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CENTRO DE INVESTIGACIONES EN GEOGRAFÍA AMBIENTAL

**CIGA**  
CENTRO DE INVESTIGACIONES  
EN GEOGRAFÍA AMBIENTAL



GACC Yale-UNAM Project

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

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Tier II :  
Kenya

## **WISDOM Kenya**

### **Analysis of woodfuel supply, demand and sustainability in Kenya**

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## 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.<sup>1</sup>

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

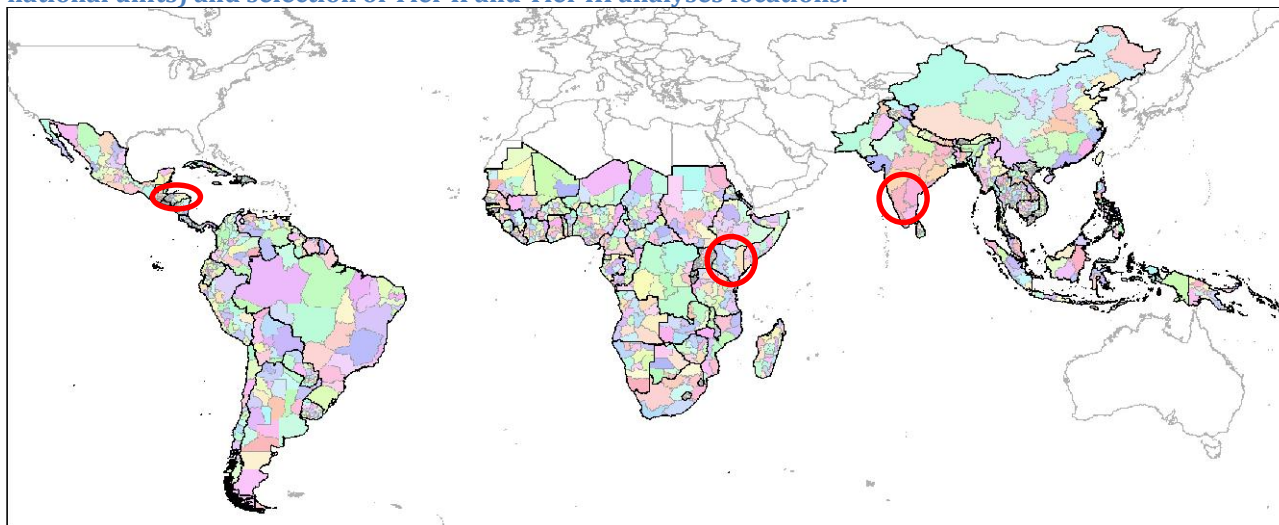
Tier 1 coverage and selected Tier 2 study sites are shown in Figure 1.

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.

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<sup>1</sup> 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](http://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<sup>2</sup> 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.

<sup>2</sup> The term "woodshed" is a neologism inspired by the familiar geographic concept of *watershed*. 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):

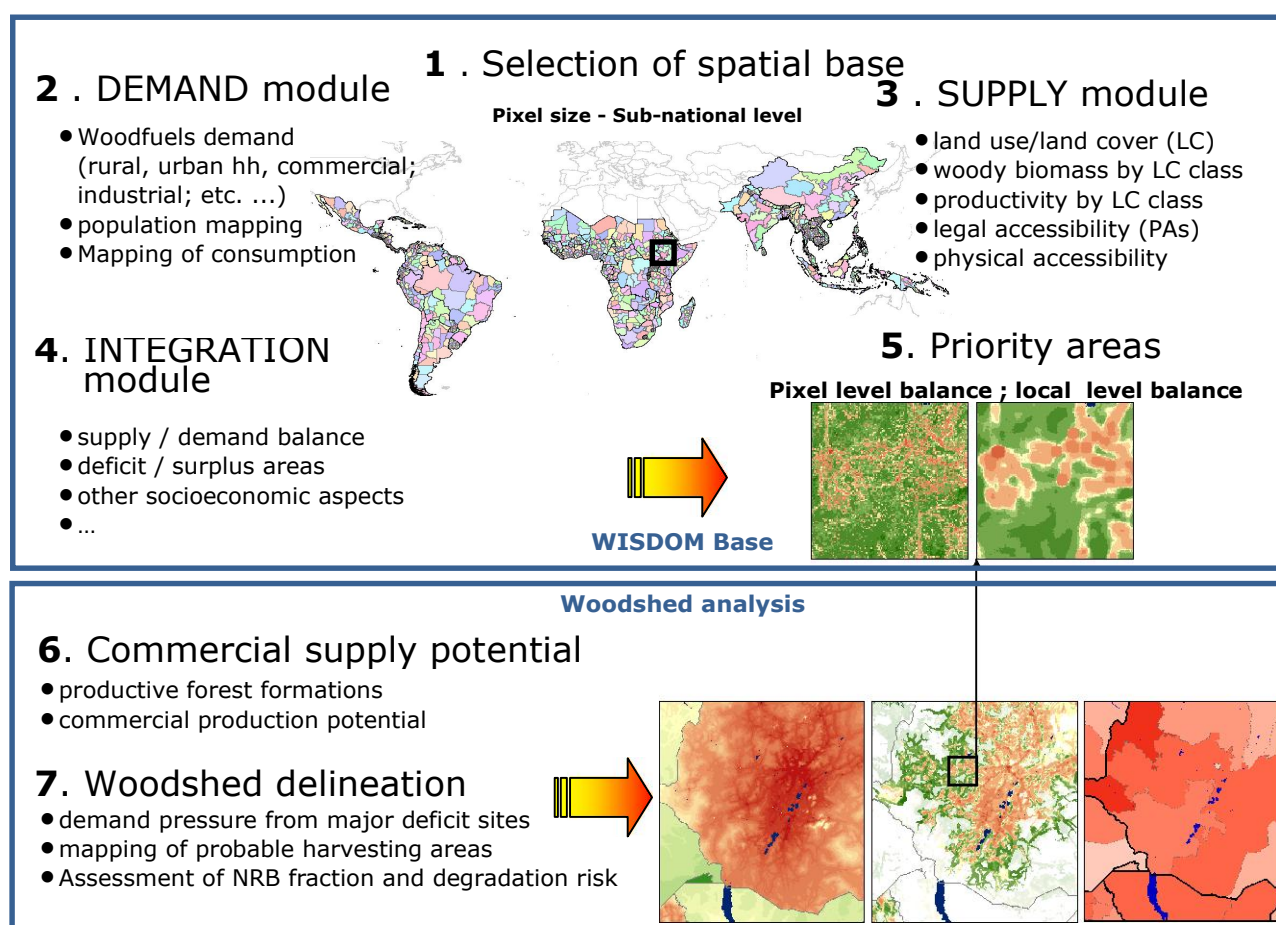
1. Definition of the minimum administrative *spatial* unit of analysis.
2. Development of the *demand* module.
3. Development of the *supply* module.
4. Development of the *integration* module.
5. Selection of the *priority* areas or woodfuel “hot spots” under different scenarios.

### **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:

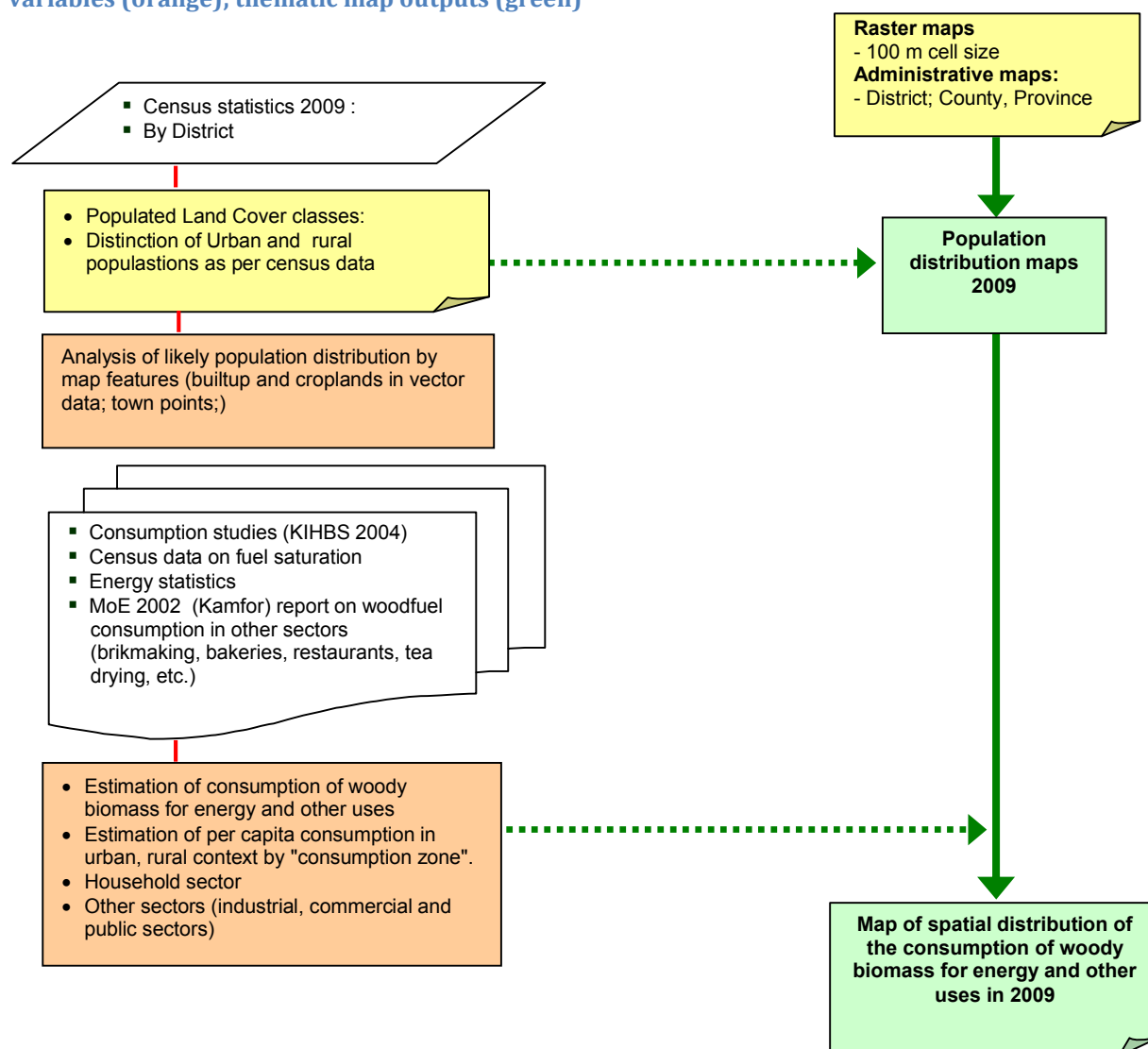
- (i) Census 2009 results at District level on the fraction of households using fuelwood or charcoal as primary cooking fuel in rural and urban areas.
- (ii) Kenya Integrated Household Budget Survey (KIHBS) (9), 2004/05 providing fuel quantities and relevant expenditures met by households from a representative 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<sup>3</sup>.
- (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

<sup>3</sup> 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  $\pm$  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<sup>4</sup> 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<sup>-1</sup> year<sup>-1</sup> in rural areas and 5.6 od kg of wood person<sup>-1</sup> year<sup>-1</sup> 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

<sup>4</sup> 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.

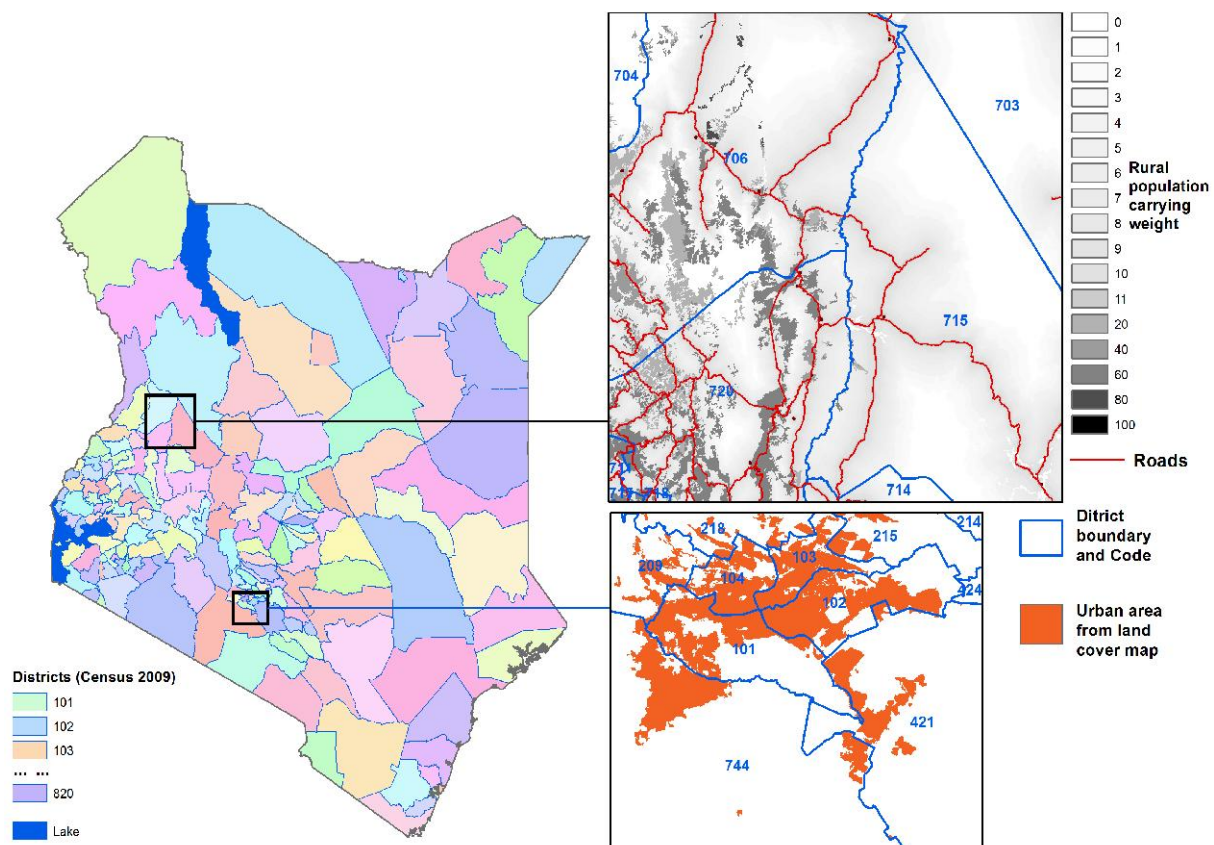
### Mapping woodfuel consumption

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 jaggery (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<sup>5</sup>.

