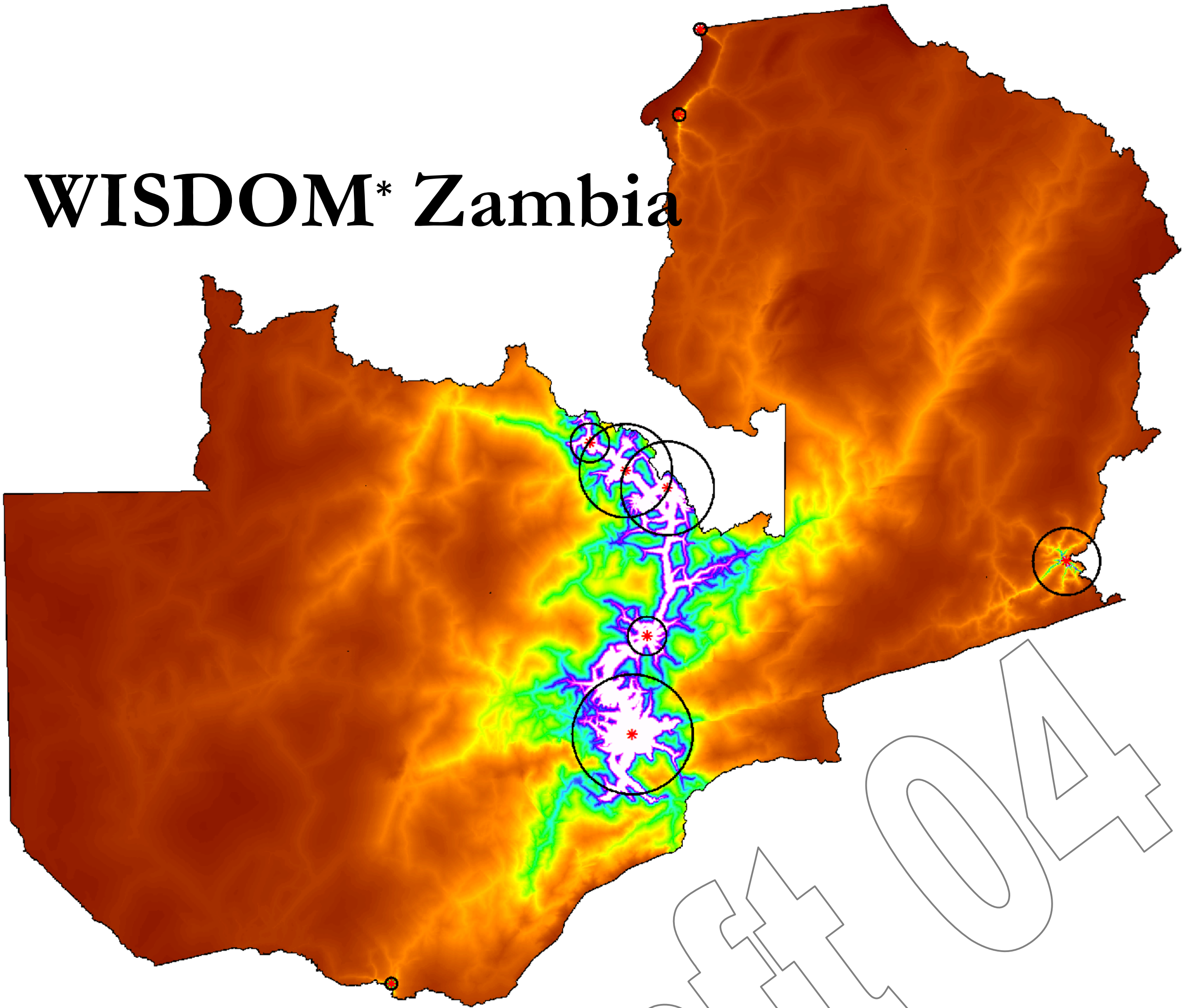
Phase II of Integrated Land Use Assessment in the Republic of Zambia GCP/GLO/194/MUL (FIN) - Zambia

WISDOM* Zambia



Analysis of demand, supply and sustainability of wood products in Zambia

Final Report

*** Woodfuel Integrated Supply/Demand Overview Mapping**

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Contents

Acronyms and abbreviations

ad	Air-dry (15 % moisture content, dry basis (ESMAP 1999)
AGB	Aboveground Biomass
Ch	Charcoal
CSO	Central Statistical Office
DEB	DendroEnergy Biomass (woody aboveground biomass less stump and twigs)
DM	Dry Matter, 0% moisture content, equivalent to oven-dry (od)
DTM	Digital Terrain Model
FAO	Food and Agriculture Organization of the United Nations
FD	Forestry Department
FLES	Forest Livelihood and Economic Survey
fNRB	fraction of Non Renewable Biomass (i.e. non sustainable fraction)
FRA	Forest Resources Assessment
FRL	Forest Reference Level
Fw	Fuelwood
GACC	Global Alliance for Clean Cookstoves
GIS	Geographic Information System
HH	Household
ILUA II	Zambia's Integrated Land Use Assessment, second phase.
kt	kilo tons ('000 metric tons)
LC	Land Cover
LCC	Land Cover Change
MAI	Mean Annual Increment
MMEWD	Zambia Ministry of Mines, Energy and Water Development
MODIS	Moderate-resolution Imaging Spectroradiometer
MRV	Measurement, Reporting and Verification of the UN-REDD Proghramme
NFI	National Forest Inventory
od	Oven-dry, at 0% moisture content, equivalent to Dry Matter (DM)
PPS	Probability Proportional to Size
REDD+	Reduced Emissions from Deforestation and forest Degradation
SIEF	Sustainable Increment Exploitation Factor
TC	Tree Cover
VCF	Vegetation Continuous Field
WCMC-IUCN	World Conservation Monitoring Centre - International Union for the Conservation of Nature
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping

Executive summary

This study contributes to the Zambia's Integrated Land Use Assessment (ILUA II) efforts to address domestic forestry information needs as well as international reporting requirements, and to provide valuable information on the forest sector to users. In particular, this study contributes to the formulation of the REDD+ Investment Plan for Zambia by analyzing the nexus between the growing national needs for woody biomass and ongoing processes of deforestation and forest degradation, by identifying the areas under unsustainable harvesting pressure as priority areas of intervention, and by quantifying the emission reduction potential of such interventions.

In this study we carried out a spatial-explicit analysis of the demand for wood products in Zambia, the supply potential and the sustainability of wood harvesting, with particular attention to fuelwood and charcoal, with the scope of identifying areas under high risk of forest degradation due to excessive harvesting and, as far as possible, concluding on drivers of forest-cover change and their underlying causes.

This required the integration of spatial and statistical data related to the demand for wood products, to the sustainable woody biomass supply potential and its physical, legal and economic accessibility.

A variety of data sources were used. The most relevant source of data has been ILUA II, which provided rich biophysical data, including georeferenced forest inventory data (3,586 field plots), land cover and carbon mapping, forest area change maps covering the periods 2000-2010 and 2010-2014, and socio-economic data from the Forest Livelihood and Economic Survey (FLES) 2014. Other important sources of data have been the Central Statistical Office, national forestry and energy agencies, academic research and development programmes.

The analysis followed the Woodfuel Integrate Supply/Demand Overview Mapping (WISDOM) methodology, whose main phases of analysis are outlined in Figure (i).

The first phase of analysis (WISDOM Base) produced quantitative and spatially detailed estimates (raster maps with 100m resolution) of wood consumption including fuelwood, charcoal, timber and construction material, and of the woody biomass stock, total productivity and its accessible fraction under physical, legal and economic criteria. The first phase concluded with the production of balance maps and statistics, combining demand and supply layers. Three type of balance maps were produced: the *pixel-level balance*, a simple accounting of supply minus demand, the *local level balance*, representing the demand and supply within the harvesting horizon of rural households for subsistence energy and other local uses, and the *commercial balance*, that, based on the local balance, defines the local deficit, i.e. demand that is not satisfied by local resources, and the "commercial" surplus that is suitable for commercial harvesting.

The second phase of the analysis (Woodshed Analysis) is dedicated to the evaluation of the commercial harvesting pressure and to the estimation and mapping of the theoretical minimum sustainable woodshed (areas within which local deficits and commercial surpluses match) and of the probable current commercial harvesting zones according to assumptions relative to market mechanism, transport time and management factor. The analysis concludes with the estimation and mapping of the expected unsustainable harvesting and the consequent degradation rates.

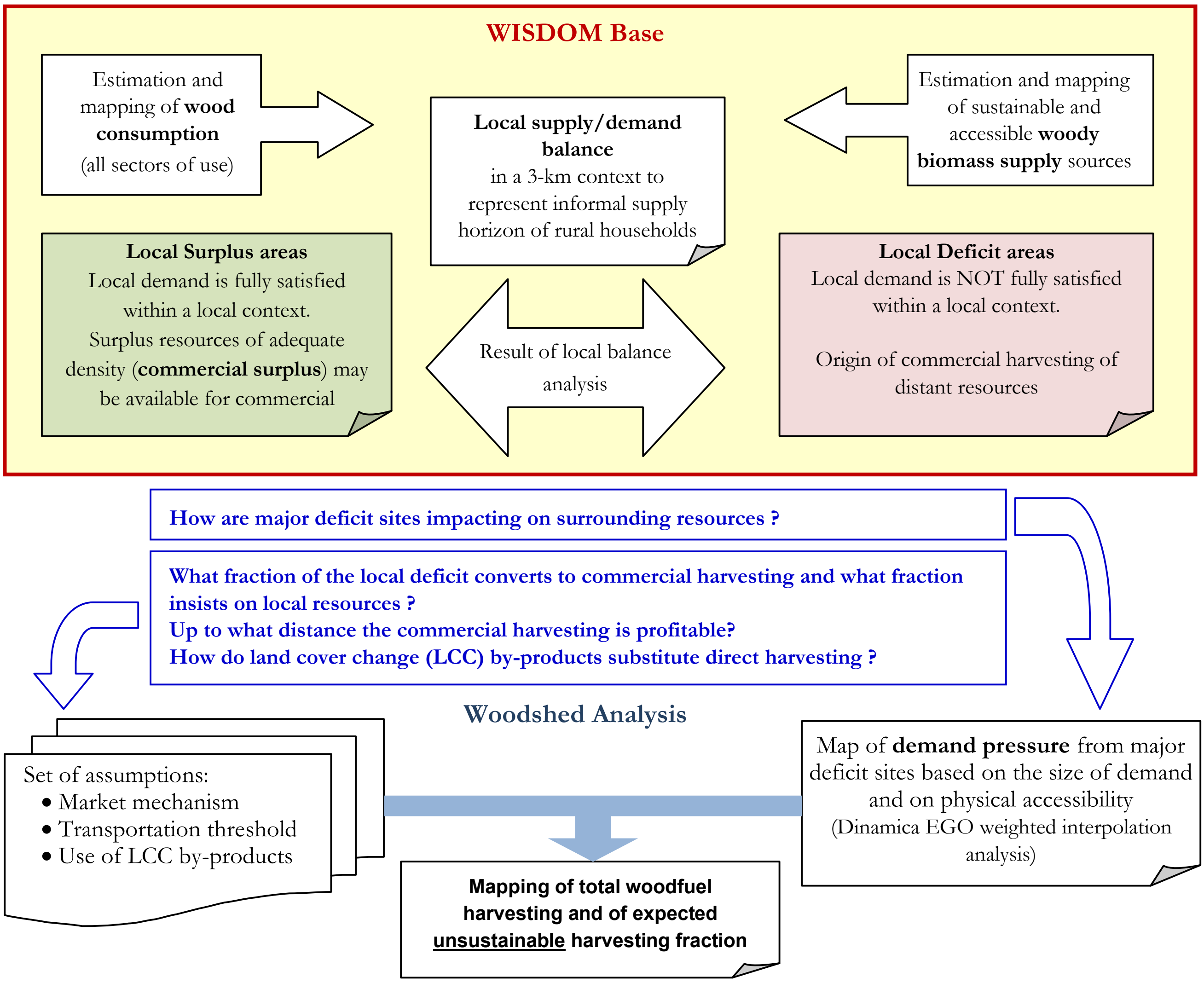
Summary of demand for wood products

- The national demand for wood products in 2010, including charcoal, fuelwood, construction material and timber is estimated to be 13 million tons DM (= 20. 7 million m^3), 82% of which as fuelwood and charcoal in the residential sector.
- The total consumption of charcoal is estimated at 1.15 million tons, corresponds to 5 million tons of wood (DM), 67% of which is consumed by urban households. The total consumption of fuelwood is estimated at 6.48 million tons DM, 94.8% of which by rural households.
- Around half of the national demand for wood products (47%) is concentrated in a relatively small area along the central axis of the country and the main markets are (North to South) Chingola, Kitwe, Ndola, Kabwe and Lusaka. In this analysis it is assumed that most of the commercial harvesting feeding these

market sites takes place within 16 hours of transport time. The accessible resources along such axis are those under highest harvesting pressure and thus under higher risk of degradation.

FIGURE (i)

Overview of the phases of analysis



Summary of supply potential

- The total stock of woody biomass[1] is estimated at slightly over 2 billion tons DM. This could be estimated with good confidence thanks to the field inventory data and land cover mapping produced by ILUA II.
- In the absence of representative growth data, the potential annual productivity is estimated by applying two generic MAI/stock equations: one based on tropical/sub-tropical broadleaved formations, representing the "High MAI" variant, and one reflecting the stock/growth values given in IPCC Guidelines, representing the "Low MAI" variant.
- According to the High MAI variant, the total potential productivity is 104 million tons DM, with 67.6 million tons physically and legally accessible. According to the Low MAI variant, the total potential productivity is 71.9 million tons DM, with 46.8 million tons physically and legally accessible. In order to be "conservative" in the estimation of the production potential the Low MAI variant has been taken as

[1] Including dendroenergy biomass (DEB) and dead wood (DW). DEB includes stem and branches and is calculated by deducting stump, twigs and foliage from aboveground biomass (AGB).

reference of sustainable supply potential for all subsequent phases of analysis

National supply/demand balance

- Taking the Low MAI variant, the local supply/demand balance, estimated within a context of 5 km, shows a large national-level surplus of 33.7 million tons DM. The commercial balance, shown in Figure (ii), estimated by excluding from the local surplus all wood resources that are too sparse for commercial exploitation, shows, for the Low MAI variant, a net surplus of 23.9 million tons DM.
- The balance analysis indicate that 61 % of the total demand (7.9 million tons DM) is satisfied by local resources (within a radius of 5 km), while 39% (5.1 million tons DM) depend on the supply from distant areas, through commercial production systems. Comparing this last value (i.e. the gap to be filled) with the commercial surplus, 23.9 million tons DM, it's evident that the Country has great abundance of wood resources.
- Except Lusaka, all provinces show surplus conditions. Out of 74 districts, deficit conditions are found only for 12, represented mainly by small urban districts. This tells that the resources of the Country are not only abundant, they are also evenly distributed.
- Even assuming the Low MAI variant, the Country shows large surplus, which indicates that there are ample possibilities for the establishment of sustainable production systems for the full satisfaction of current needs for energy and wood industries as well as for future bioenergy programmes.

Theoretical sustainable woodshed

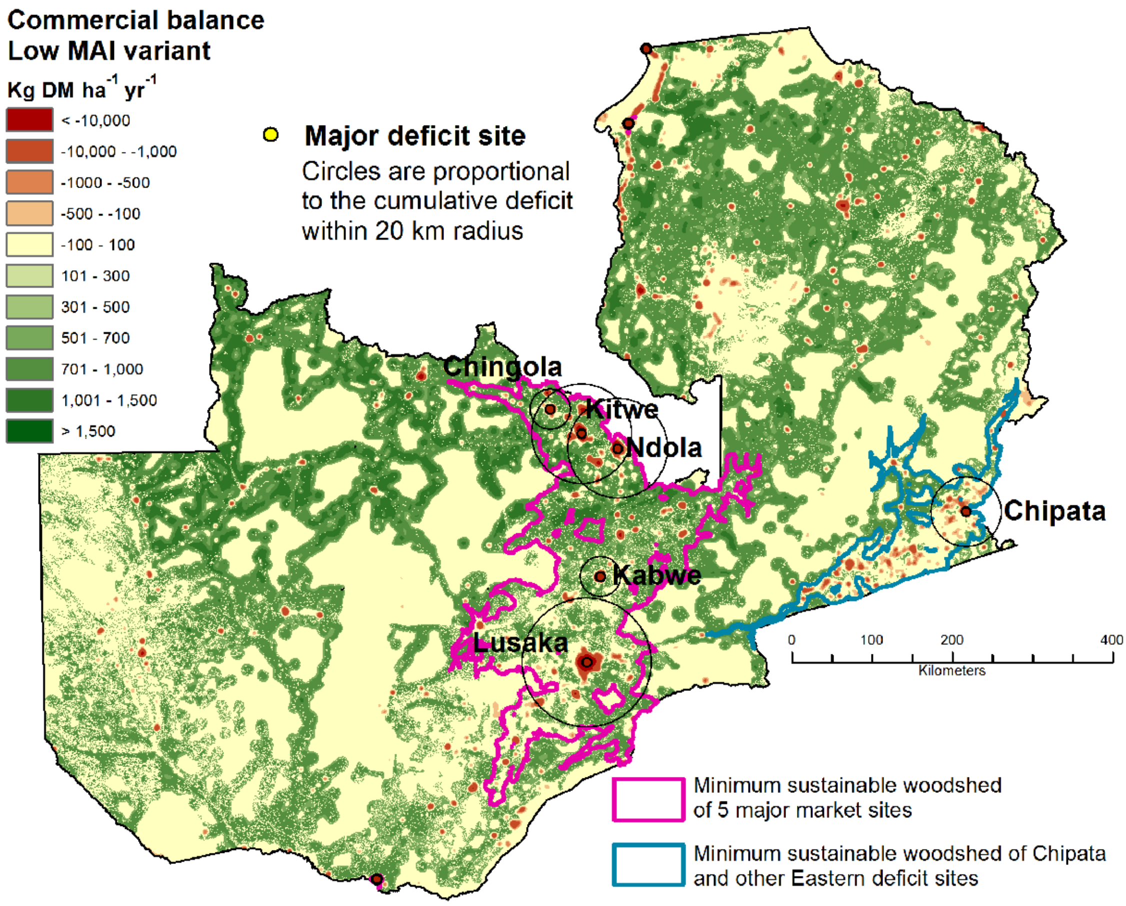
- This analysis shows that the theoretical minimum sustainable woodshed of the 5 major market sites (Chingola, Kitwe, Ndola, Kabwe and Lusaka), as well as the one of Chipata and surrounding deficit sites are well separated and relatively small in size (all necessary resources are within 150-200 km distance from market sites), as shown in Figure (ii). This indicates that the sustainable production of fuelwood, charcoal and industrial roundwood not only is feasible, it has a great potential in Zambia.
- While SFM should be implemented in all forest areas, these woodsheds clearly define the primary target of forest production and protection measures, wood energy planning and landscape management.

Expected commercial harvesting sustainability and degradation rates

- Considering current sub-optimal resource management and harvesting practices, rather than optimal practices, the degradation due to excessive exploitation of wood resource is expected to occur primarily in the harvesting zones that feed the major market sites, along the central axis of the Country (purple area in Figure ii).
- Assuming a 16-hours transportation threshold as the limit within which commercial harvesting concentrates, the expected annual degradation in all land cover classes in the central commercial harvesting zone is estimated to range between 224 and 629 thousand tons DM, assuming full-use and no-use of deforestation by-products, respectively. Considering forests only, the expected annual degradation is estimated to range between 134 and 391 thousand tons DM.
- Degradation of minor entity due to un-regulated harvesting and charcoal making is expected to occur in other areas of the Country where pressure is high, as in the territory around Chipata, for instance. In most areas, however, fuelwood, charcoal and timber are by-products of deforestation processes and thus direct harvesting (without land use change) are limited and abundantly surpassed by natural re-growth capacities.

FIGURE (ii)

Commercial balance, major deficit sites and theis minimum sustainable woodsheds



Is wood harvesting a driver of deforestation?

This study indicates that excessive wood harvesting may be a direct cause of **forest degradation**, particularly in the areas around the major urban centres, as estimated and discussed in the previous paragraphs. But what is the relation between wood harvesting and **deforestation**?

A common and widespread narrative in Zambia says that charcoal making is a major driver of deforestation, if not the main one, and that reducing charcoal making will reduce deforestation. This analysis does not support such a narrative.

The available data show that there is no evident correlation between demand for wood and deforestation rates. It appears that wood products and charcoal making are more by-products of farming expansion rather than drivers of change. Moreover, there is no apparent justification for exploiting forest resources so intensively to cause full depletion, considering:

- the sustainable production potential surpassing manifolds the demand for wood products,
- the powerful coppicing capacity of miombo formations, and
- the fair distribution of wood resources over the Country

It is also commonly asserted that charcoal making, by clearing forest areas, catalyzes farming expansion. While there is no doubt that charcoal making does have a catalytic effect on land conversion since it pays for the conversion process, it's hard to believe that an area is cultivated for the sole reason of being cleared of tree cover. The need for land for subsistence or mechanized farming is a powerful driver of change. Charcoal making is among the factors that influence the process but it's hard to believe that reducing charcoal making would have any significant impact on the need for new farmland.

If deforestation is driven by farmland expansion at the expense of existing forests, all efforts towards reducing the demand for charcoal and other wood products is very unlikely to mitigate the process of deforestation and consequent GHG emissions.

In this context, using by-products of land conversion for energy or furniture making is a better option rather than simply burning them on site, as it happens in areas where the demand for land is not accompanied by demand for wood (i.e. the Brazilian Amazon). In fact, whether deforestation can or cannot be reduced, it's in any case important to make best and maximum use of its by-products as a way to reduce its negative impact.

In fact, the use of such by-products as energy source reduces the impact of deforestation by replacing direct woodfuel harvesting and by providing energy to urban and rural households that would hardly afford alternative energy sources (electricity, LPG).

Taking charcoal as the scapegoat of deforestation appears misleading, diverting the attention from the real causes and from identifying appropriate remedial action. Rather than by wood demand, land use change processes such as the expansion of subsistence and mechanized farming throughout the country seem to be primarily driven by increasing needs for land.

Priority lines of intervention and contributions of WISDOM analysis

From REDD+ perspective it seems that the highest priorities, in order to reduce deforestation and forest degradation, be the following, by decreasing priority level:

1. Mitigate inefficient farming expansion by improving farming efficiency/productivity. (Action targeting deforestation)
2. Implement protection measures in the high degradation risk areas accompanied by well-known rotational sustainable management practices. This analysis produced a ranking of districts according to expected degradation that identifies the target areas for this action. (See Table 9 and Figure 22, main text). (Action targeting degradation)
3. Promote and support sustainable charcoal and woodfuel production through participative sustainable management practices exploiting the strong miombo coppicing capacity. This analysis produced a ranking of districts with highest production potential that identifies the target areas for this action. (See Table 9 and Figure 22, main text). (Action targeting degradation).
4. Explore other possible drivers of forest degradation such as recurrent fires and excessive grazing. Shortening fallow periods is also a likely driver of landscape degradation. (Action targeting degradation)

By providing relevant georeferenced data for any chosen territorial unit, including rural and urban population distribution, stock and growth of woody biomass, physical and legal accessibility, harvesting pressure, etc., the WISDOM analysis can contribute to the development of the REDD+ Investment Plan for all 10 strategic objectives. Most relevant is the contribution that this analysis can provide for the strategic objectives 1, 2, 5, 6 and 10, as presented in Table (i).

The WISDOM methodology supports the definition of priority areas of intervention for forestry and energy planning, which is the main reason of its development. Remaining in the REDD+ context, for instance, this study contributes by revealing the cause-effect mechanisms behind degradation processes. Beyond measuring deforestation and degradation we need to identify remedial actions and to this end WISDOM provides essential quantitative and spatial elements linking cause (demand for fuelwood) and effect (rates of degradation) that are fundamental to the formulation of focused forestry and energy policies and to the design of strategic and operational planning.

From a Sustainable Forest Management perspective, this analysis can support the formulation of locally tailored management objectives, such as productive or protective functions, quantitative production targets to meet local and commercial demand through new plantations and/or improved management practices.

TABLE (i)

REDD+ Strategic Objectives for which the WISDOM analysis can support the formulation of the REDD+ Investment Plan.

