WOODFUEL INTEGRATED SUPPLY/DEMAND OVERVIEW MAPPING (WISDOM) MALAWI

ANALYSIS OF WOODFUEL DEMAND, SUPPLY, AND HARVESTING SUSTAINABILITY

RUDI DRIGO – WINROCK INTERNATIONAL

APRIL 2019

This publication was produced for review by the United States Agency for International Development. It was prepared by Rudi Drigo of Winrock International for Tetra Tech.

This publication was produced for review by the United States Agency for International Development by Rudi Drigo, Winrock International, for Tetra Tech, through USAID Contract number AID-612-TO-14-00003, Protecting Ecosystems and Restoring Forests in Malawi (PERFORM), under the Restoring the Environment through Prosperity, Livelihoods, and Conserving Ecosystems (REPLACE) Indefinite Quantity Contract.

This report was prepared by:
Rudi Drigo
Winrock International
Località Collina 5, 53036
Poggibonsi, Italy

With contributions from:
Dorothy Tembo- Nhlema, Wezzie Chisenga, Henry Utila, Bennet Mataya, Daud Kachamba, Judith Kamoto, Kevin Brown, Timothy Pearson, Alexandre Grais, and Lara Murray, and Ramzy Kanaan

Tetra Tech
159 Bank Street, Suite 300
Burlington, Vermont 05401 USA
Telephone: (802) 658-3890
Fax: (802) 485-0282
Email: international.development@tetratech.com

Contacts:
Ramzy Kanaan, Chief of Party
Email: Ramzy.Kanaan@tetratech.com
Rudi Drigo, WISDOM Analyst
Email: Rudi.Drigo@tin.it
Anna Farmer, Project Manager
Email: Anna.Farmer@tetratech.com
Rod Snider, Deputy Project Manager
Email: Rod.Snider@tetratech.com

WOODFUEL INTEGRATED SUPPLY/DEMAND OVERVIEW MAPPING (WISDOM) MALAWI

Analysis of Woodfuel Demand, Supply, and Harvesting Sustainability

APRIL 2019

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

ad	Air-dry (15% moisture content, wet basis, according to BEST 2009)
agb	Aboveground Biomass
agwb	Aboveground Woody Biomass
BAU	Business as Usual (scenario)
BEST 2009	Malawi Biomass Energy Strategy 2009
bp	By-product (referring to the woody biomass released by land cover change [LCC] processes such as deforestation)
CC	Canopy Cover (expressed as percent of land covered)
CI	Confidence Interval
DM	Dry Matter (0% moisture content, equivalent to oven-dry)
DOF	Department of Forestry
EA	Enumeration Area
FAO	Food and Agriculture Organization of the United Nations
FE	Fuel Efficient
fNRB	Fraction of Non-Renewable Biomass (i.e. non-sustainable fraction)
FRL	Forest Reference Level
Fw	Fuelwood
GHG	Greenhouse Gas
GIS	Geographic Information System
ha	Hectare
HH	Household
HO	Half Orange
IHS	Integrated Household Survey conducted by NSO Malawi
IHPS	Integrated Household Panel Survey conducted by NSO Malawi
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
kg	Kilogram
kt	Kilotons (1,000 metric tons)
LC	Land Cover

LCC	Land Cover Change
LCCS	Land Cover Classification System
LPG	Liquid Petroleum Gas
MAI	Mean Annual Increment
MASDAP	Malawi Spatial Data Portal (maintained by the Department of Surveys, Malawi)
MODIS	Moderate-Resolution Imaging Spectroradiometer
MRV	Measurement, Reporting and Verification
Mt	Million metric tons
NCS	National Charcoal Strategy
NFI	National Forest Inventory
NSO	National Statistical Office of Malawi
PERFORM	Protecting Ecosystems and Restoring Forests in Malawi
REDD+	Reduced Emissions from Deforestation and forest Degradation
RFAS	Rural Firewood Assortments Survey
SFM	Sustainable Forest Management. In this study SFM is intended in the broad sense of sustainable management of woody biomass resources, whether from forest or non-forest areas.
SIEF	Sustainable Increment Exploitation Factor (used to represent the rationality of the management)
t	Metric Ton (1000 kg)
TBS	Tree-Based Systems
TC	Tree Cover (expressed as percent of land covered)
TOF	Trees outside the Forest
ton	Metric Ton (1000 kg)
USAID	United States Agency for International Development
WCMC-IUCN	World Conservation Monitoring Centre—International Union for the Conservation of Nature
WDPA	World Database of Protected Areas
weq	Wood-Equivalent (used to quantify the demand for charcoal in terms of wood used used for its production)
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping

GLOSSARY OF TERMS

Balance	Difference between supply and demand within a specific geography. Spatially, it is calculated as: pixel value of the demand map <minus> pixel values of the supply map. Positive values represent surplus conditions while negative values represent deficit conditions. Without further specification, balance indicates "pixel-level" balance. For "local balance" and "commercial balance" see separate definitions below.
Charcoal	Solid residue derived from carbonization distillation, pyrolysis, and torrefaction of fuelwood (UBET, FAO).
Commercial balance	The commercial balance is derived from the local balance, by assigning 0 value to local surplus areas with sparse resources, considered not suitable for commercial woodfuel production. Accessible areas with a stock above 12 tons DM ha^{-1} and a surplus above 410 kg DM ha^{-1} year^{-1} were considered as potential commercial sources. The scope of commercial balance maps is to model commercial harvesting. In commercial balance maps the deficit areas are not modified (i.e. are equal to local balance).
Commercial harvesting	Harvesting of woody biomass (to be used as fuelwood or for charcoal making or as construction material) serving distant demand, i.e. over 5km from consumption sites.
Commercial surplus	See "local commercial surplus."
Commercial woodshed	The commercial woodshed represents the actual commercial harvesting area of a given consumption site (or sites). The commercial woodshed is not based on sustainability considerations and may include unsustainable harvesting when the limits of economic accessibility induce excessive harvesting.
Construction material	Wood commonly used for construction and repair of houses, stables, fences, etc. Construction material comes mostly from the same supply sources of fuelwood and charcoal and follows the same supply system. Industrial roundwood is not included.
Consumption	See "demand." In this study the terms "demand" and "consumption" are used interchangeably. Although in principle the demand may be greater than the actual consumption, it is *de facto* estimated using consumption data and consequently demand = consumption.
Conventional demand	Demand for woodfuels and small construction material excluding marginal fuelwood, i.e. composed by conventional fuelwood, wood for charcoal and small construction material.
Conventional fuelwood	Fuelwood composed by "conventional" fuelwood assortments such as stem wood (usually split) or branch wood. Marginal fuelwood is excluded.
Degradation	In this study, "degradation" signifies the impact of unsustainable harvesting and is estimated as the quantity of woody biomass harvested in a given year that exceeds the re-growth potential or mean annual increment (MAI). In this sense, the total unsustainable harvesting at national or sub-national level corresponds to the estimated degradation taking place nationally or sub-nationally. Unless specifically referring to forest areas, the unsustainable harvesting and the corresponding degradation refer to the landscape as a whole.

Demand	Annual demand for woodfuels (fuelwood and charcoal) and small construction material (fencing, house repair material, etc.) based on the estimated annual consumption, hence here used as synonym of "consumption." Unless otherwise specified, is intended as "wood-equivalent," whereby charcoal demand is accounted for by the wood needed to produce it.
Fuelwood	Woodfuel where the original composition of the wood is preserved (UBET, FAO). Synonymous of "firewood." It includes conventional fuelwood and marginal fuelwood.
High Variant	Business-as-usual (BAU) scenario based on least favorable data variants and assumptions.
Industrial roundwood	Industrial roundwood, as defined in the FAO Forest Products Yearbook, includes all industrial wood in the rough (sawlogs and veneer logs, pulpwood and other industrial roundwood) and, in the case of trade, chips, particles, and wood residues.
Medium Variant	BAU scenario based on most probable data variants and assumptions.
Legal accessibility	Accessibility to woody biomass resources determined on the basis of protection status and categories. Expressed as percent accessible.
Local balance	Balance between supply and demand calculated in a 5km radius. The value of a local balance pixel is calculated as: average value of the pixels of the map of pixel-level balance, calculated within a circle of 5km (50 cells).
Local commercial surplus	Sum of the pixels of the commercial balance map with positive values, representing areas where the supply potential exceeds the demand within a radius of 5km and are considered suitable for commercial utilization.
Local deficit	Sum of the pixels of the local balance map with negative values, representing areas where the demand exceeds the supply potential within a radius of 5km.
Local harvesting	Harvesting of woody biomass (to be used as fuelwood or for charcoal making or as construction material) serving local demand, i.e. within 5km of consumption sites.
Local surplus	Sum of the pixels of the local balance map with positive values, representing areas where the supply potential exceeds the demand within a radius of 5km.
Low Variant	BAU scenario based on most favorable data variants and assumptions.
Marginal fuelwood	Fuelwood composed by minor wood assortments such as twigs, smaller branches, and shrub wood.
Non-residential demand	Annual demand for fuelwood and charcoal from commercial, industrial, and public sectors. The demand from the residential sector is excluded.
Physical accessibility	Accessibility of woody biomass resources from the nearest accessible feature (road, village, or city) determined by distance, slope, and land use. Expressed as percent accessible.
Residential demand	Residential sector demand: households' annual demand for fuelwood and charcoal for cooking and heating and for small construction material. Demand from other sectors (commercial, industrial, public) is excluded.