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

<sup>5</sup> 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**

The demand is considered entirely, without distinction between conventional and marginal fuelwood

**Scenario B.  
Conventional demand**

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.

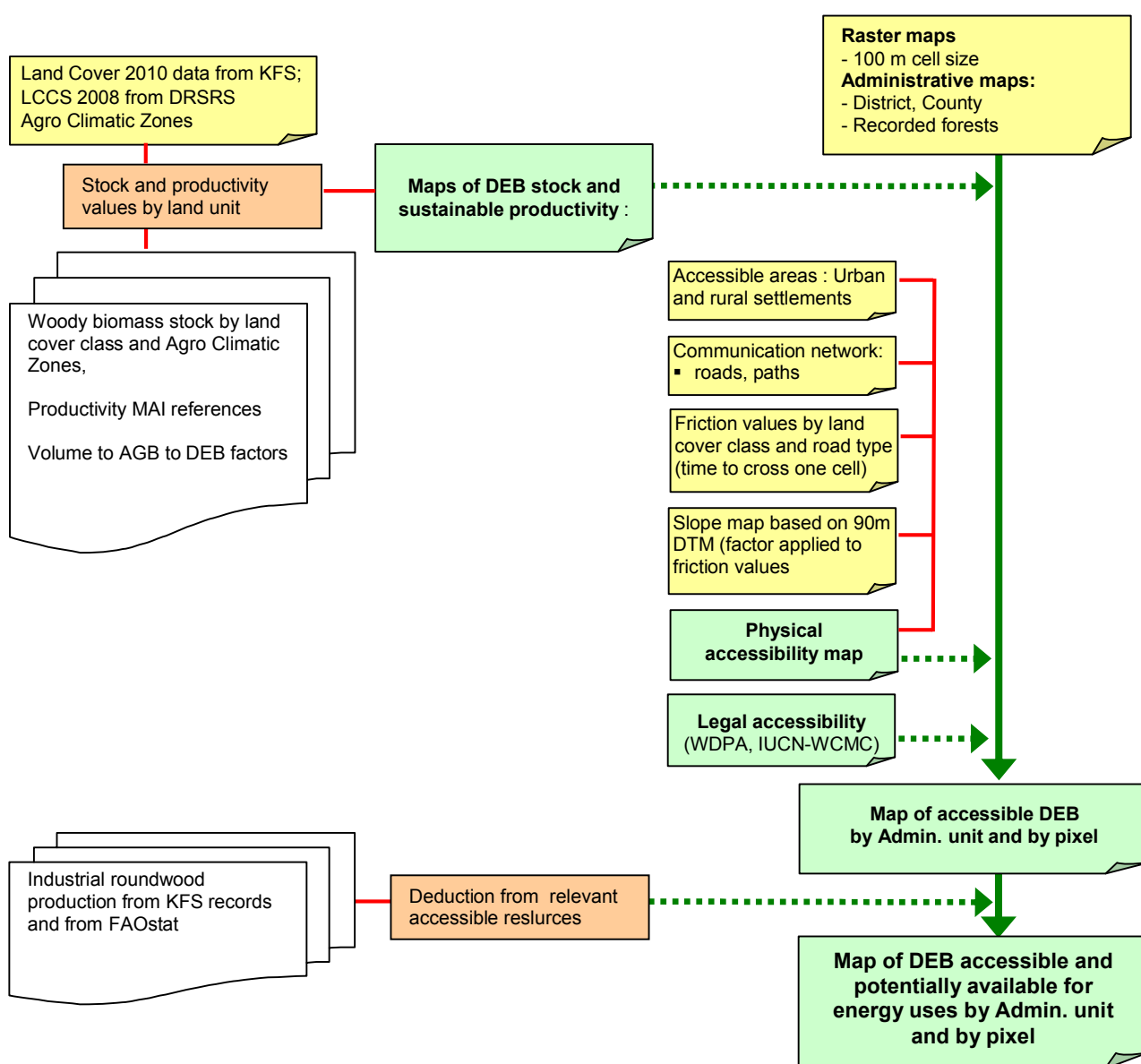
## 2.3 SUPPLY MODULE

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<sup>6</sup>. 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)**



<sup>6</sup> 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.

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

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<sup>7</sup>. 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.

<sup>7</sup> 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

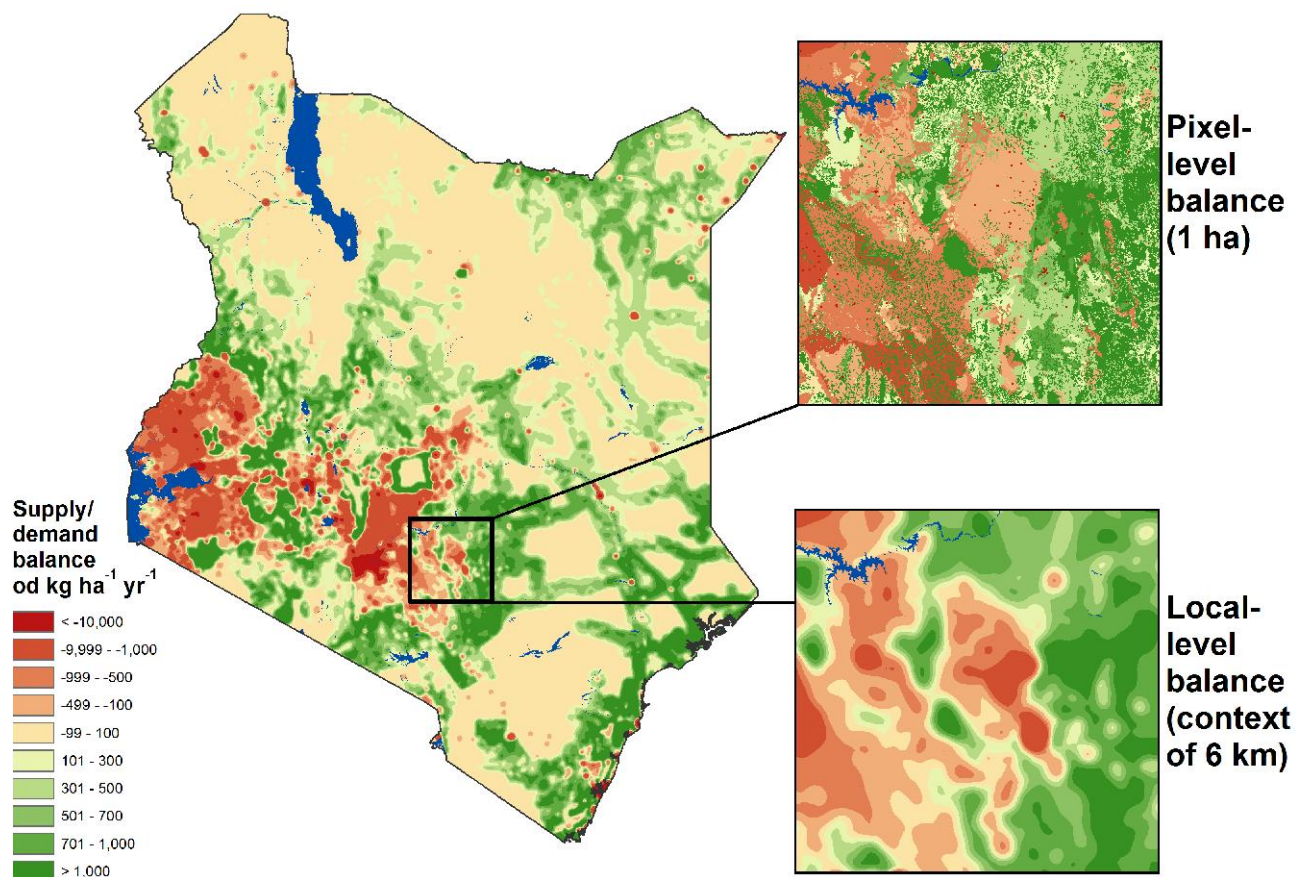
At the pixel-level, supply/demand balance is calculated by subtracting demand from available DEB MAI. The balance in each 1-hectare cell has an useful accounting function but it represents a somewhat virtual balance since individual pixels are usually either a production or a consumption site. An example 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.<sup>8</sup>

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**



<sup>8</sup> 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.