Selected strategic objectives laid down by the REDD+ Strategy	Relevance	Specific contribution of WISDOM study and supported interventions
1. By 2030, threatened and unsustainably managed national and local forests are effectively managed and protected to reduce emissions from deforestation and forest degradation and contribute with ecosystem services across selected landscapes	***	Ranking of priority areas (provinces, districts, watersheds, or any chosen area) for risk of degradation and/or sustainable supply potential (See Table 9 and Figure 22, main text). Definition of emission reduction targets and locally-tailored protection/production management objectives for each chosen unit.
2. By 2030, selected high value forests in open areas are effectively managed and monitored	**	Profiling of the selected high value forests (harvesting pressure and degradation risk; urban/rural population within and around the forests; accessibility; etc.).
5. By 2030, regulated production of wood fuel (charcoal & firewood) and its improved utilization in place	***	Definition of sustainable woodfuel production targets and locally-tailored protection/production management objectives. Basis for consumption surveys. Support to improved charcoal-making programmes. Etc.
6. By 2020, appropriate and affordable alternative energy sources widely adopted	***	Contribute to the definition of the actual impact of the substitution of wood energy on GHG emissions, reduction of deforestation, livelihood and employment in rural areas, etc.
10. By 2020, relevant institutions capacitated to enable them to plan, manage, implement and monitor REDD+ programme activities	**	The use and maintenance of the WISDOM multi-thematic GIS layers (if supported by appropriate GIS training) strengthen the institutional planning capacities.

Main conclusions on WISDOM development

With this analysis we estimated the risk of degradation, spatialized and quantitative, but still the risk and not the actual degradation, that remains to be assessed in the field and through multi-temporal high-resolution remote sensing techniques. As such, the WISDOM analysis represents an indirect approach for the estimation of forest degradation. A key contribution that the WISDOM analysis can make to the direct observation of degradation is in the stratification of forests and other landscapes according the risk of degradation (see Figure 21), thus making the data collection more efficient and cost-effective.

The WISDOM model does not allow for analysis if there are missing data, therefore its implementation implied the use of assumptions and of provisional value attributions to fill in for information gaps. In order to improve and consolidate the knowledge base the provisional estimates and assumptions applied here should be validation and replaced by solid reference data, when available.

Data weaknesses were identified concerning consumption statistics, woody biomass productivity and accessibility, which were resolved as well as could possibly be done with the available knowledge. Each weak element should be strengthened or replaced by better data. Nonetheless, the elements available were sufficient for a robust analysis and, while better quality data will certainly improve the results, it is unlikely that they will contradict or revolutionize the main conclusions of this study.

Due to limited time the analysis was limited to the most probable set of assumptions. The analysis has in fact followed a single path, applying a "conservative" supply variant and taking "most probable" assumptions concerning market mechanisms and transport time threshold. It would be useful to take alternative assumptions and data variants in order to carry out a comprehensive sensitivity analysis.

1. Introduction

1.1 Objectives

The general objective of this study is to contribute to the Zambia's Integrated Land Use Assessment (ILUA II) effort of introducing a policy relevant and integrated approach to forest resources assessment that addresses domestic forestry information needs as well as international reporting requirements, and providing valuable information on the forest sector to users. In particular, this study contributes to the formulation of the REDD+ Investment Plan for Zambia by analyzing the nexus between the growing national needs for woody biomass and ongoing processes of deforestation and forest degradation, by identifying the areas under unsustainable harvesting pressure as priority areas of intervention, and by quantifying the emission reduction potential of such interventions.

The specific objective of the study is to conduct a spatial-explicit and quantitative analysis of wood energy demand, woody biomass supply potential and woodfuel harvesting sustainability in order to identify hotspots of forest-cover change and, where possible concluding on drivers of forest-cover change and their underlying causes.

This analysis is based on the integration of spatial and statistical data from multiple sources related to the demand for fuelwood and charcoal as well as for industrial roundwood, to the sustainable woody biomass supply potential and its physical, legal and economic accessibility. Data sources include biophysical and socio-economic surveys from ILUA I and II, REDD+ reference level reporting, the Central Statistical Office, publications from national forestry and energy agencies as well as numerous studies produced by academic research and development programmes.

The analysis follows the Woodfuel Integrate Supply/Demand Overview Mapping (WISDOM) methodology[2].

1.2 Scope of the report

Scope of this report is to:

- Describe the methodological features of the WISDOM Zambia analysis
- Report on the spatial and statistical information that was used for the analysis.
- Describe and discuss the results
- Identify the hot spots of forest degradation induced by unsustainable charcoal making and fuelwood/timber harvesting
- Discuss the role of woodfuel demand as driver of deforestation

1.3 Main features of the WISDOM method

The methodological approach is based on the following three fundamental characteristics of wood energy systems:

Geographical specificity. The patterns of woodfuel production and consumption, and their associated social, economic and environmental impacts, are site specific (Mahapatra and Mitchell, 1999; FAO/RWEDP, 1997; FAO, 2003d).

Heterogeneity of woodfuel supply sources. Forests are not the sole sources of woody biomass used for energy. Other natural landscapes, such as shrublands, as well as other land uses –farmlands, orchards and agricultural plantations, agroforestry, tree lines, hedges, trees outside forest, etc. – contribute substantially in

[2] Visit www.wisdomprojects.net for a comprehensive presentation of WISDOM and its numerous applications world-wide.

terms of fuelwood and, to a lesser extent, of raw material for charcoal production.

User adaptability. Demand and supply patterns influence each other and tend to adapt to varying supply patterns and resource availability. This means that quantitative estimations of the impacts that a given demand pattern has on the environment are very uncertain, and should be avoided (Leach and Mearns, 1988; Arnold et al., 2003).

In order to cope with the various dimensions of wood energy, the Wood Energy Programme of the FAO Forest Products Service has developed and implemented the **Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology**, a spatially-explicit planning tool for highlighting and determining woodfuel priority areas or woodfuel hot spots (FAO, 2003). The WISDOM approach has been implemented in numerous case studies, at national and regional levels. Of specific relevance may be those of Mozambique, Rwanda, Sudan and Kenya[3].

Recently, WISDOM has been applied in the Project "Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and beyond" carried out by Yale University and Mexico University UNAM for the Global Alliance for Clean Cookstoves (GACC). Scope of the GACC project was the estimation and mapping the non-renewable fraction of the woody biomass used for energy at pan-tropical level (sub-national for 90 countries) based on international data sources (Drigo et al. 2014; Bailis et al. 2015; Masera et al. 2015) as well as for Kenya, Karnataka and Honduras, based on national data (Drigo et al. 2014 and 2015).

WISDOM is meant to create a spatially-explicit knowledge base on supply and demand of woody biomass for energy and thus to serve as a planning tool for highlighting and determining **priority areas** of intervention and to **focus planning options**. The result of the wall-to-wall supply/demand balance analysis is then used as starting point for the delineation of the necessary supply areas for existing or hypothetical commercial consumption sites.

WISDOM features:

- **Geo-referenced databases.** A core feature of the approach is the spatial base on which the data is framed. The analysis and presentation of results for all modules is done with the help of a Geographic Information System (GIS).
- **Minimum administrative and spatial units of analysis.** The spatial resolution is defined at the beginning of the study, on the basis of the desired level of detail (national study, regional study) and as constrained by the main parameters or proxy variables that will be used to "spatialize" the information. In most cases the basis for the definition of the administrative level of analysis is provided by the existing demographic data (i.e. census units), which represents the most detailed sub-national structure of a country. The spatial level of analysis (i.e. the size of the pixel in GIS raster data) is usually determined by the mapping detail of the available land use/land cover data.
- **Modular and open structure**. WISDOM consists of modules on demand, supply, integration and woodshed analysis. Each module requires different competencies and data sources and its contents is determined by the data available or, to a limited extent, by the data purposively collected to fill critical data gaps. Once the common spatial base of reporting is defined, each module is developed in total autonomy using existing information and analytical tools and is directed to the collection, harmonization, cross-referencing and geo-referencing of relevant existing information for the area of study.
- **Adaptable framework**. As mentioned previously, the information of relevance to wood energy comes from multiple sources, ranging from census data to local pilot studies or surveys, to projected estimates with unknown sources, and is often fragmented and poorly documented. Proxy variables may be used to "spatialize" discontinuous values. In synthesis, WISDOM tries to make all existing knowledge work for a better understanding of biomass consumption and supply patterns.
- **Comprehensive coverage of woody biomass resources and demand from different users**. The analytical framework includes of all sources of biomass potentially available for energy (i.e. fuelwood and charcoal, crop residues, industrial residues, etc.) and all users categories (rural and urban residential; industrial; commercial and public).

[3] See WISDOM case studies and relative publications at www.wisdomprojects.net

The WISDOM methodology may be divided into two sequential stages: **WISDOM Base** and **Woodshed**[4] **analysis**. Their specific steps of analysis are summarized below while a graphic overview is shown in Figure 1

WISDOM Base

The application of the standard WISDOM analysis producing supply and demand balance mapping at the local level involves the following main steps (FAO, 2003b).

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. Definition of local balance condition and identification of *priority* areas or woodfuel "hot spots".

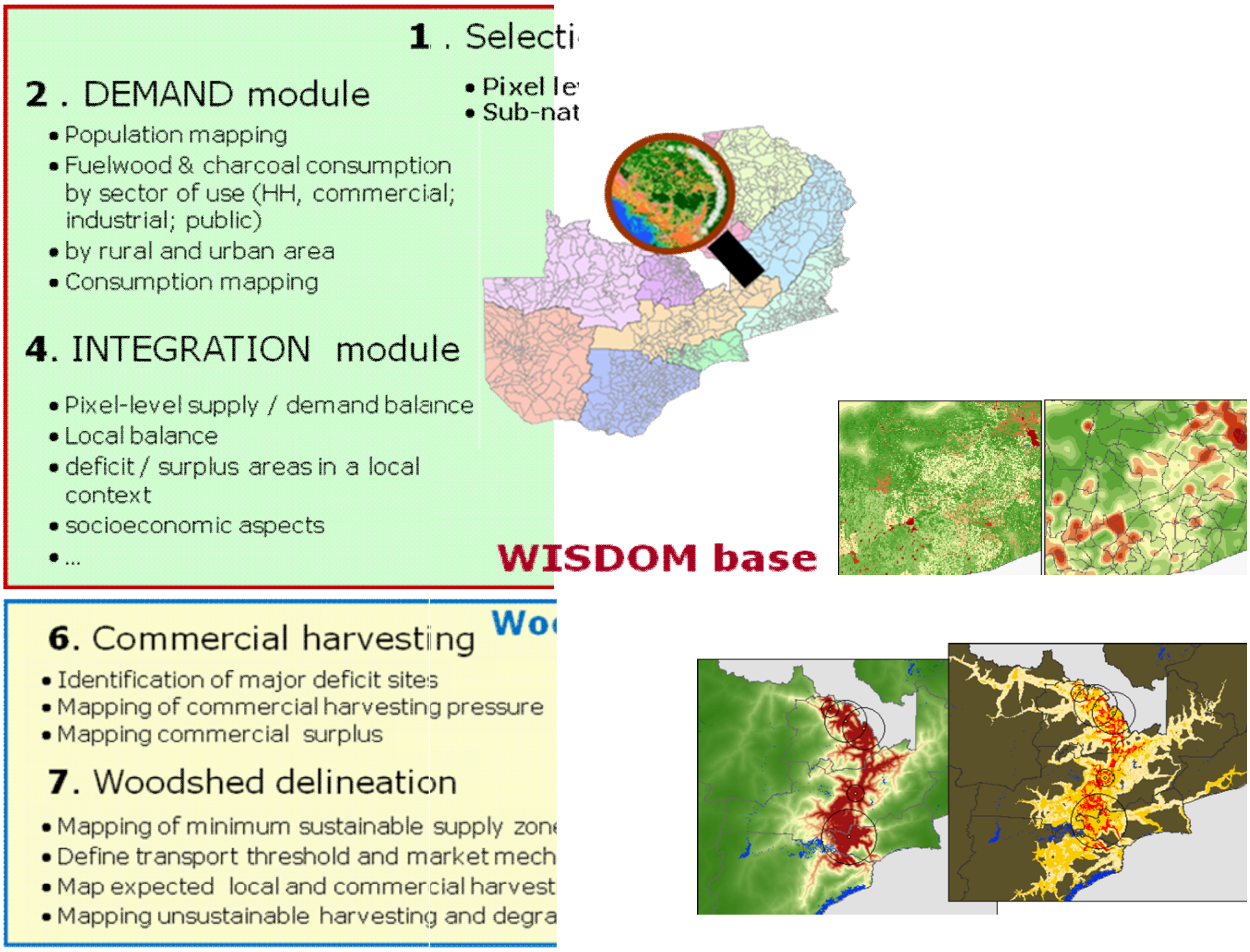
Woodshed analysis

The analysis for the delineation of woodsheds, i.e. harvesting zones of major consumption sites that depend primarily on commercial. supply systems, requires additional analytical steps that may be summarized as follows.

6. Identification of major deficit sites and mapping of the commercial harvesting pressure.
7. Mapping of <u>minimum sustainable harvesting area</u> based on demand pressure and available resources and of the <u>expected harvesting area</u> based on physical/economic accessibility parameters. Estimation of harvesting sustainability, fNRB values and of woodfuel-induce forest degradation rates.

FIGURE 1

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



[4] The term "woodshed" is inspired by the familiar geographic concept of *water*shed. It is used to indicate the portion of the territory necessary to supply the woody biomass needed by a specific consumption site (Drigo and Salbitano, 2008).

2. WISDOM Zambia analysis

2.1 Selection of spatial base and reference year of analysis

2.1.1 Scale and projection

Mapping details:

The projection selected for the analysis is UTM Central zone 35 South (single projection for whole country

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

Administrative units used for population mapping:

The minimum administrative level used for the analysis is Ward (1421 units) in the version consistent with that used for the Demographic Census 2010. Accordingly, Wards are grouped into 150 Constituencies, 74 Districts and 10 Provinces.

The administrative structure is under continuous modification and there are newer versions more or less consolidated. For the scope of this study, however, the essential requisite of the administrative structure is to reflect the demographic and socioeconomic statistics resulting from Census 2010, which are used to map 2010 rural and urban population.

2.1.2 Reference year of WISDOM analysis

The reference years of the WISDOM analysis is usually determined by the reference year of the reference land cover data and/or latest demographic census. In case of Zambia the reference year of both reference land cover map and census is **2010**, which therefore represent the reference year of the WISDOM analysis.

2.2 Demand Module

The goal of the Demand Module is to estimate the current consumption of woody biomass in the various sectors (residential, commercial, industrial and public) and to represent as accurately as possible its spatial distribution. For the subsequent analyses of supply/demand balance and harvesting sustainability it is essential that the entire annual removal of woody biomass is considered. Therefore, although the analysis focuses primarily on woodfuels, it is essential to consider also the demand for other competing uses of wood, such as industrial roundwood and timber, which are estimated to represent around 6% of the entire national wood demand.

In most WISDOM analyses the industrial roundwood production is estimated and deducted from the supply potentially available for woodfuel production. In this case, however, the information on the industrial roundwood production is very approximate and the few available estimates include in this category timber, poles and construction material. Not being able to locate the areas of industrial roundwood production as separate sources, it was decided to merge the demand for these assortments to the wood energy demand, assuming that by and large they come from the same woody biomass sources. As a result, this analysis focus on the harvesting sustainability of all wood products, not only woodfuels.

The main thematic layers and processing steps of the Demand Module are presented in the flowchart in Figure 2 and described in the following Sections.

2.2.1 Reference data

Woodfuel consumption in the residential sector

The estimation of fuelwood and charcoal consumption in the residential sector requires information on two basic aspects: fuel saturation, which tells what fraction of rural and urban households depend on fuelwood and charcoal as main cooking fuel, and per capita consumption values, i.e. the quantity of fuelwood and charcoal consumed in one year in rural and urban areas.

Saturation values tend to change over time as effect of economic trends and it's essential to use most recent data from national level surveys. In most countries the information on the primary fuel used for cooking and heating is collected during demographic censuses from all households or from a representative sample. The common limit, however, is that saturation data is limited to the main fuel, without reference to secondary fuels. As such, saturation data refer exclusively to Main Users, i.e. fraction of households using fuelwood or charcoal as main fuel, and actual fuel mix is not reported.

Per capita consumption values are less subject to change and results of older surveys or sub-national surveys may be as valid as recent ones in its estimation. The main difficulty in the use of per capita (or per household) fuel consumption data is to understand what population they represent: consumption values may in fact refer to Main Users (households that use fuelwood or charcoal as primary fuel) or to All Users (households that use fuelwood or charcoal as primary or secondary fuel), or to All Population (average of all households, including users and non-users). Unfortunately the consumption values reported by a variety of publications, scientific articles or survey reports rarely mention what population they refer to.

The references that were reviewed for the estimation of the current consumption of woodfuels in the residential sectors are reported in Annex 1 while the sources and values selected and used for the analysis are the following:

Saturation (main cooking fuel)

CSO Census 2010. Main cooking fuel in rural and urban areas by District.

Per capita fuelwood and charcoal consumption

The values of per capita fuelwood and charcoal consumption used for this analysis refer to Main Users, in order to be applied to saturation values produced by Census 2010. The review of existing references revealed significant discrepancies among the available sources, as shown in Annex 1. Among the various sources, the values considered more appropriate to represent Main Users consumption rates are given in Table 1.

TABLE 1

Main Users per capita fuelwood and charcoal consumption rates

Fuelwood	**Per capita Fuelwood consumption as air-dry wood** (kg Fw ad yr^{-1})	**Per capita Fuelwood as wood DM** (kg wood DM yr^{-1})	**Source**
Rural areas	**1,041**	**905**	Kalumiana, 1996
Urban areas	**541**	**470**	ESMAP 1990
Charcoal	**Per capita Charcoal consumption** (kg Ch yr^{-1})	**Per capita Charcoal consumption as dry wood equivalent,** (kg wood DM yr^{-1})	
Rural areas	**237**	**1,041**	MMEWD 2016
Urban areas	**279**	**1,224**	ESMAP 1990

Other sectors of woodfuel consumption

Commercial and public sectors

The annual consumption of fuelwood in the commercial and public sectors is estimated to be 200 thousand tons while that of charcoal is estimated to be 150 thousand tons (MMEWD 2016). Added and converted to wood-equivalent, this corresponds to **832 thousand tons DM**. The consumption of the commercial and public sectors was spatially distributed proportionally to the population of urban and rural settlements.

Tobacco curing

The average annual fuelwood consumption for tobacco curing in recent years is estimated to be between 214 and 530 thousand air dry (ad) tons, depending on the chosen calculation method (MMEWD 2016). For the scope of this study an intermediate value of 372 thousand tons of air dry fuelwood, corresponding to **323 thousand tons DM**. The consumption of fuelwood for tobacco curing was spatially distributed over croplands of Eastern, Central, Lusaka and Southern Provinces where tobacco production is concentrated (MMEWD 2016).

Fish drying

The average annual fuelwood consumption for fish drying in 2010 is estimated to be 409 thousand ad tons, which corresponds to 356 thousand tons DM. The consumption of fuelwood for fish drying was spatially distributed over cropland.

Industrial roundwood

In this analysis, the industrial roundwood is considered as one component of the total demand for woody biomass.

According to Ng'andwe et al.(2006), total removals of industrial roundwood in 2006 were estimated to be in the order of 1.155 million m^3, similar to the corresponding FAO statistic of 1.325 million m^3 for recent years. Other significantly different estimates exist, which proves that solid statistics on industrial roundwood production in Zambia are not available (UNEP 2015). Tentatively, the estimates reported by FAOstat for year 2010 are used as reference. Converted to wood DM, the industrial roundwood production is estimated to be **835 thousand tons DM**.

The demand for industrial roundwood was spatially distributed proportionally to population of urban and rural settlements..

2.2.2 Mapping woody biomass demand

Once the sectors of consumption are defined and quantified, the subsequent step is to distribute such consumption over the territory with the best possible approximation.

From a spatial distribution perspective, two major types of consumption patterns may be distinguished: diffuse patterns, typical of the residential consumption, and other more localized sites, typical of industrial and commercial consumption sites. In any case, the mapping of the population distribution is an essential ingredient in the process of mapping woody biomass consumption.

Urban and rural population mapping.

Statistical and cartographic information relative to the distribution of the population at the level of Wards (1421 units) from Census 2010 obtained from the Central Statistical Office (CSO). Figure 2 shows the main cartographic layers used to map the distribution of the population.

Location of Rural population:

The mapping of rural population (as defined by 2010 census) was done respecting the values reported at Ward level. Within such units, the spatial distribution of the population was based on additional cartographic elements or spatial proxies such as built up areas and available point data related to human settlements such as schools and health centres. Roads and main trails were also used to locate probable sparse roadside settlements. In addition to such proxies, cropland from the 2010 land cover map (version 2 at 12 classes) was also used to distribute sparse rural population. In practice, within a given Ward, these features were used as spatial proxies of population presence to distribute census population where it's more probable to be found.

Location of Urban population:

The mapping of urban population (as defined by 2010 census) was done respecting the definitions and values reported by the census, also by Ward. Within the Wards holding urban population, the spatial distribution of the population was based on cartographic elements or spatial proxies, such as urban polygons.

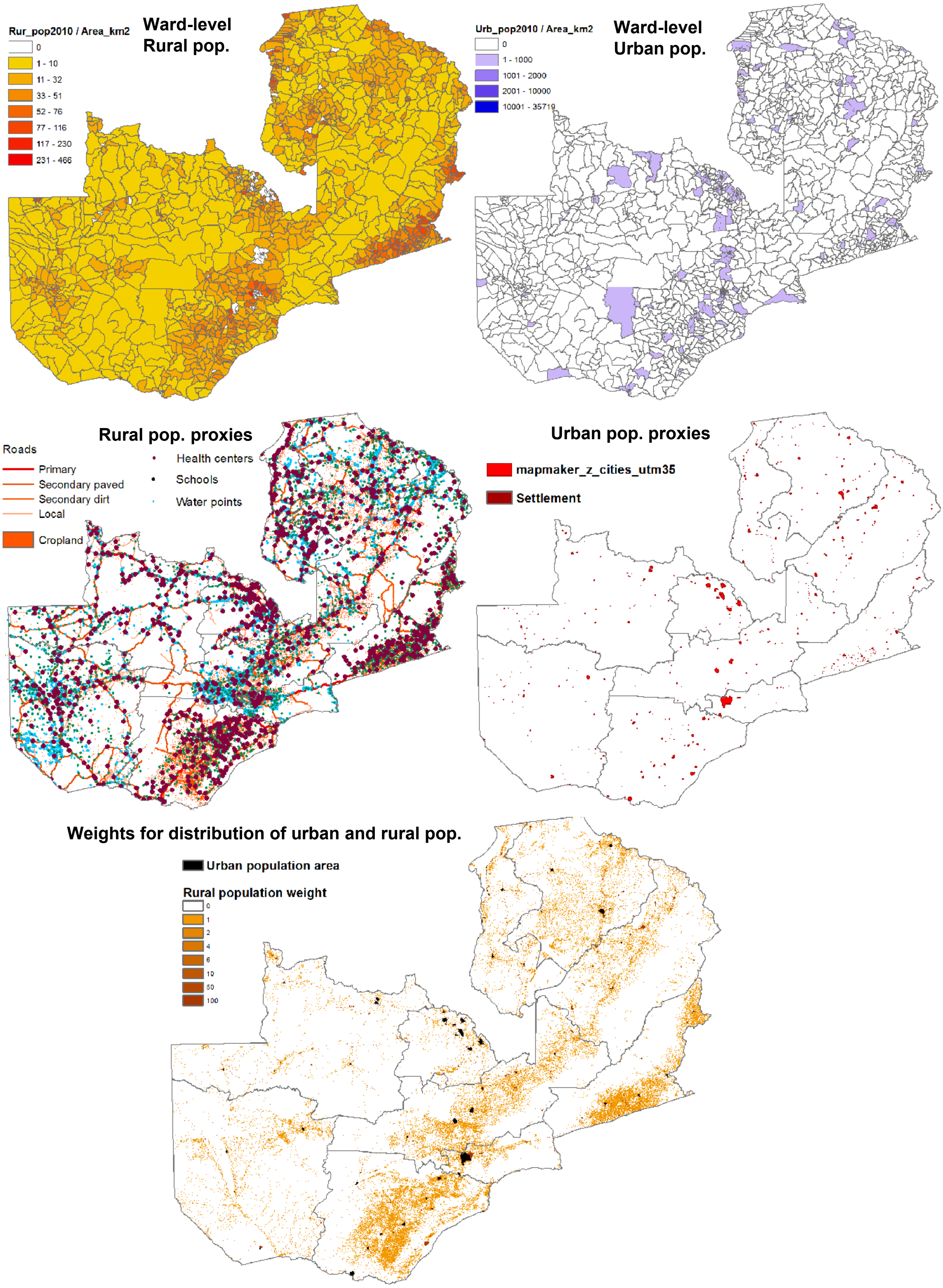
Figure 9 in Results Section shows the resulting human population distribution map.