Saturation	Fraction of the population using a given fuel as main fuel for cooking and heating.
Supply	Intended here as the MAI of aboveground woody biomass that is physically and legally accessible and potentially available to be used as woodfuel (as fuelwood or for charcoal production) or as household construction material.
Sustainable Increment Exploitation Factor (SIEF)	This factor represents how rational is the harvesting of woody biomass. SIEF ranges between 0 and 1, where 1 represents optimal management (optimal rotation) and 0 represents worst-case exploitation (stock depletion without rotations).
Sustainable woodshed	The minimum area around the consumption site(s) 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.
Unsustainable harvesting	Harvesting of woody biomass that exceeds the potential re-growth capacity (MAI).
Woodfuel(s)	All types of biofuels originating directly or indirectly from woody biomass (includes fuelwood, charcoal, and black liquor) (UBET, FAO).
Woodshed	A neologism inspired by the familiar geographic concept of watershed. It is used to indicate the portion of the territory necessary to supply the woody biomass needed by a specific consumption site (or sites) on a sustainable basis (sustainable woodshed) or that of the actual commercial harvesting area (commercial woodshed).

EXECUTIVE SUMMARY

This report presents the results of an analysis of the current and future status of the national woodfuel energy market in Malawi. Questions of woodfuel sustainability are central to Malawi's development trajectory, as over 98% of rural and 90% of urban users rely on wood and charcoal as a primary fuel, a situation that has changed little in the past two decades and is likely to continue for the foreseeable future as the population increases. Wood energy is a renewable but finite resource. When managed appropriately and used efficiently, it can be a continuing source of livelihoods and energy for Malawi. However, uncontrolled or poorly planned extraction of wood from forests and woodlands can reduce the availability of this resource over the long term, resulting in higher prices for consumers, lower standards of living, and loss of productivity of the land.

The work presented here derives from a Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) exercise that included a thorough review, collation, and analysis of spatial and statistical data in Malawi on both energy consumption and forest resources, focusing on national circumstances between 2016 and 2021.

The study found that:

- Demand is increasing for all fuel types, with a growth rate slightly higher than that of the population. This is due primarily to charcoal consumption, which is increasing very fast in urban areas (+10% year^{-1}) but also in rural areas (+4% year^{-1}).
- The supply potential is decreasing moderately at a rate of 0.8% year^{-1}, an effect of deforestation and accumulating degradation.
- Over the period 2016-2021, the national supply/demand balance changes considerably from an initial surplus to a deficit situation. This critical turning point is projected to be in 2019. This means that the rate of impact on remaining resources is gaining momentum with a likely worsening of degradation processes.
- Taking alternative assumptions, we estimate that in the worst case this transition already happened six years ago, or in the best case could happen six years from now. In any case, taking remedial action is necessary and very urgent.
- For the first time, the WISDOM analysis provides quantitative and geo-referenced estimates of unsustainable harvesting and degradation rates that allow setting national and sub-national targets for meeting wood energy sustainability.
- A preliminary review of potential interventions to offset the unsustainable harvesting in 2021 shows that none can succeed in isolation. Remedial action is needed from both supply and demand sides, including increased wood production in plantations, wood lots and increased tree cover in farmlands, implementation of Sustainable Forest Management (SFM) prescriptions, improved kiln efficiency, improved stove efficiency, and switching to alternative fuels.

It is the hope of the authors that the insights offered from this exercise can be used to formulate national and local sectoral strategies to ensure that an important energy resource remains available to future generations of Malawians, while also protecting irreplaceable biodiversity and mitigating climate impacts.

BACKGROUND

Malawi is a small country without oil or gas reserves, with limited hydro-electric potential and a growing population that depends on woody biomass as the primary source of energy. Wood resources are limited and the demand for woodfuels is high and increasing; in the short and medium term, it is likely that woodfuels will remain the only affordable fuel for the majority of the Malawian population. The relevance of woodfuels in Malawi can be summarized as follows:

- 98% of the rural and 90% of the urban population use woodfuels as the main fuel source (Integrated Household Survey [IHS] conducted by the National Statistical Office [NSO] of

Malawi, 2016). Woodfuels are also important energy sources for numerous rural industries, commercial activities, and public services.
- Woodfuels represent 81% of all wood harvesting in Malawi (Food and Agriculture Organization of the United Nations [FAO] statistic for 2016).
- Biomass meets about 80% of Malawian energy needs/supply (Department of Energy Affairs, 2018).

Despite the importance of wood energy in Malawi, the size of the demand for woodfuels and sustainable production potential is poorly understood. As a result, opinions vary widely on the role of woodfuels in driving the observed processes of deforestation and forest degradation in Malawi.

SCOPE OF THE STUDY

This study was undertaken through the support of the USAID Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) project implemented by Tetra Tech, with the objective of developing and implementing a scientifically grounded, replicable approach for determining spatially explicit estimates of unsustainable harvesting of woody biomass for woodfuel production and the relative net greenhouse gas (GHG) emissions in Malawi.

The study evaluated the current situation with wood energy in Malawi and developed near-future projections (five years) to highlight likely trends, orient remedial strategies, and discuss possible lines of intervention. As determined by the available data, 2016 was defined as reference year of analysis of the current situation, with 2021 serving as the projection year.

METHODOLOGY

The analysis followed the Woodfuels Integrated Supply/Demand Overview Mapping (WISDOM)[1] methodology, a data-intensive exercise that estimates and maps the balance of supply and demand for fuelwood. A spatially explicit evaluation of the demand for woodfuels from residential and business users is combined with a spatially explicit evaluation of woody biomass stock and productivity. The physical and legal accessibility of sustainable woodfuel supply potential is then integrated with these analyses to produce an estimate of the supply/demand balance at multiple scales, showing harvesting pressure and locations of unsustainable wood harvesting.

Furthermore, this study developed WISDOM results based both on 2016 information and projections to 2021. To reflect the uncertainties of the available data and of the assumptions made, three business as usual (BAU) scenarios were produced:

1. ***Medium Variant:*** the most likely situation, demonstrating a moderate level of forest degradation
2. ***High Variant:*** the worst situation based on least favorable data variants and assumptions
3. ***Low Variant:*** the best-case scenario for deforestation and forest degradation, based on most favorable data variants and assumptions

The large amount of statistical and geo-referenced data reviewed, harmonized, and integrated into this study came from a variety of sources, including:

- Relevant Malawian institutional sources including the National Statistical Office (census data and data from the IHS and the Integrated Household Panel Survey [IHPS]); the Department of Forestry of the Ministry of Natural Resources, Energy, and Mining (forestry data, maps); the Ministry of Energy (Malawi Biomass Energy Strategy [BEST] 2009), and the Survey Department (Malawi Spatial Data Portal [MASDAP] data);
- Data contributed by PERFORM from project activities (PERFORM forest inventories and integration of all inventories carried out in Malawi) and a variety of maps and reports produced by numerous projects; and

---

[1] http://www.wisdomprojects.net/global/.

- Data collected specifically for this study, including the Rural Firewood Assortment Survey used to estimate marginal and conventional fuelwood used in rural areas, and a review of existing data to estimate non-residential consumption.

SPATIAL HETEROGENEITY

The spatial distribution of wood resources and consumption sites is very heterogeneous in Malawi. This is due to the concentration of population in the south and central regions, areas with inaccessible topography, and transport networks that follow a predominantly north-south orientation in line with the elongated shape of the country.

Understanding national woodfuel sustainability requires more than just comparing total demand to supply. Under the WISDOM approach, local-scale imbalances in supply and demand are combined using spatial analysis to produce an evaluation of localized conditions that can be either sustainable or unsustainable for the forest resources utilized for fuel. These local-scale imbalances are driven by the heterogeneous features mentioned above, including spatial patterns of population density, accessibility, and forest resource conditions.

This study dedicated considerable effort to representing this heterogeneity and its effects by geo-referencing the demand and the supply, estimating the physical accessibility of resources from roads and settlements, and, through woodshed analysis, determining the commercial harvesting pressure exerted by major deficit sites. Thus, all parameters and results of the study are spatially explicit.

While the focus of this analysis was to evaluate the overall national situation on woodfuel dynamics in Malawi, the spatial products of the analysis (see Figure 1) can support any scale of investigation or planning. This report summarizes all parameters and results by district (or district group, in the case of 2021 projections) to provide insights on the variability within the country; however, any other portion or subdivision of the territory could be used as reporting unit.

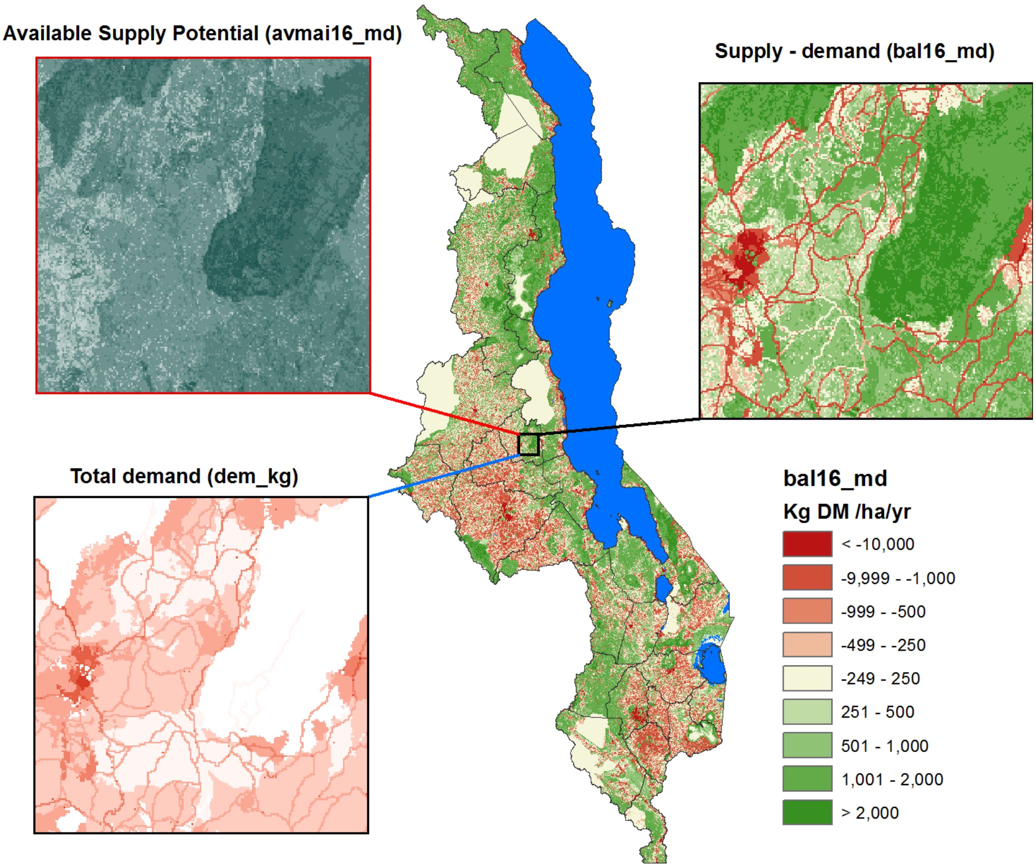


Figure 1. Pixel-level Supply–Demand Balance

KEY RESULTS (TRENDS 2016-2021)