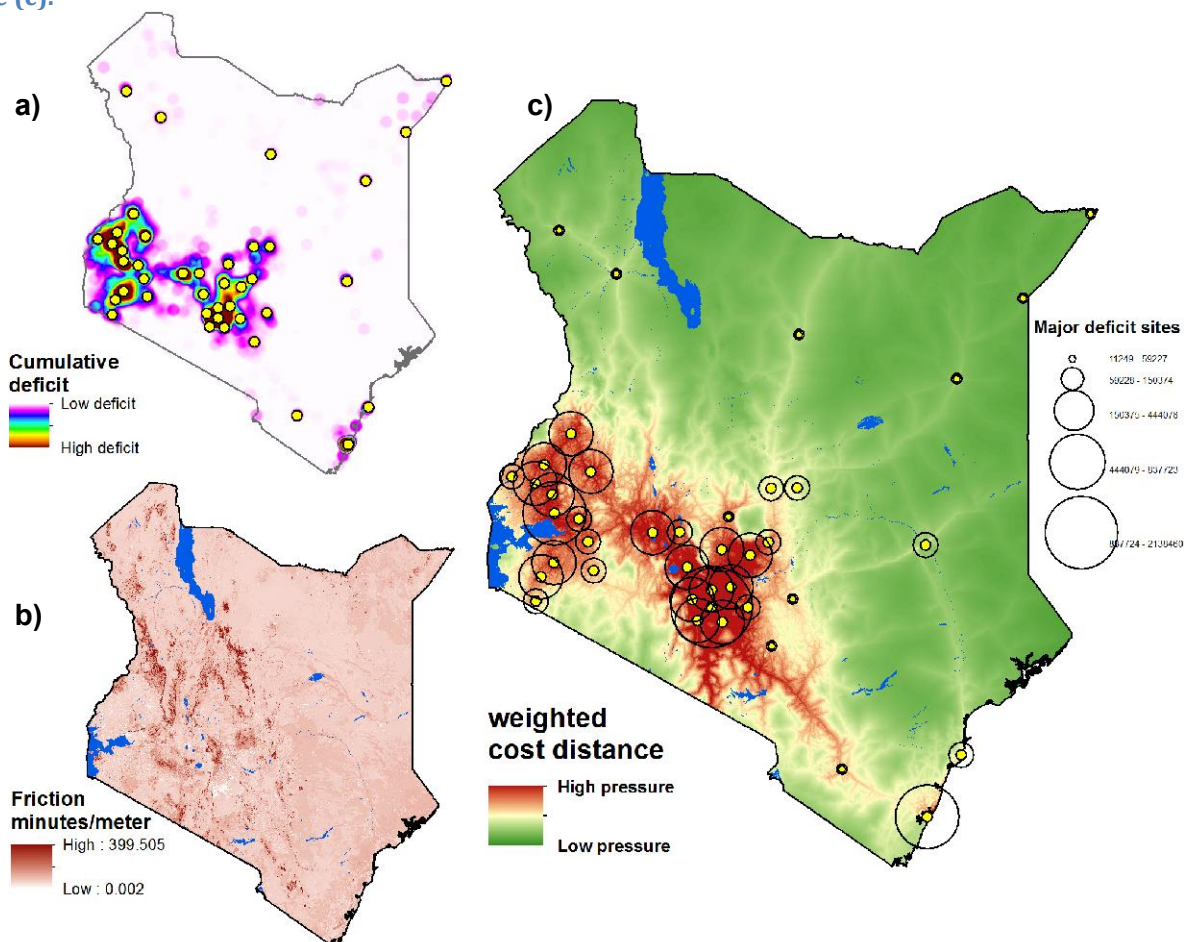


## Transport time threshold

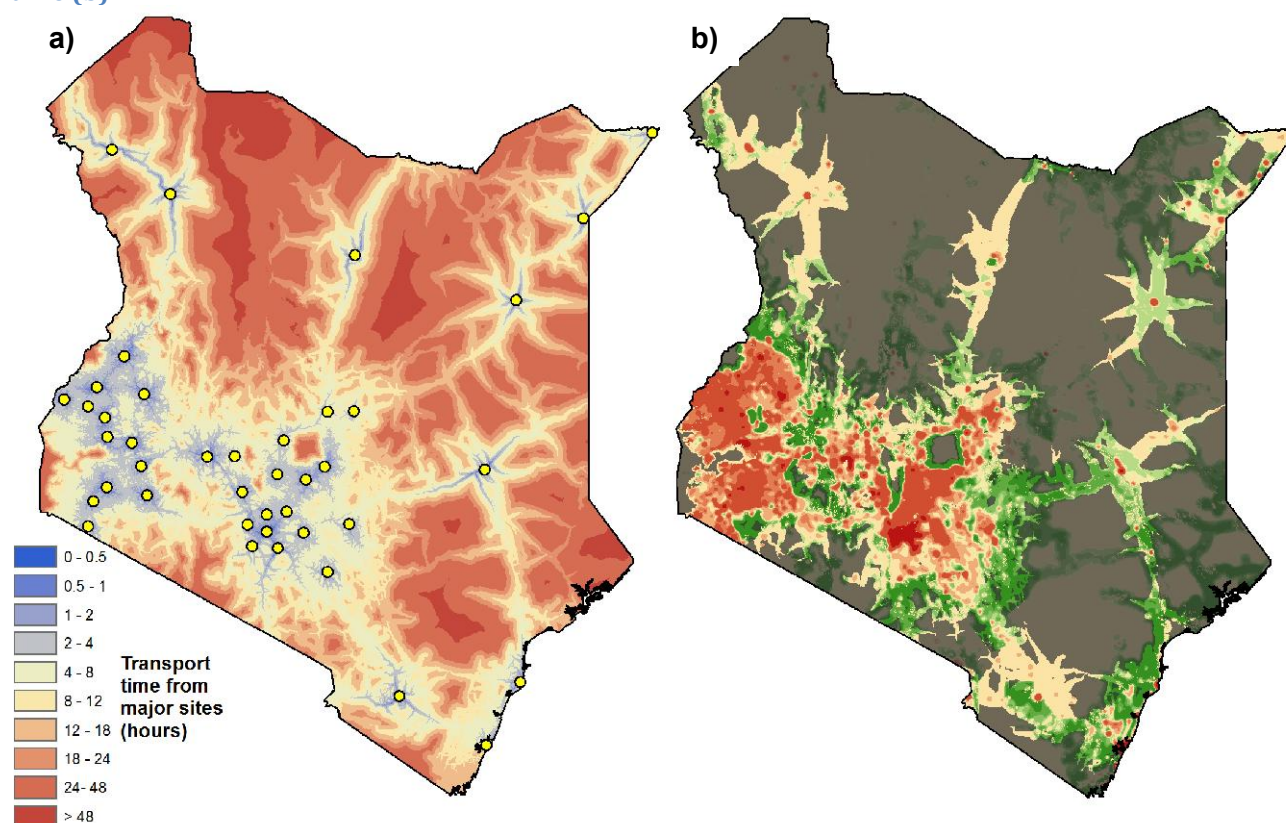
The watershed zone is determined by the availability of local surplus resources and commercial demand, which may include resources that are distant from the market. For commercial supply, we adopted a threshold of 12-hour transport time between point of harvest and market. To define the territory within such threshold we conduct a cost-distance analysis on the same major deficit points used for watershed 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 experience 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) give 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<sup>9</sup>.

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**

|                                                                                                                                                                | Demand scenarios                                                                                                            |                                                                                                                                                   |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                | <b>A. Total Demand</b><br>The demand is considered entirely, without distinction between conventional and marginal fuelwood | <b>B. Conventional demand</b><br>Only the demand for "conventional" fuelwood, is considered, excluding "marginal" fuelwood in rural deficit areas |
| <b>Woodfuels market scenarios</b>                                                                                                                              |                                                                                                                             |                                                                                                                                                   |
| <b>1. Full market (FM):</b> all conditions of local deficit, including urban and rural areas, originate commercial harvesting of distant resources             | <b>Scenario A</b> (M <sub>n</sub> , M <sub>d</sub> , M <sub>x</sub> ) <b>FM</b>                                             | <b>Scenario B</b> (M <sub>n</sub> , M <sub>d</sub> , M <sub>x</sub> ) <b>FM</b>                                                                   |
| <b>2. Partial market (PM):</b> all urban deficit originates commercial harvesting while ½ rural deficit remains "local" and ½ originates commercial harvesting | <b>Scenario A</b> (M <sub>n</sub> , M <sub>d</sub> , M <sub>x</sub> ) <b>PM</b>                                             | <b>Scenario B</b> (M <sub>n</sub> , M <sub>d</sub> , M <sub>x</sub> ) <b>PM</b>                                                                   |

### 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:

$$Har_i = w_{s_i} * (\sum c_d / (\sum w_s)) \quad [eq. 2]$$

where:

- Har<sub>i</sub> = commercial harvesting in pixel <sub>i</sub>
- w<sub>s<sub>i</sub></sub> = weighted surplus = commercial surplus in pixel <sub>i</sub> \* pressure level in pixel <sub>i</sub>)
- ∑c<sub>d</sub> = Total commercial deficit within woodshed
- ∑w<sub>s</sub> = Total w<sub>s</sub> 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 minimum NRB (mNRB) resulting from optimal management, but this is not a realistic estimation of the actual exploitation practices.

<sup>9</sup> 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 ( $NRB_{dh}$ ).



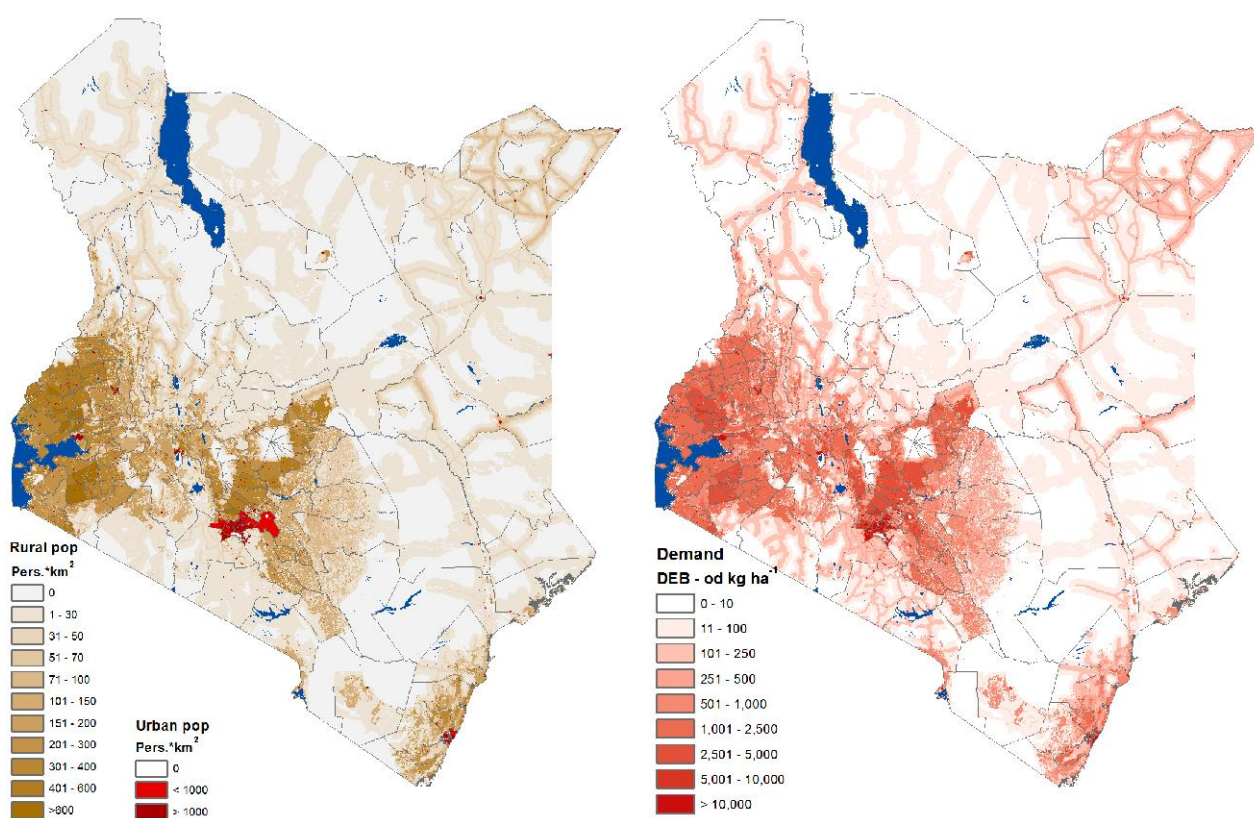
### 3. RESULTS

#### 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<br>(wood eq.)<br><b>County</b> | <b>Scenario A:<br/>Total demand<br/>(conventional + marginal woodfuels)</b> |           |           | <b>Scenario B:<br/>Conventional demand<br/>(excluding marginal assortments )</b> |           |           |
|--------------------------------------|-----------------------------------------------------------------------------|-----------|-----------|----------------------------------------------------------------------------------|-----------|-----------|
|                                      | <b>Mn</b>                                                                   | <b>Md</b> | <b>Mx</b> | <b>Mn</b>                                                                        | <b>Md</b> | <b>Mx</b> |
| 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       |
| <b>Kenya</b>                         | 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.**

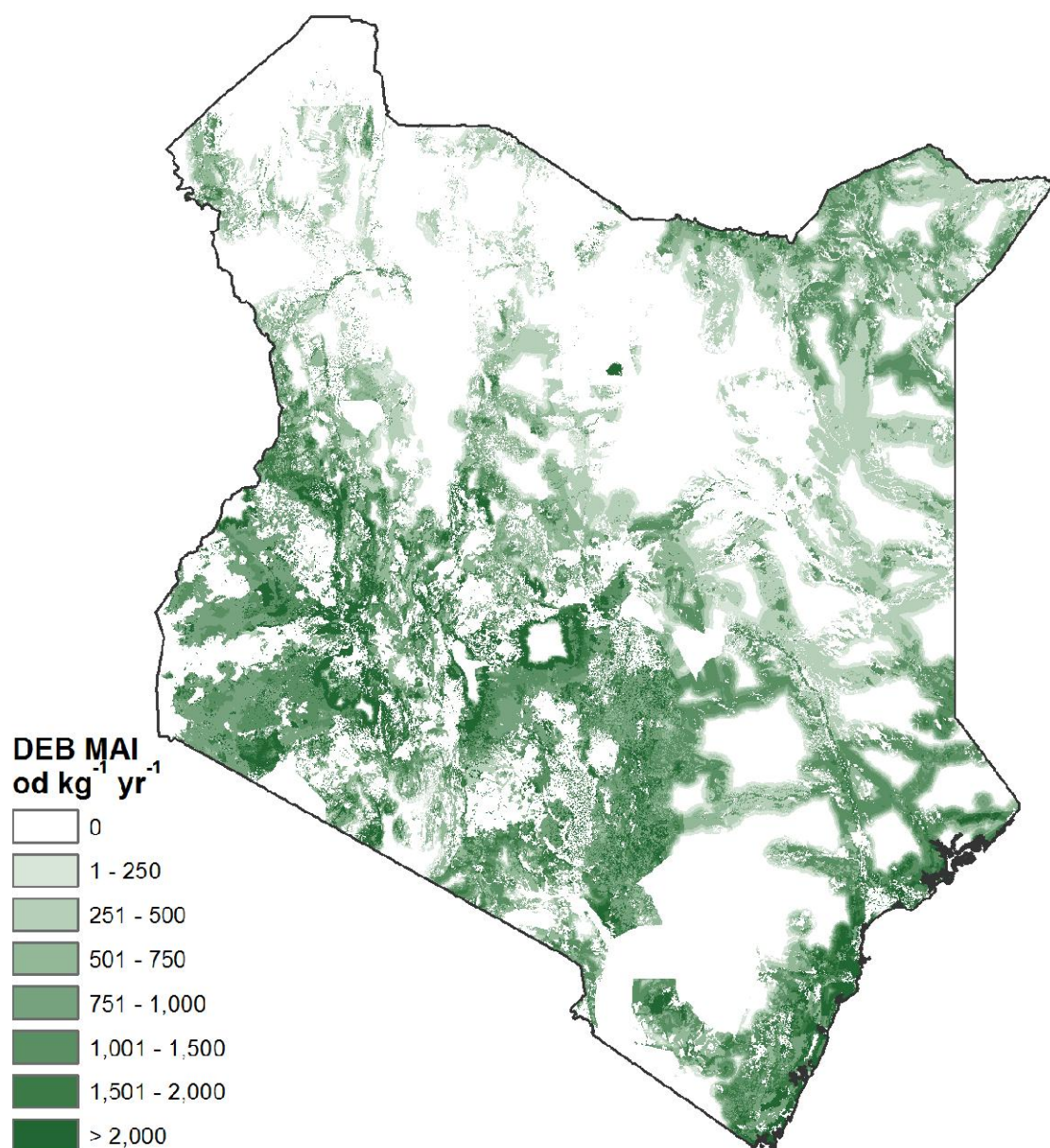


Table 3: County-level supply potential

| kt od<br>(wood eq.) | DEB Stock      | Tot MAI       | Physically & Legally<br>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            |
| <b>Kenya</b>        | <b>937,313</b> | <b>42,921</b> | <b>28,069</b>                          | <b>27,481</b> |

