). The estimated effect of slope on offroad speed and on crossing time are shown in Table A3.2.

Table A3.2: Effect of slope on offroad speed and on crossing time

slope %	gradient meter per meter	crossing time factor	speed decrease factor
0	0	1.00	1.00
1	0.01	1.03	0.97
2	0.02	1.07	0.94
5	0.05	1.17	0.85
10	0.1	1.38	0.72
15	0.15	1.62	0.62
20	0.2	1.90	0.53
25	0.25	2.24	0.45
30	0.3	2.63	0.38
35	0.35	3.09	0.32
40	0.4	3.62	0.28
45	0.45	4.26	0.23
50	0.5	5.00	0.20
60	0.6	6.90	0.14
70	0.7	9.52	0.11
80	0.8	13.13	0.08
90	0.9	18.12	0.06
100	1	25.00	0.04
200	2	625.00	0.00

Costdistance analysis

The cost feature is represented by the cell crossing friction (in minutes per km) resulting from the combination of the friction surface components described above, as follows:

- The friction of land cover classes (no roads and paths) considering slope (in minutes per km considering round trip with return trip loaded) [**fric_mkm**]

Adding friction of land cover classes (considering slope) and roads, tracks and footpaths. [**fric2lcslpmkm**]

Final friction map for local accessibility to nearest target feature as minutes per meter : **fric_m_m** (=**fric_mkm / 1000**). Friction and target maps are shown in Figure A3.1.

Offroad travel time to nearest accessible feature resulting from costdistance analysis (minutes):