Demand. The total demand for fuelwood, charcoal, and small construction material was estimated to be 11.2 million metric tons (Mt) dry matter (DM) in 2016 and is projected to increase to 13.3 Mt DM by 2021. This increase is primarily due to population growth and continued dependency on woodfuels as an energy source. Most striking are the changes taking place in urban areas, where a rapid increase in charcoal demand of 10% annually is only partially compensated by a 5% annual reduction of fuelwood demand. The change from fuelwood to charcoal has major implications on harvesting intensity and sustainability because for each unit of energy output, charcoal requires twice as much wood than fuelwood.

Households typically prefer larger pieces of wood if available ("conventional" wood) but will turn to smaller sticks and twigs ("marginal" wood) if necessary. In 2021, according to the medium variant, marginal fuelwood assortments are estimated to meet 23% of the total demand (see Figure 2 below) while conventional wood is estimated to meet the remaining 77%.

While the impact of marginal fuelwood harvesting remains undetermined, this study indicates that a consistent and growing fraction of the "conventional" demand is unsustainably sourced, with consequent mounting degradation and GHG emissions. According to the medium variant (Figure 2), the unsustainably sourced conventional demand increases from 15.5% to 20.3 % between 2016 and 2021.

Supply potential. According to the medium variant, over the five-year period, the national sustainable supply of physically and legally accessible wood is estimated to reduce from 9.85 to 9.45 Mt DM, resulting from the impact of deforestation and degradation on forest productivity.

Supply/demand balance. The integration of supply and demand layers reveals that Malawi stands at a major turning point from a national surplus to deficit conditions, which presents serious challenges for the environment as well as the majority of the population that depends on natural resources for their basic needs.

According to the medium variant (representing the most probable assumptions), the supply/demand balance in 2016 was <u>positive</u> by 0.8 Mt DM, representing a surplus of 9%, while in 2021 projections the balance will be <u>negative</u> by 1.1 Mt DM, representing a deficit of 11%. This indicates that the transition from a condition of surplus to that of deficit will approximately take place in 2019. In a situation of widening deficit, the pressure on the remaining resources is likely to speed up, with progressively worsening processes of degradation.

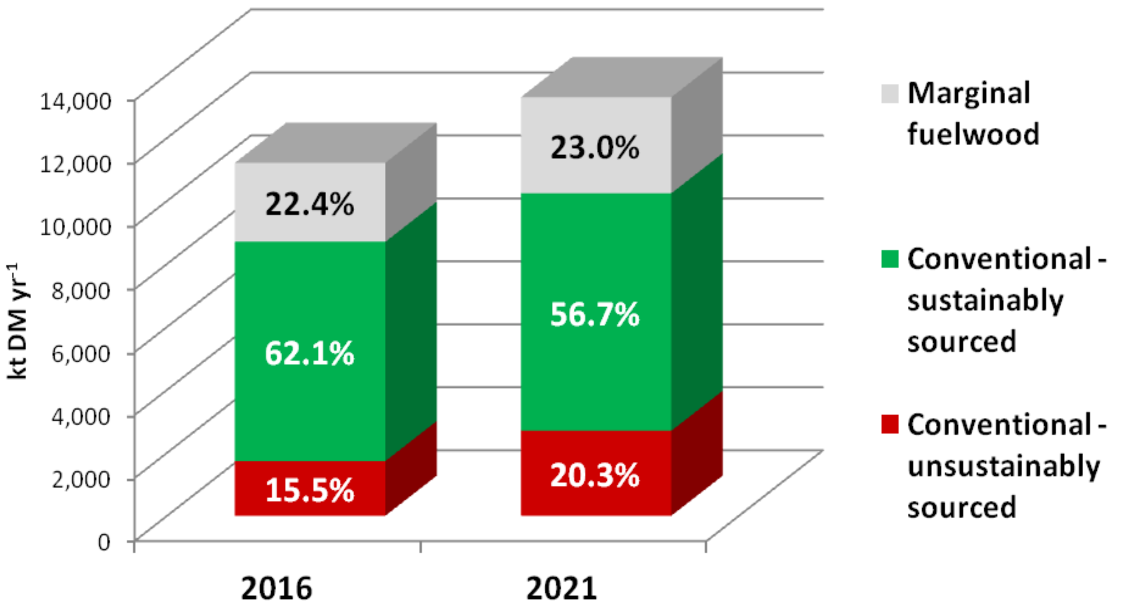


Figure 2. Total Demand in 2016 and 2021 by Main Components (Medium Variant)

Alternative scenarios indicate that the moment of transition already happened six years ago (high variant) or will happen six years from now (low variant). These alternatives reveal that the situation is seriously compromised, no matter the level of uncertainty characterizing data and assumptions, and that powerful remedial actions are imperative and urgent.

Unsustainable harvesting. The degradation rate due to unsustainable harvesting of woody biomass is estimated to be 1.7 Mt DM in 2016, increasing to 2.7 Mt DM in 2021 (medium scenario) showing an annual growth rate of 11%. Comparing this to the population growth rate (3.4%), it is therefore evident the level of unsustainable harvesting is a non-linear response. The degradation in 2021 is estimated to be determined in part by insufficient supply potential (1.1 Mt DM) and lack of management (1.6 Mt DM), whereby wood harvesting is heavily concentrated in certain areas leaving others untapped, rather than applying rational rotation systems.

Undetermined impact of marginal fuelwood harvesting. The results presented above reflect the supply potential of conventional wood harvesting and to the corresponding conventional demand. The impact of marginal fuelwood harvesting on its supply sources is undetermined but may be serious and certainly different from that of conventional woodfuels.

REMEDIAL ACTION EVALUATION

Formulating and designing effective action requires a clear definition of the problem and desired results. In the case of planning wood energy in Malawi, the problem may be summarized as being the quantity and distribution of unsustainable harvesting.

The WISDOM approach was developed to aid in wood energy planning, with its first and foremost contribution being to provide a quantitative and geo-referenced estimation of the relation between demand and supply potential, as well as the rate of degradation due to unsustainable harvesting. Such estimates define the problem to be solved and therefore the scope and target of remedial actions.

This study does not attempt to propose a specific metric; however, several metrics that had not been previously available in Malawi are presented herein, and provide a more objective measure of the actual impact on the sustainability of woodfuel. While the national deficit of 1.1 Mt DM shown by the 2021 commercial balance (medium variant) could be used, bridging that gap would eliminate degradation only if all resources were managed under strict sustainable management practices, which is an unrealistic assumption in the medium term. Instead, a more sensible target of 2.7 Mt DM of total unsustainable harvesting projected for 2021[2] is suggested and applied as the basis for exploring the cumulative impact of various lines of interventions to meeting this target.

Such an ambitious target cannot be achieved through a single intervention at the national level. The remedial strategy will require the simultaneous implementation of several lines of intervention, prioritized according to feasibility, cost efficiency, interactions with other interventions, and synergies with ongoing activities. While this study does not offer specific policy action recommendations, the PERFORM study team evaluated a hypothetical suite of policy options aligning with the National Charcoal Strategy (NCS) to offer a preliminary review of potential interventions. These options and evaluations are summarized below:

- ***Penetration of alternative cooking fuels:***
  - Liquid petroleum gas (LPG) is the most likely alternative fuel to be adopted but would be limited to the urban context due to infrastructure needs for delivery.
  - Boost in use of LPG requires both significant economic growth (not as likely in the short term) and/or subsidies.

[2] The 2.7 Mt DM of unsustainable harvesting includes direct harvesting (1.8 Mt) and the use of byproducts of deforestation (0.9 Mt) that substitute direct harvesting. It may be assumed, however, that if deforestation is stopped, then the whole amount would come from unsustainable direct harvesting.