Mapping woody biomass consumption

Using the rural and urban population distribution maps and the per capita consumption calculated to include the consumption of all sectors of use it is possible to map the total woody biomass demand, as shown in the Results Section.

FIGURE 2

Map data used as proxies of rural and urban population distribution



2.3 Supply Module

The scope of the WISDOM Supply Module is to produce a spatial representation of all sources of woody biomass, their stocking and production potential. The Supply Module analysis includes woody biomass entirely, comprising the components that may serve as fuelwood as well as other non-energy uses such as industrial roundwood and construction material.

2.3.1 Cartographic layers

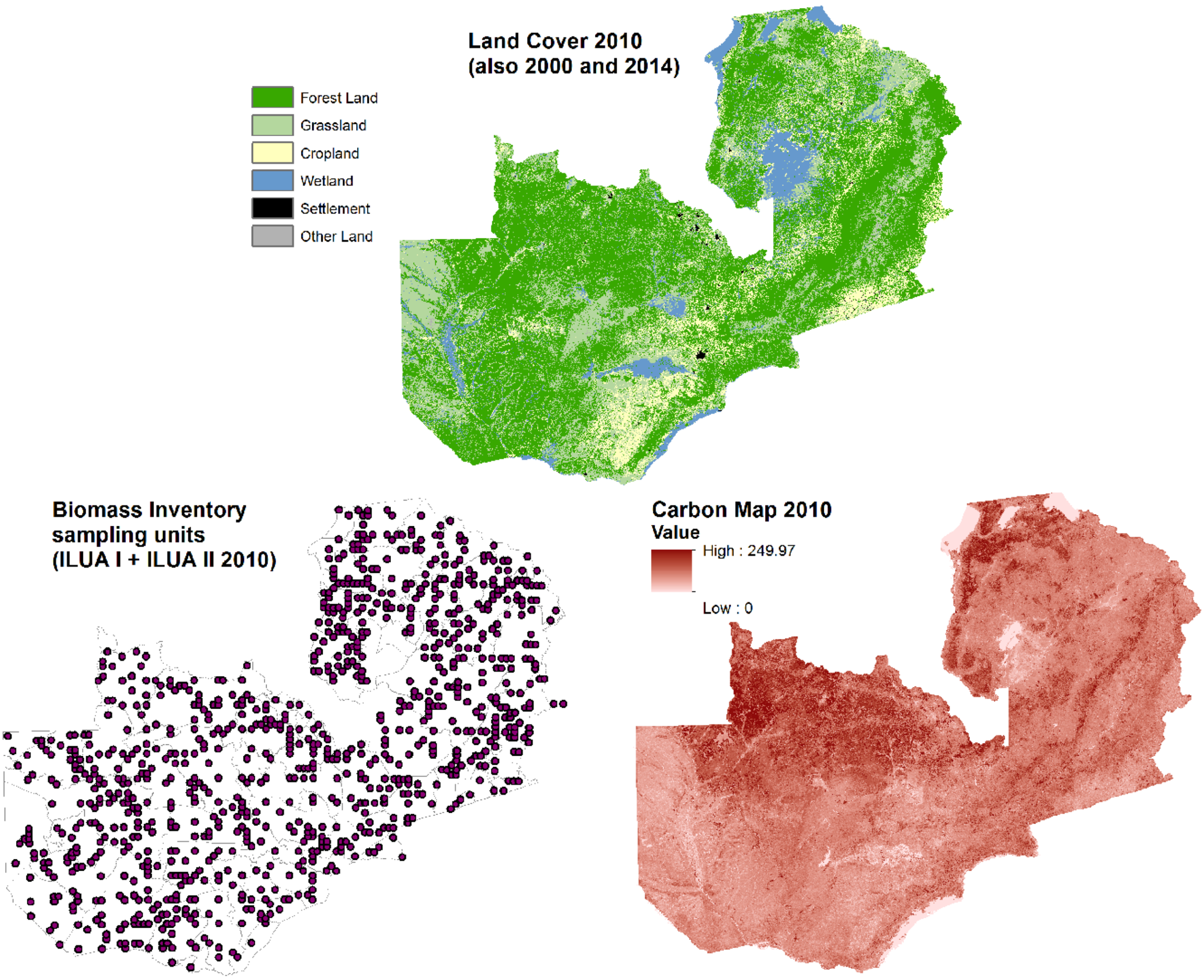
The most relevant cartographic data used to estimate and map woody biomass stock are shown in Figure 3 and are include the following list:

- Georeferenced field inventory data (3,586 plots) collected by ILUA II
- Carbon Map produced by ILUA II for the FREL submission.
- Land Cover 2010 with IPCC categories
- Derived Land Cover versions for 2000 (adding 2000-2010 forest losses to 2010 forest) and for 2014 (deducting forest losses 2010-2014 from 2010 forest)

Several other maps were used to develop the accessibility layer, as described in Annex 3

FIGURE 3

ILUA II data used as reference for mapping DendroEnergy Biomass (DEB) stock



2.3.2 Stock and productivity

Woody biomass stock

The estimation of woody biomass stock was based on 3586 geo-referenced field plots data collected by ILUA II National Inventory, reporting total biomass and total carbon, aboveground biomass (AGB) and dead wood (DW).

The ILUA II Carbon map was used as stratification tool for field plot data, as done for the FREL (draft 2016), as well as spatial proxy for mapping AGB and DW. Detailed stratification criteria and mean AGB and DW values per strata are presented in Annex 2.

The woody biomass parameter of relevance for WISDOM analysis is the **dendroenergy biomass (DEB)**, which includes the aboveground woody biomass of stems and branches but excludes stumps and twigs. In this context, DEB was estimated and mapped by deducting foliage, twigs and stumps from the map of AGB. In consideration of the availability of DW data, DEB and DW were added to form the woody biomass of relevance for this analysis.

To be noted that the stock map that was produced using mean plot values represents "medium" stock levels. It would be possible to create "minimum" and "maximum" stock variants by deducting or adding the 95% confidence intervals around the mean values of AGB and DW (see Annex 2).

Productivity

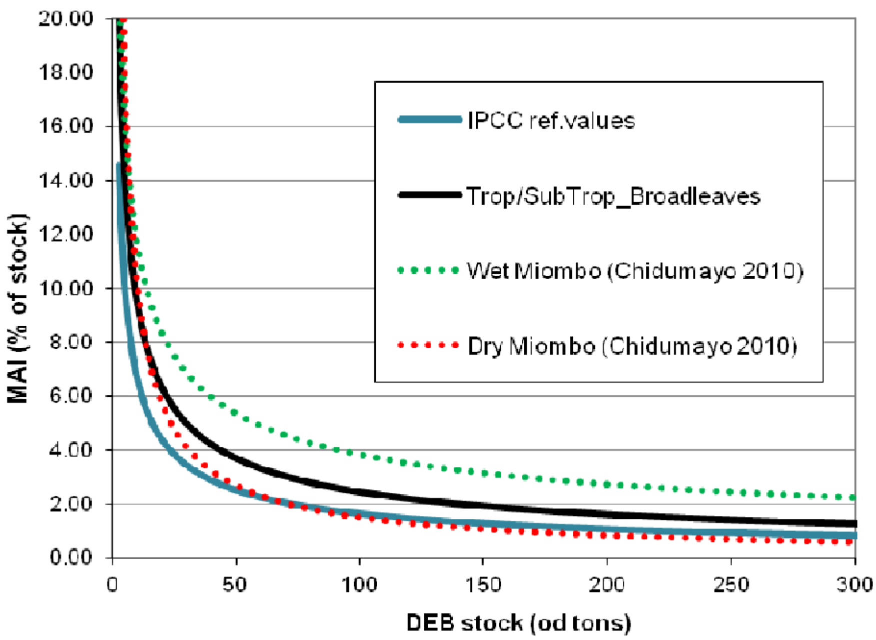
As usual, the sustainable productivity of natural formations is a far less known parameter than the stock due to the scarcity of permanent sample plots, which are the only reliable sources of data for the estimation of the Mean Annual Increment (MAI). In order to fill this critical data gap, the MAI was estimated by applying simple equations relating stock and MAI values as percent of stock.

Figure 4 shows the MAI/stock equations that were reviewed, including two equations derived from Chidumayo and Gumbo 2010 to represent Dry and Wet Miombo formations, one based on global observations of broadleaves formations in tropical and subtropical regions and one based on default values proposed by IPCC guidelines covering all ecological regions.

The curve relative to Wet Miombo appears rather optimistic, as agreed by Prof. Chidumayo, probably due to the limited number of observations available. It's interesting to note that the "IPCC" curve practically matches the Dry Miombo curve derived from Chidumayo and Gumbo 2010 but with slightly lower (and probably more realistic) MAI values for low stock values.

FIGURE 4

Stock vs MAI relations from various sources



Finally, two MAI/Stock equations were used for this analysis, one based on tropical and subtropical broadleaves formations, which yield higher MAI values (termed **High MAI variant**) and one based on the general "IPCC equation", which yield lower MAI values (termed **Low MAI variant**):

High MAI variant: $$y = 37.058x^{-0.5879}$$ (Eq. 1)

Low MAI variant: $$y = 27.221x^{-0.6061}$$ (Eq. 2)

Where:

y = MAI as percent of stock

x = DEB stock in tons DM per hectare

The equations were applied to the stock map to obtain a high MAI map variant and a low MAI map variant.

In view of the limited time available for the analysis and in order to maintain a "conservative" approach, the woodshed analysis and the estimation of the degradation rates due to unsustainable harvesting were based on the low MAI variant.

2.3.3 Accessibility

In this assessment the accessibility has two components. One component is legal accessibility, which is based on the legal rights of wood harvesters to extract wood from a particular area. The second component is physical accessibility, which is based on the ability of wood harvesters to reach a given location. This may be determined by the distance between human settlements and woodfuel resources, but is mediated by infrastructure characteristics such as the existence of footpaths, roads, as well as factors like topographical gradients and other obstacles. We explore details of each component below.

2.3.3.2 Physical accessibility

The estimation of the physical accessibility of biomass resources is based on a **fuelwood transport time map** created for Zambia following and adapting the procedure described by Nelson (2008) and by Drigo (Drigo et al., 2014). The analysis includes the definition of target locations and friction factors to estimate the transport time including going and returning with fuelwood load.

This map is the result of an accessibility model that considers target locations (accessible features such as populated places and roads) and cost, or friction surface, based on several national datasets that represent terrain features (slope, altitude) and land cover.

The subsequent fundamental step for the scope of this study is to convert transport time values (minutes) into accessibility factor to be applied to DEB supply sources. This is done under the assumption that the higher the transport time to the nearest populated place or communication infrastructure, the lower the percentage of accessible resources.

In the absence of specific reference data, it was here assumed that wood resources (for energy use) that are more than 16 hours of transport time from the nearest accessible feature may be considered as totally inaccessible and that the accessible fraction of DEB resources decreases progressively with the increase of travel time.

In this study the physical accessibility is used in two separate phases of analysis:

1. In the Supply Module, the off-road accessibility of woody biomass resources is used to estimate the fraction of the total MAI that is accessible to rural users and to commercial woodfuel producers.
2. In the woodshed analysis, accessibility is referred to Zambia's major woodfuel market sites such as urban centers and densely populated rural areas. In addition to the off-road accessibility, this analysis also includes distances along roads to reach the selected consumption sites.

Details of the travel time map development process, data sources and results are provided in Annex 3.

2.3.3.1 Legal accessibility

The legal accessibility to woody biomass resources is determined on the basis of protection status and categories.

Legal restrictions may range from total access interdiction to harvesting limitations of varying degrees. In most cases fuelwood harvesting if permitted to local communities for their own use while commercial fuelwood and charcoal production are forbidden. In case of Zambia all National Parks are off limits for fuelwood and charcoal production for either local or commercial use. The only exception seems to be the Liuwa Plains NP, which includes several villages within its boundaries. For this Park a fraction of the sustainable productivity (tentatively defined as 30% of physically accessible MAI) is assumed to be accessible for local needs, while the commercial production remains prohibited.

2.3.3.3 Physical and legally accessible MAI

The estimation and mapping of accessible productivity is done by applying the legal and physical access limitations, in form of percent accessible maps, to the map of DEB MAI.

2.4 Integration Module

The scope of the Integration Module is to combine the parameters developed in the demand and supply modules by discrete land units (pixels-level and sub-national unit-level) in order to discriminate areas of potential 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 and available potential productivity and the total consumption of woody biomass for energy generation and other uses.

The supply/demand balance analysis is carried out at the following three levels:

(i) Pixel-level balance, which is the basis of all other balance analyses,

(ii) balance in a local context, 5 km around consumption sites, representing the informal self-supply horizon of rural and peri-urban households and,

(iii) "commercial" balance, based on the "commercial" fraction of the local surplus (resulting from the previous level). The deficit condition are exactly those of the local balance while surplus is limited to the fraction considered suitable for commercial woodfuel production.

2.4.1 Pixel-level balance

The supply/demand balance at the level of individual map pixel (or cell) is calculated by deducting the pixel-level consumption from the pixel-level available productivity. The calculation of the supply/demand balance by individual 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 5 (left-side map).

2.4.2 Local neighborhood balance

In order to achieve a realistic perception of the supply/demand balance it is necessary to combine the consumption and the supply potential within an area related to the real supply zone. In the case of rural and peri-urban households, the distance that household's members are prepared to go to fetch fuelwood, on foot or by local transport means are good parameters to estimate the actual supply area. This should be estimated in terms of time needed to reach the resources and to transport them to the village but the underlying spatial modeling would be too complex and the harvesting horizon is here simplified to a radius of 5 km around each pixel.

An example of the balance analysis in a local context is shown in Figure 5 (middle map). Comparing the local balance to the pixel-level balance it is interesting to see how the local context tends to render more visible the deficit areas, giving a more realistic perception of deficit and surplus zones

2.4.3 "Commercial" balance and "commercial" surplus

The analysis of the "commercial" balance is based on the consideration that the management and commercial exploitation of sparse resources may be uneconomical. In a local supply/demand context dominated by direct fuelwood collection all wood resources may be considered suitable for local (rural) consumers, but when the demand and supply areas are far apart and the supply system is market driven, then only the wood resources that are economically viable to exploit are likely to be utilized.

For woodfuels markets such as those of urban centers, the supply potential consists of the "commercial" fraction of surplus resources resulting from local balance. The "commercial" surplus is estimated by first accounting for the supply that is utilized for local demand, which includes all available DEB production potential, and second, estimating the quantity of remaining DEB that is suitable for commercial utilization, which is limited to the legally accessible resources that justify transport and management costs. To assess the commercial surplus some basic quantitative thresholds related to stock and productivity were defined as follows:

- One threshold concerned the minimum stocking required for profitable fuelwood production, which is here preliminarily set to 14.6 tons / ha, air dry[5].
- The second threshold concerned the rotation period determined by the estimated annual surplus of the local supply/demand balance: only the areas with surplus levels that guarantee rotation periods lower than 30 years were considered eligible. To reach such condition the available surplus MAI must exceed 0.5 ad t/ha/year.

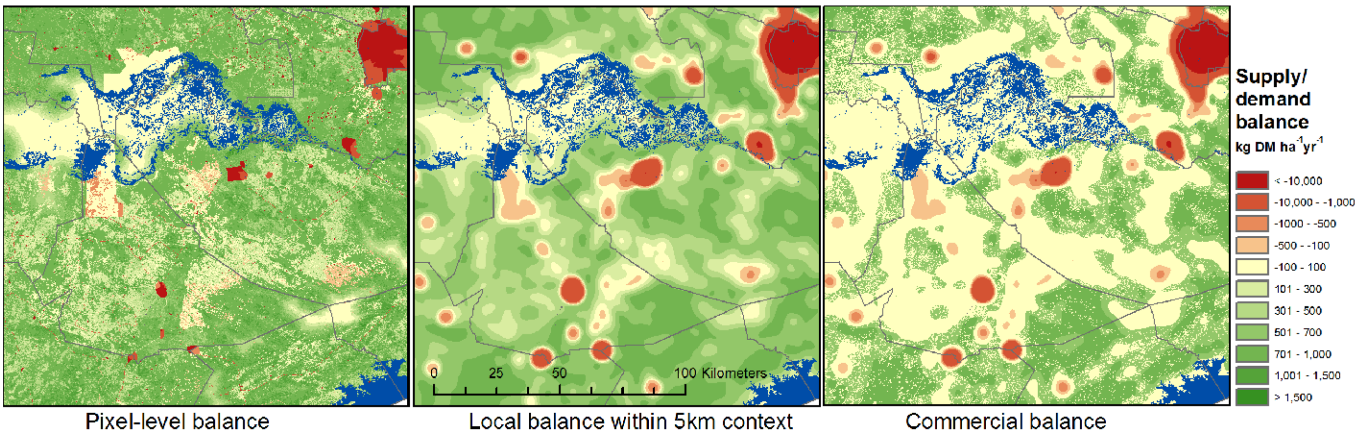
Consequently, only the accessible areas with a stock above 14.6 ad t/ha and a surplus above 0.5 odt/ha/year were considered as potential commercial sources. In addition, all Protected Areas are excluded from commercial exploitation. An example of commercial balance analysis is shown in Figure 5 (right hand map).

At the local level of analysis it is important to verify the economic viability of the various situations with operators and managers and to define the "economically viable" minimum surplus values that apply locally. .

The commercial balance analysis remains theoretical since it implies that the economically viable resources are rationally managed, such that the potentially sustainable increment is exploited entirely, without depleting the forest capital. The commercial balance is therefore useful for defining the theoretical limits of sustainable forest management but is unlikely to represent existing processes. Current exploitation is often unregulated, leading to overexploitation in some areas and under-exploitation in others.

FIGURE 5

Example of balance calculated at pixel-level, on a 5-km local context and commercial balance excluding non-commercial surplus resources. Example located over Southern Province.



2.5 Woodshed analysis

Once the development of the WISDOM Base is complete, the subsequent step is to understand how conditions of local deficit, i.e. demand for woodfuel that cannot be met by local resources, translate into commercial

[5] There is no reference to the minimum stock for profitable fuelwood production in Zambia. The value here proposed was derived from a study on charcoal production in Mozambique (Mancini et al, 2007). In this study, the DEB stock threshold was set at 15 t / ha air-dry considering that below such level the cost of kiln preparation would be unprofitable.

harvesting and how such harvesting impacts on the available resources.

Taking into account the woodfuel demand that cannot be satisfied by local resources (deficit areas in local balance maps) as well as the resources available and their accessibility from the main demand sites, it is possible to outline the supply zones where harvesting will likely concentrate. These zones are termed "woodsheds" in analogy with the familiar geographical concept of watersheds (Drigo e Salbitano, 2008).

We may distinguish two types of woodsheds:

1. The **minimum sustainable woodshed** that represent what the supply zone should be for the sustainable supply of the needed DEB. The minimum sustainable woodshed is defined as the minimum area around the consumption sites in which the cumulative woodfuels balance between the local deficit and the (commercial) surplus is non-negative. This is a theoretical area, not the current harvesting area, and is meant to define the target area for sustainable forest management planning.
2. The **current** (or probable) **commercial woodshed**, or actual commercial harvesting area of a given consumption site, which is determined by the level of demand exceeding local resources, the available commercial surplus and its economic accessibility based on transport time considerations. The commercial woodshed is not based on sustainability considerations and may include unsustainable harvesting when the limits of economic accessibility induce excessive harvesting. The analysis of the current commercial woodshed is particularly relevant because it produces quantitative and spatial-explicit estimates of probable degradation processes due to excessive harvesting.

Figure 6 provides an overview of the steps of woodshed analysis, which are described in detail in the following sections.

2.5.1 Mapping commercial demand pressure

The first part of the analysis, leading to the map of the commercial demand pressure exerted by major deficit sites contributes to the analysis of the **minimum sustainable woodshed** as well as to that of the **current** (or probable) **commercial woodshed**.

The commercial demand pressure is here assumed to depend on the combined effect of (i) the woodfuel demand exerted by the local deficit sites and (ii) physical accessibility features.

In order to combine efficiently these two components, the analysis is carried out through weighted interpolation using Dinamica EGO processing environment (Soares-Filho et al., 2010; Ghilardi et al. 2016). The model applied considers:

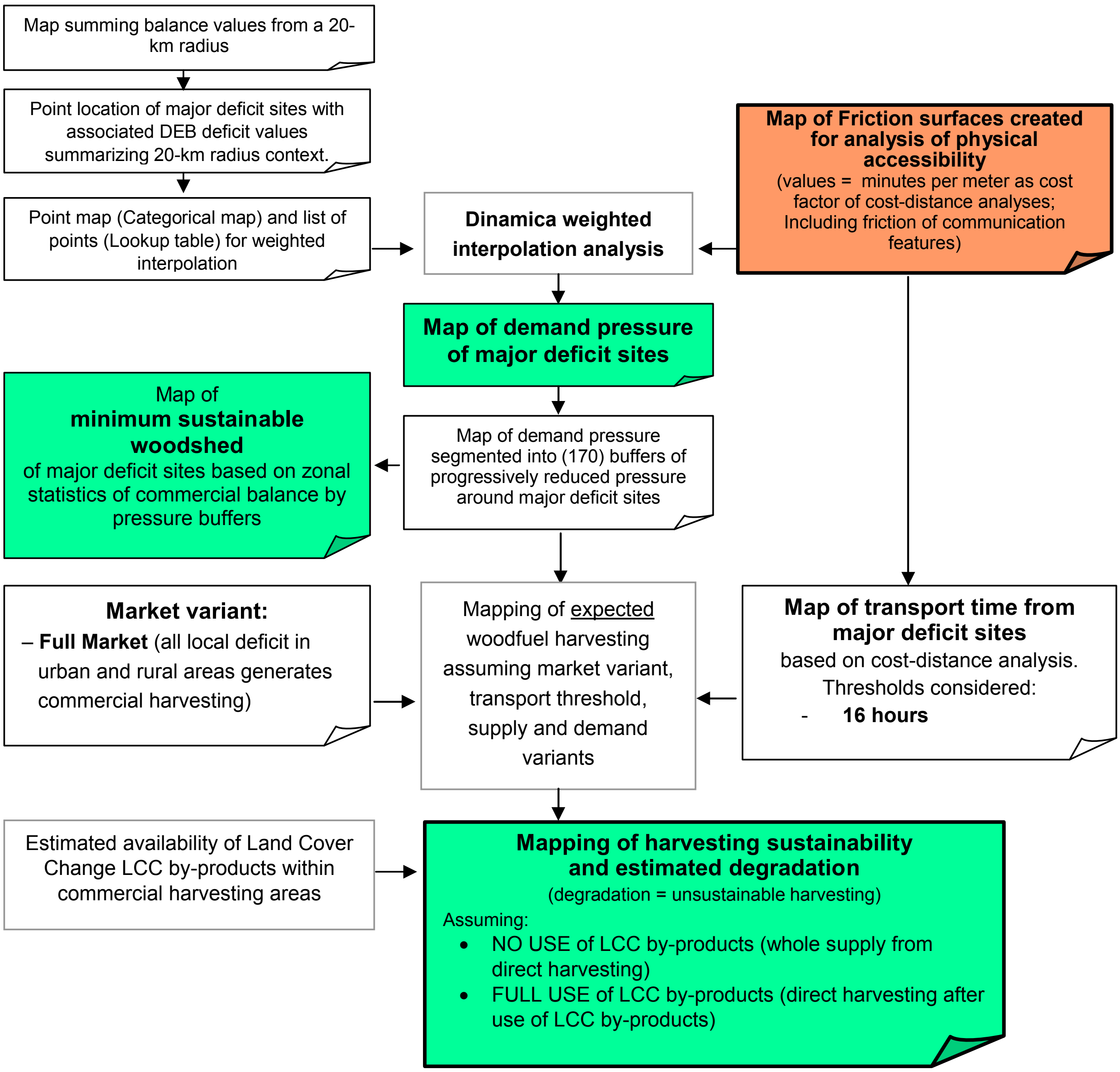
- as staring points of analysis, the location of deficit peaks (Categorical Map) with the associated local deficit values. These points represent the major deficit sites and are determined by the cumulative deficit values within a predefined horizon (in this case 20 km)[6]
- as weighting factor of interpolation, the friction map created for the analysis of accessibility, reporting the travel time needed to cross the cells, in minutes per meter, including roads and settlements.