Source: **target_0**; Cost: **fric_m_m** = **cd_min_t_0**

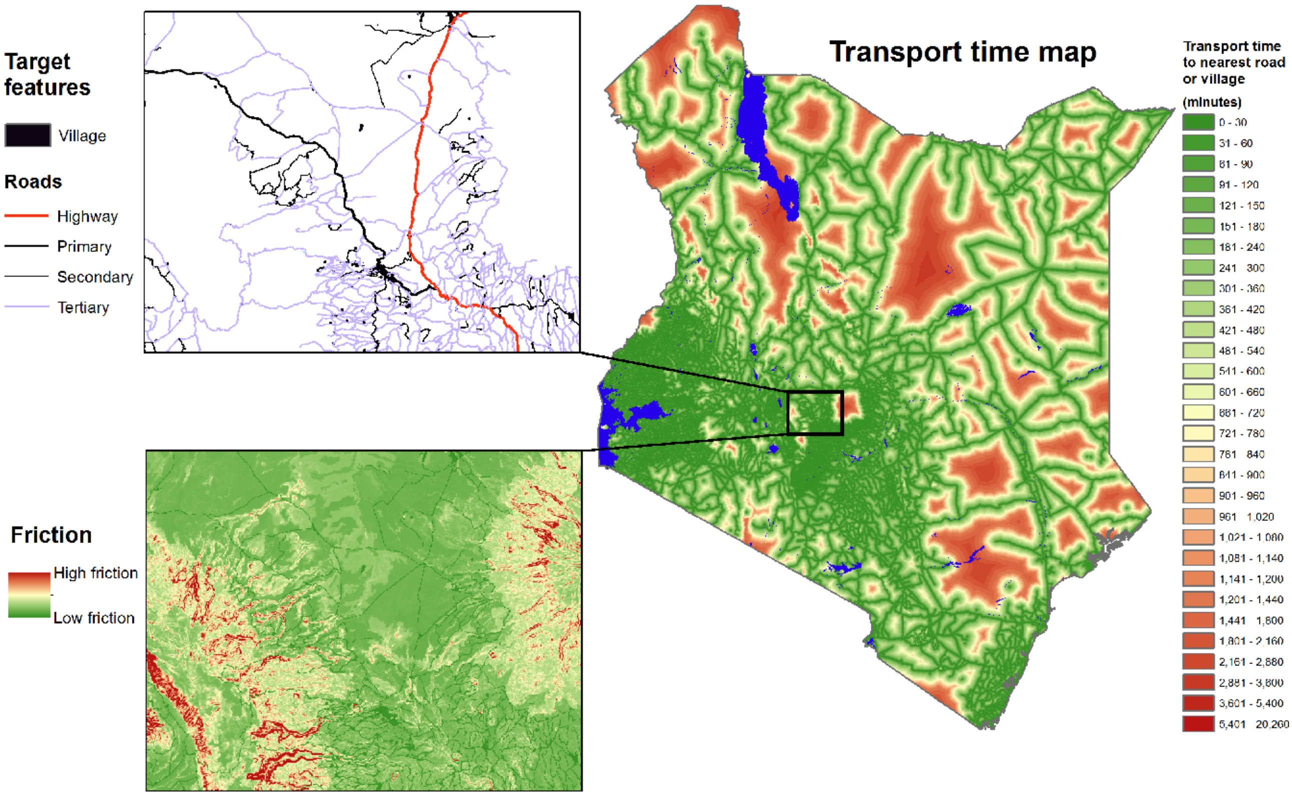
Results of transport time mapping

The results of the analysis are presented in Figure A3.2 that shows the map of travel time to nearest

[11] Digital terrain model data downloaded from : http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/Eurasia/
[12] van Wagtendonk, J. W. and Benedict, P. R. 1980. Travel time variation on backcountry trails. Journal of Leisure Research 12 (2): 99-106.

accessible feature (minutes of transport to nearest target feature, return trip).

Figure A3.1: Transport time map (minutes from the nearest target feature) with examples of Target features and Friction map.



From transport time to accessibility

Next step of analysis is to develop a map of accessibility based on the travel time map that helps to assess what fraction of the existing (and legally accessible) DEB resources may be considered as truly accessible.

The conversion of travel time to percent of accessibility is based on the hypothesis that resources further than 8 hours offroad transport time to the nearest accessible feature are non accessible. Table A3.3 presents the hypothesis of conversion of travel time into percent of accessibility applied, by which 69.7 % of all resources are physically accessible and 30.3 % inaccessible.

2 Legal accessibility Protected Area Management Categories

IUCN has defined a series of six protected area management categories, based on primary management objective. These are summarized in Table A3.4.

These definitions do not explicitly determine the level of access to wood energy resources in a given protected area, which probably varies depending on the level of capacity and strength of environmental institutions in each country. Nevertheless, access is likely to be more limited in the first categories and less limited in higher numbered categories. However, only Category VI explicitly includes provisions for sustainable use to meet (local) communities' needs. Based on this, we assume only the wood resources of Category VI are available to satisfy the woodfuel demand of local communities. Other categories are considered as inaccessible to local communities and ALL categories are EXCLUDED from commercial fuelwood extraction and charcoal production. Therefore, in the calculation of the local balance Category VI is considered moderately accessible (50% of MAI), while in the calculation of the commercial balance (that considers surplus resources available for commercial woodfuel production) all IUCN categories are excluded.

The map of legal accessibility based on WDPA data is shown in Figure A3.2.