- ***Further penetration of improved stoves:***
  - Current use of improved stoves is estimated to be low (~8%), but actual use is hard to evaluate as data on the use of improved stoves is not systematically collected through nationwide surveys and data from programs promoting their use is fragmented.
  - Assuming a wood saving of 23% for fuel efficient (FE) fuelwood stoves and of 30% for FE charcoal stoves, we can conclude that the target of 2.7 Mt DM cannot be met solely by replacing inefficient stoves.
- ***Better management of existing forests:***
  - Total unsustainable harvesting has two components: lack of resources (1.1 Mt) and the irrational harvesting system/lack of management planning (1.6 Mt).
  - Under optimal sustainable management conditions of all existing legally accessible wood resources, unsustainable harvesting could be reduced by a maximum of 1.6 Mt DM, representing 60% of the target.
- ***Establishment of new plantations and woodlots:***
  - An analysis of available land for reforesting was undertaken as part of this study, resulting in an estimate of approximately 588,000 hectares (ha).
  - Assuming an average yield of 10 m3 ha-1 year-1 (corresponding to a mean annual increment [MAI] of 5.9t DM), Malawi would need 457,000 ha of plantations and woodlots to generate the target woodfuel supply.
  - While there is available land, the task of generating such a large amount of wood in the short term solely through new plantations and woodlots is not likely.
- ***Tree planting in farmlands and agroforestry:***
  - Trees planting in farmlands is already increasing as farmers recognize the need for more wood resources to be used as fuel and construction material. Therefore, farmers are likely to respond positively to this line of intervention.
  - According to the results obtained in integrating land cover data and sample data from five districts, rain-fed farmlands have a tree cover of 8% on average, with some 15 t DM of stock and a MAI of 1 t DM ha-1 yr-1 (Medium Variant).
  - Rain-fed farmlands cover 4.3 million hectares (FAO 2010), so meeting this target through this line of intervention alone would require a 63% increase of trees on farmlands. Such an increase would imply the successful planting of some 31 million additional trees managed on a rotational basis.
- ***More efficient charcoal making:***
  - The introduction of efficient kiln systems to reduce the consumption of wood for charcoal making would be effective only if combined with a clear regulatory context and in synergy with SFM planning.
  - If all charcoal were produced through high-performing Half Orange (HO) kilns, 1.09 Mt DM of wood (40% of the target) would be saved, whereas if all charcoal were produced through improved earthen kilns the savings would be 0.539 Mt DM of wood (20% of the target).
  - Both improved systems should be considered. The stable HO kilns should be built in areas where the wood flow is expected to be constant and sustainable based on SFM planning. The improved earthen kiln should be promoted as part of training programs for professional charcoal making and operated where the supply of wood is expected to be less frequent or sporadic.

FINAL CONCLUSIONS AND RECOMMENDATIONS

By integrating data and knowledge from various sectors, WISDOM favors dialogue among institutions (forestry, energy, and agriculture). Previous experiences in several countries indicate that by recognizing and integrating the contributions of the various sectors, the WISDOM analysis is accepted as a shared product through which dialogue between forestry, energy, and agriculture actors can develop more easily.

The numerous parameters and factors defined for the WISDOM analysis (per capita consumption, number and distribution of users, stove efficiencies, charcoal yields, biomass stock and productivities, current tree cover, etc.) can also contribute to the definition of remedial actions. Specifically, they can contribute to the estimates of the expected impacts of interventions per unit of action, such as fuel replaced, stove upgraded, improved charcoal making, hectares planted or put under SFM, tree cover increase in farmlands, etc.

The development of WISDOM Malawi required assumptions and some tentative value attributions to fill in information gaps. To improve future WISDOM analyses in Malawi and consolidate the knowledge base, assumptions should be validated and tentative estimates should be replaced by solid reference data. The most relevant information gaps to prioritize filling in include the following:

- Further study on the role and consistency of marginal fuelwood, incorporating the distinction between conventional and marginal fuelwood assortments in the questionnaires of censuses and socio-economic surveys that collect data on the preferred fuels used for cooking and heating in Malawi households.
- Carrying out consumption surveys in the various sectors and requesting that representatives of major enterprises and reference institutions keep record of the woodfuels annually used.
- Scientific data on current charcoal yields is missing, so it is recommended that a survey of current charcoal production be undertaken.
- To develop and implement sustainable forest management plans, it is essential to proceed with well-designed nationwide inventories of all biomass sources, specifically focused on their sustainable growth potential.
- Future forest inventories should include a component aiming at farmlands and agro-forestry systems to assess the production potential of "conventional" wood from trees outside forests and woodlots, as well as "marginal" wood assortments (twigs, deadwood, annual and periodic pruning of farm trees and shrubs, etc.).
- In view of the high proportion of marginal wood assortments harvested to satisfy rural fuelwood needs and of the total absence of information on the impact of such a practice, it is recommended to study the impact of excessive marginal fuelwood harvesting (soil fertility loss, landscape degradation, etc.).

1.0 INTRODUCTION

1.1 BACKGROUND AND SCOPE OF THE STUDY

Fuelwood and charcoal play a key role in most Malawians' everyday lives. Together, they represent the main source of household energy for cooking and heating in rural (98%) and urban (90%) areas (Integrated Household Survey [IHS] 2016). They are also important energy sources for numerous rural industries, commercial activities, and public services.

To meet these consumer needs, fuelwood and charcoal represent 81% to 97% of wood products harvested annually in Malawi from forests, other wooded lands, and farmlands, which exerts significant pressure on forest resources in Malawi. In the past, Malawi had abundant woody biomass resources in its forests, woodlands, and farmlands, and the annual sustainable growth potential of this abundant woody biomass exceeded the demand for fuelwood of the country. Now, however, the growing demand has reached the limits of the sustainable supply potential. Moreover, the demand for woodfuels and supply sources is unevenly distributed, and so is the pressure on resources, resulting in excessive harvesting in certain areas while other areas remain untapped.

While sustainable harvesting with adequate rotation periods would not permanently reduce the biomass stock and would not diminish the productive potential of the forests, unsustainable harvesting (i.e. excessive and repeated wood extractions) is the cause of forest degradation with loss of biomass stock and diminished regrowth capacity. As such, over time, sustainable harvesting would not result in net emissions since removals after harvesting (represented by forest re-growth) compensate for emissions caused at the time of harvesting. However, when harvesting exceeds re-growth capacity, it causes forest degradation associated with net emissions.

As a result, consumption and harvesting of woody biomass is an important element of national forestry, energy, and climate change policy. However, a rigorous approach to estimating the impact of biomass energy utilization on net greenhouse gas (GHG) emissions had not been attempted, and significant uncertainties remain.

To produce an analysis and guidance that supports Malawi's national Reduced Emissions from Deforestation and Forest Degradation (REDD+) program, its wood energy policy, and its ability to monitor and manage its GHG emissions, the USAID project Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) developed and implemented a scientifically grounded and replicable approach for determining spatially explicit estimates of unsustainable harvesting of woody biomass for woodfuel production and relative net GHG emissions. The analysis follows the Woodfuels Integrated Supply/Demand Overview Mapping (WISDOM) methodology, describes the situation in 2016 (the most recent date permitted by the available data), and makes projections to 2021 in order to highlight likely trends and orient remedial strategies and define lines of intervention.

In order to identify the areas where fuelwood extraction may be higher than sustainable productivity and therefore cause forest degradation, it is first necessary to analyze the spatial distribution of fuelwood demand and of supply sources, which is the scope of the WISDOM methodology. WISDOM, which has been implemented in many countries and in various planning contexts, is applied to provide quantitative and spatially explicit estimates of the risk of forest degradation due to current and projected demand for fuelwood.

1.2 MAIN FEATURES OF THE WISDOM METHOD

The WISDOM methodology is a spatially explicit planning tool for highlighting and determining woodfuel priority areas or woodfuel hot spots (Drigo et al, 2002; FAO, 2003). Over time, WISDOM has been implemented at national and regional levels in Africa, Latin America, Asia and Europe, covering more than 30 countries (see http://www.wisdomprojects.net/global/cs.asp). Recently, WISDOM has been applied in a pan-tropical study to estimate and map the non-renewable fraction of the woody biomass used for energy at the sub-national level (Drigo et al, 2014; Bailis et al, 2015).

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 forests, etc.—contribute substantially in terms of fuelwood and, to a lesser extent, 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 (Leach and Mearns, 1988; Arnold et al., 2003).

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 minimum necessary supply areas for sustainable supply or for the current harvesting area.

In recent studies, with the progressive development of woodshed analysis, WISDOM allowed the estimation and mapping of harvesting areas and intensities, thus supporting the estimation of forest degradation processes due to unsustainable harvesting, and contributing to the definition of national Forest Reference Emission Level (FREL) in the REDD+ context (Kenya 2015, Nepal 2016, Zambia 2017).

WISDOM features:

- ***Geo-referenced data bases.*** 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). In case of Malawi, the spatial base is set by the map from the Survey Department used by the National Statistical Office for censuses and surveys.
- ***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, regional) and as constrained by the main parameters or proxy variables that are used to "spatialize" the information. In the case of Malawi, the basis for the definition of the administrative level of analysis is provided by the map of Enumeration Areas used for Census 2008, which represents the most detailed sub-national structure of the country. The spatial resolution (i.e. the size of the pixel in GIS raster data) is set to 100m, which reflects 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 contents are determined by the data available or (to a limited extent) by the data purposefully 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 and non-woody biomass resources and demand from different users***. The analytical framework includes all sources of biomass potentially available for energy (i.e. fuelwood and charcoal, crop residues, industrial residues, etc.) and all user categories (rural and urban residential, industrial, commercial, and public).

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

1. ***WISDOM Base***. This stage of analysis covers the entire territory of the study area.
2. ***Woodshed[3] analysis***. This second stage of the analysis uses the result of the WISDOM Base to delineate the harvesting zones of major consumption sites that depend primarily on commercial supply systems. Depending on the scale and objectives of the analysis, the selected sites could be all major deficit areas (those that depend on commercial supply chains) or specific urban centers, rural villages, and existing/planned biomass plants.

The specific steps of analysis are summarized below while a graphic overview is shown in Figure 3 on the following page.

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; and
5. Selection of the *priority* areas or woodfuel "hot spots" under different scenarios.

WOODSHED ANALYSIS

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

1. Mapping of potential "commercial" woodfuel supplies suitable for urban, peri-urban, and rural markets;
2. Definition of woodsheds, or woodfuel harvesting areas, based on the level of commercial and non-commercial demand, woodfuel production potentials, and physical/economic accessibility parameters; and
3. Estimation of harvesting sustainability, of woodfuel-related non-renewable biomass fraction (fNRB) values at subnational level, and of woodfuel-induced forest degradation rates.