The model creates an interpolation map for each individual point using the deficit value associated to the point as staring value and the friction map as weighting factor. These maps are then added together to form the cumulative "pressure" map determined by the intensity and location of the major deficit areas. The final result is shown in Figure 16 in Results Section. By means of this combined cost factor, the cities with higher demand "produce" wider woodshed buffers while the cities with lower demand "produce" narrower buffers, well representing the territory under urban influence/pressure.

[6] The horizon for the cumulative deficit is designed so that the cumulative deficit of even large consumption areas, such as a large city or a cluster of nearby villages, can be summed to a single "peak" point. For this analysis, 9 major deficit points were identified.

FIGURE 6

Flowchart showing the main element of woodshed analysis.



2.5.2 Delineation of the minimum sustainable woodshed

Once the country-cumulative weighted interpolation map is produced, the procedure for the delineation of the **minimum sustainable woodshed** of the selected deficit sites is to calculate the supply/demand balance of each buffer (applying zonal statistics to the commercial balance) and to progressively expand the area buffer by buffer until the cumulative value of the commercial balance reaches a positive value, indicating that within such territory the supply potential (i.e. the commercial surplus) matches the demand. The minimum sustainable woodshed resulting from this analysis, is shown in Figure 17 in Results Section.

To be noted, however, that the analysis of the minimum sustainable woodshed tells what should be the harvesting area in order to guarantee the sustainable supply of the needed woody biomass, assuming the implementation of a rational and sustainable resources management system. This analysis doesn't tell what the actual harvesting area is, which is the scope of the next section, but it provides a vision of the territory under urban influence and a clear target for forest management and sustainable wood energy planning.

2.5.3 Commercial woodsheds and estimation of harvesting intensity

The definition of the actual commercial woodshed and the estimation of harvesting intensity depend on several factors other than the distribution of resources and accessibility. Some factors influence the extent of the commercial harvesting area, other factors influence the response to local deficit conditions and the creation of commercial supply systems, while other factors influence the intensity of commercial harvesting, such as the availability of deforestation by-products and overall resource management practices, as discussed in the following sections.

2.5.3.1 Delineation of commercial harvesting area - Transport time threshold

We assume that the area of the commercial woodfuel harvesting depends primarily on economic considerations related to transport costs and market prices. We assume that beyond a certain transport time the cost of fuelwood at market place would be too high and the exploitation of those distant resources would be uneconomic. The transport cost of distant wood resources may become too high and the actual harvesting is likely to be concentrated on wood resources that are closer to market areas.

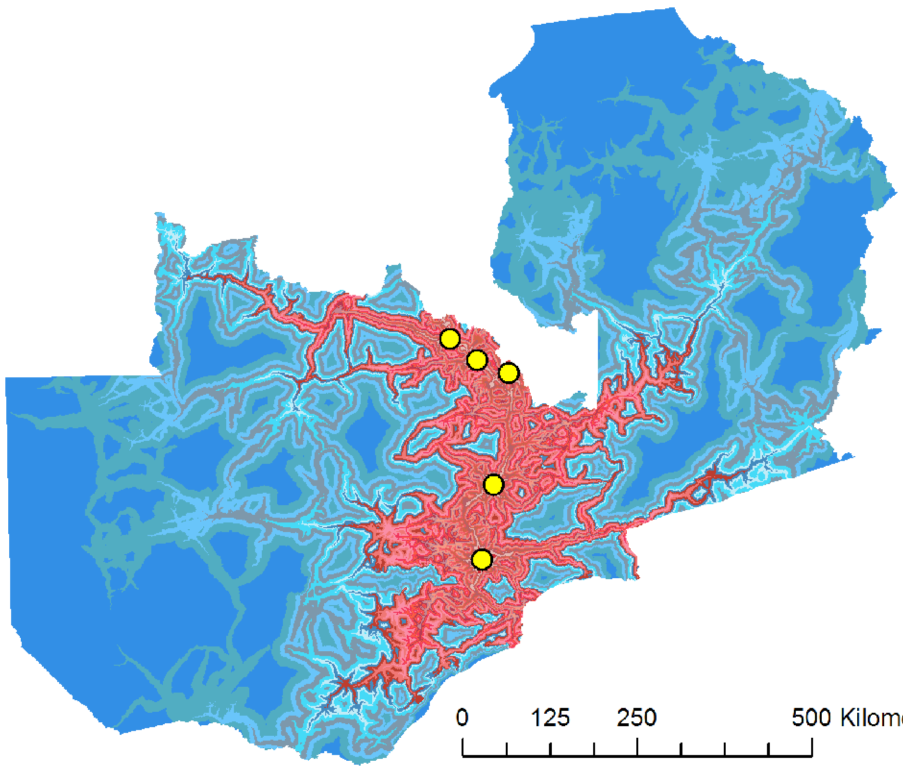
By conducting cost-distance analysis on the major woodfuel market sites, identifies as the 5 urban centers shown in Figure 7, using transport time as cost factor (see Annex 5 for a description of physical accessibility model), we can segment the resources according to transport time and thus we can apply threshold values as limit of actual supply zones in consideration of transport costs. Figure 7 shows the results of the transport time analysis.

We don't know with precision what such transport time threshold would be, although there seems to be a fair agreement that a truckload of fuelwood should not occupy a truck for more than one day.

In this analysis, in absence of clear evidence, a **16-hours travel time threshold** was applied (i.e. from market site to harvesting place and then loaded from harvesting place to roadside and to market), which represents approximately two days of transport, one to go and load and one to reach the market site. This threshold is not based on direct observations but only through "expert opinions" and needs to be verified in the field. Other thresholds could be considered with the scope of testing the impact of transport time component on the results of the study.

FIGURE 7

Transport time to the 5 major woodfuel market sites. Red shades delimit the area within 16 hours of transport time. Blue shades are above 16 hours.



2.5.3.2 From local deficit to commercial harvesting - Market variants

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) depending on commercial supply.

In Zambia wood resources are fairly ubiquitous, factor that minimizes the occurrence of deficit conditions in rural areas and tends to concentrate the local deficit in densely populated settlements. In this analysis, given the characteristics of deficit areas, the scenario that appears more appropriate is the one where local deficit originates the exploitation of distant resources, called **"Full Market"** scenario. According to this scenario all conditions of local deficit, including urban and rural areas, give origin to commercial harvesting of distant resources. Under the "Full Market" scenario, we assume that demand in rural settlements, like urban sites, is met by commercial harvesting rather than overexploitation of local rural resources. This assumption shifts pressure toward accessible forest resources and other distant areas with surplus biomass and reduces the pressure on local resources.

It may be mentioned that in further analyses other market scenarios could also be considered (precluded here due to time constraints), such as, for instance, the **"Partial Market"** scenario in which only part of rural deficit is assumed to originate commercial harvesting, the rest being met by overexploitation of local resources. This alternative assumption would reduce commercial harvesting pressure on forest resources, in comparison to the Full Market scenario, and would increase the overexploitation of woody biomass in farmlands and woodlands close to sources of rural demand.

2.5.3.3 Accounting for Land Cover Change by-products

The relation between deforestation and wood harvesting has been subject of a lively and long-lasting debate whereby wood harvesting, in the case of Zambia charcoal making, has been considered as a primary driver of deforestation or, on the contrary, as a simple by-product of a change process induced by farming expansion. A comparison between the woody by-products of deforestation and the demand for wood products at District level (Figure 8) reveals no apparent relation between the two, indicating that the satisfaction of local needs for charcoal, fuelwood and timber is not a primary driver of deforestation.

However, though not directly linked to woodfuel demand, land cover change (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 or within the commercial harvesting area, the cleared woody biomass may be utilized as timber, woodfuel and construction material. 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.

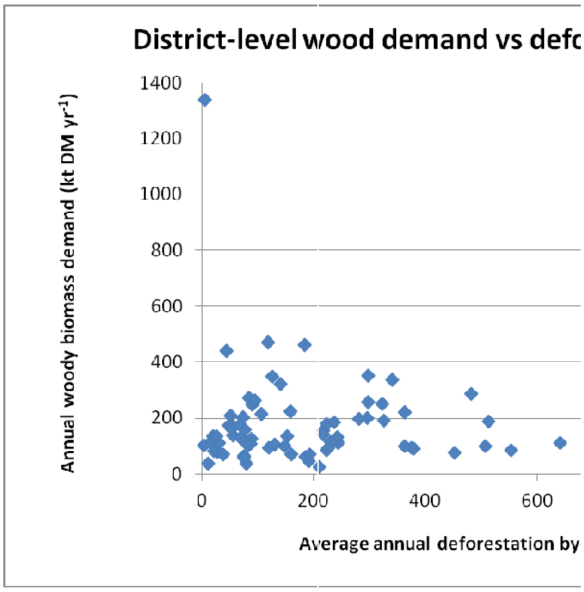
- In the first scenario we assume LCC by-products are NOT used and that all demand originates direct woodfuel harvesting.
- In the second scenario, we assume that 80% of the DEB by-products are used as woodfuel and construction material or timber while the rest is burned or left on site. To be noted that deforestation by-products are considered entirely non-renewable while those becoming available through afforestation are considered renewable. In any case, their availability within harvesting areas reduces direct wood harvesting.

In this analysis we make reference to LCC data produced by ILUA II for the periods 2000-2010-2014 for forest loss (forest gain was not considered in that multi-temporal analysis. We used the average annual loss of forest area for the period 2000-2014 and estimated the quantities of DEB generated in the process (Annex 4). According to map data, the annual deforestation rate for the period 2000 – 2014 has been 118,473 ha, releasing

4.3 million tons DM of wood[7].

FIGURE 8

Comparison of District-level demand for wood products (charcoal, fuelwood and timber) and wood derived from deforestation processes. Deforestation by-products are estimated as annual average of the period 2000-2014 (ILUA II).



2.5.4 Harvesting sustainability and degradation rates

2.5.4.1 Spatial distribution of commercial harvesting

Harvesting intensity within the commercial harvesting areas defined through the commercial 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 and on the commercial surplus available, as per the Equation 3:

$$Har_i = w\_s_i * (\sum c\_d \;/\; (\sum w\_s) \qquad \text{[Eq. 3]}$$

where:

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

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

2.5.4.2 Estimating harvesting sustainability and degradation rates

The sustainability 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 "commercial"than the sustainable supply, then that harvesting is sustainable; when the harvesting is greater than the sustainable supply, the quantity exceeding the supply represents the unsustainable component of harvesting.

In this analysis we define degradation as the quantity of woody biomass harvested in excess of the sustainable supply potential. Hence, the quantity of estimated unsustainable harvesting, measured in tons DM of wood-

[7] By applying the adjustment factors indicated in the FREL document to mapped deforestation, the average annual by-products increases to 14.9 million tons DM, which is greater of the entire annual demand (13 million tons DM).

equivalent per hectare or aggregated by reporting unit, corresponds to the quantity of degradation induced by excessive woodfuel harvesting.

2.5.4.3 Resource management factor

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 unsustainable harvesting resulting from optimal management, but this is not a realistic estimation of the actual exploitation practices.

We can approximate the expected unsustainable harvesting by applying a reduction factor representing sub-optimal resource management. Lacking reliable parameters describing actual exploitation practices, we refer to the "Sustainable Increment Exploitation Factor" (SIEF) defined in the pan-tropical WISDOM analysis (ref. Bailis et al. 2015, Drigo et al 2014), where statistics on the fraction of forest resources under management plans and forest plantation statistics (ref FAOstat 2010) were used as indicators of the national management status. SIEF ranges between 0 and 1, where 1 represents optimal management (optimal rotation) and 0 represents worst-case exploitation (stock depletion without rotations). In the process of analysis, the SIEF is applied to the available commercial surplus to reduce the sustainable increment used by harvesting and consequently increase the unsustainable harvesting fraction that impact on the stock.

In the pan-tropical study, the SIEF applied to commercial harvesting in Zambia was 0.76, which is a relatively high value, indicating a somewhat rational resource management status. In this study, in the absence of other information about "management parameters", we apply the same value of SIEF to estimate the expected unsustainable fraction of commercial harvesting.

3. Results

3.1 Demand Module results

The map of 2011 population distribution, essential ingredient in the development of the Demand Module, is shown in Figure 12. The map representing the total consumption of woody biomass in Zambia, including fuelwood and charcoal in all sectors of use and industrial roundwood, is shown in Figure 13.

Table 2 shows the estimated consumption of fuelwood and charcoal by rural and urban households, while Table 3 summarizes all sectors and uses of woody biomass. Residential wood energy dominates, covering 82% of the whole woody biomass demand. The use of wood for charcoal production covers 33.6% of the whole demand.

TABLE 2

Household consumption of fuelwood and charcoal

code	Province	Rural Fuelwood kt DM	Rural Charcoal w_eq ktDM	Urban Fuelwood kt DM	Urban Charcoal w_eq ktDM	Tot HH Fuelwood kt DM	Tot HH Charcoal w_eq ktDM	Tot HH demand w_eq ktDM
1	Central	765	103	18	227	783	330	**1,113**
2	Copperbelt	233	112	25	1,083	258	1,195	**1,453**
3	Eastern	1,196	57	16	146	1,212	204	**1,416**
4	Luapula	381	386	7	192	387	578	**965**
5	Lusaka	191	58	11	1,101	202	1,159	**1,361**
6	Muchinga	489	45	9	104	498	148	**646**
7	Northern	721	101	20	163	741	263	**1,004**
8	North-West.	458	53	19	107	478	160	**638**
9	Southern	1,022	46	24	218	1,045	264	**1,309**
10	Western	682	24	17	61	700	85	**784**
	Zambia	**6,139**	**985**	**166**	**3,401**	**6,305**	**4,386**	**10,691**

TABLE 3

Total woody biomass demand by sector/use

code	Province	Tot HH Wf demand w_eq ktDM	Other sectors & uses w_eq ktDM	Tobacco curing kt DM	Fish drying ktDM	Total demand w_eq ktDM	Total demand w_eq kt air-dry	Total demand '000 m³
1	Central	1,113	153	100	66	**1,432**	1,647	2,271
2	Copperbelt	1,453	313	0	9	**1,775**	2,042	2,816
3	Eastern	1,416	163	79	52	**1,710**	1,967	2,713
4	Luapula	965	139	0	15	**1,120**	1,288	1,776
5	Lusaka	1,361	351	15	10	**1,738**	1,999	2,757
6	Muchinga	646	86	0	33	**766**	881	1,215
7	Northern	1,004	118	0	42	**1,165**	1,340	1,848
8	North-West.	638	99	0	14	**751**	864	1,191
9	Southern	1,309	138	129	84	**1,659**	1,908	2,632
10	Western	784	107	0	30	**921**	1,059	1,461
	Zambia	**10,691**	**1,667**	**323**	**356**	**13,038**	**14,993**	**20,680**

Note: "Other sectors & uses" includes woodfuel consumption in commercial and public sectors as well as the entire demand for industrial roundwood.

FIGURE 9

Map of 2010 Population distribution

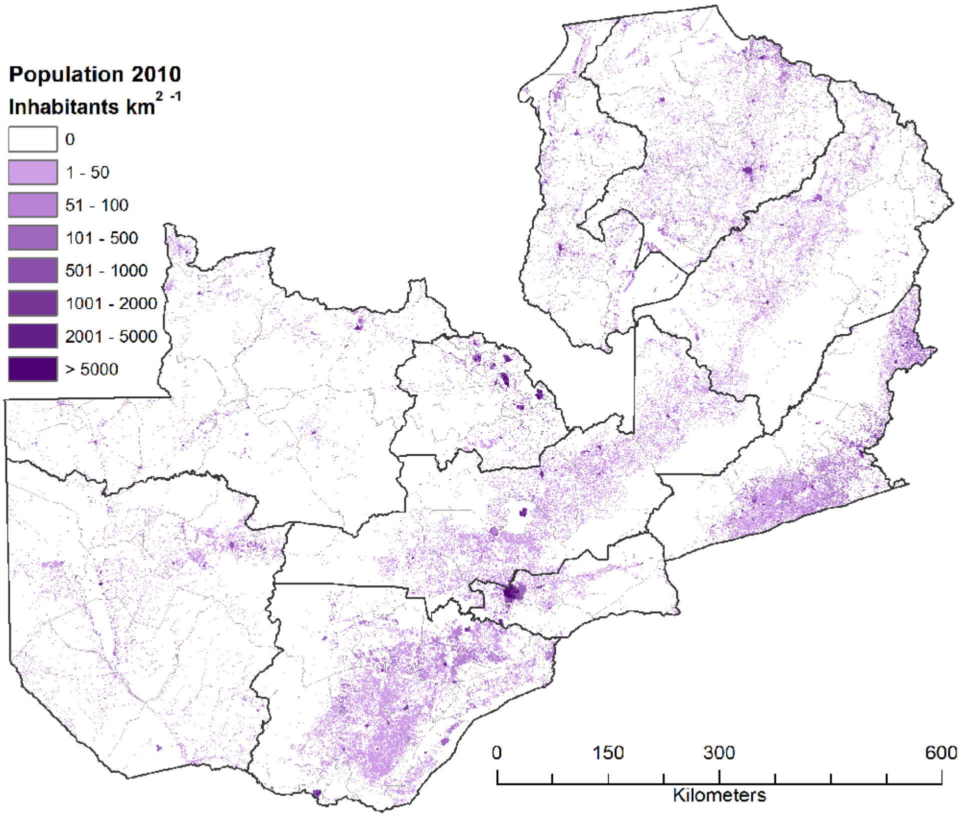
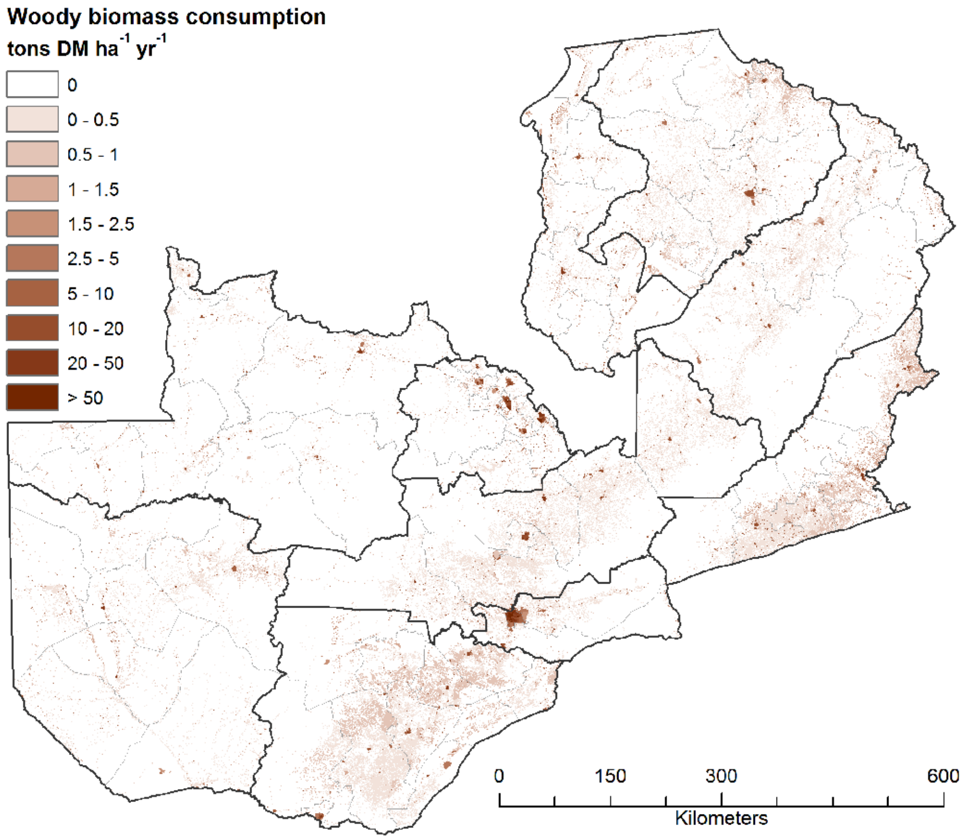


FIGURE 10

Map of total woody biomass consumption (all sectors, all uses)



3.2 Supply Module results

Based primarily on ILUA II sample plots data, the stock of Zambia's vegetation is summarized in Table 4, including standard parameters, such as total carbon (above + below ground) and aboveground biomass, and those more relevant for this analysis: dendroenergy biomass (DEB = AGB minus stump, twigs and foliage) and dead wood (DW). The map of woody biomass stock per hectare (and per pixel) is shown in Figure 11.

Most important for the analysis of sustainability is the estimated annual productivity (or MAI) of woody biomass. Provincial summaries of total and physically & legally accessible MAI for two productivity variants (Low and High MAI) are presented in Table 5. Summary results indicate that the total accessible productivity exceeds the demand by a factor of 3.6 for the Low MAI variant (5.2 for High MAI). Maps of per hectare values of total MAI, and physically & legally accessible MAI for the Low MAI variant are shown in Figure 12 and 13, from which it appears also that woody biomass is relatively well distributed over the whole country.

TABLE 4

Total Carbon, Aboveground Biomass, Dendroenergy Biomass and Dead Wood by Province

		Carbon	Aboveground Biomass (AGB)	Dendroenergy Biomass (DEB)	Dead Wood (DW)	DEB + DW
code	**Province**	kt DM	kt DM	kt DM	kt DM	kt DM
1	**Central**	178,773	273,897	222,750	14,903	237,653
2	**Copperbelt**	86,347	132,914	110,695	6,223	116,918
3	**Eastern**	95,169	145,726	118,080	8,086	126,166
4	**Luapula**	103,422	158,814	130,837	8,070	138,907
5	**Lusaka**	42,687	65,453	53,285	3,477	56,762
6	**Muchinga**	164,785	252,713	205,343	13,273	218,616
7	**Northern**	153,452	235,650	192,483	11,886	204,370
8	**North-Western**	372,169	573,303	479,141	26,232	505,373
9	**Southern**	126,099	191,792	154,341	12,747	167,088
10	**Western**	197,186	299,599	241,755	20,499	262,254
	Zambia	**1,520,088**	**2,329,861**	**1,908,710**	**125,397**	**2,034,107**

TABLE 5

Total and accessible productivity of Dendroenergy Biomass by Province according to High and Low MAI variants

		MAI High variant	MAI Low variant	Accessible MAI High variant	Accessible MAI Low variant
code	**Province**	kt DM	kt DM	kt DM	kt DM
1	**Central**	12,896	8,935	8,548	5,926
2	**Copperbelt**	4,948	3,404	3,637	2,506
3	**Eastern**	7,016	4,864	4,519	3,138
4	**Luapula**	6,648	4,591	5,023	3,473
5	**Lusaka**	3,030	2,099	1,682	1,167
6	**Muchinga**	11,925	8,263	6,746	4,680
7	**Northern**	10,508	7,269	8,003	5,542
8	**North-Western**	20,583	14,140	11,285	7,762
9	**Southern**	10,337	7,189	7,053	4,908
10	**Western**	16,042	11,155	11,087	7,712
	Zambia	**103,932**	**71,908**	**67,583**	**46,813**

FIGURE 11

Map of dendroenergy biomass and deadwood (DEB + DW) distribution

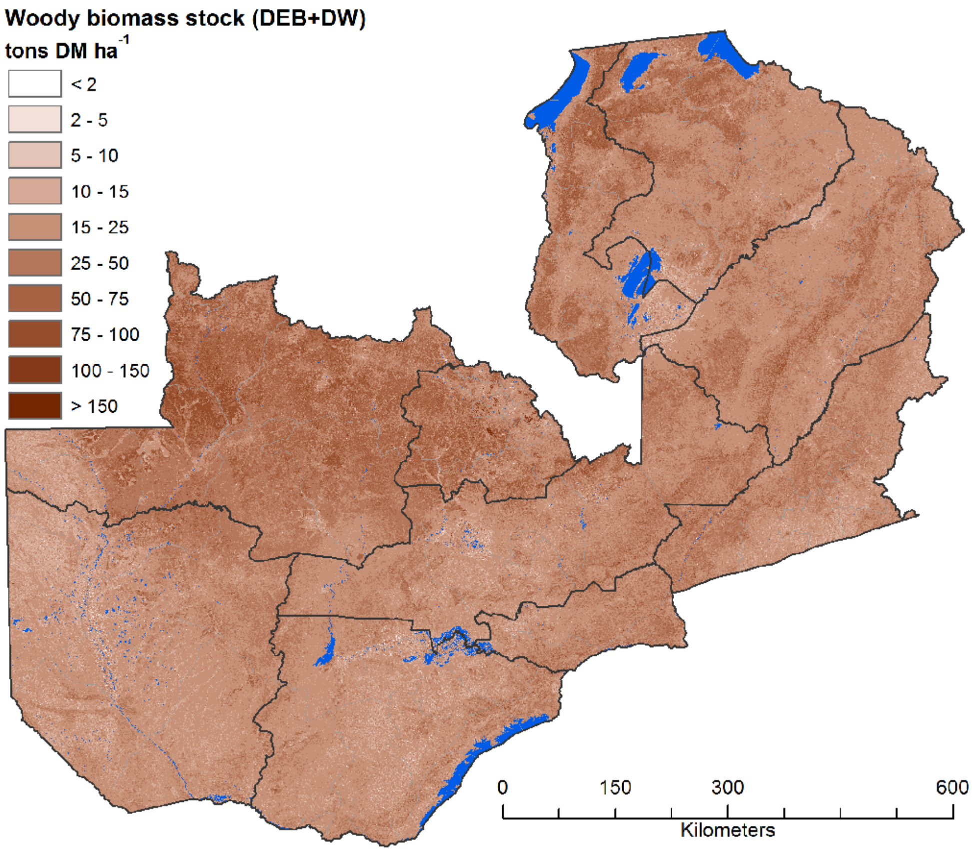


FIGURE 12

Map of total mean annual increment of dendroenergy biomass (DEB MAI) – Low MAI variant