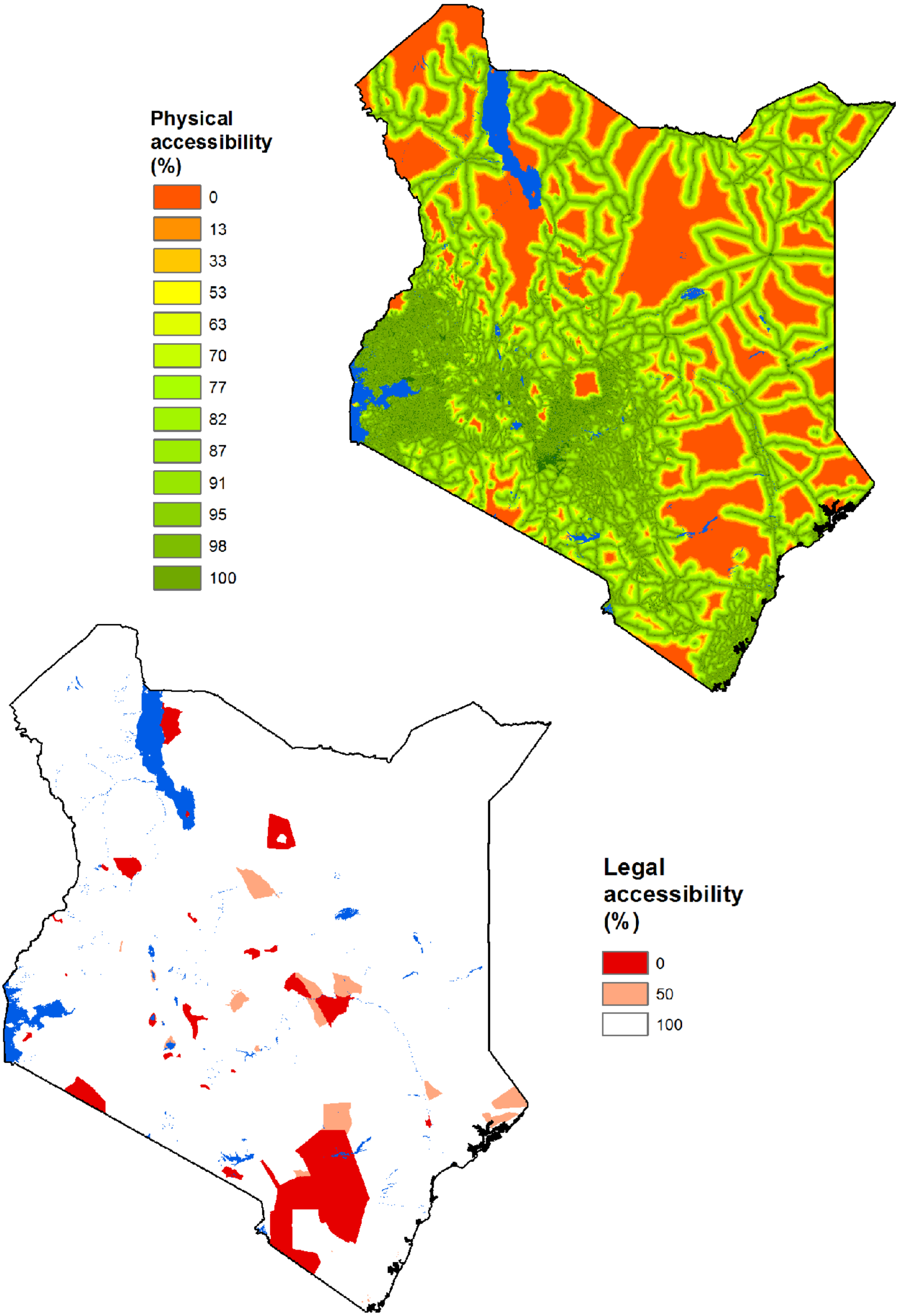
Table A3.3: Hypothesis of accessibility factors to be applied to DEB MAI resources based on travel time

					Nonaccessible MAI (%) :		30.3
					Accessible MAI (%) :		69.7
	Transport time from nearest target feature						accessible MAI
cd2_20	minutes	hours	Legally accessible MAI odt	% of MAI	access loss (%)	% accessible	kt od
1	60	1	9,043	22.5		**100**	**9,043**
2	120	2	4,930	12.2	2	**98**	**4,831**
3	180	3	3,567	8.9	3	**95**	**3,389**
4	240	4	2,801	7.0	4	**91**	**2,549**
5	300	5	2,316	5.8	4	**87**	**2,015**
6	360	6	1,973	4.9	5	**82**	**1,618**
7	420	7	1,706	4.2	5	**77**	**1,313**
8	480	8	1,492	3.7	7	**70**	**1,045**
9	540	9	1,304	3.2	7	**63**	**822**
10	600	10	1,157	2.9	10	**53**	**613**
11	720	12	1,950	4.8	20	**33**	**643**
12	840	14	1,577	3.9	20	**13**	**205**
13	960	16	1,292	3.2	13	**0**	**0**
14	1,080	18	1,070	2.7	0	**0**	**0**
15	1,200	20	891	2.2	0	**0**	**0**
16	1,440	24	1,308	3.2	0	**0**	**0**
17	1,800	30	1,074	2.7	0	**0**	**0**
18	2,160	36	447	1.1	0	**0**	**0**
19	2,880	48	334	0.8	0	**0**	**0**
20	> 2,880	> 48	36	0.1	0	**0**	**0**
			40,268				**28085**

Table A3.4 Summary descriptions of IUCN Protected Area Management Categories (40)

Category	Description
Ia	Strict Nature Reserve: protected area managed mainly for science
	Definition: Area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.
Ib	Wilderness Area: protected area managed mainly for wilderness protection
	Definition: Large area of unmodified or slightly modified land, and/or sea, retaining its natural character and influence, without permanent or significant habitation, which is protected and managed so as to preserve its natural condition.
II	National Park: protected area managed mainly for ecosystem protection and recreation
	Definition: Natural area of land and/or sea, designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.
III	Natural Monument: protected area managed mainly for conservation of specific natural features
	Definition: Area containing one, or more, specific natural or natural/cultural feature which is of outstanding or unique value because of its inherent rarity, representative or aesthetic qualities or cultural significance.
IV	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention
	Definition: Area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species.
V	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation
	Definition: Area of land, with coast and sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.
VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems
	Definition: Area containing predominantly unmodified natural systems, managed to ensure long term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs.