### 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).**

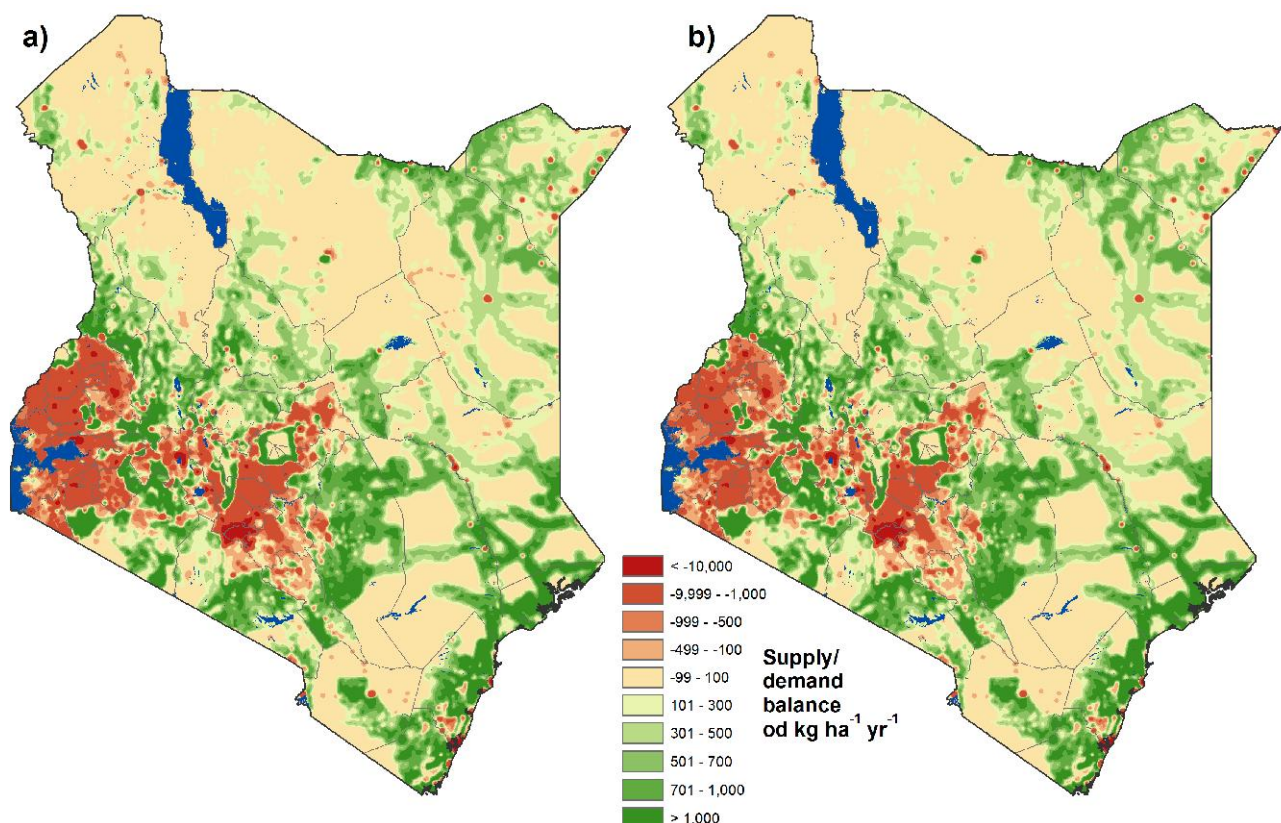


Table 4: County-level simple Supply / demand balance

|                | Balance Sc. A:<br>Total demand<br>(conventional + marginal woodfuels) |             |             | Balance Sc. B:<br>Conventional demand<br>(excluding marginal assortments ) |             |             |
|----------------|-----------------------------------------------------------------------|-------------|-------------|----------------------------------------------------------------------------|-------------|-------------|
|                | Mn<br>kt od                                                           | Md<br>kt od | Mx<br>kt od | Mn<br>kt od                                                                | Md<br>kt od | Mx<br>kt od |
| County         |                                                                       |             |             |                                                                            |             |             |
| 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

| County         | Scenario A             |                             | Scenario B             |                             |
|----------------|------------------------|-----------------------------|------------------------|-----------------------------|
|                | Local balance<br>kt od | Commercial balance<br>kt od | Local balance<br>kt od | Commercial balance<br>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                        |
| <b>Kenya</b>   | <b>349</b>             | <b>-2,193</b>               | <b>2,509</b>           | <b>-53</b>                  |

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.

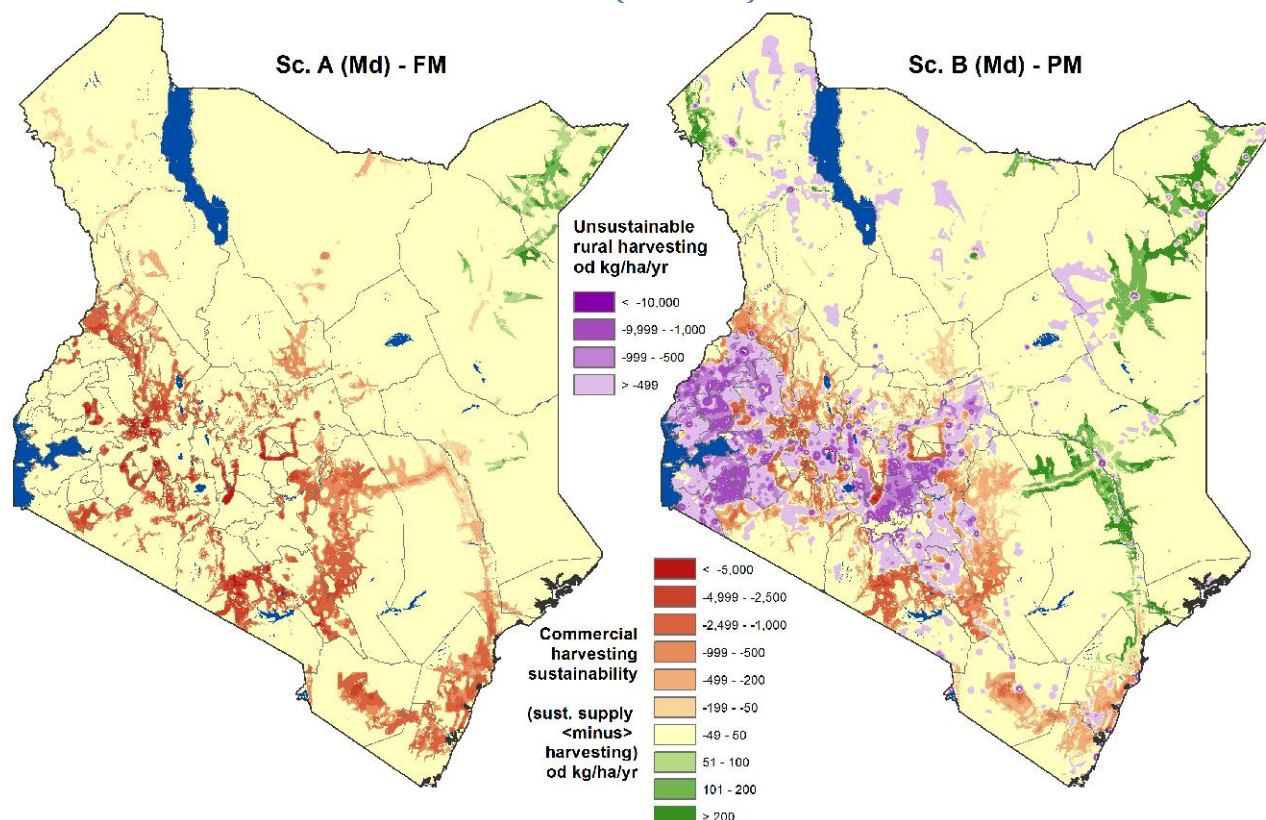
**"Partial Market" scenario :** Under the "Partial Market" scenario, we assume that urban demand is satisfied by commercial harvesting, but demand in rural deficit sites is met by a combination of local overexploitation and commercial supplies. Lacking specific data, we assume these two sources contribute 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.

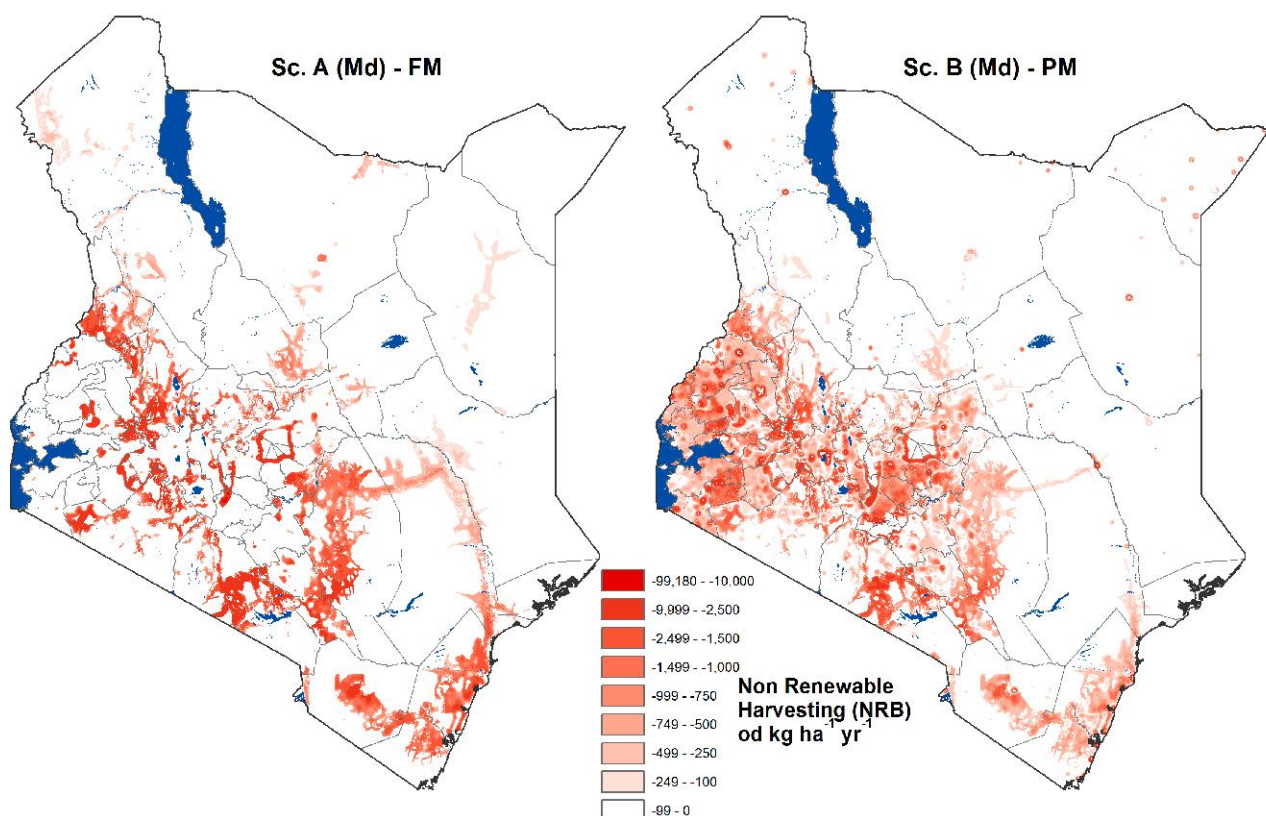
By excluding the woody biomass becoming annually available as by-products of land cover change, and thus referring to direct woodfuel harvesting only, fNRB rates 35%, or 9.5 Mt for Scenario A(Md)-FM and 31.2% or 7.8 Mt for Scenario B(Md)-PM. Thus, the by-products of annual deforestation, although non-renewable in their own right, avoid 1.7 Mt of direct NRB harvesting.