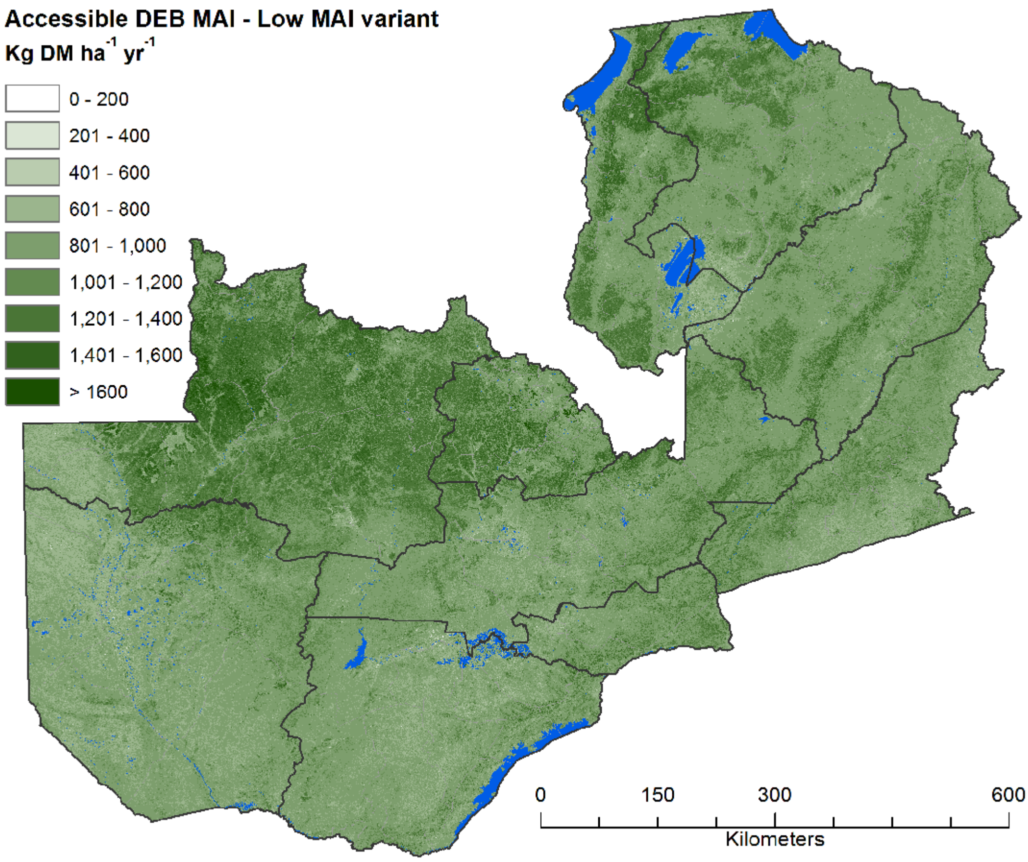
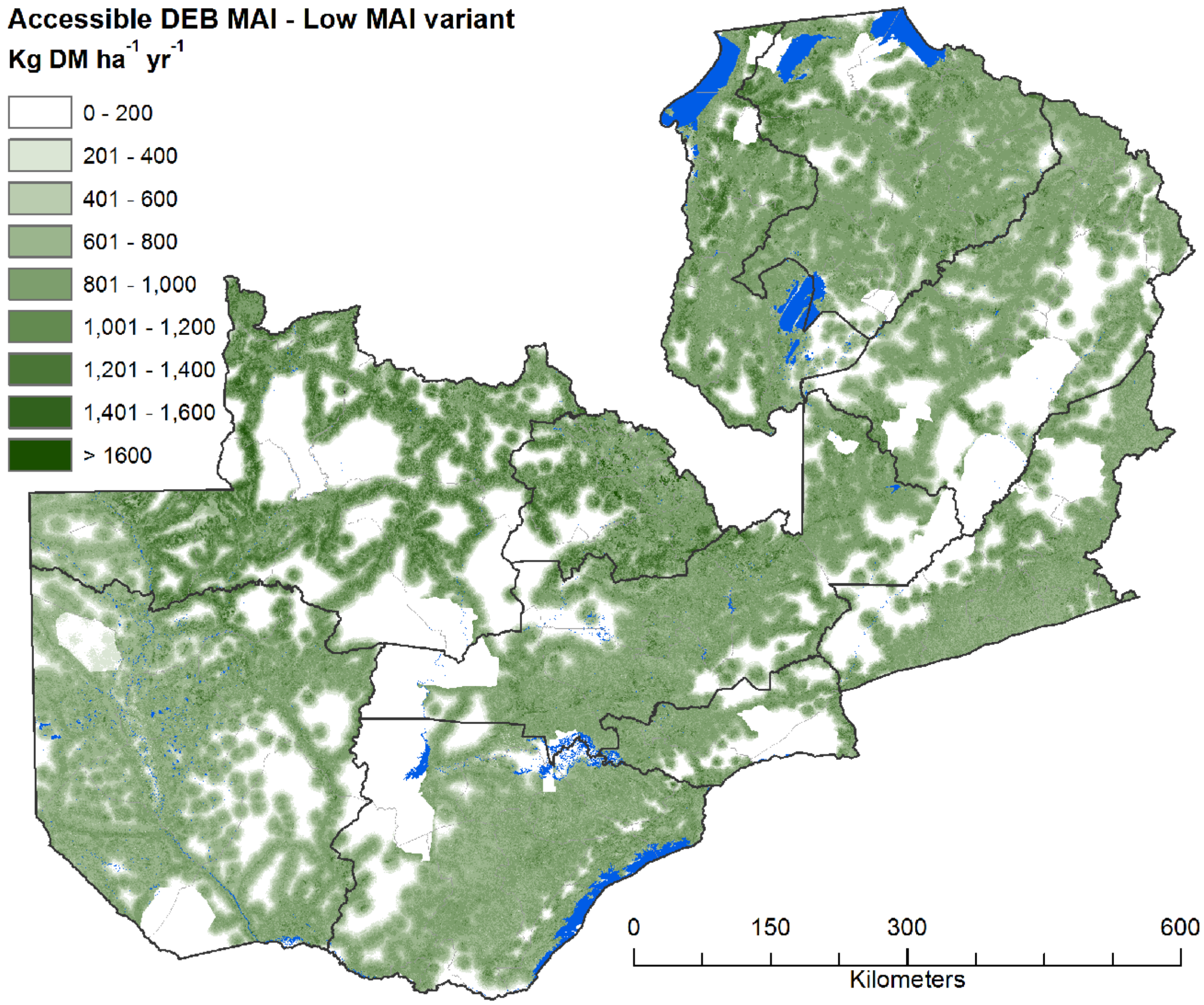


FIGURE 13

Map of physically and legally accessible DEB MAI – Low MAI variant



3.3 Integration Module results

As explained in Section 2.4, the **pixel-level balance** is simply the difference between the supply potential and the demand, pixel-by-pixel, while the **local balance** is calculated by averaging the pixel-level balance of the surrounding 5 km. The province-wise supply and demand parameters, and the resulting "pixel-level" balance are presented in Table 6.

The map of the **local balance** estimated within local harvesting context of 5 km is shown in Figure 14. The local balance produces a "smoothing" effect and the balance statistics by sub-national units vary slightly compared to pixel-level balance, remaining virtually equal at the national level. (cfr. Table 6 and 7).

The third type of balance is the "commercial" balance, summarized in Table 7. The map of commercial balance (Figure 15) shows the deficit areas entirely (red areas) but only the local surplus (green areas) considered suitable to commercial fuelwood production. The commercial balance shows a national total that is considerably lower than the local balance (23.9 Mt vs 33.7 for Low MAI; 42.8 Mt vs 54.5 for High MAI), sign that in many areas the resources are too sparse for commercial harvesting. Nevertheless, the national balance remains largely positive, indicating a condition of surplus.

The commercial balance is the most important ingredient of woodshed analysis as it shows the amount and distribution of local deficit and the resources potentially available to commercial harvesting.

TABLE 6

Supply/demand balance by Province according to High and Low MAI variants

code	Province	Accessible MAI High variant kt DM	Accessible MAI Low variant kt DM	Total Demand w_eq ktDM	Pixel-level balance - High MAI variant kt DM	Pixel-level balance - Low MAI variant kt DM
1	Central	8,548	5,926	1,432	**7,116**	**4,494**
2	Copperbelt	3,637	2,506	1,775	**1,862**	**730**
3	Eastern	4,519	3,138	1,710	**2,809**	**1,427**
4	Luapula	5,023	3,473	1,120	**3,903**	**2,353**
5	Lusaka	1,682	1,167	1,738	**-57**	**-572**
6	Muchinga	6,746	4,680	766	**5,980**	**3,914**
7	Northern	8,003	5,542	1,165	**6,838**	**4,377**
8	North-West.	11,285	7,762	751	**10,534**	**7,011**
9	Southern	7,053	4,908	1,659	**5,393**	**3,248**
10	Western	11,087	7,712	921	**10,166**	**6,791**
	Zambia	**67,583**	**46,813**	**13,038**	**54,545**	**33,776**

TABLE 7

Local and Commercial supply/demand balance by Province according to High and Low MAI variants

code	Province	Local balance - High MAI variant kt DM	Local balance - Low MAI variant kt DM	Commercial balance - High MAI variant kt DM	Commercial balance - Low MAI variant kt DM
1	Central	7,111	4,487	5,810	3,373
2	Copperbelt	1,864	732	1,579	471
3	Eastern	2,810	1,430	2,064	785
4	Luapula	3,864	2,313	3,335	1,841
5	Lusaka	-42	-557	-312	-805
6	Muchinga	5,981	3,913	5,015	3,001
7	Northern	6,842	4,380	6,127	3,707
8	North-West.	10,531	7,009	9,241	5,856
9	Southern	5,397	3,250	3,549	1,763
10	Western	10,158	6,786	6,382	3,920
	Zambia	**54,516**	**33,742**	**42,789**	**23,913**

FIGURE 14
Local supply/demand balance – Low MAI variant

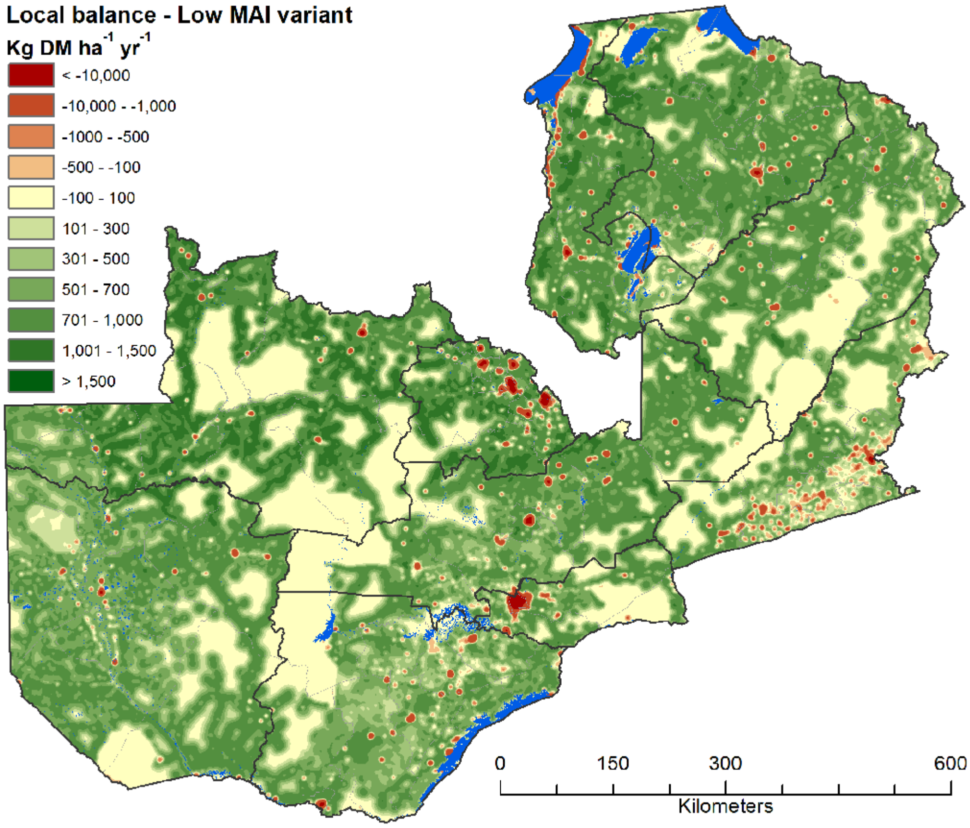
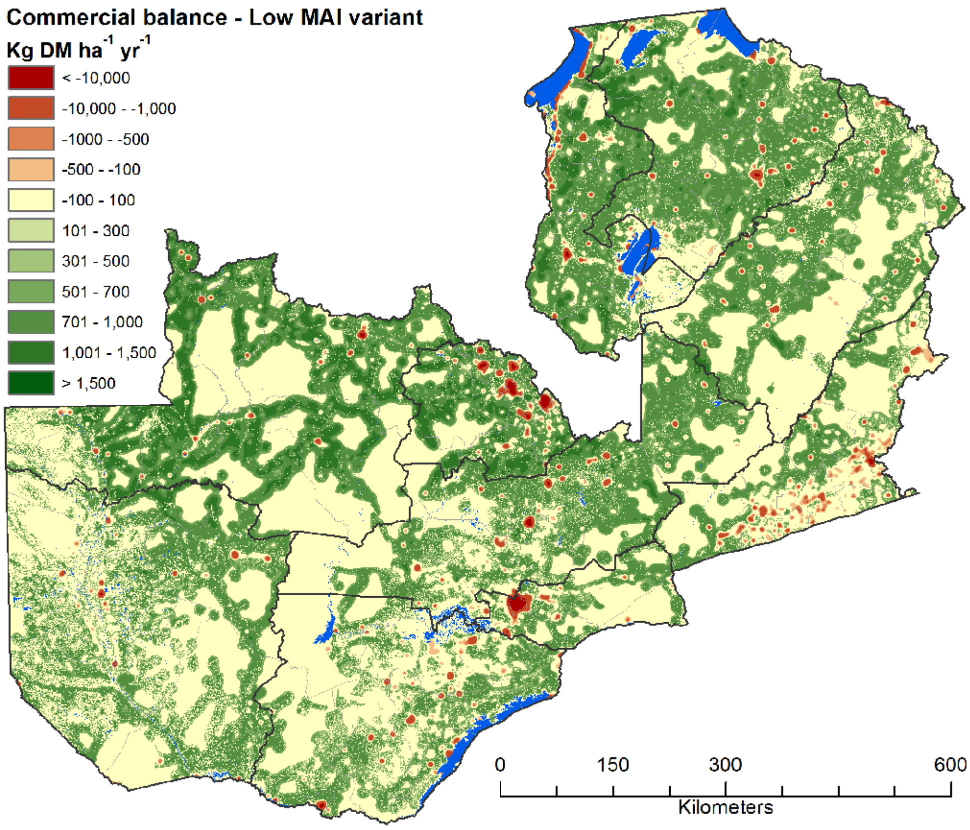


FIGURE 15
Commercial supply/demand balance – Low MAI variant



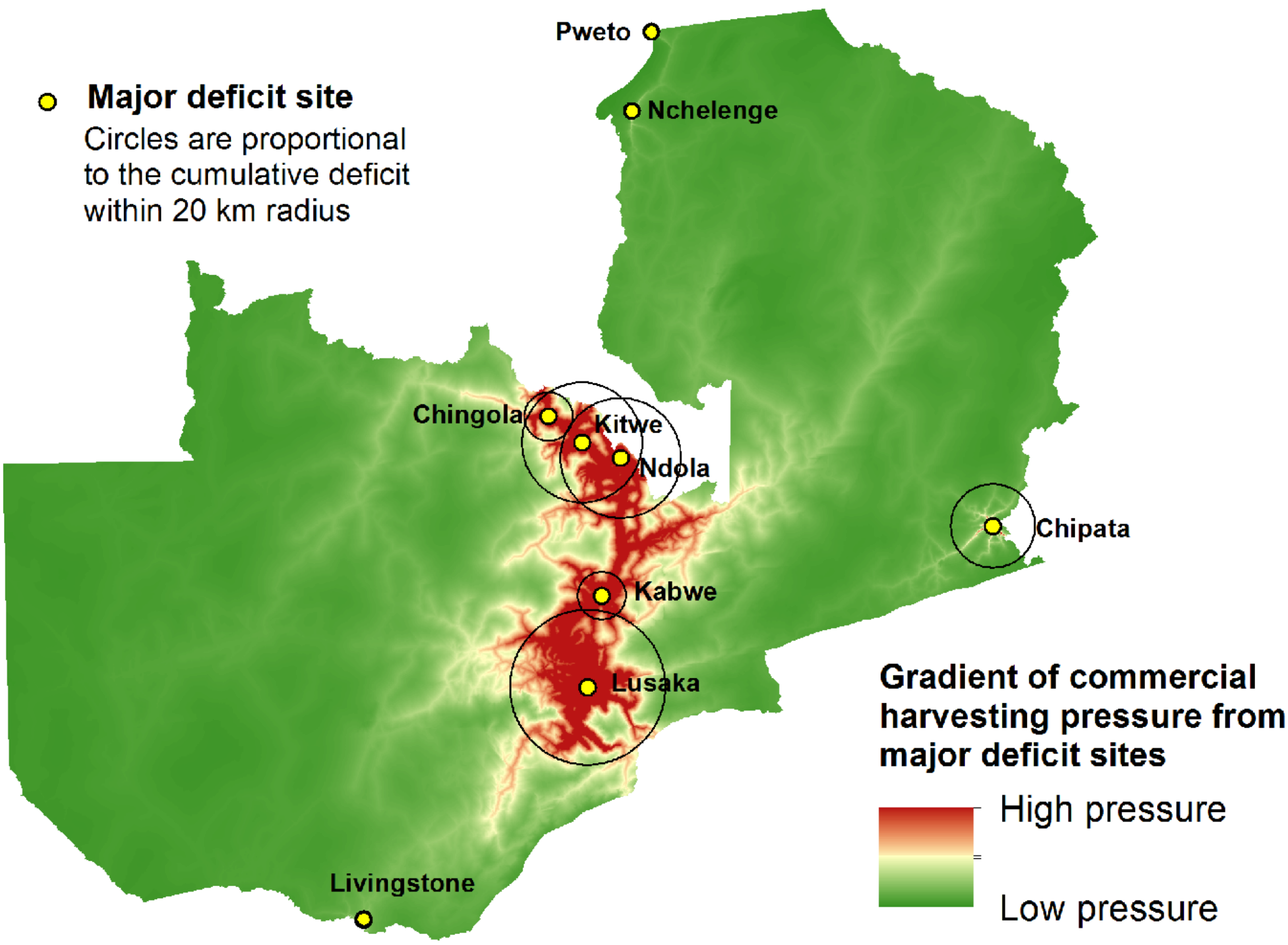
3.4 Woodshed analysis and expected forest degradation

The map in Figure 16 (below) shows the expected commercial harvesting pressure determined by the combined effect of the demand for fuelwood exerted by the 9 major deficit sites and the physical accessibility of surplus resources. From the map it appears that the commercial demand is concentrated in the central axis of the Country, represented by the 5 major deficit sites Chingola, Kitwe, Ndola, Kabwe and Lusaka,that represent the main woodfuel and timber markets of the Country. The other 4 deficit sites located along the national borders in the North (Pweto and Nchelenge), East (Chipata) and South (Livingstone) exert a harvesting pressure of lower intensity limited to the surrounding resources. These sites are far from the central market sites and their supply zones are completely separated from the supply zone of the 5 major woodfuel and timber market sites[8].

Considering the spatial pattern of the commercial harvesting pressure, the woodshed analysis discussed below is focused on the 5 central woodfuel and timber market sites in view of their paramount importance in the national context and of the geographic separation from the other minor market sites.

FIGURE 16

Commercial woodfuel demand pressure and major deficit sites.



[8] The supply zone of Chipata and other deficit sites of the Eastern Province is relatively large, as shown in Figure 6 (bottom), but clearly separated from that of the 5 central market sites.

3.4.1 Sustainable woodshed

The **minimum sustainable woodshed** represents the smallest accessible areas wherein the sustainable supply potential (represented by the commercial surplus) matches the commercial demand (represented by the local deficit) and that may be totally self-sufficient if managed with sustainable forest management criteria.

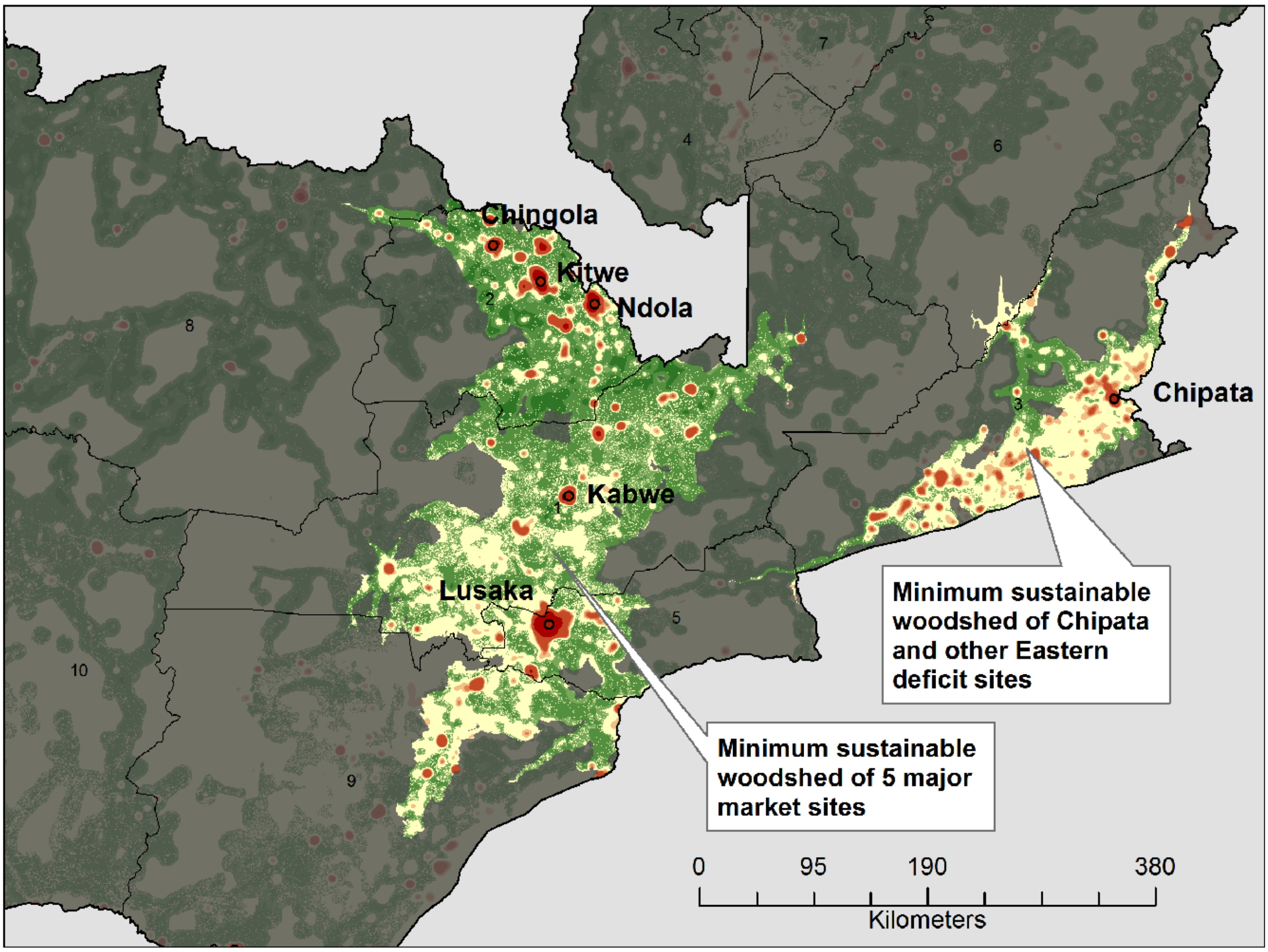
The map portion shown in Figure 17 (bottom) shows the theoretical minimum sustainable woodsheds of the 5 major market sites and of Chipata according to the Low MAI variant and without consideration for the deforestation taking place and the by-products becoming available in these areas.