Figure A3.2: Maps of Physical and Legal accessibility



ANNEX 4: LAND COVER CHANGE (LCC) BY-PRODUCTS

Average annual gain and loss of forest area over the period 2000-2010 derived from changes reported by Hansen and colleagues (47).

	annual gain	annual loss	avg MAI in forests	avg stk in forests	annual gain (based on MAI)	annual loss (based on Stk)	byproduct potentially available (70%)
County	Ha	Ha	t od /ha	t od /ha	kt od	kt od	kt od
Nairobi	11	-29	3.0	105	0	-2	**1.3**
Nyandarua	423	-459	3.4	174	0	-6	**4.4**
Nyeri	466	-223	3.1	164	1	0	**0.5**
Kirinyaga	77	-46	2.8	152	0	0	**0.1**
Murang'a	172	-124	2.7	144	0	0	**0.1**
Kiambu	813	-371	3.4	163	1	0	**1.0**
Mombasa	2	-91	2.8	133	0	-12	**8.3**
Kwale	46	-1,636	2.8	140	0	-222	**155.4**
Kilifi	43	-2,270	2.5	106	0	-236	**165.1**
Tana River	19	-897	1.5	35	0	-31	**21.7**
Lamu	26	-1,305	2.3	87	0	-112	**78.1**
Taita Taveta	102	-135	2.2	82	0	-3	**1.9**
Marsabit	5	-4	1.6	43	0	0	**0.0**
Isiolo	0	-5	1.4	25	0	0	**0.1**
Meru	396	-124	2.6	121	1	0	**0.5**
Tharaka	20	-656	2.8	166	0	-106	**74.0**
Embu	43	-653	2.7	143	0	-88	**61.3**
Kitui	71	-3,592	1.6	39	0	-138	**96.8**
Machakos	70	-206	2.4	82	0	-11	**7.8**
Makueni	115	-759	2.2	73	0	-47	**33.1**
Garissa	4	-127	2.0	62	0	-8	**5.4**
Wajir	0	0	1.3	22	0	0	**0.0**
Mandera	0	0	1.2	18	0	0	**0.0**
Siaya	69	-195	2.7	118	0	-15	**10.4**
Kisumu	41	-218	3.1	162	0	-29	**20.1**
Homa Bay	51	-118	3.5	126	0	-9	**6.0**
Migori	56	-92	3.1	133	0	-5	**3.4**
Kisii	277	-58	6.5	183	1	0	**1.0**
Nyamira	499	-138	6.3	172	2	0	**1.6**
Turkana	1	-47	1.7	43	0	-2	**1.4**
West Pokot	99	-1,076	2.7	139	0	-136	**95.2**
Samburu	63	-45	2.2	84	0	0	**0.0**
Trans Nzoia	166	-497	3.4	161	0	-53	**37.3**
Baringo	271	-828	2.4	92	0	-51	**35.8**
Uasin Gishu	406	-774	3.9	191	0	-70	**49.2**
Keiyo-Marakwet	389	-1,301	3.2	158	0	-144	**100.8**
Nandi	621	-806	4.2	226	0	-42	**29.1**
Laikipia	62	-658	2.5	105	0	-63	**43.8**
Nakuru	790	-2,473	3.5	157	0	-264	**184.6**
Narok	1,306	-4,938	2.9	157	0	-569	**398.5**
Kajiado	54	-141	1.9	57	0	-5	**3.5**
Kericho	462	-704	4.3	204	0	-49	**34.6**
Bomet	865	-634	3.4	210	1	0	**0.6**
Kakamega	396	-439	3.7	194	0	-8	**5.8**
Vihiga	34	-25	4.6	214	0	0	**0.0**
Bungoma	99	-314	3.4	197	0	-42	**29.5**
Busia	32	-197	4.5	131	0	-22	**15.2**
Kenya	**10,032**	**-30,427**			**7.7**	**-2,598**	**1,825**