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

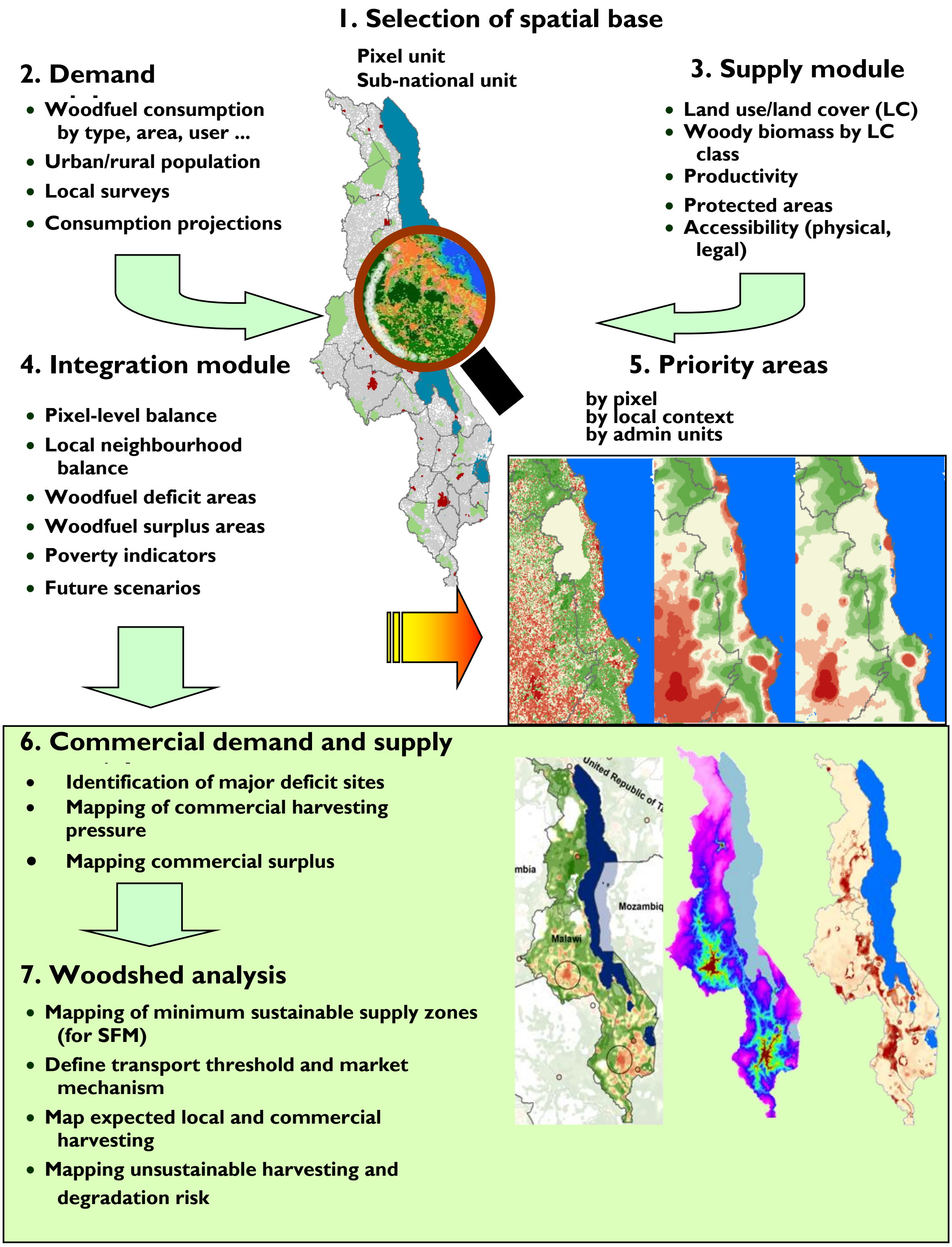


Figure 3. WISDOM Analytical Steps

2.0 WISDOM ANALYSIS

The following sections describe the steps of analysis undertaken during the development of WISDOM Malawi, following the procedure of analysis summarized in the previous section.

2.1 SELECTION OF SPATIAL BASE AND REFERENCE YEAR OF ANALYSIS

2.1.1 SCALE AND PROJECTION

Mapping details. Projection: Preferred/common projection for Malawi: WGS 1984 UTM 36S (single projection for whole country). Cell size of raster layers: 100 meters (1-ha cells).

Administrative units used for population mapping. Census results are provided down to Enumeration Area (EA) level (12,642 units), which are used to map population distribution. In all census statistics the distinction between urban and rural areas is based on how each individual EA is defined. EAs defined as "Boma/Township" are classified as urban areas while all other EA types are classified as rural areas. This EA-based urban/rural distinction was adopted throughout this study.

Most published census results related to the saturation of fuelwood in the residential sector (fraction of households using fuelwood) are at the district level. In total, there are 32 Districts: four are entirely urban (Mzuzu City, Lilongwe City, Zomba City, and Blantyre City) and 28 are almost entirely rural, with small urban areas representing district headquarters.

2.1.2 REFERENCE YEAR OF WISDOM ANALYSIS

The reference years of the WISDOM analysis are usually determined by the available land cover data and demographic census. In Malawi, the last census was carried out in 2008 and the last Integrated Household Survey No. 4 (IHS4) was carried out in 2016. The most recent land cover maps at the time of the WISDOM analysis were produced with reference year circa 2010 and 2014. The one that appeared adequately detailed and most suitable for the analysis was prepared by FAO in 2014, applying the Land Cover Classification System (LCCS) using Landsat time series of 1990, 2000, and 2010 and thus providing consistent land cover change rates.

In consideration of the rapid increment in the use of charcoal in urban areas, confirmed by the IHS4 2016, WISDOM Malawi used 2016 as the reference year of analysis.

2.2 DEMAND MODULE

The goal of the Demand Module is to estimate the current consumption[4] of woody biomass for energy in the various sectors (residential, commercial, industrial and public) and to represent as accurately as possible its spatial distribution. The main thematic layers and processing steps of the Demand Module are presented in the flowchart in Figure 4 and described in the following Sections.

2.2.1 REFERENCE DATA

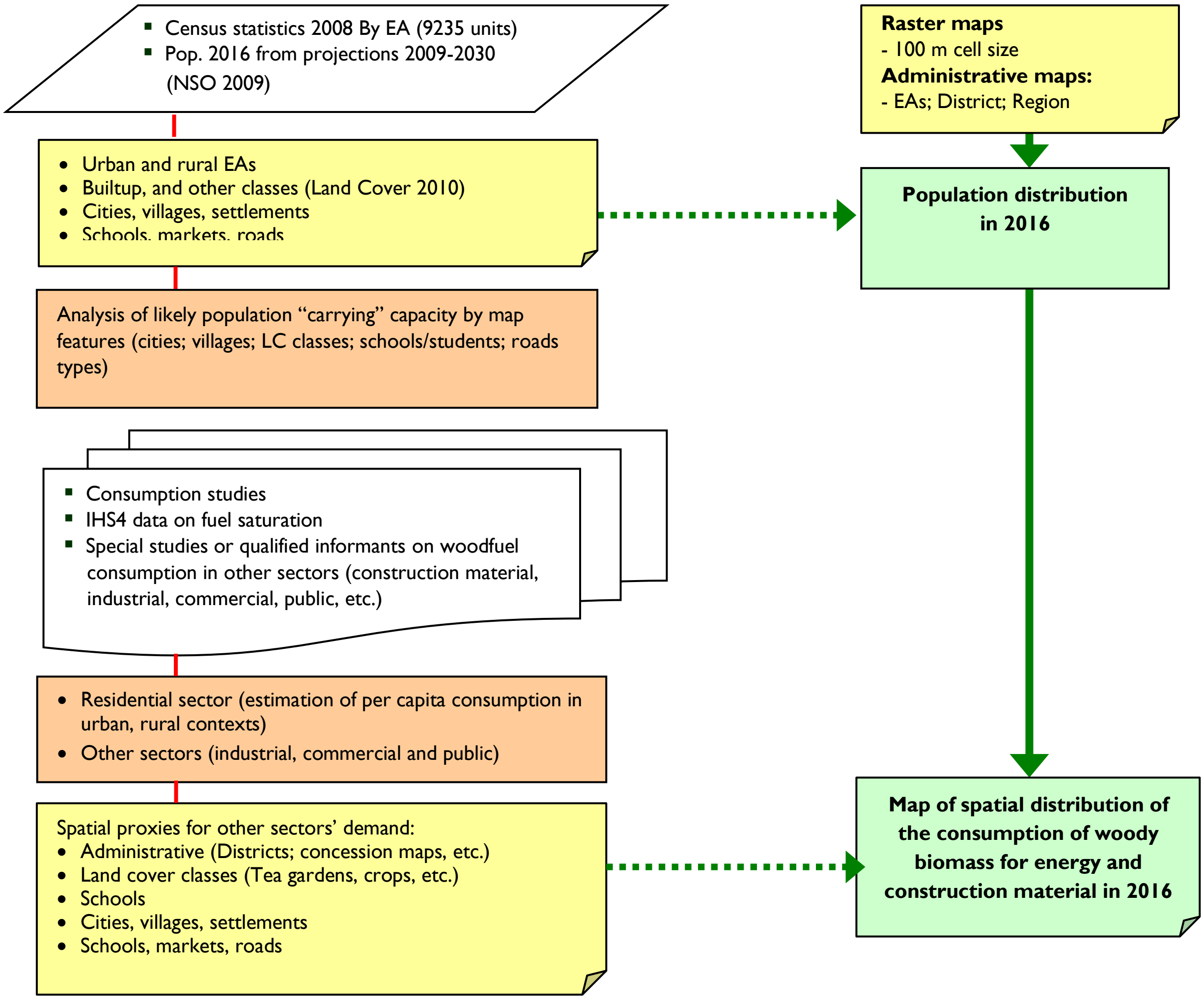
[4] In this study the terms "demand" and "consumption" are used interchangeably. Although in principle the demand may be greater than the actual consumption, it is *de facto* estimated using consumption data and consequently demand = consumption.