These woodsheds are theoretical since they don't represent the actual harvesting areas, but they are important because they indicate the minimum territory where sustainable forest management, forest protection measures and wood energy planning should become the primary target of forest and landscape management.. Obviously, SFM should be implemented on all forest resources. These areas, however, deserve highest attention in order to prevent forest degradation due to excessive harvesting and to guarantee the stable and economical supply of charcoal and wood products to the main market sites.

Overall, it's important to evidence that the sustainable woodsheds are finite (not all countries have a sustainable supply potential that match the demand) and they are relatively small, factors indicating that the sustainable production of fuelwood, charcoal and industrial roundwood is not only feasible, but has great potential in Zambia.

FIGURE 17

Minimum sustainable harvesting areas of the 5 central market sites and of Chipata (visible portions of the commercial balance map).



3.4.2 Probable commercial woodshed and expected degradation rates

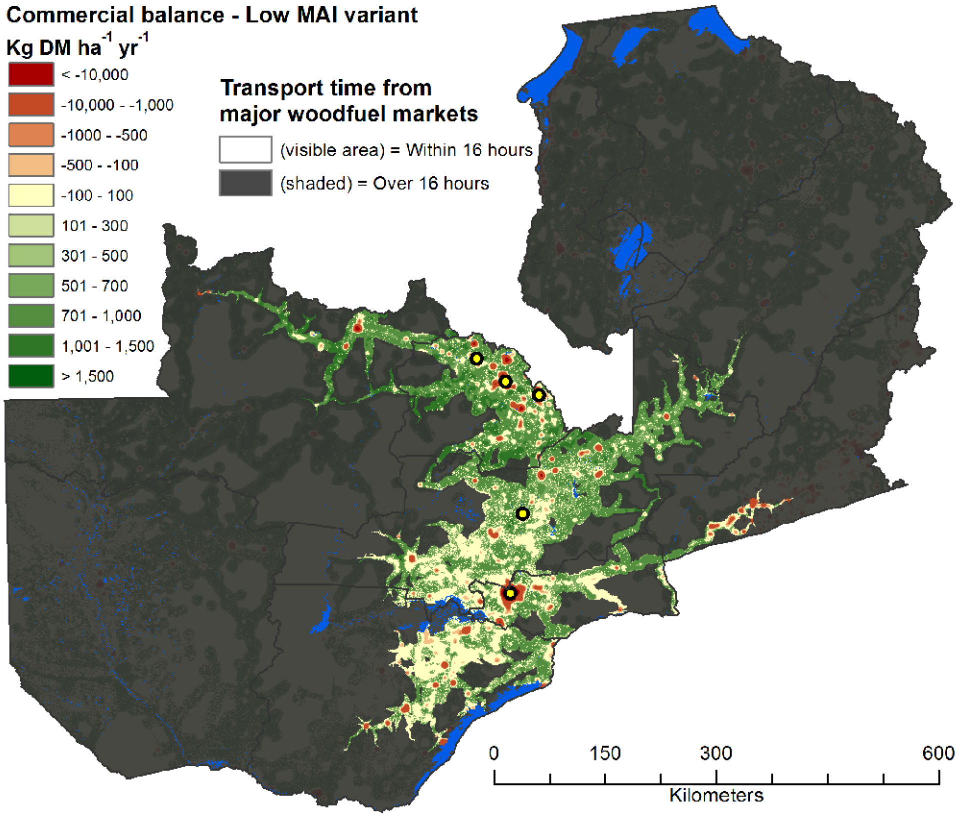
Taking a concrete perspective, we believe that current fuelwood harvesting practices are not guided primarily by principles of sustainable resource management. Demand pressure and economic accessibility of resources strongly influence harvesting intensities. In this study we considered several factors that may influence the intensity and distribution of the commercial harvesting that is necessary to fill the local deficit estimated through the analysis of local balance.

Assuming 16 hours transport threshold and Full Market scenario, as discussed in Section 2.5.3, we outline the expected area and intensity of commercial harvesting relative to the 5 major market sites.

The map in Figure 18 shows the area within 16 hours transport time from the major market sites, while Figure 19 shows the intensity of commercial harvesting within such zone.

FIGURE 18

Limits of commercial harvesting areas used for scenarios building: transport time threshold of 16 hours. – Low MAI variant



Expected degradation rate assuming NO Use of LCC by-products

As summarized in Table 7, the annual commercial demand of the central zone (corresponding to the local deficit) is estimated at 3.44 million tons. This demand converts to commercial harvesting, estimated using harvesting pressure and accessibility of woody resources.

Table 7 shows also the annual unsustainable commercial harvesting in all land cover classes (628.5 thousand tons) and in forests only (390.7 thousand tons) assuming that all supply comes from direct harvesting, without contribution from independent deforestation processes.

FIGURE 19

Map of commercial harvesting intensity for the 5 major central market sites – Low MAI variant – Full Market scenario

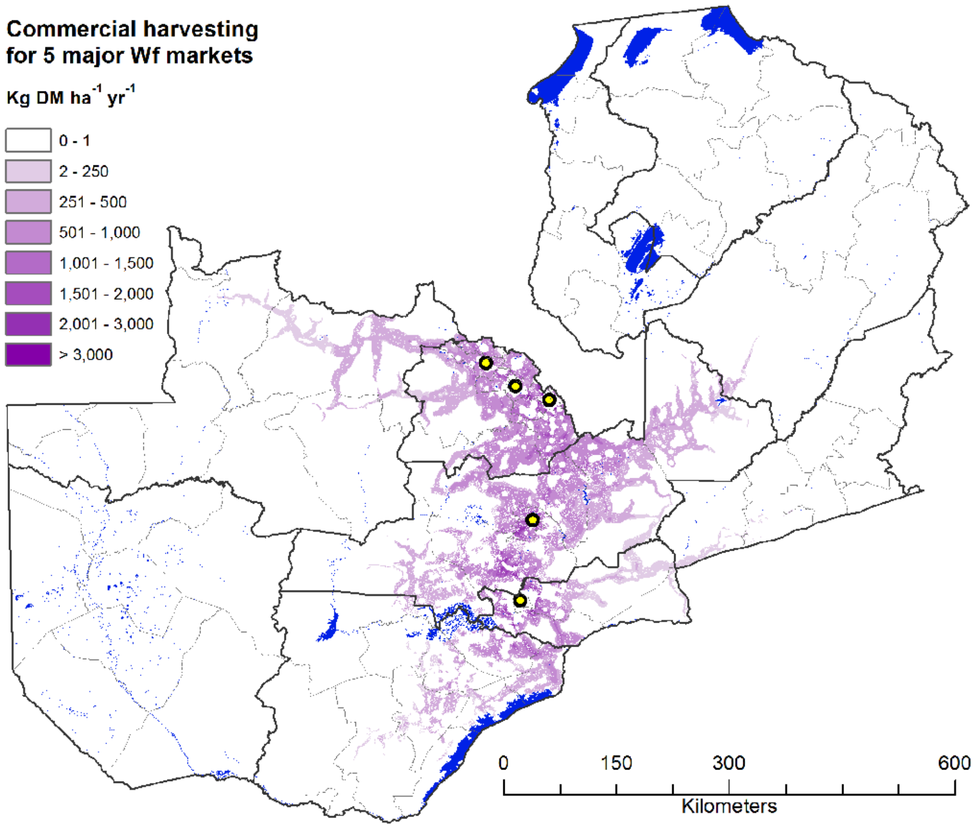


FIGURE 20

Map of unsustainable harvesting within the commercial harvesting area of the 5 major market sites – Low MAI variant – Full Market scenario

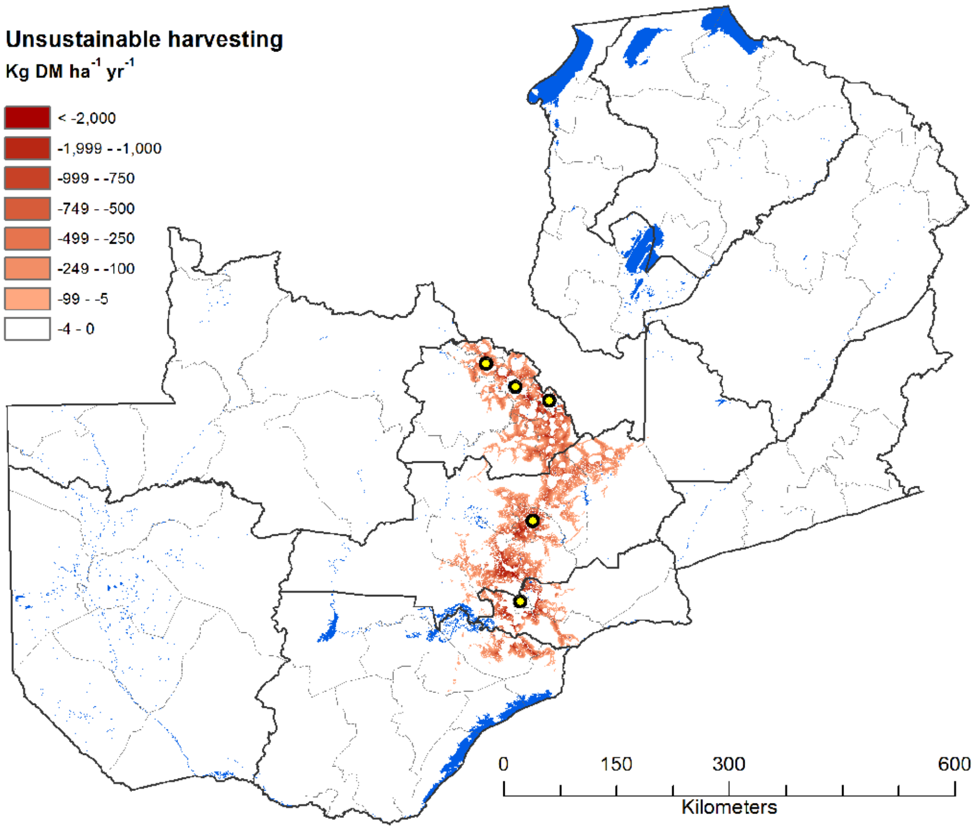


TABLE 7

Estimated commercial harvesting and unsustainable harvesting within the 16-hours commercial woodshed. Assuming NO Use of LCC by-products

				Assuming NO use of LCC by-products	
		Total local deficit within 16h from 5 major Wf markets	Commercial harvesting within 16h from 5 major markets	Unsustainable commercial harvesting (all areas)	Unsustainable commercial harvesting (forests)
code	Province	t DM	t DM	t DM	t DM
1	Central	-364,532	1,541,256	-283,033	-193,428
2	Copperbelt	-1,252,594	1,028,210	-211,620	-127,484
3	Eastern	-76,686	9,160	0	0
4	Luapula	0	0	0	0
5	Lusaka	-1,422,430	323,998	-95,818	-50,059
6	Muchinga	0	14,463	0	0
7	Northern	0	0	0	0
8	North-West.	-112,140	192,311	-48	-44
9	Southern	-212,166	331,156	-38,014	-19,664
10	Western	0	0	0	0
	Zambia	**-3,440,549**	**3,440,555**	**-628,534**	**-390,679**

Expected degradation rate assuming FULL Use of LCC by-products

As an alternative and probably more realistic scenario, the analysis considered also the deforestation by-products annually available within the commercial harvesting area, assuming that they are used as fuelwood, timber and for charcoal production, thus replacing, at least in part direct harvesting (see Section 2.5.3.3).

Table 8 shows the amount of LCC by-products potentially available within the commercial harvesting area (927.8 thousand tons) and the estimated direct harvesting needed after use of LCC by-products (2.5 million tons). Under the assumption that available by-products are used entirely, the unsustainable portion of the residual direct harvesting is estimated to be 224 thousand tons, all land cover classes included, and 133.8 thousand tons in forests only.

TABLE 8

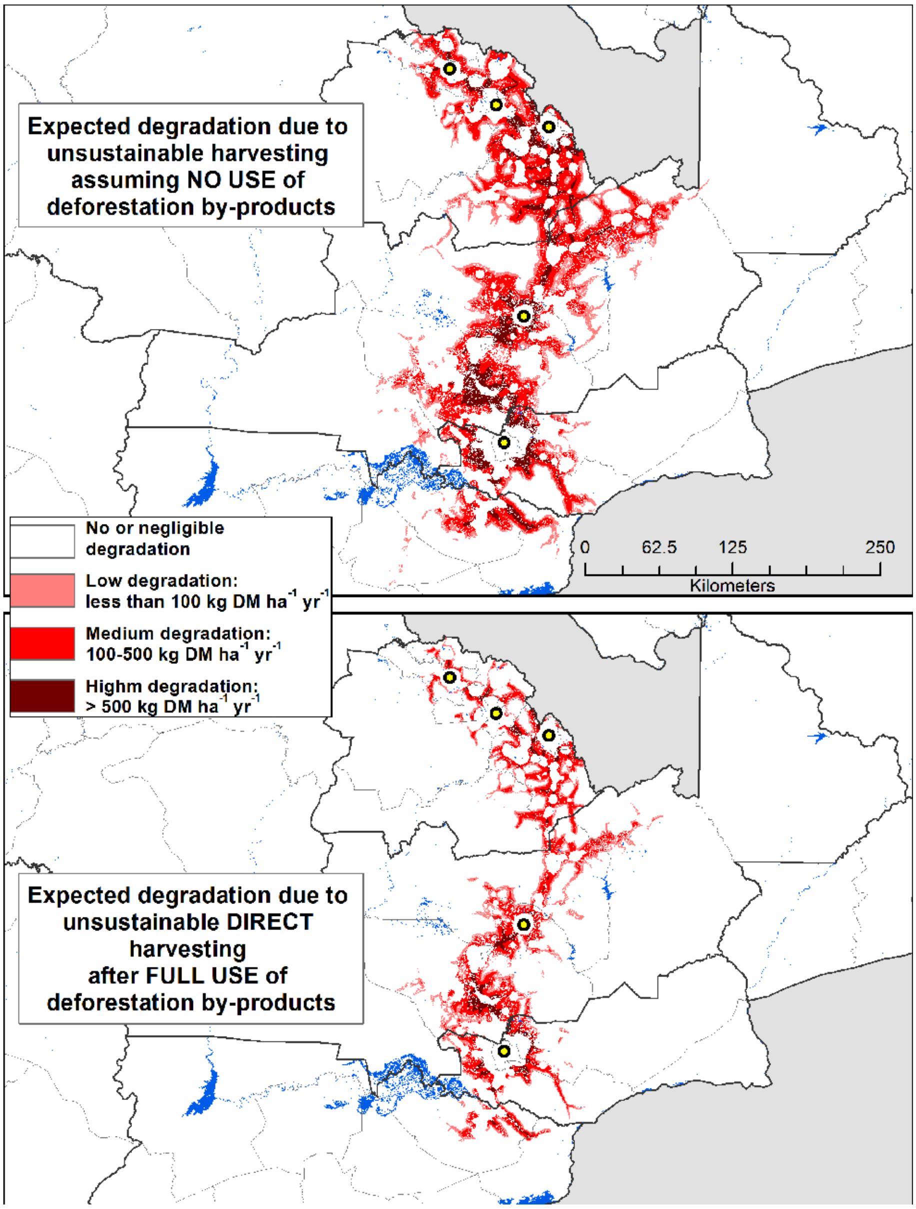
Estimated commercial harvesting and unsustainable harvesting within the 16-hours commercial woodshed. Assuming FULL Use of LCC by-products

				Assuming FULL use of LCC b-p	
		LCC bp Md within 16h commercial harvesting zone	Direct commercial harvesting after deduction of LCCbp	Unsustainable commercial harvesting (all areas)	Unsustainable commercial harvesting (forests)
code	Province	t DM	t DM	t DM	t DM
1	Central	270,634	1,125,578	-98,896	-68,160
2	Copperbelt	352,578	750,901	-70,011	-38,804
3	Eastern	15,471	6,690	0	0
4	Luapula	0	0	0	0
5	Lusaka	100,219	236,617	-42,760	-20,675
6	Muchinga	874	10,562	0	0
7	Northern	0	0	0	0
8	North-West.	92,482	140,445	0	0
9	Southern	95,551	241,843	-12,527	-6,119
10	Western	0	0	0	0
	Zambia	**927,809**	**2,512,636**	**-224,194**	**-133,758**

The difference in the intensity and distribution of unsustainable harvesting and relative degradation considering NO Use / FULL Use of LCC by-products is clearly visible in Figure 21, where the two situations are compared.

FIGURE 21

Ranking of expected degradation intensity due to unsustainable harvesting, assuming NO Use and FULL Use of deforestation by-products (Low MAI variant – Full Market scenario)



The unsustainable direct wood harvesting represents the quantity of woody biomass removed in excess of re-growth capacity, representing the degradation of the biomass stock and consequent GHG emission induced by direct wood harvesting. It also represents the maximum emission reduction that may be achieved by reducing or rationalizing wood harvesting.

The quantity of wood coming as by-product of deforestation (as result of land use conversion, here estimated at 0.928 million tons within the commercial harvesting zone) is considered entirely "non-renewable" in UNFCCC terms, and represents a net emission.

Hence, when calculating the overall non-renewable fraction of the woody biomass used in Zambia (fNRB) assuming the use of deforestation by-products, we should add the two components: the unsustainable fraction of direct harvesting (224.2 kt) and the quantity of deforestation by-products used (927.8 kt). In this case the total non-renewable biomass in the harvesting zone of the 5 major market sites adds to 1.152 million tons DM, or 19% of the wood products consumed within the same zone.

It must be emphasized, however, that unlike the direct harvesting, the emissions relative to the use of by-products of deforestation due to land use change cannot be offset by reducing the demand for wood products, as discussed further below.

Priority areas of intervention

Priorities may be defined in many different ways, depending on the perspective chosen. Specific criteria for the definition of priority areas of intervention and investment will arise from the on-going socio-economic analysis. Meanwhile, based on the results of this study, the following priority areas can be identified:

Taking the REDD+ perspective, the priority areas of intervention may be defined as those areas where the reduction of GHG emissions from forest degradation due to excessive wood harvesting appears more urgent. To represent this perspective, Figure 22 (top map) shows the districts where degradation due to excessive harvesting related to the major market sites is expected. Table 9 (left columns) lists the districts in decreasing order of expected degradation intensity (expressed as % of accessible woody biomass stock).

Taking the SFM perspective, we may define as priority the areas where interventions of forest protection are most urgent (that coincides with REDD+ priorities) as well as those areas where interventions favoring forest production are more promising. The best way to reduce unsustainable harvesting is to guarantee a sustainable production of the needed wood products, if resources are adequate. Figure 22 (bottom map) shows the district-wise estimated local commercial surplus after fulfillment of local urban and rural demand and Table 9 (right columns) lists the districts with highest surplus and, therefore, with highest production potential. The list does not include all surplus Districts but only those with higher surplus (only 12 out of 74 Districts present a negative commercial balance). The production potential is so high that the first 15 Districts (shaded green), alone, could produce the total wood demand of the Country.

TABLE 9

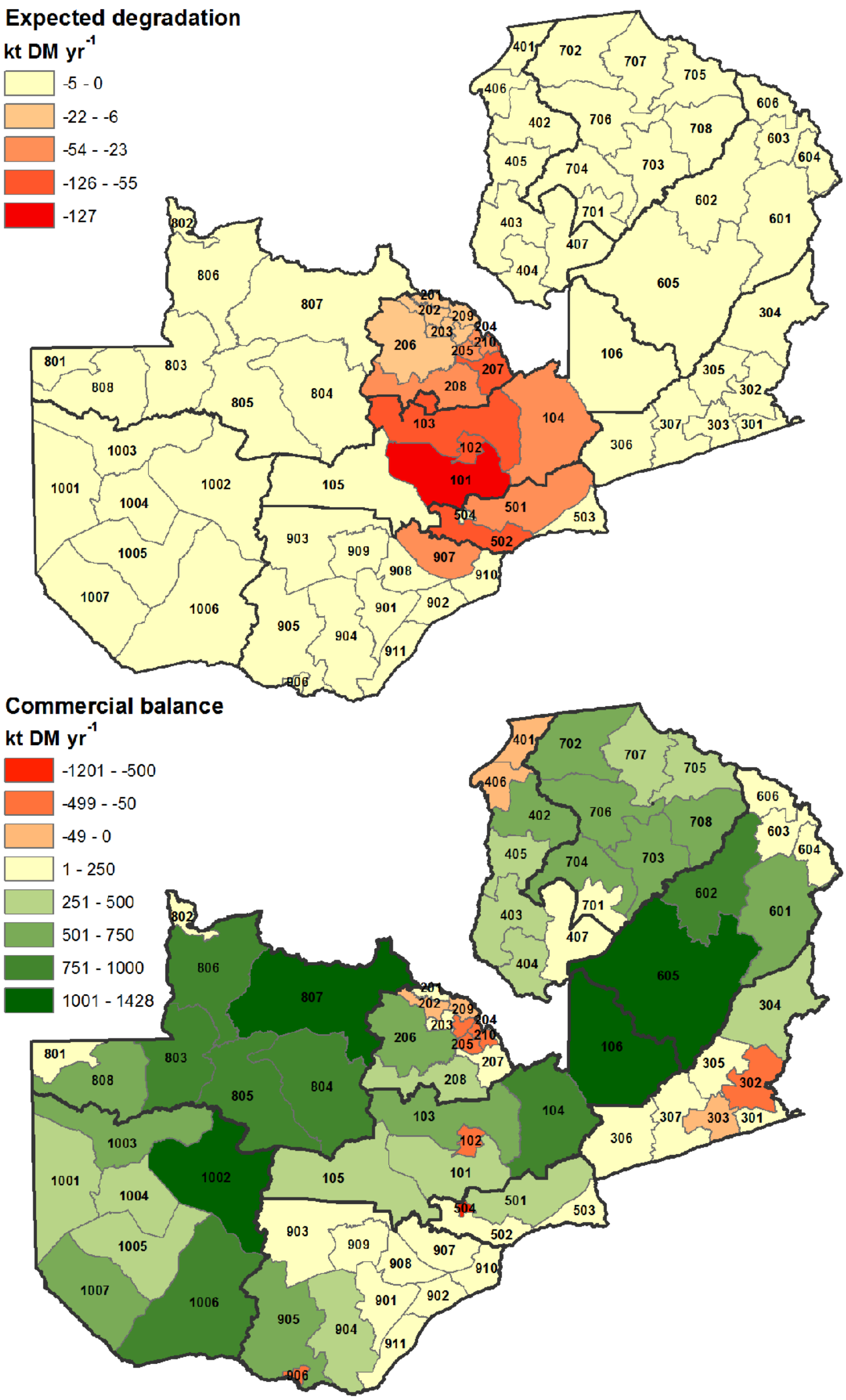
Priority districts from two different perspectives. Left side: Expected annual degradation intensity (% of accessible stock), assuming NO use of LCC by-products. Right side: Sustainable commercial production potential after fulfillment of local demand.

Priority Districts for Degradation risk			
		Expected annual degradation in all lands	
Code	District	t DM	%of accessible stock
102	Kabwe	-54,880	-1.60
205	Luanshya	-24,080	-1.06
210	Ndola	-26,020	-0.86
207	Masaiti	-77,680	-0.81
502	Kafue	-54,714	-0.72
101	Chibombo	-126,661	-0.70
209	Mufulira	-15,312	-0.53
203	Kalulushi	-13,511	-0.40
907	Mazabuka	-33,449	-0.36
501	Chongwe	-40,785	-0.34
103	Kapiri Mposhi	-73,882	-0.34
204	Kitwe	-6,201	-0.33
201	Chililabombwe	-8,394	-0.30
202	Chingola	-9,213	-0.20
208	Mpongwe	-23,319	-0.16
104	Mkushi	-26,382	-0.12
910	Siavonga	-4,448	-0.07
504	Lusaka	-320	-0.05
206	Lufwanyama	-7,892	-0.04
105	Mumbwa	-1,217	-0.01
…	….. …..		