There is a wide variability among Counties, with some experiencing significantly fNRB 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.**

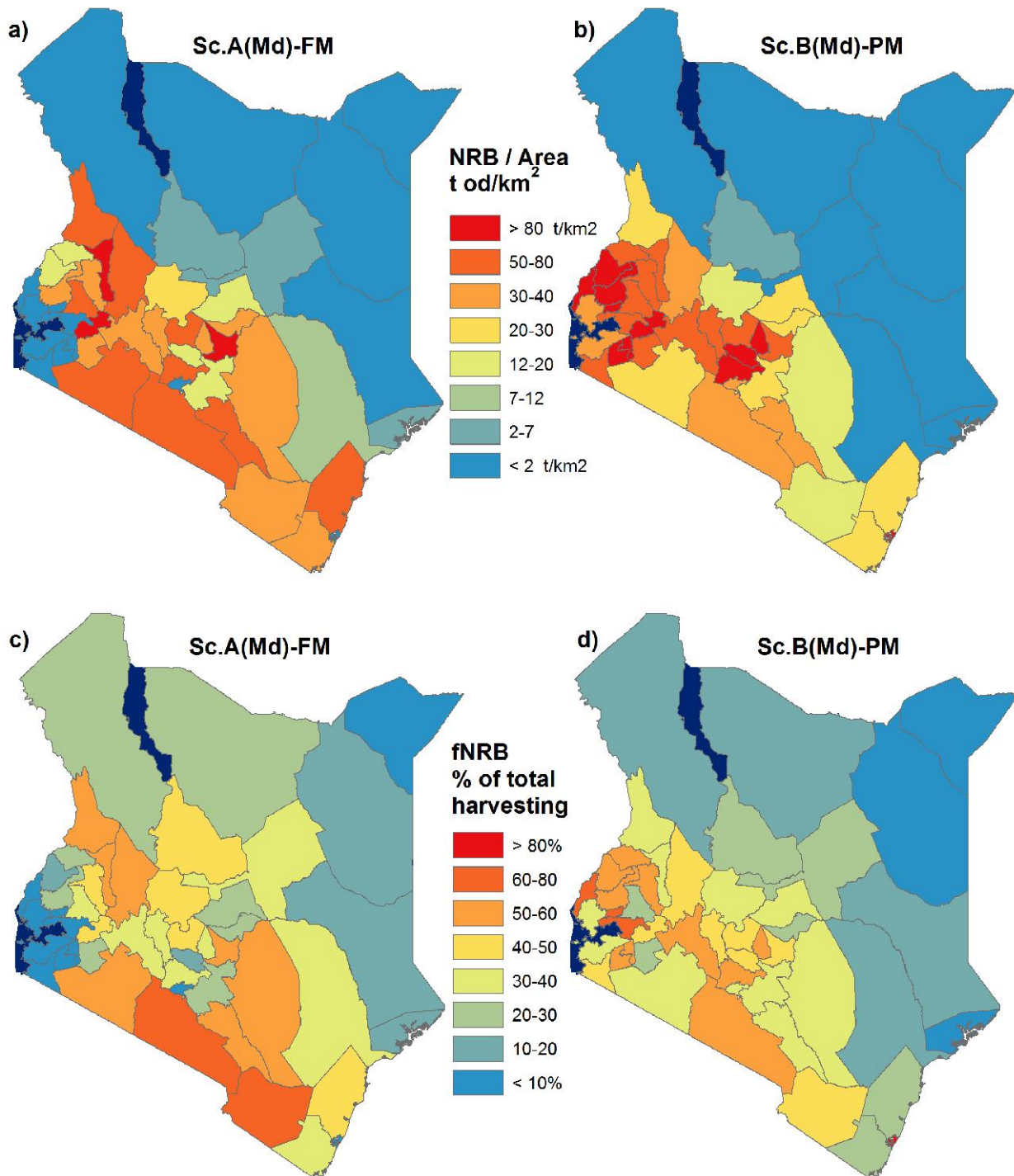


**Table 6: County level NRB values according to A (Md) Full Market Scenario and to B (Md) Partial market-scenario.**

| County         | Scenario A (Md) FM<br>"Total demand - Full market" |             |                                                                |             | Scenario B (Md) PM<br>"Conventional demand - Partial market" |             |                                                                |             |
|----------------|----------------------------------------------------|-------------|----------------------------------------------------------------|-------------|--------------------------------------------------------------|-------------|----------------------------------------------------------------|-------------|
|                | NRB Total<br>Direct harv. + LCC byprod.            |             | NRB <sub>dh</sub> Direct harvesting<br>only (less LCC byprod.) |             | NRB Total<br>Direct harv. + LCC byprod.                      |             | NRB <sub>dh</sub> Direct harvesting<br>only (less LCC byprod.) |             |
|                | 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        |
| <b>Kenya</b>   | <b>11,179</b>                                      | <b>41.3</b> | <b>9,470</b>                                                   | <b>35.0</b> | <b>9,516</b>                                                 | <b>38.3</b> | <b>7,770</b>                                                   | <b>31.2</b> |



Figure 15: County level NRB, represented as tons per km<sup>2</sup> (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<br>(without distinction between conventional and marginal):<br><b>27.4 Mt (24.5-32.5)</b>                                                | B. Conventional demand<br>(demand for "conventional" fuelwood only, excluding "marginal" fuelwood):<br><b>25.2 Mt (22.6-30)</b>                                                                           |
| <b>1. Full market (FM):</b> all conditions of local deficit, including urban and rural areas, originate commercial harvesting of distant resources             | <b>Scenario A (Md)-FM:</b><br><b>11.2 Mt = 41.3 %</b><br><b>NRB of Direct harvesting only:</b><br><b>9.5 Mt = 35 %</b><br>Highest impact in forest areas | Not implemented<br>-<br>Expected NRB would be close to the values below but concentrated on forest areas                                                                                                  |
| <b>2. Partial market (PM):</b> all urban deficit originates commercial harvesting while ½ rural deficit remains "local" and ½ originates commercial harvesting | Not implemented<br>-<br>Expected NRB would be close to the values above but distributed on forest and rural areas                                        | <b>Scenario B (Mn, Md, Mx)-PM</b><br><b>9.5 Mt (7.2-13.9) = 38.3 % (33-47)</b><br><b>NRB of Direct harvesting only:</b><br><b>7.8 Mt (5.6-12.1) = 31.2 % (25-41)</b><br>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%.

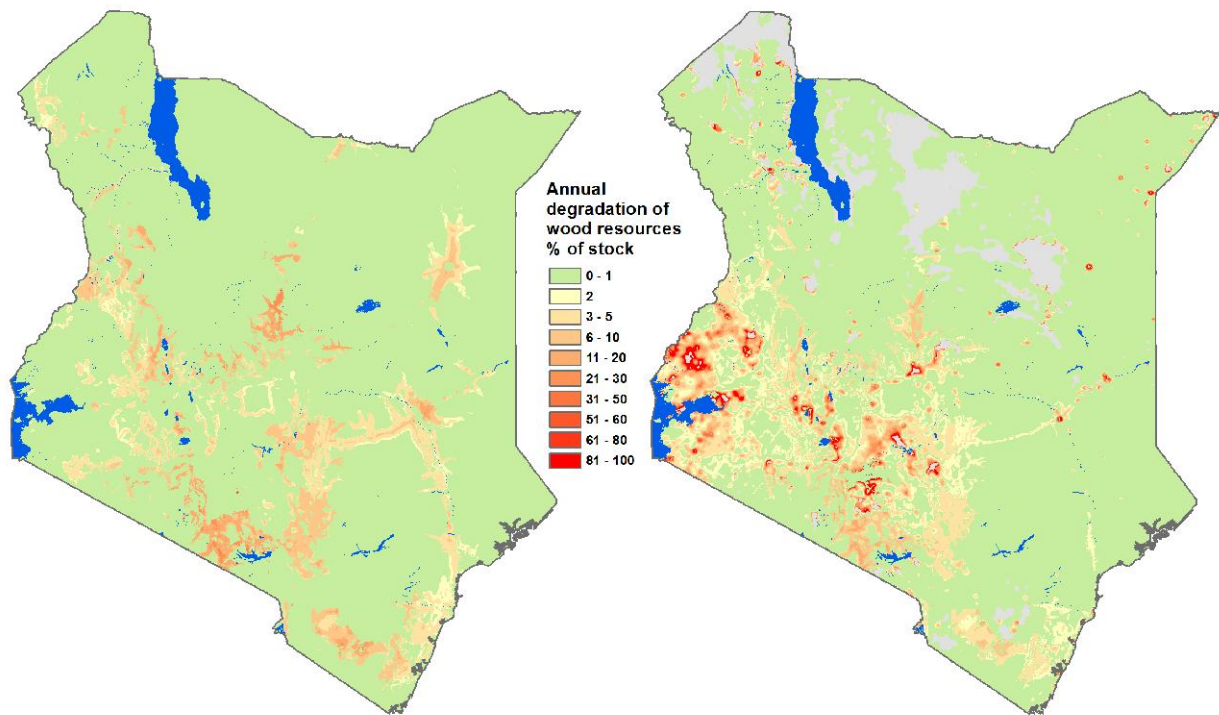
In Figure 17, all areas classified in KFS 2010 as non-forested are masked (gray areas) in order to allow comparison of the expected degradation of forest stock according to the two scenarios considered. In A(Md)-FM, the forest degradation rate in most accessible forest areas is 3-5 % with peak values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

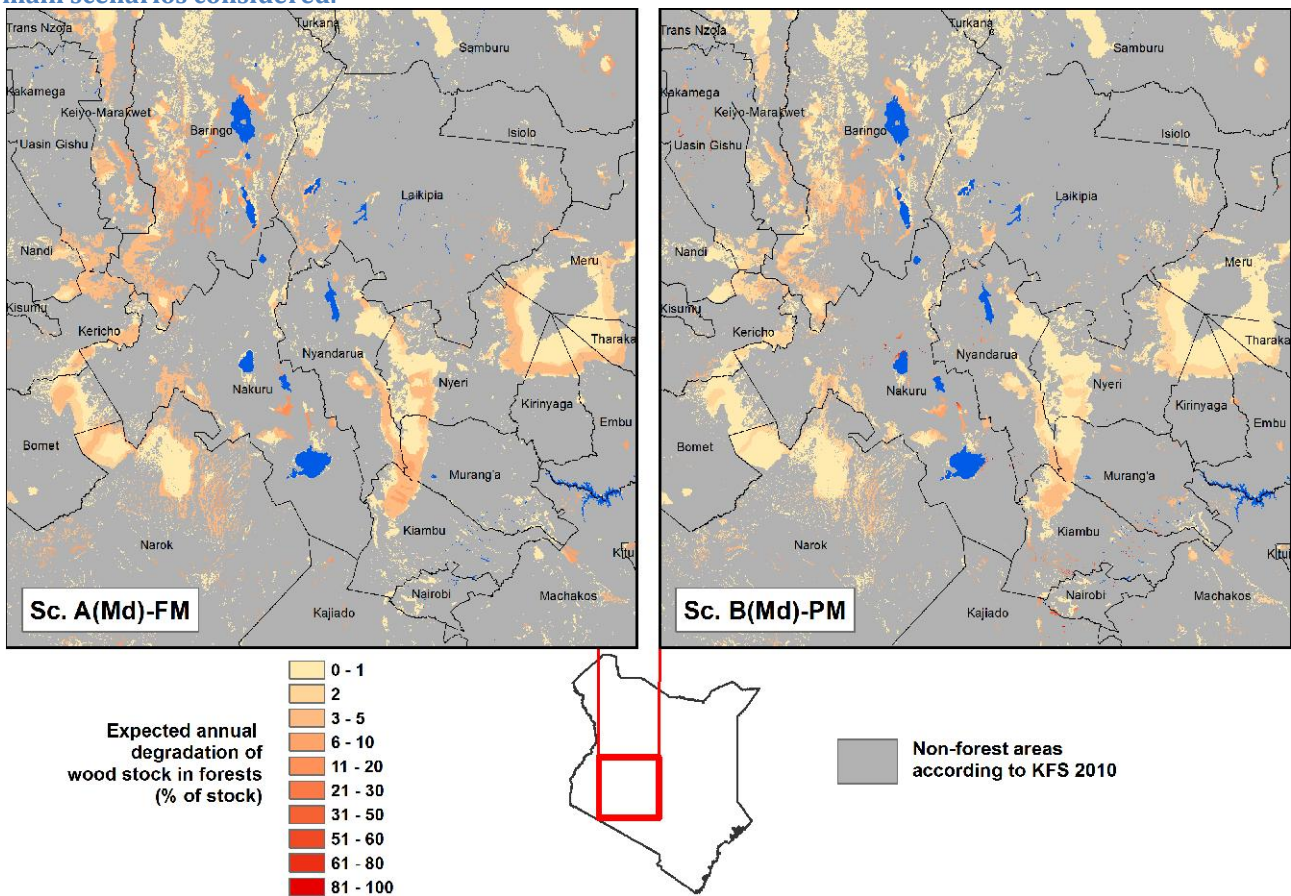


economic factors are key to determine the proportions of the responses to rural deficit (i.e. market vs local overexploitation) and may serve as weighting factor in future analyses.