RESIDENTIAL SECTOR DEMAND

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

1. Latest demographic census statistics (Census 2008), providing rural and urban population data at EA level and fuel saturation data at the district level;
2. IHS4 2016, providing saturation of cooking and heating fuels, including fuelwood and charcoal, at the district level. The time series composed by IHS4 2016 and previous surveys (Census 1998, Census 2008, IHS3 2010-11, IHPS 2013) provided good evidence on the current saturation trends in rural and urban areas; and
3. Malawi Biomass Energy Strategy 2009 (BEST 2009), providing per capita fuelwood and charcoal consumption values for rural and urban households by region. BEST consumption values were based on previous studies for urban consumption and on new survey data for rural consumption (851 households [HH] interviewed throughout the country).

Saturation values and per capita consumption values derived from the references listed above are presented in Annex 1. The total consumption in the household sector, estimated by applying saturation and consumption values to the rural and urban population, is **10,054 kt DM** of woody biomass (including conventional and marginal fuelwood and wood used for charcoal production).



Note: Input data: cartographic (yellow); statistical (white); estimated variables (orange); thematic map outputs (green).

Figure 4. Demand Module: Flowchart of Main Analytical Phases

CONSTRUCTION MATERIAL

At the household level, woody biomass is also commonly used for construction and repair of houses, stables, fences, etc. Construction material comes mostly from the same supply sources as fuelwood and charcoal and follows the same supply system. Moreover, construction material is not accounted for in industrial wood demand statistics.

For these reasons, in this analysis, household demand for construction material is added to the demand for fuelwood and charcoal to form the total household demand for woody biomass.

Annual household consumption of construction material is not known in Malawi. A tentative estimate is made on the basis of the few available references encountered during WISDOM analyses in Mozambique (Drigo et al. 2008) and Zambia (Drigo 2017), which indicated 13.6 and 10.7 kg DM per capita and per year, respectively.

In this study, in the absence of specific data, a tentative mid-range per capita value of 12.2 kg DM per year was adopted and applied to the rural population, while half of this rate (6.1 kg DM) was applied to the urban population. By applying these values to the rural and urban population, the amount of woody biomass used as construction material at the national level is estimated at **187 kt DM**.

OTHER SECTORS' DEMAND

The quantities of fuelwood and charcoal annually consumed in other sectors, including industrial, commercial, and public sectors, are not systematically reported and are rarely studied. Nonetheless, other sectors' demand for woodfuels is certain and cannot be deemed irrelevant just because reliable data is lacking.

An attempt to estimate non-residential consumption in Malawi was made for BEST 2009, based on a specific study (Muukungwa, 2008) and on several other sources (BEST 2009). For the present study, BEST estimates were thoroughly reviewed, updated, and integrated on the basis of new references in the study carried out by Bennet Mataya and estimates made in other neighboring countries. Some additional sectors of consumption were also added, such as the poultry industry and fish smoking/drying.

The results of this review are presented in Table 1, where the sectors of consumption are listed along with the sources used and the estimated quantities of woody biomass annually consumed. The total non-residential demand is estimated at 966 kt DM. Brickmaking is the highest sector of consumption given the demographic growth and the increasing fraction of brick houses in both urban and rural areas, tentatively estimated at 453 kt DM or almost half of all non-residential demand. Preparation of meals for boarding schools throughout the country is the second highest area of consumption, estimated at 133 kt DM.

It should be highlighted that—with the exception of tobacco curing and tea drying, for which reasonable information on fuelwood consumption is available—all other estimates are preliminary and, in some cases, purely indicative due to the absence of supporting data. Further investigation and well-targeted field data collection is needed and highly recommended in order to estimate non-residential woodfuel consumption with acceptable reliability.

Table 1. Non-Residential Woodfuel Demand (2016)

DEMAND SECTOR	BASIS OF ESTIMATED DEMAND	DEMAND 2016 (t DM wood equivalent)	SPATIAL DISTRIBUTION (spatial proxy)
Lime production	Average reported lime production and per-unit fuelwood consumption Ref.: Makungwa 2008; Chenkumbi Hill data	**3,484**	Mining Cadastre
Poultry industry	Reported number of charcoal bags consumed in small scale and large-scale units Ref.: Poultry Industry Association data 2018	**34,787**	Rural Blantyre and Lilongwe regions
Tobacco curing	Reported production of Flue and dark-fired (NDDF) tobacco, and relative per unit fuelwood consumption Ref.: Tobacco Control Commission data 2018	**93,106**	Croplands (LCCS 2010)
Brickmaking	Own elaboration. Annual house building and renewal; average bricks per house in urban and rural areas and fuelwood used per unit Ref.: Welfare Monitoring Survey 2014; Pop projections 2008-2016 (NSO 2009)	**452,945**	Urban and rural population
Fish smoking/ drying	Catch of fish and fraction smoked or roasted and per unit fuelwood consumption Ref.: FAO report (2005); FAOstat 2013; Zione Thesis 2017	**63,623**	Lake shore population
Boarding schools	Tentative, assuming 1 million boarding students in 2016 and use of high-efficiency stoves Ref.: Mary's Meal website	**132,942**	Student distribution
Tea drying	Update of BEST 2009 estimates on 2016 tea production Ref.: BEST 2009; FAOstat production 2016	**86,114**	Tea estates (LCCS 2010)
Restaurants and resorts	Tentative, assuming 5% of urban HH demand (1/2 of Moz. rate) Ref.: Brower and Falcao 2001 (WISDOM Mozambique)	**99,194**	Urban population
Total, Non-HH		**966,195**	

2.2.2 DEMAND MAPPING

Once the demand for fuelwood and charcoal in the various sectors is defined and quantified, the subsequent step is to distribute such demand over the territory with the best possible approximation. In general, from a spatial distribution perspective, two major types of demand patterns may be distinguished: 1) *diffuse* patterns typical of the residential sector, and 2) other more *localized* sites, typical of industrial and commercial consumption sites or even specific locations such as biomass power plants and large tea factories.

The first type is directly related to the distribution of the rural and urban population, while the second type associates the consumption with special areas (i.e. urban areas only) or specific locations, such as towns or sub-urban areas or through geographic coordinates of known locations.

Between these two extremes, some types of consumption, such as small industries and commercial and public users, are not ubiquitous but have exact locations that are unknown. In these cases the distribution may be based on spatial proxies (elements of known spatial distribution) that are directly or indirectly correlated to the type of consumption considered.

In the case of Malawi, the information on non-residential consumption sites is very approximate and without precise coordinates; therefore, the spatial distribution of the demand for woodfuels in those sectors is based primarily on spatial proxies or areas of probable occurrence. The last column of Table 1 indicates the spatial or geographic elements used to distribute with best possible approximation the non-residential demand over the Malawi landscape.

URBAN AND RURAL POPULATION MAPPING

The residential sector dominates woodfuel consumption in Malawi, and mapping human population is the prerequisite to mapping the relative consumption. Population mapping is also useful in mapping the consumption of other sectors such as brickmaking and restaurants/resorts, as reported in Table 1, since they are also more or less strongly related to population concentrations.

Statistical and cartographic information relative to the distribution of the population at the level of Enumeration Areas (9,235 units) relative to Census 2008 and 2016 population projections at the district level was obtained from the National Statistical Office. Figure 5 shows the population ranking according to assumed "carrying" capacity, based on land cover classes and other spatial features, and the final rural and urban population distribution map.

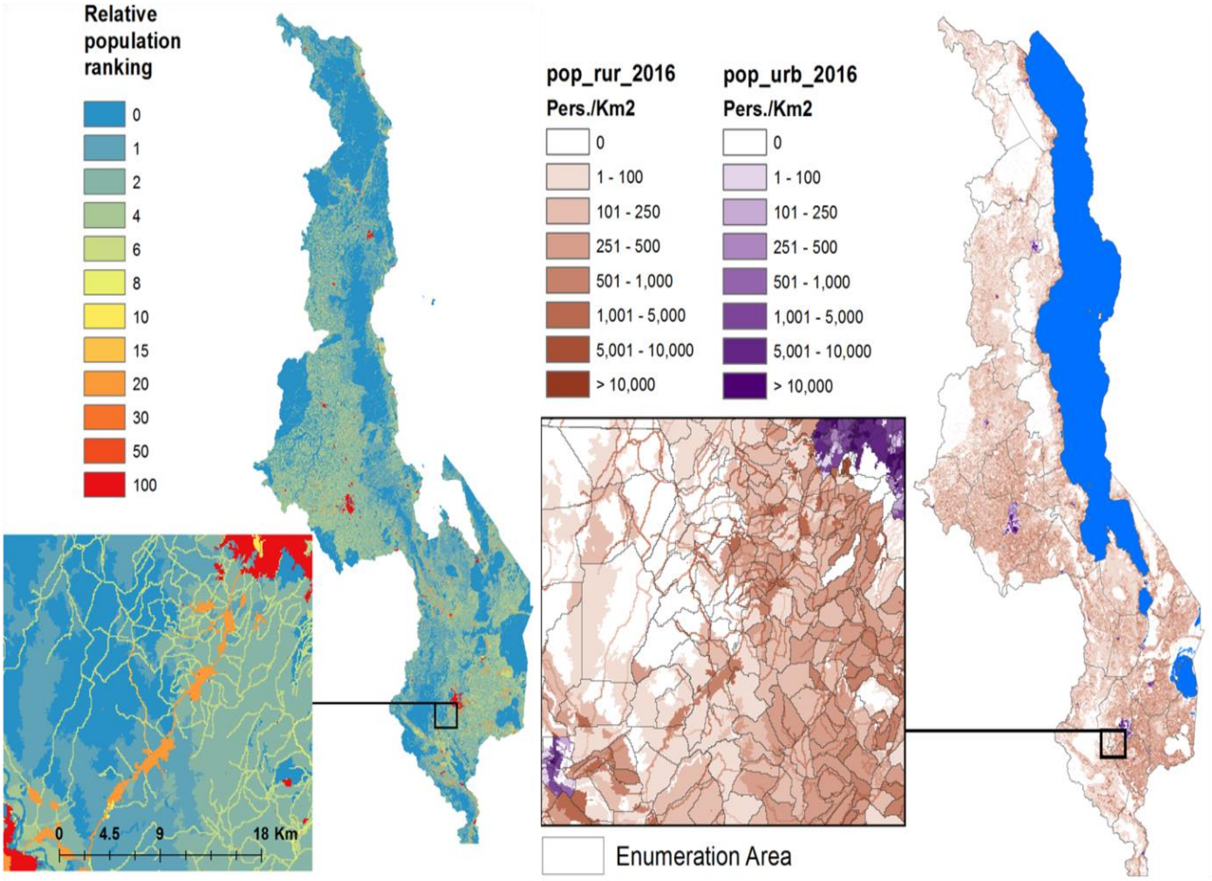


Figure 5. Mapping Rural and Urban Populations

The 2016 rural and urban populations were mapped with respect to the values reported at EA level from Census 2008, augmented by application of district growth rates 2008-2016 estimated by NSO 2009. Within such units, the spatial distribution of the population was based on additional cartographic elements or spatial proxies such as built-up areas and point settlement data. Roads and main trails were also used to locate probable sparse roadside settlements. Within a given unit, these features were used as spatial proxies of population presence to distribute census population where it is more probable to be found.