Priority Districts for production potential		
		Commercial balance (surplus)
Code	District	kt DM
807	Solwezi	1,428
605	Mpika	1,173
106	Serenje	1,044
1002	Kaoma	1,044
806	Mwinilunga	960
104	Mkushi	936
803	Kabompo	870
804	Kasempa	855
1006	Sesheke	823
805	Mufumbwe	797
602	Chinsali	766
706	Mporokoso	736
206	Lufwanyama	674
808	Zambezi	649
103	Kapiri Mposhi	635
704	Luwingu	578
1007	Shang'ombo	577
601	Chama	548
702	Kaputa	525
703	Kasama	519
…	… …	

FIGURE 22

Priority Districts for degradation due to excessive commercial harvesting (top) and for sustainable production potential (bottom)



Some considerations about wood harvesting and deforestation

This study indicates that excessive wood harvesting may be a direct cause of **forest degradation**, particularly in the areas around the major urban centres, as estimated and discussed in the previous section. But what is the relation between wood harvesting and **deforestation**?

A common and widespread narrative in Zambia says that charcoal making is a major driver of deforestation, if not the main one, and that reducing charcoal making will reduce deforestation.

This analysis does not support such narrative. The available data show that there is no correlation between District-level demand for wood and deforestation rates. Moreover, there is no apparent justification for exploiting forest resources so intensively to cause full depletion, considering:

- the sustainable production potential surpassing manifolds the demand for wood products,
- the powerful coppicing capacity of miombo formations, and
- the fair distribution of wood resources over the Country

Even without proper forest management, it's unlikely that charcoal makers would return too soon on the same forest site (to the level of causing full depletion) if there are enough resources accessible in the surroundings. Excessive harvesting and consequent degradation is a frequent condition, in absence of proper rotation and management planning, leading to loss of density and re-growth capacities. Full depletion of tree cover (or deforestation) as effect of wood extraction alone is seldom happening, especially if wood resources are relatively abundant as seems to be the case in Zambia.

The practice of clearing forest patches is common to several land uses, including conversion to agriculture, shifting cultivations and sustainable forest management. What matters is what happens AFTER the clearing. If the forest is allowed to grow back and if the rotation period between harvesting events is adequate, the process can be perfectly sustainable. If after the clearing the stumps are burned to prevent re-shooting and the land use is changed to permanent agriculture, then we have true deforestation. In both cases we have woody by-products and maybe charcoal production, but there is a fundamental difference between the two processes.

It is also commonly asserted that charcoal making, by clearing forest areas, catalyzes farming expansion. While there is no doubt that charcoal making does have a catalytic effect on land conversion since it pays for the conversion process, it's hard to believe that an area is cultivated for the sole reason of being cleared of tree cover. The need for land for subsistence or mechanized farming is a powerful driver of change. Charcoal making is among the factors that influence the process but it's hard to believe that reducing charcoal making would have any significant impact on the need for new farmland.

If deforestation is driven by farmland expansion at the expense of existing forests, all efforts towards reducing the demand for wood are very unlikely to mitigate the process of deforestation and consequent GHG emissions.

But using by-products of land conversion for energy or furniture making is better than simply burning them on site, as it happens in areas where the demand for land is not accompanied by demand for wood (i.e. the Brazilian Amazon). In fact, whether deforestation can or cannot be reduced, it's in any case important to make best and maximum use of its by-products as a way to reduce its negative impact.

Taking charcoal as the scapegoat of deforestation appears misleading, diverting the attention from the real causes and from identifying appropriate remedial action.

Supporting efficient farming systems and agro-forestry practices and developing rational land conversion programmes where necessary seem to be far more effective lines of intervention against widespread deforestation than reducing charcoal production.

To reduce forest degradation due to excessive wood extraction and charcoal making, the lines of intervention should focus on establishing community-based sustainable forest (and landscape) management and rational rotational harvesting systems.

Rather than scapegoat of deforestation, charcoal making, along with other wood products, should be considered as a solid national asset, with great potential for becoming thoroughly sustainable.

Conclusions and recommendations

Demand for wood products

- The national demand for wood products in 2010, including charcoal, fuelwood, construction material and timber is estimated to be 13 million tons (wood-equivalent, DM), which corresponds to 20.7 million m^3. The consumption of fuelwood and charcoal in the residential sector accounts for 82% of the total demand, followed by industrial roundwood (6.41%), woodfuel consumption in the commercial and public sector (6.38%), fish drying (2.7%) and tobacco curing (2.5%).
- The total consumption of charcoal is estimated at 1.15 million tons, which corresponds to 5 million tons of wood (DM). 87% of charcoal consumption occurs in the residential sector (67% by urban households). The total consumption of fuelwood is estimated at 6.48 million tons DM, 97.3% of which in the residential sector (94.8% by rural households).
- The demand is concentrated along the central axis of the country. 47% of the national demand is concentrated in 14% of the country area, within 16 hours transport time from Chingola, Kitwe, Ndola, Kabwe and Lusaka. The accessible resources along such axis are those under highest harvesting pressure and thus under higher risk of degradation.

Supply potential

- The total stock of woody biomass[9] is estimated at slightly over 2 billion tons DM.
- In the absence of representative growth data, the potential annual productivity is estimated by applying MAI/stock equations. Two equations were used: one based on data relative to tropical/sub-tropical broadleaved formations, yielding higher growth values, and one reflecting the stock/growth values given in IPCC Guidelines, yielding lower growth values.
- According to the High MAI variant, the total potential productivity is 104 million tons DM, with 67.6 million tons physically and legally accessible. According to the Low MAI variant, the total potential productivity is 71.9 million tons DM, with 46.8 million tons physically and legally accessible.

Supply/demand balance

- The local supply/demand balance, estimated within a context of 5 km, shows a large national-level surplus of 54.5 million tons DM for the High MAI variant and a surplus of 33.7 million tons for the Low MAI variant. The commercial balance, estimated by excluding from the local surplus all wood resources that are too sparse for commercial exploitation, shows net surplus of 42.8 million tons DM for High MAI variant, and 23.9 million tons DM for the Low MAI variant.
- Except Lusaka, all provinces show surplus conditions. Out of 74 districts, deficit conditions are found only for 12, represented mainly by small urban districts. This indicates that the resources of the country are not only abundant, they are also evenly distributed.
- Even assuming the Low MAI variant the Country shows large surplus, which indicates that there are ample possibility for the establishment of sustainable production systems for the full satisfaction of current needs for energy and wood industries as well as for future bioenergy programmes.

Minimum sustainable woodsheds

- The delineation of the minimum sustainable woodshed of a major deficit site is theoretical but very useful because it defines the supply zones that could produce on a sustainable basis the woody biomass necessary to satisfy the demand, if properly managed.
- The analysis shows that the minimum sustainable woodshed of the 5 major market sites, as well as the one of Chipata and surrounding deficit sites are well separated and relatively small in size (all necessary

[9] Including dendroenergy biomass (DEB) and dead wood (DW). DEB includes stem and branches and is calculated by deducting stump, twigs and foliage from aboveground biomass (AGB).

resources are within 150-200 km distance from market sites), which indicates that the sustainable production of fuelwood, charcoal and industrial roundwood is not only feasible, but it has a great potential in Zambia.

- While SFM should be implemented in all forest areas, these woodsheds clearly define the minimum territory in which forest production and protection measures and wood energy planning should become the primary target of forest and landscape management.

Expected degradation rate

- The degradation due to excessive exploitation of wood resource is expected to occur primarily in the harvesting zone that feeds the major market sites, along the central axis of the Country. The expected degradation was estimated taking a 16-hours transportation threshold as the limit within which commercial harvesting concentrates.
- The total expected degradation (all land cover classes) in the central commercial harvesting zone is estimated to range between 224 and 629 thousand tons DM per annum, assuming full-use and no-use of deforestation by-products, respectively.
- The expected degradation of forest within the same zone is estimated to range between 134 and 391 thousand tons DM, also assuming, respectively, full-use and no-use of deforestation by-products.
- Degradation of minor entity due to un-regulated harvesting and charcoal making is expected to occur in other areas of the Country where pressure is high, as in the territory around Chipata, for instance. In most areas, however, fuelwood, charcoal and timber are by-products of deforestation processes and thus direct harvesting (without land use change) is limited and abundantly surpassed by natural re-growth capacities.
- The available data show that there is no evident correlation between demand for wood and deforestation rates. It appears that wood products and charcoal making are more by-products of farming expansion rather than drivers of change. Moreover, there is no apparent justification for exploiting forest resources so intensively to cause full depletion, considering:
    - the sustainable production potential surpassing manifolds the demand for wood products,
    - the powerful coppicing capacity of miombo formations, and
    - the fair distribution of wood resources over the Country

Priority lines of intervention and contributions of WISDOM analysis

From a general REDD+ perspective it seems that the highest priorities, in order to reduce deforestation and forest degradation, be the following, by decreasing priority level:

1. Mitigate inefficient farming expansion by improving farming efficiency/productivity. (Action targeting deforestation)
2. Implement protection measures in the high degradation risk areas accompanied by well-known rotational sustainable management practices. This analysis produced a ranking of districts according to expected degradation that identifies the target areas for this action. (Action targeting degradation)
3. Promote and support sustainable woodfuel production through participative sustainable management practices exploiting the strong miombo coppicing capacity and improve charcoal yield through training and support to charcoal makers associations. This analysis produced a ranking of districts with highest production potential that identifies the target areas for this action. (Action targeting degradation).
4. Explore other possible drivers of forest degradation such as recurrent fires and excessive grazing. Shortening fallow periods is also a likely driver of landscape degradation. (Action targeting degradation)

The specific relevance and potential contribution of the WISDOM analysis to the development of the REDD+

Investment Plan (IP) for Zambia may be defined with reference to the 10 strategic objectives that guide it, as presented in Table 10.

TABLE 10

REDD+ Strategic objectives and specific contributions of the WISDOM analysis to the formulation of the REDD+ Investment Plan.

The 10 strategic objectives laid down by the REDD+ Strategy	Relevance	Specific contribution of WISDOM study and supported interventions
1. By 2030, threatened and unsustainably managed national and local forests are effectively managed and protected to reduce emissions from deforestation and forest degradation and contribute with ecosystem services across selected landscapes	***	Ranking of priority areas (provinces, districts, watersheds, or any chosen area) for risk of degradation and/or sustainable supply potential (See Table 9 and Figure 22). Definition of emission reduction targets and locally-tailored protection/production management objectives for each chosen unit.
2. By 2030, selected high value forests in open areas are effectively managed and monitored	**	Profiling of the selected high value forests (harvesting pressure and degradation risk; urban/rural population within and around the forests; accessibility; etc.).
3. By 2030, all timber concession areas have management plans that are enforced and monitored with the full participation of local communities	*	Profiling of timber concession areas (rural population within and around concession areas; accessibility; etc.) .
4. By 2030, good agricultural practices that mitigate carbon emissions adopted	*	Contribute to the decision-support system through multi-thematic GIS layers
5. By 2030, regulated production of wood fuel (charcoal & firewood) and its improved utilization in place	***	Definition of sustainable woodfuel production targets and locally-tailored protection/production management objectives. Basis for consumption surveys. Support to improved charcoal-making programmes. Etc.
6. By 2020, appropriate and affordable alternative energy sources widely adopted	***	Contribute to the definition of the actual impact of the substitution of wood energy on GHG emissions, reduction of deforestation, livelihood and employment in rural areas, etc.
7. By 2020, threatened and sensitive protected areas legislated as "no-go areas" for mining and infrastructure development	*	Contribute to the decision-support system through multi-thematic GIS layers
8. By 2025, mining industry contributing to management of surrounding indigenous forests and establishment of forest plantations for own timber needs	*	Contribute to the decision-support system through multi-thematic GIS layers
9. By 2025, land and resource rights on customary land legislated and secured	*	Contribute to the decision-support system through multi-thematic GIS layers
10. By 2020, relevant institutions capacitated to enable them to plan, manage, implement and monitor REDD+ programme activities	**	The use and maintenance of the WISDOM multi-thematic GIS layers (if supported by appropriate GIS training) strengthen the institutional planning capacities.

Besides providing an indirect estimation of woodfuel-induced degradation, the WISDOM methodology supports the definition of priority areas of intervention for forestry and energy planning, which is the main reason of its development. The results of this analysis, in fact, can be used in several forestry and energy contexts:

- Remaining in the REDD+ context, for instance, this study contributes by revealing the cause-effect mechanisms behind degradation processes. Beyond measuring deforestation and degradation we need to identify remedial actions and to this end WISDOM provides essential quantitative and spatial elements linking cause (demand for fuelwood) and effect (rates of degradation) that are fundamental to the formulation of focused and locally tailored forestry and energy policies and to the design of strategic and operational planning.
- From a Sustainable Forest Management perspective, this analysis can support the formulation of locally tailored management objectives, such as productive or protective functions, quantitative production targets to meet local and commercial demand through new plantations and/or improved management practices.
- In the agro-forestry context, this analysis can support the formulation and implementation of field programmes oriented to increase woody biomass production for energy self-sufficiency in rural areas where scarcity is most serious and where the systematic use of farm residues for energy impacts nutrients cycles and soil fertility.

The direct observation and measurement of forest degradation is challenging and expensive (far more than the assessment of deforestation) both in terms of field measurements and resolution of remote sensing data (Verhegghen et al. 2014; GFOI/GOFC-GOLD, 2014). A key contribution that the WISDOM analysis can make to the direct assessment of forest degradation is in the stratification of forests and other landscapes according the risk of degradation (see Figure 21). Since the measurement of changes in biomass stock requires very costly surveys based on very high resolution data and intensive field sampling, the use of robust stratification criteria will make the sampling design more efficient and less expensive. Such stratification will allow to distribute the observations where the phenomenon is more likely to happen, for instance through a statistically efficient PPS approach, and thus reduce the costs of the assessment.

Limitations of the methodological approach

With this analysis we estimated the risk of degradation induced by excessive wood harvesting, spatialized and quantitative, but it is still a risk and not the actual degradation, whose direct measurement is far more challenging than assessing deforestation and is not currently available. As such, the WISDOM approach represents an indirect method to estimate forest degradation. However, the WISDOM analysis can effectively support the direct observation of forest degradation by providing stratification criteria that would reduce the costs and increase the efficiency of direct observations.

The development of WISDOM Zambia implied several assumptions and some provisional value attributions to fill in for information gaps, as discussed in the previous sections. Due to limited time this analysis could not carry out a comprehensive sensitivity analysis taking alternative assumptions, and was limited to the most probable set of assumptions.

Moreover, the assumptions remain assumptions and, in order to improve and consolidate the knowledge base they need validation and the provisional estimates and assumptions applied here should be replaced by solid reference data. The most relevant information gaps to be filled in with priority include the following:

Data weakness on supply

- No particular weakness on woody biomass stock, thanks to the biophysical data produced by ILUA I and II, including field inventory and mapping of land cover and carbon stock.
- As common in most countries, there is little data on sustainable productivity of forest formations and nothing at all on productivity of shrublands and farmlands. The use of MAI/stock equations represented the only way to estimate the productivity, but the underlying data refer only to forest formations, excluding other wooded lands and farmlands. Non-forest classes are important sources of woody biomass that must be well understood in order to assess with accuracy their role and, consequently, the true impact on forest resources.
- ILUA II mapping 2000-2010-2014 produced forest loss estimate that, among many other aspects, are useful in assessing woody biomass by-products released in the process. It would be important and interesting to observe the gain in forest area over the same periods, to understand what part of the

clearing reverted back to forest and thus differentiate the permanent change from the temporary one. Considering the strong coppicing capacity of miombo formations, this aspect seems particularly relevant for forestry planning and a step forward towards understanding of land cover change processes in Zambia.

- It should be noted also that the deforestation rate used in this analysis was derived directly from the maps produced by ILUA II, which differ from the bias-corrected deforestation statistics produced for the FREL submission. The map data was preferred because it allowed to locate deforestation areas (unlike the corrected national statistics) and because the mapped deforestation is significantly less than the adjusted figures. The impact of this choice is that by using a lower deforestation rate and thus accounting for a lower in-flow of deforestation by-products, the estimated degradation rate due to direct woodfuel harvesting is higher, which was assumed as an acceptable conservative approach.
- The estimation of the physical accessibility of wood resources is very important in this analysis. The available road network data is missing secondary roads and local tracks (as evidenced by numerous schools and health centers disconnected from the mapped road network). Updated road network data, including non-motorable trails is essential for a correct estimation of accessible resources.

Data weakness on demand

- The reference data on fuelwood and charcoal consumption in the residential sector show significant discrepancies on consumption rates, which made the definition of reference values for this analysis quite difficult. Such discrepancies are apparently due to poor definition of the population represented (general average, all users, main users).
- Following the energy crisis in recent years (2015 and 2016) it is likely that the demand for charcoal has increased significantly. This means that the situation depicted in this analysis, referring to 2010 supply and demand conditions, may no longer reflect the current situation. If there is sufficient evidence on the rapid change, and increase, of woodfuels in Zambia it may be justify to update the analysis using new consumption data.
- FLES provides an excellent basis for the socioeconomic analysis but could not yet produce quantitative consumption data due to the heterogeneity of consumption units used (bundles, bags, tins, head loads, etc.) and the difficulty of associating weight values. In future, woodfuel consumption surveys must adopt quantitative measurement techniques avoiding as much as possible people's estimates of consumption per month or per year. FAO produced useful practical guidelines on fuelwood consumption surveys (FAO, 2002) that offer interesting solutions. In particular, the "average day consumption" approach seems very effective as it allows to measure a day's consumption with good accuracy with only one visit.
- The use of woodfuels in other sectors (commercial, public, industrial) is only approximate. A recent study by MMEWD started to produce useful data in this respect but reliable estimates are still missing.
- Similarly, estimates on the national use of industrial roundwood are few and rather tentative (UNEP 2015). This is an important information for the forestry sector, deserving high quality data on the quantity of wood extracted and processed and on their sources.

Assumptions made in the analysis of commercial woodshed

- Due to time constraints, a sensitivity analysis of the WISDOM model based on alternative assumptions and data variants could not be done. The analysis has in fact followed a single path, applying a “conservative” supply variant and taking “most probable” assumptions concerning market mechanisms and transport time threshold. A complete sensitivity analysis would be beneficial as it would increase our understanding of the processes and provide a sort of confidence interval around leading degradation estimates.
- The hypothesis whereby local deficit generates commercial harvesting was considered the most appropriate for Zambia, but it’s is just one of the possible alternatives. Local deficit could also lead to the overexploitation of local resource. Since this assumption has important consequences on degradation estimates, it is advisable to conduct a sensitivity analysis taking alternative assumptions. Most important, however is to verify these assumptions in the field for fine tuning of WISDOM model.

- The assumptions made concerning the efficiency, or rationality, of commercial wood harvesting are only provisional. A relatively high efficiency was assumed in this study (SIEF=0.76) based on previous studies but this was only tentative. Detailed knowledge on the official and customary management practices, on the areas under community management plans and un-managed public forests will allow to fine tune this parameter for a more accurate estimation and mapping of actual forest degradation.

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Annexes

Annex 1 – Household demand - Fuel saturation and per capita consumption values

District-level cooking fuel saturation (Census 2010)

District		Rural areas			Urban areas		
code	Name	Number of households	Main Fuelwood Users	Main Charcoal Users	tot households	Main Fuelwood Users	Main Charcoal Users
			%	%		%	%
101	Chibombo	50566	**83.5**	**10.0**	2613	**16.1**	**58.6**
102	Kabwe	0	**0.0**	**0.0**	39862	**11.9**	**49.6**
103	Kapiri-Mposhi	37235	**84.2**	**13.1**	8742	**3.4**	**74.4**
104	Mkushi	24558	**86.7**	**10.3**	3831	**7.5**	**73.8**
105	Mumbwa	32655	**89.1**	**9.5**	6487	**16.1**	**62.6**
106	Serenje	25690	**91.2**	**7.1**	3311	**23.5**	**56.1**
201	Chililabombwe	2936	**45.0**	**52.4**	14390	**0.3**	**35.5**
202	Chingola	6251	**64.6**	**31.5**	33406	**0.9**	**46.2**
203	Kalulushi	4911	**55.3**	**35.2**	14292	**2.5**	**56.5**
204	Kitwe	3530	**57.6**	**31.1**	93136	**1.0**	**55.1**
205	Luanshya	4878	**56.2**	**38.9**	24165	**2.7**	**53.7**
206	Lufwanyama	15197	**75.8**	**22.8**	400	**68.8**	**26.0**
207	Masaiti	20104	**68.2**	**29.3**	407	**28.7**	**35.4**
208	Mpongwe	14339	**79.2**	**17.9**	3011	**39.3**	**46.3**
209	Mufulira	2395	**39.5**	**53.9**	27670	**3.1**	**45.9**
210	Ndola	0	**0.0**	**0.0**	85707	**6.2**	**67.3**
301	Chadiza	19268	**96.0**	**2.8**	554	**35.4**	**39.5**
302	Chipata	65212	**93.4**	**5.2**	22853	**12.1**	**61.9**
303	Katete	42513	**95.7**	**3.2**	4339	**21.5**	**60.1**
304	Lundazi	58872	**96.3**	**2.7**	3197	**6.5**	**67.8**
305	Mambwe	12045	**91.1**	**5.8**	1151	**73.8**	**8.3**
306	Nyimba	14610	**93.9**	**5.0**	1430	**30.8**	**55.0**
307	Petauke	53263	**94.8**	**4.2**	5891	**23.4**	**61.3**
401	Chienge	23648	**16.6**	**82.2**	767	**8.1**	**88.7**
402	Kawambwa	19259	**42.3**	**55.5**	5937	**4.9**	**88.9**
403	Mansa	28847	**76.5**	**22.1**	14784	**3.2**	**83.2**
404	Milenge	7028	**90.6**	**9.0**	566	**67.7**	**31.3**
405	Mwense	19557	**18.8**	**79.6**	4433	**6.9**	**87.6**
406	Nchelenge	22989	**23.2**	**75.7**	7168	**6.1**	**89.0**
407	Samfya	36104	**88.5**	**9.4**	3875	**31.7**	**59.7**
501	Chongwe	33918	**69.4**	**14.7**	2401	**21.7**	**43.7**
502	Kafue	26871	**50.6**	**19.4**	17685	**10.2**	**44.3**
503	Luangwa	3729	**85.8**	**12.8**	943	**48.6**	**32.2**
504	Lusaka	0	**0.0**	**0.0**	358871	**0.5**	**48.8**
601	Chama	18144	**97.9**	**1.8**	1276	**57.4**	**28.7**

District		Rural areas			Urban areas		
code	Name	Number of households	Main Fuelwood Users	Main Charcoal Users	tot households	Main Fuelwood Users	Main Charcoal Users
602	Chinsali	25702	**91.0**	**7.2**	2966	**37.2**	**50.8**
603	Isoka	10678	**91.1**	**8.6**	3458	**22.2**	**68.0**
604	Mafinga	12648	**96.9**	**2.8**	0	**0.0**	**0.0**
605	Mpika	32374	**89.3**	**8.8**	7582	**12.0**	**69.9**
606	Nakonde	15216	**85.1**	**13.5**	8739	**2.3**	**84.3**
701	Chilubi	15813	**95.5**	**3.6**	903	**93.6**	**4.7**
702	Kaputa	22047	**67.7**	**31.7**	1693	**20.9**	**67.2**
703	Kasama	25744	**88.0**	**9.9**	20118	**15.7**	**67.6**
704	Luwingu	22202	**94.1**	**5.2**	2105	**37.4**	**50.6**
705	Mbala	35419	**89.6**	**8.7**	4677	**5.0**	**81.8**
706	Mporokoso	16219	**91.7**	**7.7**	3128	**52.2**	**40.0**
707	Mpulungu	13643	**84.5**	**14.8**	6007	**9.5**	**80.9**
708	Mungwi	29355	**93.6**	**5.7**	1488	**53.8**	**34.3**
801	Chavuma	5785	**92.6**	**5.1**	885	**76.3**	**18.9**
802	Ikelenge	5830	**94.0**	**4.6**	0	**0.0**	**0.0**
803	Kabompo	12452	**97.9**	**1.5**	4084	**77.9**	**14.5**
804	Kasempa	11235	**89.9**	**8.2**	735	**7.2**	**67.2**
805	Mufumbwe	8354	**90.9**	**7.3**	1765	**70.6**	**26.9**
806	Mwinilunga	15401	**96.1**	**3.4**	2702	**26.3**	**59.3**
807	Solwezi	28392	**76.0**	**20.2**	18182	**3.8**	**70.8**
808	Zambezi	13117	**96.0**	**2.7**	1884	**46.4**	**38.9**
901	Choma	32431	**94.2**	**2.6**	12052	**14.8**	**51.0**
902	Gwembe	9336	**97.6**	**1.0**	510	**48.2**	**16.3**
903	Itezhi-tezhi	9587	**92.3**	**4.1**	2650	**35.5**	**44.0**
904	Kalomo	41093	**96.1**	**2.6**	3635	**9.7**	**62.3**
905	Kazungula	19295	**96.1**	**2.5**	729	**31.1**	**47.9**
906	Livingstone	1234	**75.8**	**8.3**	29227	**5.8**	**42.4**
907	Mazabuka	28429	**85.0**	**7.5**	14982	**7.4**	**47.8**
908	Monze	24635	**93.2**	**4.2**	8214	**22.6**	**53.3**
909	Namwala	15570	**95.6**	**2.9**	1092	**42.6**	**22.6**
910	Siavonga	12470	**90.7**	**5.9**	5287	**21.1**	**50.7**
911	Sinazongwe	16997	**95.6**	**2.4**	2724	**37.4**	**26.7**
1001	Kalabo	25809	**96.5**	**1.2**	671	**86.4**	**9.1**
1002	Kaoma	32021	**95.3**	**4.4**	4047	**18.2**	**58.7**
1003	Lukulu	14551	**98.5**	**1.2**	2125	**64.9**	**25.4**
1004	Mongu	26140	**87.9**	**7.8**	10465	**21.4**	**49.5**
1005	Senanga	22224	**96.7**	**1.3**	2938	**28.9**	**51.6**
1006	Sesheke	16697	**98.2**	**0.9**	3462	**63.7**	**14.3**
1007	Shang'ombo	18584	**98.4**	**0.9**	445	**79.3**	**5.2**

Per capita charcoal consumption from various sources

Charcoal

Source	Ref. year	Urb/Rur	Per capita Charcoal consumption as wood equivalent, DM			Remarks
			Main Users	All Users	All population	
			Ch Weq.DM kg/cap/yr	Ch Weq.DM kg/cap/yr	Ch Weq.DM kg/cap/yr	
Chidumayo, 1994	1983	urban		906		
Chidumayo, 1994	1988	urban		855		
Chidumayo, 1994	1994	urban		964		
Kalumiana, 1996	*1996*	urban		613		
Kalumiana, 1996 (Kabwe District)	1996	urban		952		
Kalumiana, 1996 (Kitwe District)	1996	urban		474	343	
Kalumiana, 1996 (Lusaka Districts)	1996	urban		481	348	
Mwitwa &Makano, 2012	2012	urban			1,425	
ESMAP 1990	1988	urban			759	
ESMAP 1990	**1988**	**urban**	**1,224**			Selected as main reference for Ch cons. in urban areas. Although rather old, this seems the most reliable ref for urban Ch consumption. Value for Main Users based on energy needs for cooking, heating, ironing, etc.
Kalumiana, 1996	1996	rural		419		
Kalumiana, (Kabwe District)	1996	rural		319		
Kalumiana, (Rural Copperbelt Distr.)	1996	rural		397	60	
Forestry Department, 1999	1999	???		594		
MMEWD 2016	2015	???		**1,041**		This is a preliminary reference for Ch cons. in rural areas. Recent but not specifically focused on main Charcoal users in rural areas

Notes:

The original charcoal consumption values were harmonized to per capita values and expressed as wood-DM equivalent using the following:

Household to per capita based on Census 2010 data for rural and urban populations.