**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**

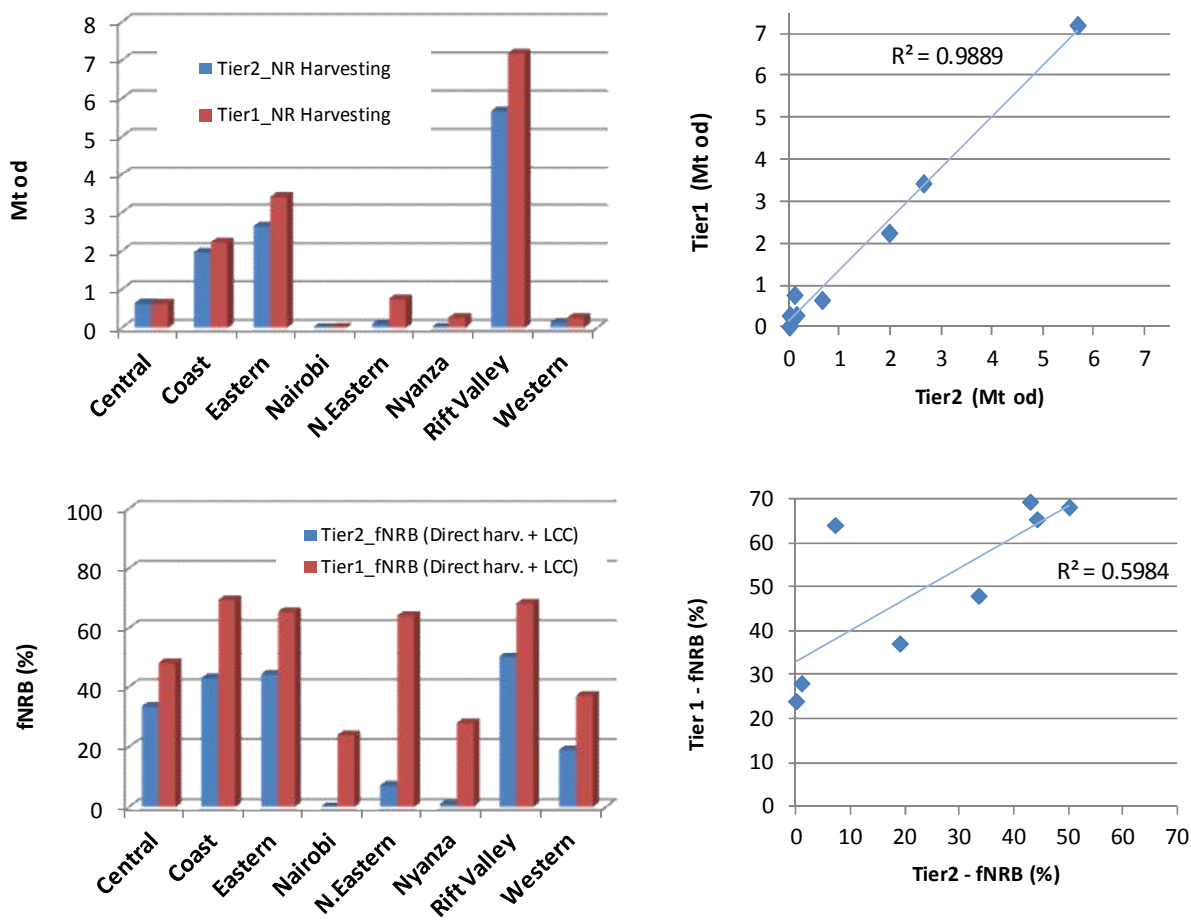
|                                               | Available supply potential |               | DEB Demand    |               | NRB Total (direct+LCC) |               |             |            |
|-----------------------------------------------|----------------------------|---------------|---------------|---------------|------------------------|---------------|-------------|------------|
|                                               | 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         |
| <b>KENYA</b>                                  | <b>27,481</b>              | <b>20,804</b> | <b>27,380</b> | <b>23,154</b> | <b>11,179</b>          | <b>14,761</b> | <b>42</b>   | <b>64</b>  |
| <b>% Difference between Tier 1 and Tier 2</b> | <b>24%</b>                 |               | <b>15%</b>    |               | <b>+32%</b>            |               | <b>+53%</b> |            |

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 magnitude 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.

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## REFERENCES

1. Bailis R, Drigo R, Ghilardi A, Masera O. 2015. The Carbon Footprint of Traditional Woodfuels. *Nature Climate Change*
2. Drigo R, Bailis R, Ghilardi A, Masera O. 2014. *Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and beyond (Tier I: Final Report)*, Global Alliance for Clean Cookstoves, Washington DC
3. Drigo R, Bailis R, Ghilardi A, Masera O. 2014. *Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and Beyond - Tier II: Karnataka, India*, Global Alliance for Clean Cookstoves, Washington DC
4. Drigo R, Masera O, Trossero M. 2002. Woodfuel Integrated Supply/Demand Overview Mapping- WISDOM: a geographical representation of woodfuel priority areas. *Unasylva (English ed.)* 53: 36-40
5. Masera O, Ghilardi A, Drigo R, Trossero MA. 2006. WISDOM: A GIS-based supply demand mapping tool for woodfuel management. *Biomass and Bioenergy* 30: 618-37
6. Drigo R, Salbitano F. 2008. *WISDOM for cities: Analysis of wood energy and urbanization using WISDOM methodology*, FAO Forestry department report, Rome
7. Land cover of Kenya 2008 - Map provided by Kenya Department of Resource Surveys and Remote Sensing (DRSRS), produced by FAO and DRSRS applying the Land Cover Classification System (LCCS), with WRI funding in Project MTF/KEN/072/WRI
8. KNBS. 2009. Population and Housing Census 2009. Nairobi: Kenya National Bureau of Statistics
9. KNBS. 2006. Kenya Integrated Household Budget Survey 2005-2006. Nairobi: Kenya National Bureau of Statistics
10. Bailis R. 2005. *Fuel from the Savanna: the Social and Environmental Implications of the Charcoal Trade in Sub-Saharan Africa*. PhD thesis. University of California, Berkeley, CA. 250 pp.
11. ESMAP. 1991. *Rwanda: Commercialization of Improved Charcoal Stoves and Carbonization Techniques - Mid-Term Progress Report. Rep. Report No. 141/91*, The Energy Sector Management Assistance Programme of the World Bank, Washington DC
12. Hibajane SH. 1994. *Assessment of Earth Kiln Charcoal Production Technology. Rep. 39*, Stockholm Environmental Institute, Stockholm
13. Schenkel Y, Bertaux P, Vanwijnberghe S, Carre J. 1998. An evaluation of the mound kiln carbonization technique. *Biomass and Bioenergy* 14: 505-16
14. Drigo R, Munyehirwe A, Nzabanita V, Munyampundu A. 2013. *Update and upgrade of WISDOM Rwanda*, Agriconsulting S.p.A., Kigale
15. Drigo R. 2012. *WISDOM Sudan - Spatial analysis of woodfuel supply and demand in Sudan based on WISDOM methodology and new land cover mapping*, UN FAO, Rome
16. Drigo R, Cuambe C, Lorenzini M, Marzoli A, Macuacua J, et al. 2008. WISDOM Mozambique. pp. 67. Rome: República de Moçambique Ministério de Agricultura - Direcção Nacional de Terras e Florestas
17. Ministry of Energy. 2002. *Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments: Final Report*, KAMFOR Company Limited, Nairobi
18. Githiomi J, Mugendi D, Kung'u J. 2012. Household tree planting and its related constraints in meeting woodfuel production in Kiambu, Thika and Maragwa Districts of Central Kenya. *Journal of Horticulture and Forestry* 4: 120-25

19. Githiomi KJ. 2011. *Microlevel wood energy planning for Kiambu, Thika and Maragwa districts: a case study for decentralised wood energy plan in Kenya*. Kenyatta University, Nairobi
20. Drigo R, Anschau A, Marcos NF, Carballo S, Roveda EB, Trossero M. 2009. *Análisis del balance de energía derivada de biomasa en Argentina WISDOM Argentina: Informe final*, FAO, Rome
21. Ghilardi A. 2009. Estimation of the fraction of non-renewable fuelwood in the residential and institutional sectors in El Salvador. "Woodfuel Integrated Supply/Demand Overview Mapping" (WISDOM)
22. Sombroek W, Braun H, van der Pouw B. 1982. *Exploratory soil map and agro-climatic zone map of Kenya*. Nairobi: Kenya Soil Survey
23. MENR. 1992. *Kenya Forestry Master Plan: Main Report and Annex I*, Ministry of Environment and Natural Resources, Nairobi
24. FAO. 1997. *Biomass assessment and fuelwood potential from woodlands in the western lowlands*, Ministry of Agriculture of Eritrea
25. Drigo R. 2005. WISDOM, East Africa. Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology. Spatial woodfuel production and consumption analysis of selected African countries.
26. Kairo J, Kiviyatu B, Koedam N. 2002. Application of remote sensing and GIS in the management of mangrove forests within and adjacent to Kiunga Marine Protected Area, Lamu, Kenya. *Environment, Development and Sustainability* 4: 153-66
27. Glenday J. 2006. Carbon storage and emissions offset potential in an East African tropical rainforest. *Forest Ecology and Management* 235: 72-83
28. Touré A, Rasmussen K, Diallo O, Diouf A. 2003. Actual and potential carbon stocks in the north-sudanese zone. A case study: The forests of Delhi and Panities in Senegal. *Geografisk Tidsskrift-Danish Journal of Geography* 103: 63-70
29. Drichi P. 2005. *Global Forest Resources Assessment: Uganda Country Report*, FAO, Rome
30. World Bank. 1986. *Sudan Forestry Sector Review: Main Report*, Washington DC
31. Woome PL, Touré A, Sall M. 2004. Carbon stocks in Senegal's Sahel transition zone. *Journal of arid environments* 59: 499-510
32. Pukkala T. 1993. *Yield and management of the indigenous forests and fuelwood plantations of Bura*. Presented at Proceedings of the Bura Fuelwood Project Research Seminar, Nairobi, 9–10 March 1993
33. FAO. 1995. *Handbook of forestry sector statistics, Sudan*, Khartoum (Sudan)
34. KFS. 2013. *Report on National Forest Resource Mapping and Capacity Development for the Republic of Kenya. Rep. Programme KEF09/11494/01*, Kenya Forest Service, Nairobi
35. KFS. 2012. *National Forest Management Inventory*, Kenya Forest Service, Nairobi
36. Saenger P. 2002. *Mangrove ecology, silviculture and conservation*. Dordrecht: Kluwer Academic Publishers
37. Cannell MG. 1982. *World forest biomass and primary production data*. London: Academic Press
38. IPCC. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Hayama, Kanagawa, Japan: Institute for Global Environmental Strategies (IGES)
39. Nelson A. 2008. *Estimated travel time to the nearest city of 50,000 or more people in year 2000*, Global Environment Monitoring Unit-Joint Research Centre of the European Commission, Ispra Italy

40. Dudley N, ed. 2008. *Guidelines for Applying Protected Area Management Categories*. Gland, Switzerland: IUCN (International Union for Conservation of Nature)
41. KFS. 2012. *Timber Sale Records 2011-2013*, Kenya Forest Service, Nairobi
42. An L, Linderman M, Qi J, Shortridge A, Liu J. 2005. Exploring complexity in a human–environment system: an agent-based spatial model for multidisciplinary and multiscale integration. *Annals of the Association of American Geographers* 95: 54-79
43. Bhatt BP, Sachan MS. 2004. Firewood consumption along an altitudinal gradient in mountain villages of India. *Biomass and Bioenergy* 27: 69-75
44. Njenga M, Karanja N, Karlsson H, Jamnadass R, Iiyama M, et al. 2014. Additional cooking fuel supply and reduced global warming potential from recycling charcoal dust into charcoal briquette in Kenya. *Journal of Cleaner Production* 81: 81-88
45. Mancini M, Mattioli E, Morganti M, Bruschi P, Signorini M. 2007. *Conhecimento e exploracao de produtos florestais nao madeiros e carvao na zona de Muda, Provincia de Manica*, Maputo, Mozambique
46. Soares-Filho B, Rodrigues H, Costa W. 2010. *Modeling Environmental Dynamics with Dinamica EGO*, Centro de Sensoriamento Remoto - Universidade Federal de Minas Gerais, Belo Horizonte, Brazil
47. Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, et al. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* 342: 850-53



## 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        |
|                    | %             | %           | %             | %          | %           | %          |
| <b>Kenya total</b> | <b>19.8</b>   | <b>90.1</b> | <b>37.8</b>   | <b>7.2</b> | <b>42.4</b> | <b>2.6</b> |
| 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        |
| NZAU               | 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 |      | Saturation Ch |      | Other fuels |      |
|------------------|---------------|------|---------------|------|-------------|------|
|                  | Urb           | Rur  | Urb           | Rur  | Urb         | 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%     |
| <b>Rural Avg</b> | <b>467</b>     | <b>11</b> | <b>93</b>      | <b>13</b> | <b>201</b>          | <b>73</b> | <b>74</b>   | <b>22</b> |
| 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        |
| <b>Urban Avg</b> | <b>431</b>     | <b>42</b> | <b>14</b>      | <b>2</b>  | <b>31</b>           | <b>47</b> | <b>7</b>    | <b>3</b>  |
| 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         |
| <b>Tot Kenya</b> | <b>464</b>     | <b>11</b> | <b>36</b>      | <b>4</b>  | <b>176</b>          | <b>64</b> | <b>15</b>   | <b>4</b>  |

## Use of Charcoal (kg/person/year)

| Area             | Fuelwood users |          | Charcoal users |           | Farm residues users |           | Other users |           |
|------------------|----------------|----------|----------------|-----------|---------------------|-----------|-------------|-----------|
|                  | avg            | ±@95%    | avg            | ±@95%     | avg                 | ±@95%     | avg         | ±@95%     |
| <b>Rural Avg</b> | <b>11</b>      | <b>1</b> | <b>238</b>     | <b>16</b> | <b>3</b>            | <b>2</b>  | <b>94</b>   | <b>21</b> |
| 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        |
| <b>Urban Avg</b> | <b>20</b>      | <b>4</b> | <b>269</b>     | <b>10</b> | <b>14</b>           | <b>12</b> | <b>71</b>   | <b>6</b>  |
| 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        |
| <b>Tot Kenya</b> | <b>12</b>      | <b>1</b> | <b>260</b>     | <b>8</b>  | <b>5</b>            | <b>3</b>  | <b>74</b>   | <b>6</b>  |

**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%     |
| <b>Rural Avg</b> | <b>442</b>     | <b>11</b> | <b>1072</b>    | <b>71</b> | <b>184</b>          | <b>62</b> | <b>456</b>  | <b>90</b> |
| 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       |
| <b>Urban Avg</b> | <b>452</b>     | <b>44</b> | <b>1131</b>    | <b>41</b> | <b>86</b>           | <b>71</b> | <b>300</b>  | <b>25</b> |
| 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       |
| <b>Tot Kenya</b> | <b>443</b>     | <b>11</b> | <b>1115</b>    | <b>35</b> | <b>169</b>          | <b>54</b> | <b>319</b>  | <b>24</b> |