MAPPING RESIDENTIAL DEMAND

The residential consumption of fuelwood and charcoal in rural and urban areas of each district, which was estimated considering saturation data and per capita consumption of main woodfuel users, was subsequently applied to the population map, creating demand maps of rural fuelwood, rural charcoal, urban fuelwood, and urban charcoal. Added together, these four maps represent the entire 2016 residential consumption.

MAPPING OTHER SECTORS' DEMAND

Similar to residential demand, the demand estimated for each of the other sectors considered was divided by the assumed proxy indicator (either hectares, persons, or students) and applied to the respective map layers to represent each sector of consumption separately.

Added together, they represent the spatial distribution of the entire non-residential demand. Residential and non-residential demand maps are finally added to create the map of total demand.

2.2.3 USE OF MARGINAL FUELWOOD BY RURAL HOUSEHOLDS

Fuelwood itself can be made of stem wood or branch wood, which are the more "conventional" fuelwood assortments, or made of twigs, smaller branches, and shrub wood (Figure 6), which can be described as "marginal" fuelwood assortments usually excluded from forest inventories and thus not accounted for among the conventional supply sources.

Courtesy of A. Munyehirwe

Figure 6. Example of Marginal Fuelwood (Twigs Produced by Annual Pruning of Farm

The fuelwood consumption by rural households is based on available survey data that does not distinguish between conventional and marginal fuelwood—therefore, it may be misleading to assume that the entire consumption is made of conventional fuelwood. While the latter assumption may be true for the regions sufficiently rich in wood resources, it may overestimate the real wood consumption in wood-poor areas, where conventional fuelwood is in part replaced by marginal fuelwood. Where wood resources are particularly scarce, like in the densely populated rural areas of Southern and Central Malawi, the most likely effect of shortage of "conventional" fuelwood is that rural households use a higher proportion of twigs and small branches from annual pruning in the mix of fuels used to satisfy basic household needs. Twigs and small branches that are harvested annually are woody and therefore usually classified as "fuelwood" in consumption surveys, but they are not accounted for by conventional forest inventories and are not considered in the estimation of the productivity of natural forests, shrublands, and plantations (based on MAI) that includes stem and branch wood available at end rotation (and thinning cycles, if applied).

In this study, in order to fill the void of information on the actual fraction of marginal fuelwood in the mix of wood assortment used by rural households, the study team specifically designed and carried out a Rural Firewood Assortments Survey (RFAS) (a type of field survey) in April-May 2018.

In this field survey, described in detail in Appendix 2, the fuelwood stored and used by rural households was characterized by type and provenance. In total, 318 households were interviewed, 246 in deficit areas and 72 in surplus areas. The deficit and surplus villages were selected on the basis of a previous pan-tropical WISDOM study (Drigo et al. 2014) that included Malawi providing local supply/demand balance estimates at approximately a 1km resolution.

The results of the survey, summarized in

Table 2. Fuelwood Assortments Stored/Used by Rural Households in Deficit and Surplus Areas, indicate a clear distinction in fuelwood type and source between deficit and surplus areas. In deficit areas the purchased fraction is 16% while in surplus areas the purchased fraction is only 1%.

In some cases, the definition of some sources as conventional or marginal is not straightforward, as for "FARMLANDS: Pruning of trees and shrubs done irregularly, several years apart" and "FORESTS: Pruning of trees and shrubs (i.e. cutting branches from the crown, not the main stem)" that appear as sources in the table below. In the medium marginal variant, the doubtful cases were considered ½ marginal and ½ conventional resulting in a marginal fuelwood fraction of 42% in deficit areas and 13% in surplus areas. Conversely, the conventional fuelwood is 42% in deficit areas and 85% in surplus areas.

Taking alternative classification approaches on doubtful cases, the survey shows a high marginal variant where the marginal fraction increases to 53% in deficit areas and to 22% in surplus areas, and a low marginal variant where the marginal fraction reduces to 31% in deficit areas and to 5% in surplus areas. These alternative variants are used in the development of the range of degradation estimates, the first contributing to the low variant and the second to the high variant.

Table 2. Fuelwood Assortments Stored/Used by Rural Households in Deficit and Surplus Areas

SOURCE	DEFICIT AREA (% BY SOURCE)	SURPLUS AREA (% BY SOURCE)	CLASSIFICATION AS CONVENTIONAL OR MARGINAL
FARMLANDS			
Whole trees and shrubs cut in farmlands	17	16	Conventional
Pruning of trees and shrubs done irregularly, several years apart	10	6	Marginal or conventional? Taken ½and ½
Pruning of trees and shrubs done regularly every year	21	2	Marginal
Uprooted / Tree stump	2	1	Marginal
Woody material collected in the farm (e.g., pigeon pea)	7	2	Marginal
FORESTS			
Cut whole trees and shrubs	6	14	Conventional
Dead woody material collected from the forest floor	8	47	Wood cut and left drying in the forest? Taken as conventional
Pruning of trees and shrubs (i.e. cutting branches from the crown, not the main stem)	12	12	Marginal or conventional? Taken ½and ½
Purchased	16	1	Conventional
Total	**100**	**100**	

Marginal assortments	42	13	Medium Marginal variant
Conventional assortments	42	85	
Alternative conventional/marginal proportions			
Marginal assortments	53	22	High Marginal variant (taking doubtful types as marginal)
Conventional assortments	31	77	
Marginal assortments	31	5	Low Marginal variant(taking doubtful types as conventional)
Conventional assortments	53	94	

The values presented in Table 2 may be considered as general averages of deficit and surplus areas. This represents useful information, but the spatial analysis needs a way to modulate marginal fuelwood fractions in relation to the level of demand fulfilled by local resources.

It may be assumed that the fraction of marginal assortments is inversely proportional to the availability of conventional fuelwood sources locally, i.e. to the percent of the demand locally fulfilled by conventional sources. The percent of rural households' demand for fuelwood fulfilled by local resources resulting from the preliminary supply/demand balance analysis is shown in Figure 7.

Based on the assumption mentioned above on RFAS results and on the map of locally fulfilled demand, the fraction of marginal fuelwood in rural deficit areas was hence defined following a simple linear regression that, starting from the marginal/conventional fractions of surplus area, would progressively increase in such a way to produce as total average for the marginal/conventional proportions of deficit areas, as shown for the three variants in Figure 8.