Charcoal to wood DM applying a charcoal yield of 23.2% (tons of charcoal / tons of wood DM)

Per capita fuelwood consumption from various sources

Fuelwood			**Per capita Fuelwood as DM wood**			
			Main Users	**All Users**	**All population**	
Source	**Ref. year**	**Urb/Rur**	Fw DM kg/cap/yr	Fw DM kg/cap/yr	Fw DM kg/cap/yr	**Remarks**
Kalumiana, 1996	1996	urban		215		
Kalumiana, 1996 (Central Pr.)	1996	urban		212		
Kalumiana, 1996 (Kitwe District)	1996	urban		115		
Kalumiana, 1996 (Lusaka Districts)	1996	urban		112		
Forestry Department, 1999	1997	urban		209		
ESMAP 1990	1988	urban			131	
ESMAP 1990	1988	urban	**470**			Selected as main reference for Fw cons. in urban areas. Although rather old, this seems the most reliable ref for urban Fw consumption. Value for Main Users based on energy needs for cooking, heating, ironing, etc.
Kalumiana, 1996	1996	rural	892			
Kalumiana, 1996 (Kabwe District)	1996	rural	931			
Kalumiana, (Rural Copperbelt Distr.)	1996	rural	893			
Kalumiana, average value	1996	rural	***905***			Being well focused on rural areas, this seems to be the best reference
MMEWD 2016	2015	???		695		

Notes:

The original fuelwood consumption values were harmonized to per capita values and expressed as wood-DM using the following:

Household to per capita based on Census 2010 data for rural and urban populations.

Air-dry fuelwood to wood DM applying a factor of 0.87 (ref: ESMAP 1999 ; ad = 15% moisture, dry basis = 13.04% moisture, air-dry basis)

Annex 2: Supply Module - Reference data

The 3586 geo-referenced field plots data collected by ILUA II National Inventory, reported per-plot values of total biomass and total carbon (C), aboveground biomass (AGB) and dead wood (DW). The ILUA II Carbon map was used as stratification parameter, as done for the FREL (draft 2016).

Since average carbon values for the strata differ significantly from average map values, it was decided to use the carbon map only as spatial proxy for the wall-to-wall distribution of AGB and DW resources estimated on plot data.

Detailed stratification criteria and mean C, AGB and DW values per strata are shown below.

ILUA II Carbon map values

			Carbon map values		**Plot data**				
pixels (ha)	Stratum	Strata intervals	t C/ha	Total C kt	No plots	t C/ha	Total C kt	std (tC/ha)	95% conf. Int. (tC/ha)
3,171,732	1	1 (C t/ha 0 -10)	3.48	11,030	26	7.30	23,143	16.35	6.29
13,101,426	2	2 (C t/ha 10 -20)	16.44	215,428	384	10.33	135,275	14.21	1.42
32,639,766	3	3 (C t/ha 20 -30)	25.05	817,464	1601	15.68	511,782	15.31	0.75
11,948,766	4	4 (C t/ha 30 -40)	35.24	421,080	745	22.57	269,653	16.41	1.18
14,450,971	5	5 (C t/ha > 40)	52.44	757,747	830	40.18	580,591	39.58	2.69
75,312,661				2,222,749	3586		1,520,443		

		Aboveground Biomass (AGB)				**Dead wood (DW)**			
Stratum	No plots	AGB t DM/ha	Total AGB kt DM	std (tDM/ha)	95% conf. Int. (tDM/ha)	DW tDM/ha	Total DW kt DM	std (tDM/ha)	95% conf. Int. (tDM/ha)
1	26	10.46	33,174	24.84	9.55	1.9	5,964	13.05	1.26
2	384	15.20	199,114	20.36	2.04		24,637		
3	1601	24.05	785,107	23.63	1.16	1.2	40,335	5.18	0.25
4	745	34.87	416,651	25.91	1.86	1.5	17,479	5.05	0.36
5	830	62.06	896,761	62.72	4.27	2.6	37,279	7.71	0.52
	3586		2,330,808				125,694		

The map of **dendroenergy biomass (DEB)** stock was then derived from mapped AGB (agb_kg_md) by deducting foliage, twigs and stumps applying the equation below[10].

Map of DEB = Con("agb_kg_md" < 46300, "agb_kg_md" * 0.8, "agb_kg_md" * 0.85)

Finally, the woody biomass stock of relevance for this analysis was calculated and mapped by adding the map of DEB stock to that of DW stock.

[10] From AGB to DEB (exclusion of twigs, leaves and stumps): 0.80 for AGB stock < 46.3 od t and 0.85 for AGB stock >= 46.3 odt (S. Brown, personal communication, and Ketterings, Coe et al. 2001)

Annex 3: Analysis of physical and legal accessibility

A3.1 Physical accessibility

Off-road 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 wood or charcoal load).

In order to associate a parameter of physical accessibility to woody biomass resources, a **fuelwood transport time map** is produced following and adapting the procedure described by Nelson[11] and by Drigo[12] . The specific features of the Zambia study include the definition of target locations based on the most detailed available national maps (road, builtup areas, cities and towns, villages, schools, Health Centres), the use of 90m elevation model and of best available land cover data (Land cover 2010 v.2 by ILUA II), and the adaptation of friction factors and slope factors to Zambia situation.

Target locations

The target locations are all accessible areas, including:

1. Populated places,:

    a. Urban areas. Data: mapmaker_z_cities_utm35.shp; Urban settlements derived from class 11 of map lc10v2_100m; Global Urban Footprint (GUF, Esch et al. 2014. Transport time (return trip loaded) = 8 min/km.

    b. Rural settlements. In absence of village maps, this is mapped using proxies based on schools, health centers and water points. Data: schools_utm35.shp; health_utm35.shp; wps_utm35.shp Transport time (return trip loaded) = 8 min/km.

2. Communication features:

    a. Road network (map: gROADS.shp; mapmaker_z_roads_utm35.shp), composed by:

i.	primary_highway & terminal	Trans. time=	2 min/km
ii.	Major-arterial	Trans. time=	4 min/km
iii.	Secondary_road	Trans. time=	4 min/km
iv.	Minor-arterial	Trans. time=	6 min/km
v.	LOCAL & non-traffic & undefined	Trans. time=	8.8 min/km

    b. Railways (not relevant for this analysis)

The target locations (or source features of cost-distance analysis) is composed by the layers described above, merged into a single map.

Friction surface components

[11] 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. Available at http://bioval.jrc.ec.europa.eu/products/gam/index.htm

[12] Pan-tropical map of accessibility for the YALE-GACC Tier I analysis of woodfuels supply and demand (Drigo et al., 2014).

Land cover friction

The base friction values applied to land cover classes, intended as transport speed in minutes per km assuming flat terrain are reported in Table A3.1

TABLE A3.1

Friction values (minutes / km return trip) applied to land cover classes, assuming flat terrain

LAND_COVER	Going m/km	loaded factor	Return loaded	tot return trip min/km
Moderate Dense Fores	30	1.5	45	**75**
Low Dense Forest	28	1.5	42	**70**
Open Dense Forest	26	1.5	39	**65**
Closed Grassland	18	1.5	27	**45**
Open Grassland	18	1.5	27	**45**
Closed Shrubland	24	1.5	36	**60**
Open Shrubland	20	1.5	30	**50**
Cropland	16	1.5	24	**40**
Wetland	36	1.5	54	**90**
Water Body	120	1	120	**240**
Settlement	4	1	4	**8**
Otherland	18	1.5	27	**45**

Slope factor

The slope map was produced on the basis of the SRTM 90m. The effect of slope on travel speed is estimated following Nelson's approach, which was based on van Wagtendonk and Benedict (1980)[13] and is computed as follows: **v = v0e-ks** , where:

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

For the Zambia 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 foot-based travel components (map = **slp_factor**). The estimated effect of slope on off-road speed and on crossing time are shown in Table A3.2.

TABLE A3.2

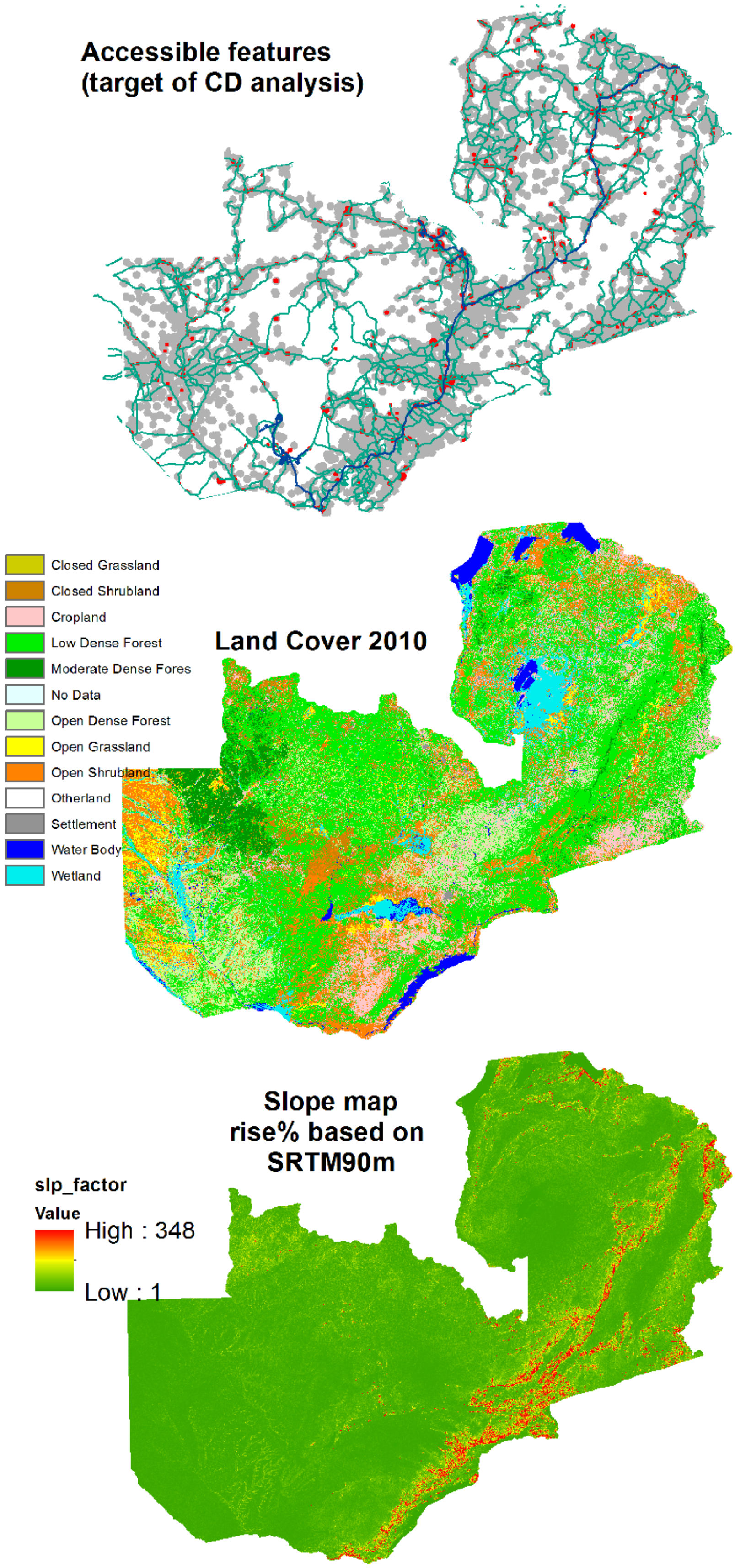
Effect of slope on off-road speed and on crossing time

slope %	gradient meter per meter	crossing time factor	speed decrease factor
0	0	1.00	1.00
1	0.01	1.03	0.95
2	0.02	1.07	0.91
5	0.05	1.17	0.79
10	0.1	1.38	0.62
20	0.2	1.90	0.38
30	0.3	2.63	0.23
40	0.4	3.62	0.14
50	0.5	5.00	0.09
60	0.6	6.90	0.06
70	0.7	9.52	0.03
80	0.8	13.13	0.02
100	1	25.00	0.01
200	2	625.00	0.00

[13] van Wagtendonk, J. W. and Benedict, P. R. 1980. Travel time variation on backcountry trails. Journal of Leisure Research 12 (2): 99-106.

FIGURE A3.1

Friction and target features



Cost-distance 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:
friclcslpmkm (float) = "fric_lcv2mkm2" * "slp_factor "

friclcslpmkm / 1000 = fric_m_m = (friction as minutes/meter)

Off-road travel time to nearest accessible feature resulting from cost-distance analysis (minutes):

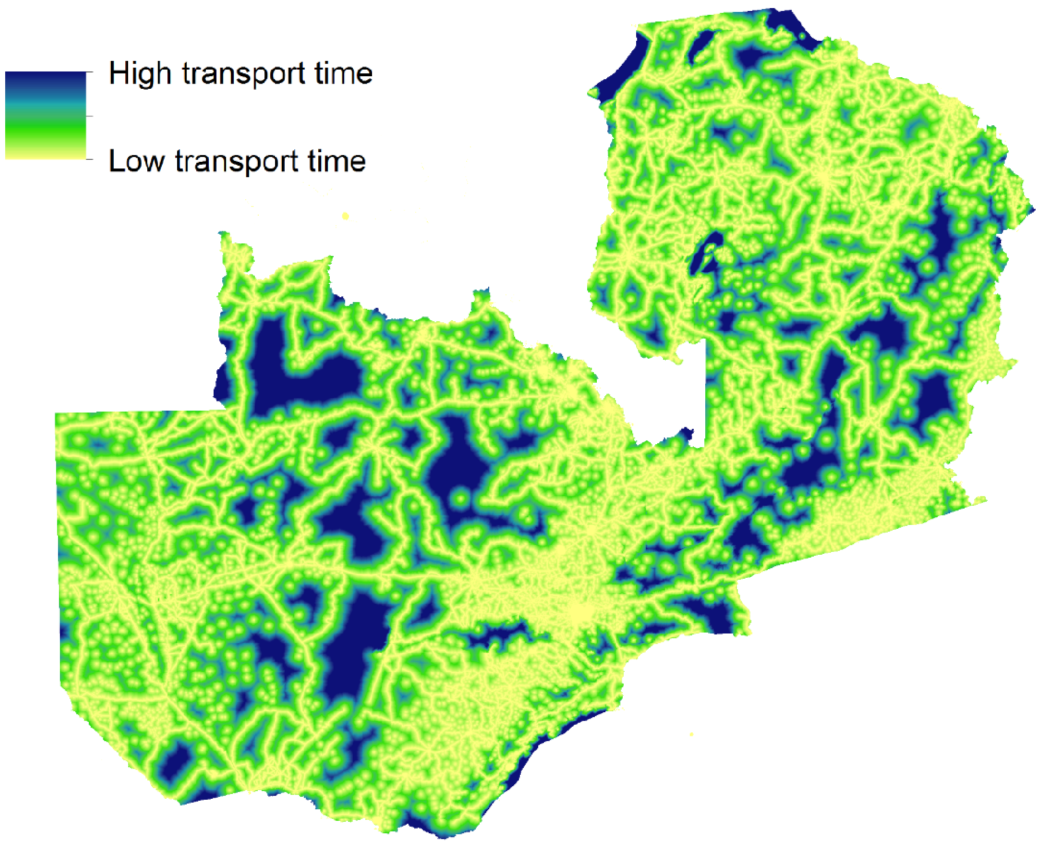
Source: **target2_mkm**; Cost: **fric_m_m = cd_m_2**

Results of travel time

The results of the analysis are presented in Figure A3.2 that shows the map of travel time to nearest accessible feature (minutes of transport, return trip).

FIGURE A3.2

Transport time map (hours from the nearest target feature)



From transport time to accessibility

The next fundamental step of analysis is to develop a map of accessibility based on the travel time map that help 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 10 hours off-road transport time to the nearest accessible feature are non accessible. Table A.3.3 presents the hypothesis of conversion of travel time into percent of accessibility applied, by which 68.3% of all resources are physically accessible and 31.7 inaccessible.

TABLE A3.3

Hypotheses of accessibility factors to be applied to estimate DEB resources based on travel time (ref. cd_02_clip)

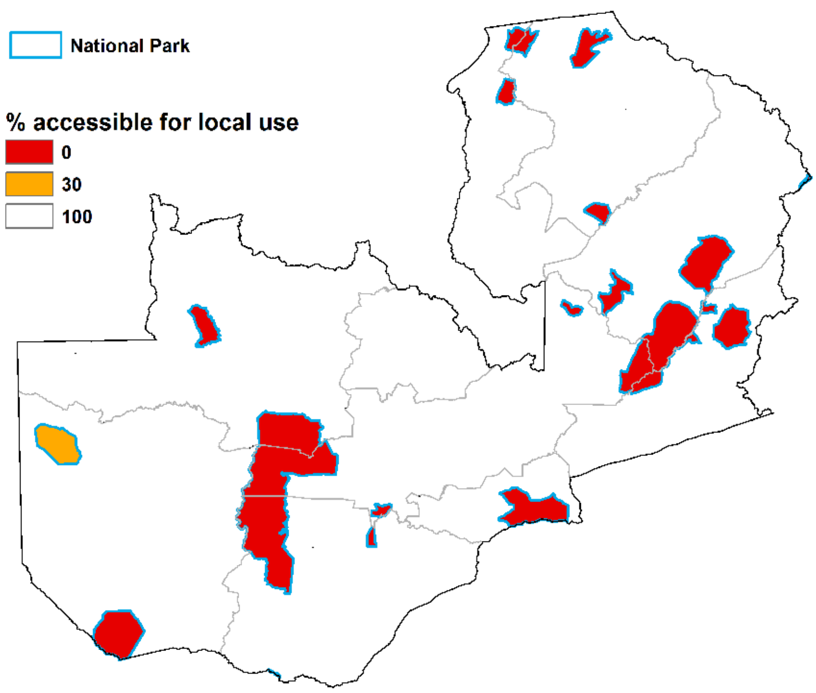
					Non-accessible MAI (%) :		**31.7**
				High MAI	**Accessible MAI (%) :**		**68.3**
	Transport time from nearest target feature			variant			accessible MAI
cd2_20	minutes	hours	work days	**MAI ktad**	access loss (%)	% accessible	k t ad
1	60	1	0.1	12,891		**100**	12,891
2	120	2	0.3	11,708	2	**98**	11,474
3	180	3	0.4	10,335	2	**96**	9,921
4	240	4	0.5	8,858	3	**93**	8,238
5	300	5	0.6	7,583	4	**89**	6,749
6	360	6	0.8	6,591	5	**84**	5,536
7	420	7	0.9	5,746	6	**78**	4,482
8	480	8	1.0	4,960	7	**71**	3,521
9	540	9	1.1	4,300	9	**62**	2,666
10	600	10	1.3	3,753	11	**51**	1,914
11	720	12	1.5	6,082	13	**38**	2,311
12	840	14	1.8	4,603	15	**23**	1,059
13	960	16	2.0	3,578	17	**6**	215
14	1,080	18	2.3	2,778	6	**0**	0
15	1,200	20	2.5	2,173	0	**0**	0
16	1,440	24	3.0	3,056	0	**0**	0
17	1,800	30	3.8	2,597	0	**0**	0
18	2,160	36	4.5	1,352	0	**0**	0
19	2,880	48	6.0	976	0	**0**	0
20	> 2,880	> 48	> 6	7	0	**0**	0
				103,926			**70,978**

A3.2 Legal accessibility

In Zambia all National Parks are off limits for fuelwood and charcoal production for either local or commercial use, while no particular restrictions are applied for Game Reserves and for the rest of the territory. The only exception is assumed for the Liuwa Plains NP, which includes several villages and for which a limited accessibility (30%) for local use is assumed. In Figure A3.3 National Parks and accessibility for local use.

FIGURE A3.3

Distribution of National Parks and their assumed accessibility for local use (for commercial use all NP have 0%accessibility)



Annex 4: Deforestation by-products

Deforestation data produced by ILUA II for the periods 2000-2010-2014. The average annual loss of forest area was based on the whole period 2000-2014 and the per hectare quantities of DEB generated in the process were estimated with reference to the stock of the forest areas cleared during the period 2010-2014.

code	Province	Mapped deforestation 2000-2010	Mapped deforestation 2000-2010	Average annual deforestation (period 2000-2014)	Average DEB stock/ha of deforested areas	Annual deforestation by-products (average 2000-2014)
		Ha	Ha	Ha	tons DM	kt DM
1	**Central**	97,263	176,073	19,524	30	577
2	**Copperbelt**	47,177	103,115	10,735	51	551
3	**Eastern**	54,906	103,427	11,310	30	338
4	**Luapula**	47,323	93,642	10,069	38	389
5	**Lusaka**	22,789	78,752	7,253	31	224
6	**Muchinga**	31,738	52,733	6,034	32	189
7	**Northern**	44,419	46,603	6,502	34	223
8	**North-West.**	84,707	171,448	18,297	56	1,030
9	**Southern**	57,514	167,069	16,042	24	377
10	**Western**	42,606	135,324	12,709	30	385
	Zambia	**530,442**	**1,128,186**	**118,473**		**4,282**