Table A1.3 : Total fuelwood and charcoal consumption

| County        | Fuelwood consumption |                   |                     | Charcoal consumption |                    |                      |
|---------------|----------------------|-------------------|---------------------|----------------------|--------------------|----------------------|
|               | Urban HH<br>kt od    | Rural HH<br>kt od | Other uses<br>kt od | Urban HH<br>Ch. kt   | Rural HH<br>Ch. kt | Other uses<br>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                    |
| <b>Kenya</b>  | <b>1095</b>          | <b>9454</b>       | <b>4302</b>         | <b>1655</b>          | <b>718</b>         | <b>634</b>           |



**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                                                              |
|---------------|-----------------------|------------|------------------------------|------------------------------------------------------------------------------------------------|
|               | Urban HH              | Rural HH   | Schools, Hospitals, prisons) | Medium variant<br>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                                                                                             |
| <b>Kenya</b>  | <b>70</b>             | <b>502</b> | <b>1,553</b>                 | <b>4,816</b>                                                                                   |

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

| <b>Total DendroEnergy Biomass (DEB) consumption</b><br>kt od (wood equivalent) |                                |                                   |                                 |
|--------------------------------------------------------------------------------|--------------------------------|-----------------------------------|---------------------------------|
| <b>County</b>                                                                  | <b>Low variant<br/>(31%CY)</b> | <b>Medium variant<br/>(24%CY)</b> | <b>High variant<br/>(17%CY)</b> |
| 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                             |
| <b>Kenya</b>                                                                   | <b>24,552</b>                  | <b>27,380</b>                     | <b>32,540</b>                   |

## 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**

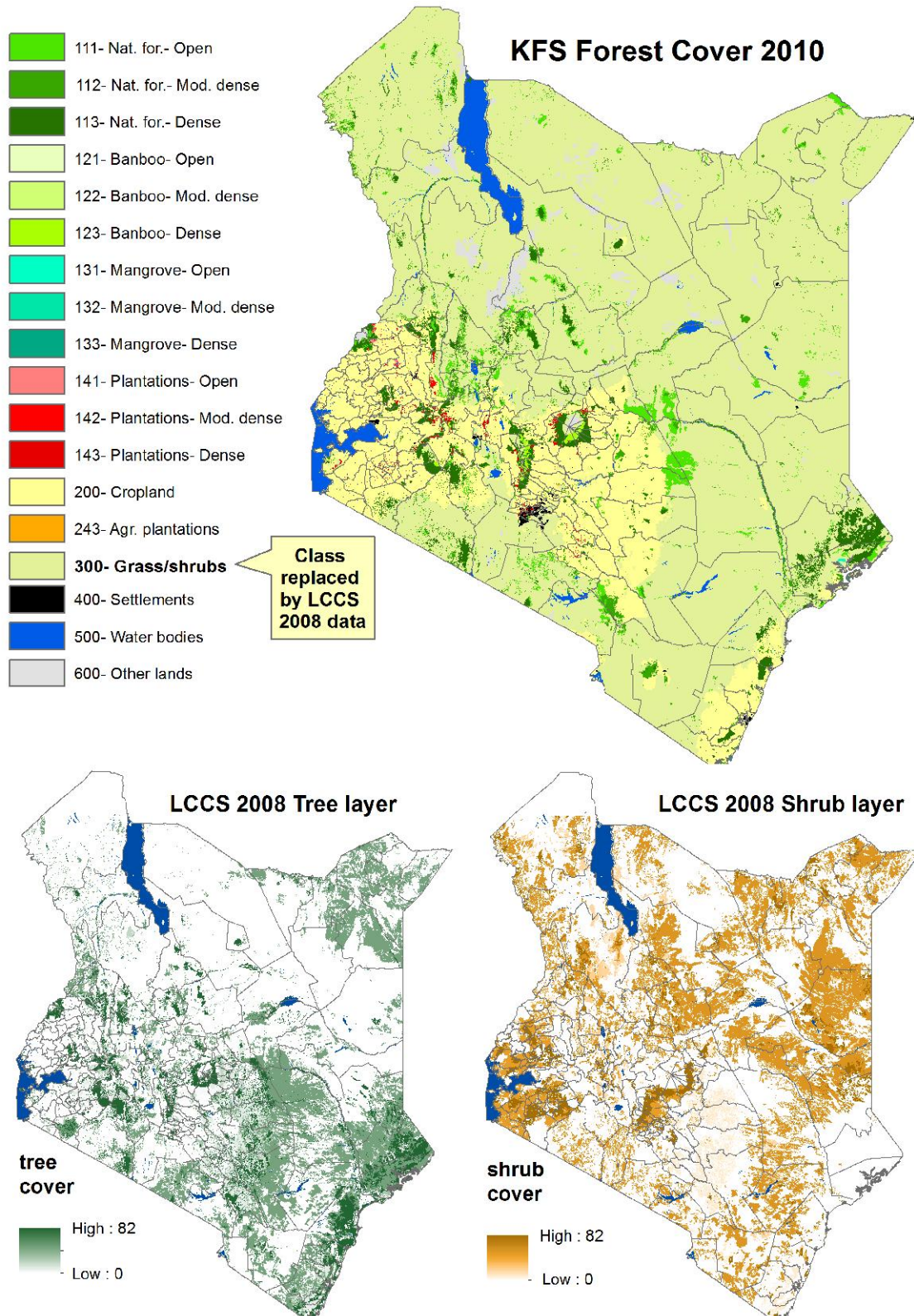


Table A2.1 : Reference stock values by Agro Climatic Zones (Values : DEB in od t / ha)

| Agro Climatic Zones |             |                                                                                                                         |       |          |           |                       |          |      |           |
|---------------------|-------------|-------------------------------------------------------------------------------------------------------------------------|-------|----------|-----------|-----------------------|----------|------|-----------|
| Land Use            | Type        | Density                                                                                                                 | 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 40-65% 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/<br>shrub     | na          | Vegetation density from LCCS2008:<br>For tree cover and bamboo cover, use values above.<br>For shrubs, use values below |       |          |           |                       |          |      |           |
| Otherlands          | 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/<br>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)

|                     |                     |                             | Agro Climatic Zones          |          |           |                       |          |      |           |
|---------------------|---------------------|-----------------------------|------------------------------|----------|-----------|-----------------------|----------|------|-----------|
| Land Use            | Type                | Density                     | 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/<br>shrub     | na                  | Apply the MAIStock Equation |                              |          |           |                       |          |      |           |
| Otherlands          | na                  |                             |                              |          |           |                       |          |      |           |
| Shrubs              | Mod.Dense 40-65% CC |                             |                              |          |           |                       |          |      |           |
| Settlements         | na                  |                             |                              |          |           |                       |          |      |           |
| Water/<br>Wetlands  | na                  |                             |                              |          |           |                       |          |      |           |

Figure A2.2 : Agro Climatic Zones

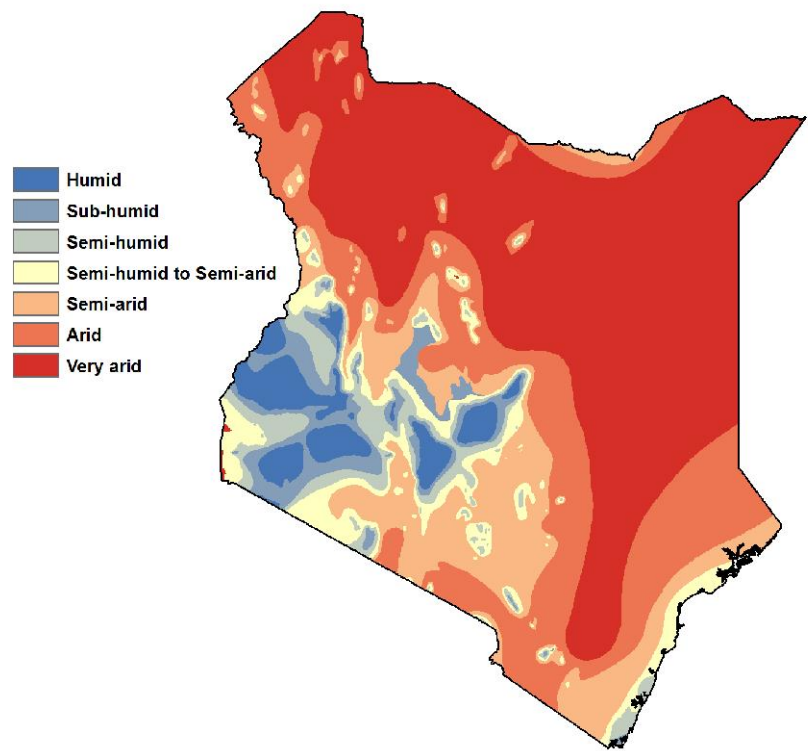


Figure A2.3 : Stock vs MAI relations for natural broadleaves and coniferous formations in tropical and subtropical zones

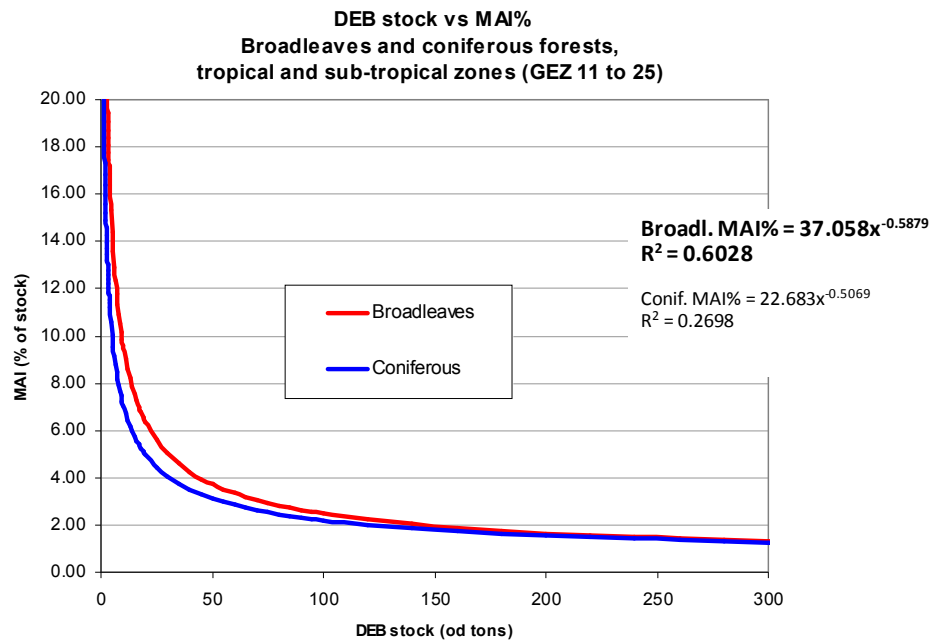
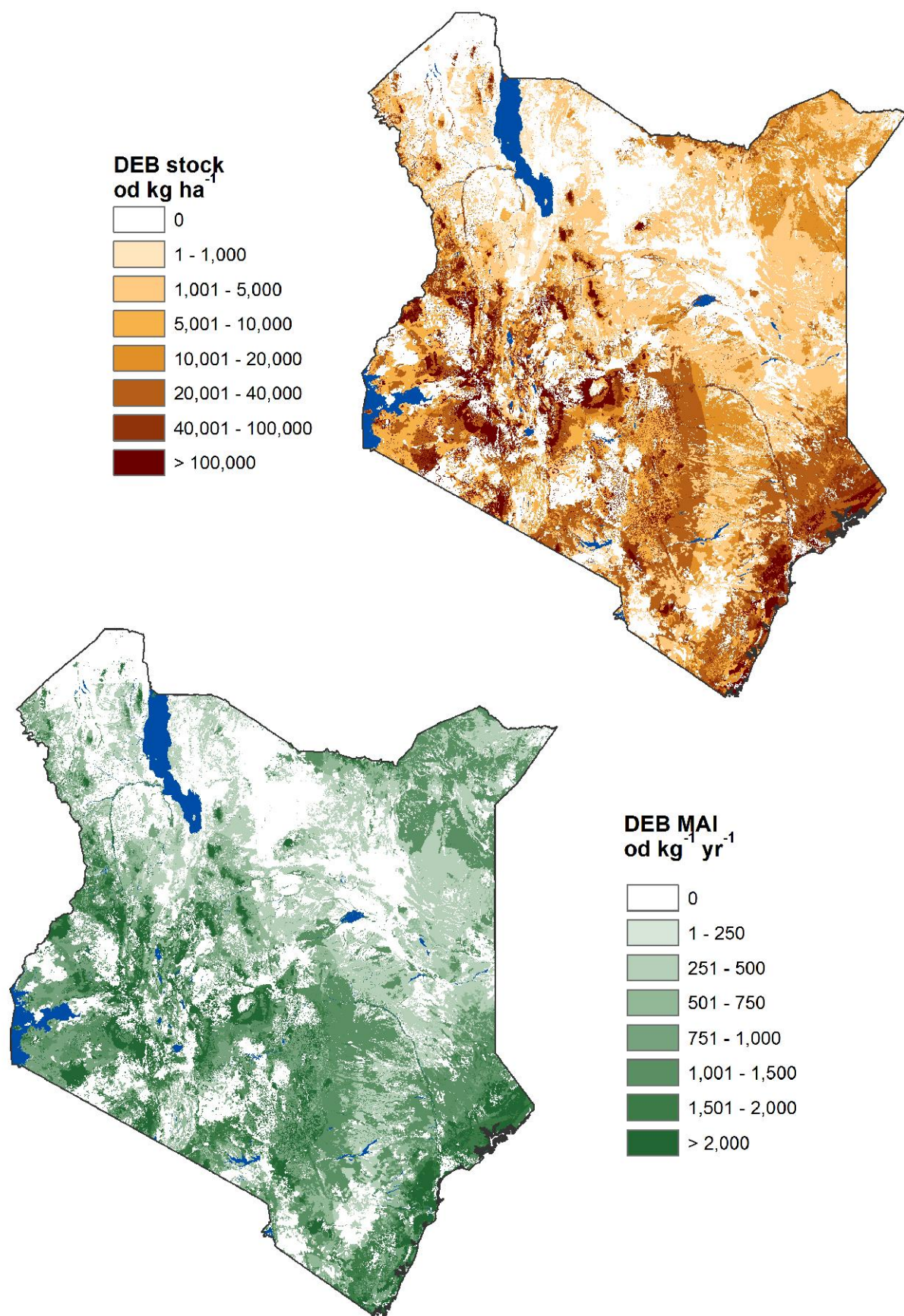




Figure A2.4 : Maps of DEB stock and MAI





## ANNEX 3: ACCESSIBILITY OF BIOMASS RESOURCES

### 1 Physical accessibility

#### Offroad accessibility Travel 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 legally accessible 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 |
|----------------------------------------------------|---------------------|------------|---------------|---------------|------------------------|
| Nat.forest                                         | Open 15 40% CC      | 26         | 1.5           | 39            | 65                     |
|                                                    | Mod.Dense 40 65% CC | 28         | 1.5           | 42            | 70                     |
|                                                    | Very Dense > 65% CC | 30         | 1.5           | 45            | 75                     |
| Bamboo                                             | Open 15 40% CC      | 26         | 1.5           | 39            | 65                     |
|                                                    | Mod.Dense 40 65% CC | 28         | 1.5           | 42            | 70                     |
|                                                    | Very Dense > 65% CC | 30         | 1.5           | 45            | 75                     |
| Mangroves                                          | Open 15 40% CC      | 40         | 1.5           | 60            | 100                    |
|                                                    | Mod.Dense 40 65% CC | 40         | 1.5           | 60            | 100                    |
|                                                    | Very Dense > 65% CC | 40         | 1.5           | 60            | 100                    |
| Plantations                                        | Open 15 40% CC      | 16         | 1.5           | 24            | 40                     |
|                                                    | 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                    |
| <b>LCCS2008 Classes</b>                            |                     |            |               |               |                        |
| 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 |
| <b>1=Highway</b>                                   | 1=Paved             | 1          | 1             | 1             | 2                      |
|                                                    | 2=Gravel            | 1.5        | 2             | 3             | 4.5                    |
|                                                    | 3=Dirt/Sand         | 2          | 3             | 6             | 8                      |
| <b>2=Primary</b>                                   | 0=Unspecified       | 2          | 4             | 8             | 10                     |
|                                                    | 1=Paved             | 1.5        | 5             | 7.5           | 9                      |
|                                                    | 2=Gravel            | 2          | 6             | 12            | 14                     |
| <b>3=Secondary</b>                                 | 3=Dirt/Sand         | 3          | 7             | 21            | 24                     |
|                                                    | 0=Unspecified       | 3          | 8             | 24            | 27                     |
|                                                    | 1=Paved             | 2          | 9             | 18            | 20                     |
| <b>4=Tertiary</b>                                  | 2=Gravel            | 3          | 10            | 30            | 33                     |
|                                                    | 3=Dirt/Sand         | 4          | 11            | 44            | 48                     |
|                                                    | 0=Unspecified       | 3          | 12            | 36            | 39                     |
| <b>6=Trail</b>                                     | 1=Paved             | 2.5        | 13            | 32.5          | 35                     |
|                                                    | 2=Gravel            | 3          | 14            | 42            | 45                     |
|                                                    | 3=Dirt/Sand         | 4          | 15            | 60            | 64                     |
| <b>Railway</b>                                     | 0=Unspecified       | 6          | 16            | 96            | 102                    |
|                                                    |                     | 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<sup>10</sup> 3 arcsecond). The effect of slope on travel speed is estimated following Nelson's approach, which was based on van Wagtenonk and Benedict (1980)<sup>11</sup> and is computed as follows:  $v = v_0eks$ , where:

- v = off road foot based velocity over the sloping terrain,
- v<sub>0</sub> = 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**

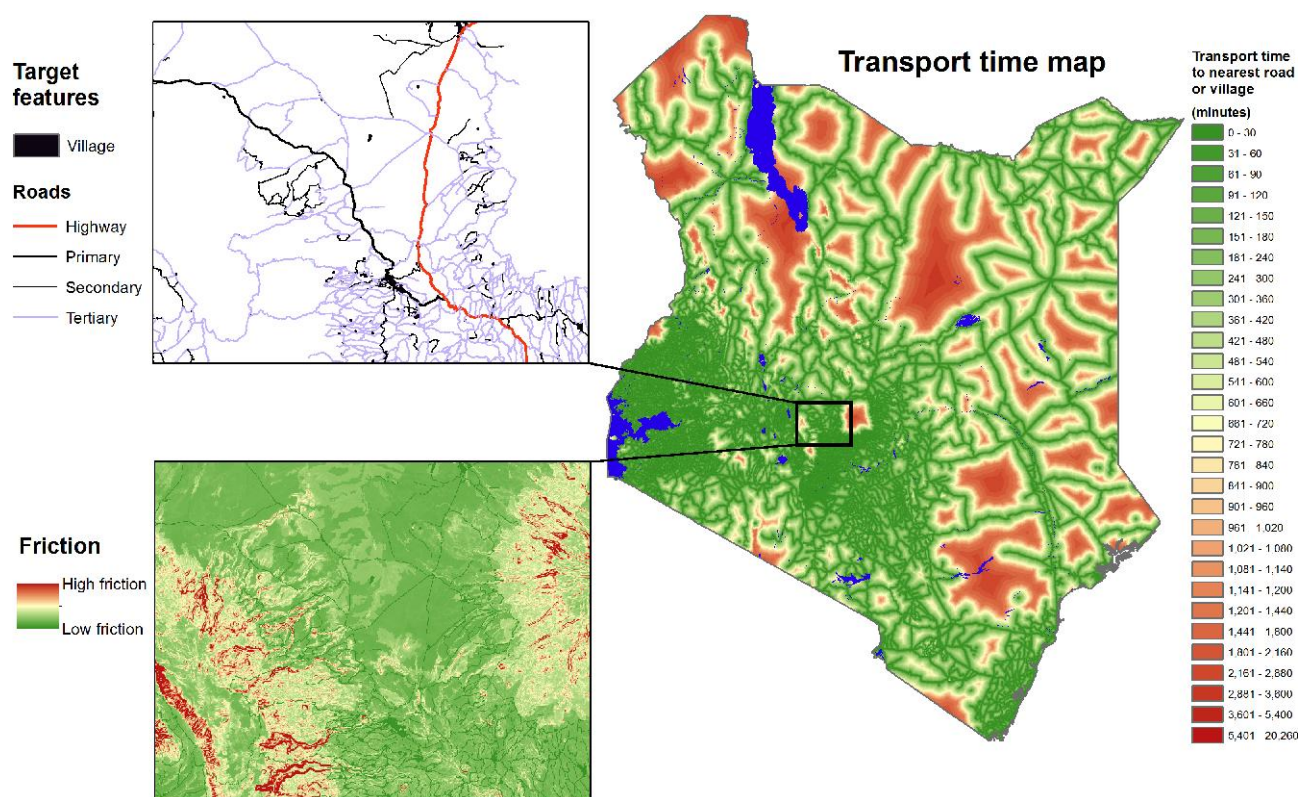
The results of the analysis are presented in Figure A3.2 that shows the map of travel time to nearest

<sup>10</sup> Digital terrain model data downloaded from : [http://dds.cr.usgs.gov/srtm/version2\\_1/SRTM3/Eurasia/](http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/Eurasia/)

<sup>11</sup> van Wagtenonk, 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**

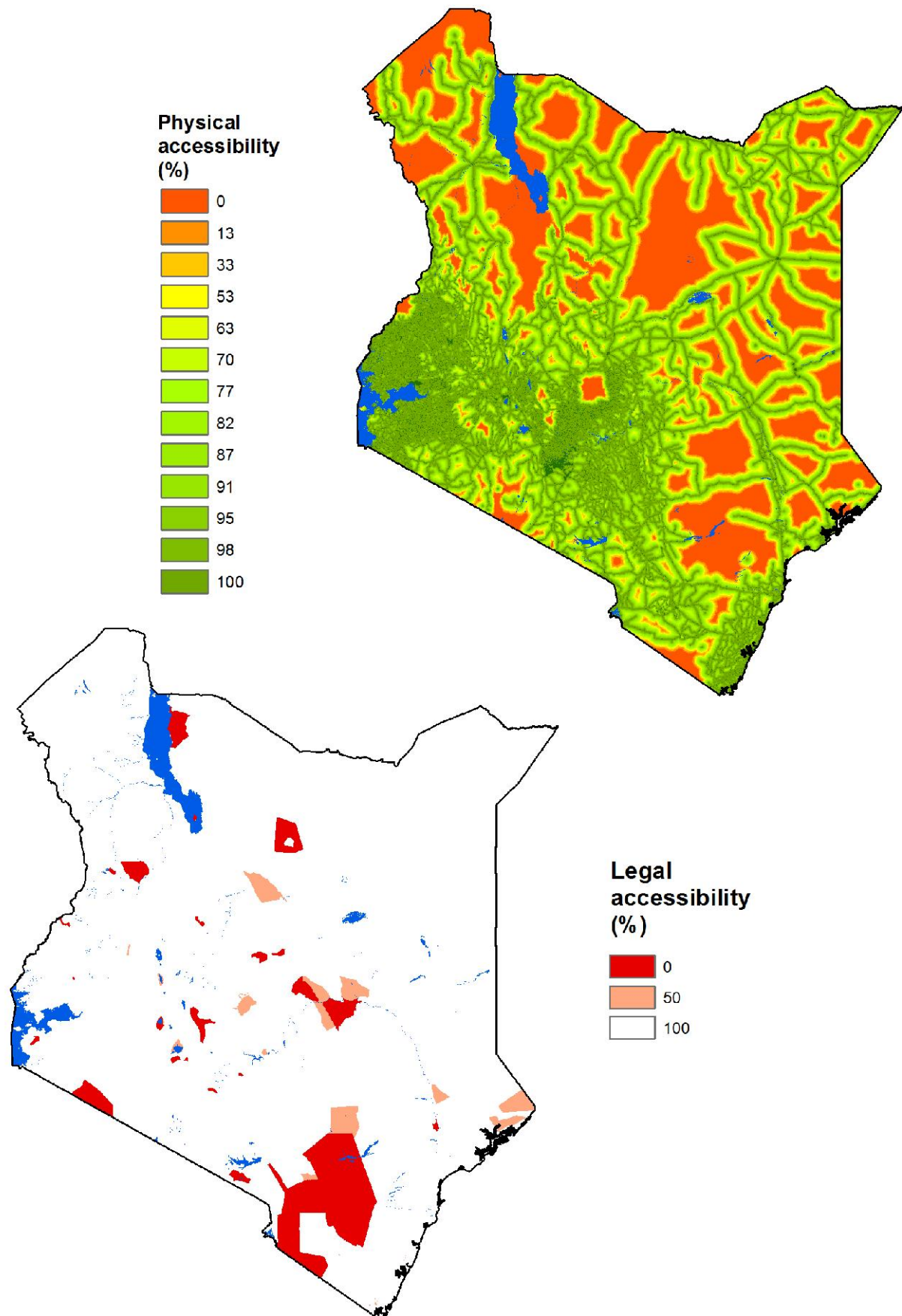
|        |                                            |       |                            |          | Nonaccessible MAI (%) : |              | 30.3   |
|--------|--------------------------------------------|-------|----------------------------|----------|-------------------------|--------------|--------|
|        |                                            |       |                            |          | Accessible MAI (%) :    |              | 69.7   |
|        |                                            |       |                            |          | accessible MAI          |              |        |
| cd2_20 | Transport time from nearest target feature |       | Legally accessible MAI odt | % of MAI | access loss (%)         | % accessible | kt od  |
|        | minutes                                    | hours |                            |          |                         |              |        |
| 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      |
|        |                                            |       |                            |          |                         |              | 28085  |
|        |                                            |       |                            |          |                         |              | 40,268 |

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

| Category   | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Ia</b>  | Strict Nature Reserve: protected area managed mainly for science<br><b>Definition:</b> 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.                                                                                                                                                                                                                           |
| <b>Ib</b>  | Wilderness Area: protected area managed mainly for wilderness protection<br><b>Definition:</b> 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.                                                                                                                                                                                                   |
| <b>II</b>  | National Park: protected area managed mainly for ecosystem protection and recreation<br><b>Definition:</b> 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. |
| <b>III</b> | Natural Monument: protected area managed mainly for conservation of specific natural features<br><b>Definition:</b> 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.                                                                                                                                                                                               |
| <b>IV</b>  | Habitat/Species Management Area: protected area managed mainly for conservation through management intervention<br><b>Definition:</b> 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.                                                                                                                                                                                                                |
| <b>V</b>   | Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation<br><b>Definition:</b> 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.      |
| <b>VI</b>  | Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems<br><b>Definition:</b> 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                                  |
| <b>Kenya</b>   | <b>10,032</b> | <b>-30,427</b> |                    |                    | <b>7.7</b>                 | <b>-2,598</b>              | <b>1,825</b>                          |