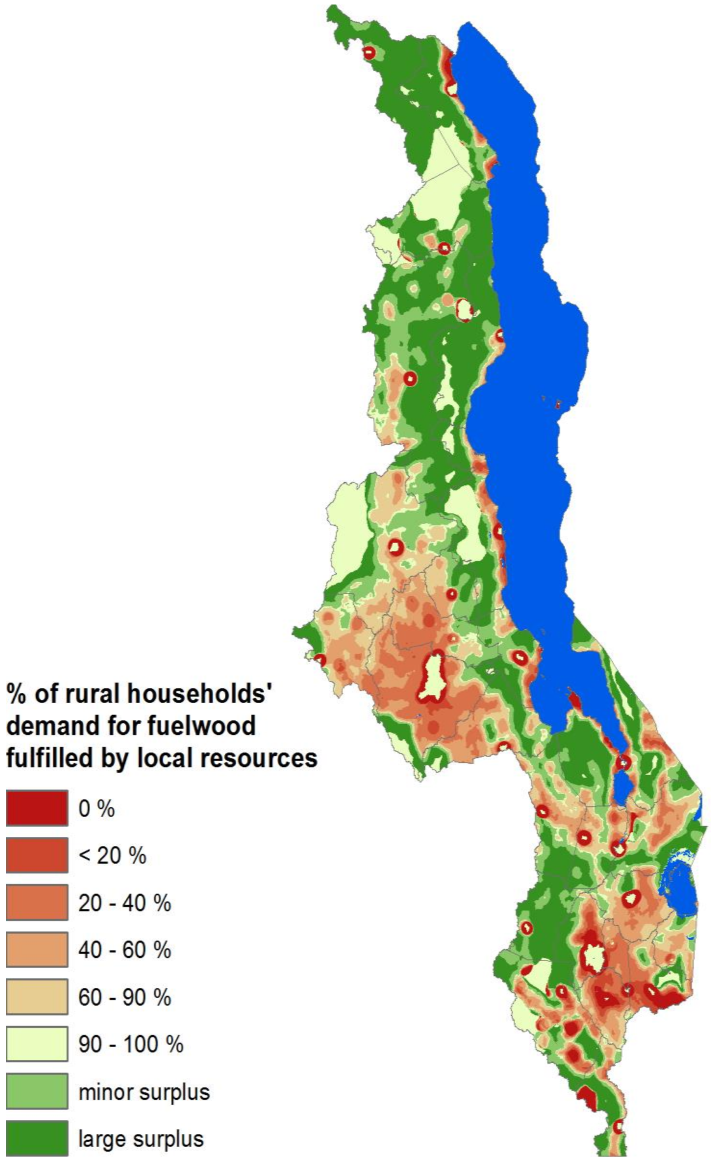


Figure 7. Map of Percent of Rural Fuelwood Demand Locally Fulfilled

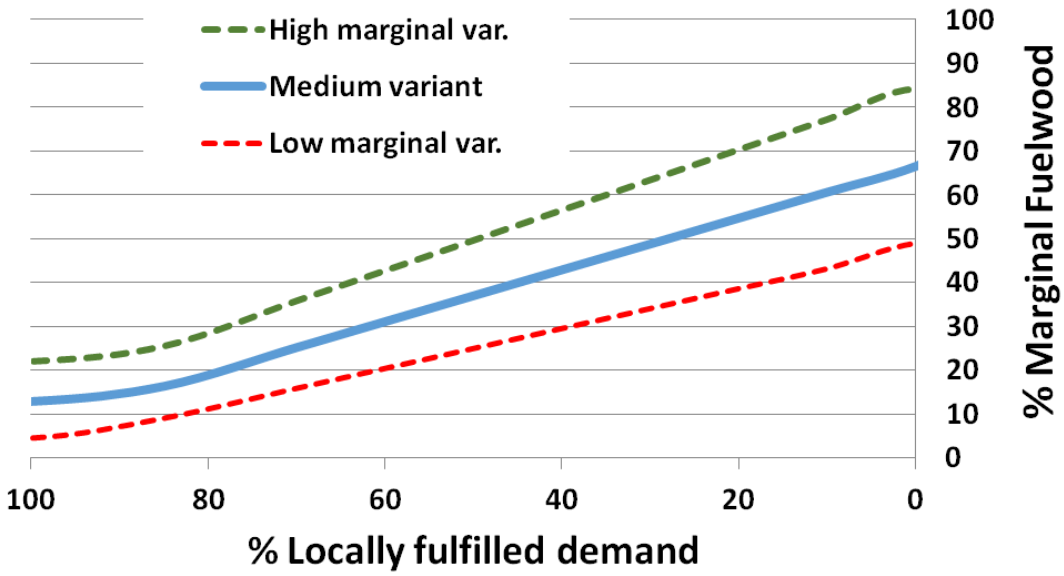


Figure 8. Estimated Marginal Fuelwood Fraction vs. Locally Fulfilled Demand

The fraction of marginal fuelwood is estimated to be 2.4 Mt DM or 22% of total demand for the medium variant where the medium marginal variant is applied to the medium supply variant[5].

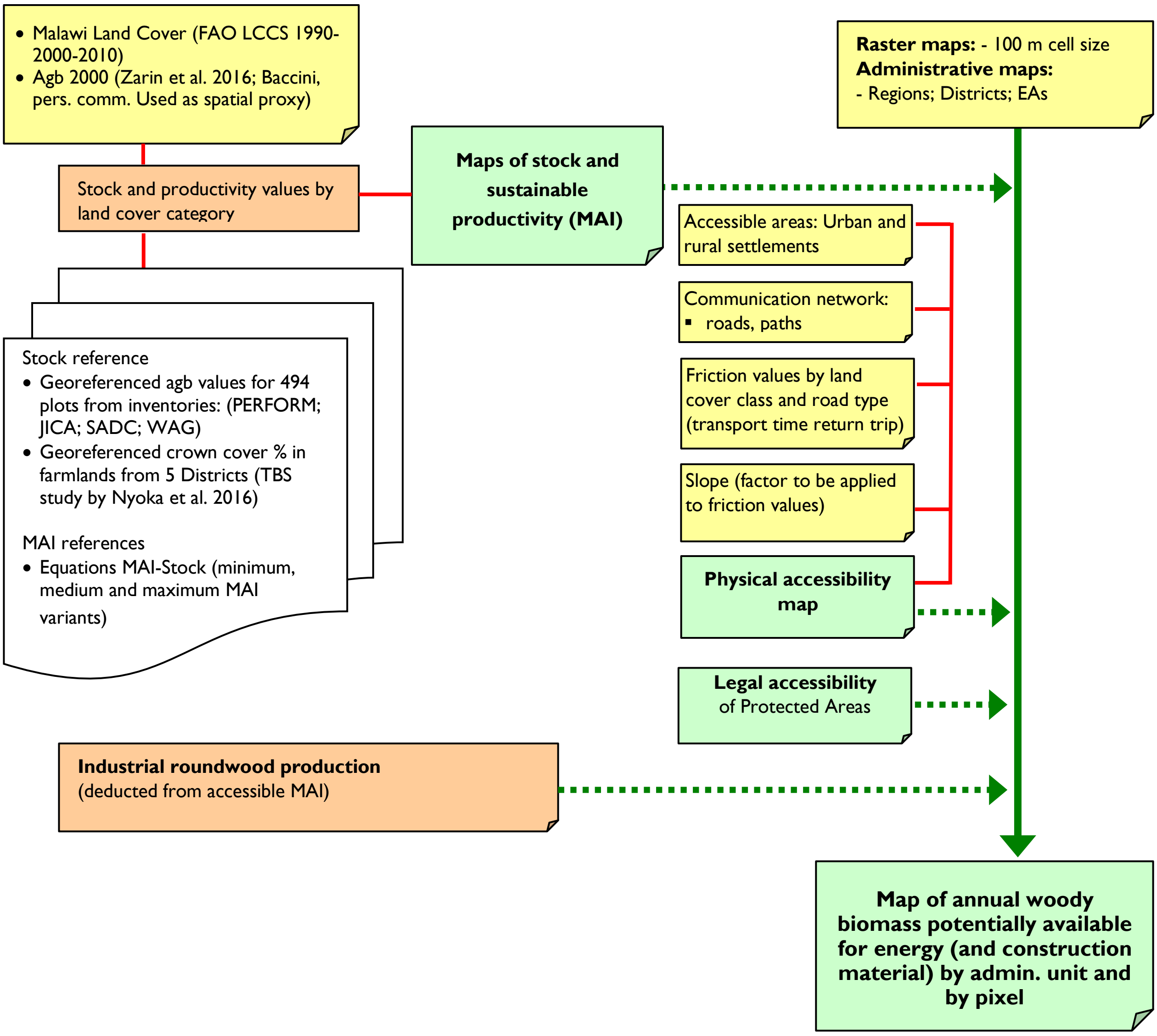
The impact of the harvesting of marginal fuelwood on the rural environment is largely unknown. It seems, however, that using these marginal wood products and woody farm residues has greater impact on soil fertility than on the forest resources and woody biomass stock. The main impact is probably on the reduced re-integration of twigs, leaves, and residue nutrients into the soil of agricultural fields, farmlands, plantations, and forests. This is likely to produce a progressive loss of soil fertility, with consequent reduction of crop productivity and an increased level of vulnerability and worsened living conditions. The nexus between rural subsistence energy and soil fertility in Malawi certainly deserves a dedicated analysis, and this study may represent a starting point of forthcoming investigations.

2.3 SUPPLY MODULE

The scope of the WISDOM Supply Module is to produce a spatial representation of natural and manmade sources of woody biomass, and their stocking and production potential. The Supply Module analysis includes woody biomass components that may serve as fuelwood, construction material, and for charcoal production. The estimated annual industrial roundwood production, which comes almost exclusively from plantations and follows a separate supply system, is deducted from the final estimated supply potential. The flowchart in Figure 9 shows the source data and the main analytical steps of the Supply Module.

---

[5] In the high variant, where the minimum marginal variant is applied to the minimum supply variant, the marginal fuelwood is estimated to be 1.9 Mt DM, or 17% of total demand. In the low variant, where the maximum marginal variant is applied to the maximum supply variant, the marginal fuelwood is estimated to be 2.9 Mt DM, or 26% of total demand.



Input data: cartographic (yellow); statistical (white); estimated variables (orange); thematic map outputs (green).

Figure 9. Supply Module: Flowchart of Main Analytical Phases

2.3.1 CARTOGRAPHIC LAYERS

Among the land cover maps available for Malawi (FAO LCCS, Japan International Cooperation Agency [JICA], LTS International, Regional Center for Mapping of Resources for Development [RCMRD]) the one that was most suited to the requirements of this analysis, considering the year(s) represented, the details of classification, and the availability of consistent time series, is the Land Cover Map produced by FAO representing the situation in 1990, 2000, and 2010 (full resolution version). This map was produced applying the LCCS (FAO, 2000) that separates as many as 44 land cover classes. The details of this map are presented in Appendix 3.

2.3.2 STOCK AND PRODUCTIVITY

WOODY BIOMASS STOCK

As a first step, the average aboveground woody biomass (agwb) stock was estimated for each land cover class on the basis of the available forest inventory plots and estimates of tree cover in farmlands (Nyoka et al. 2016). Details on the distribution of field data and average stock values are given in Appendix 3.

On the basis of average class values of agwb and confidence intervals, three stock values per land cover class were produced: a Medium stock value based on the average of plot data; a Minimum stock value based on the average minus 90% confidence interval; and a Maximum stock value based on the average plus 90% confidence interval.

In order to achieve a more discrete distribution of the agwb stock than the mapping of simple average class values, the pan-tropical map of aboveground biomass (agb) for year 2000 (agb2000) at 30m resolution (Zarin et al. 2016) was used as spatial proxy for the modulation of stock within land cover classes. Agb2000 provides estimates of agb per 30m pixels that, once resampled to 100m to match our resolution, were considered a suitable indicator of stock variability within the classes. Although the specific values of agb2000 may be of limited use for a specific national level study, the spatial variations of such values can provide a valuable insight on the spatial distribution of biomass resources.

From agb2000 data, the mean value of each land cover (LC) class was calculated. The average agwb stock was then allocated to the average agb2000 values and the final pixel-level agwb stock value was calculated as follows:

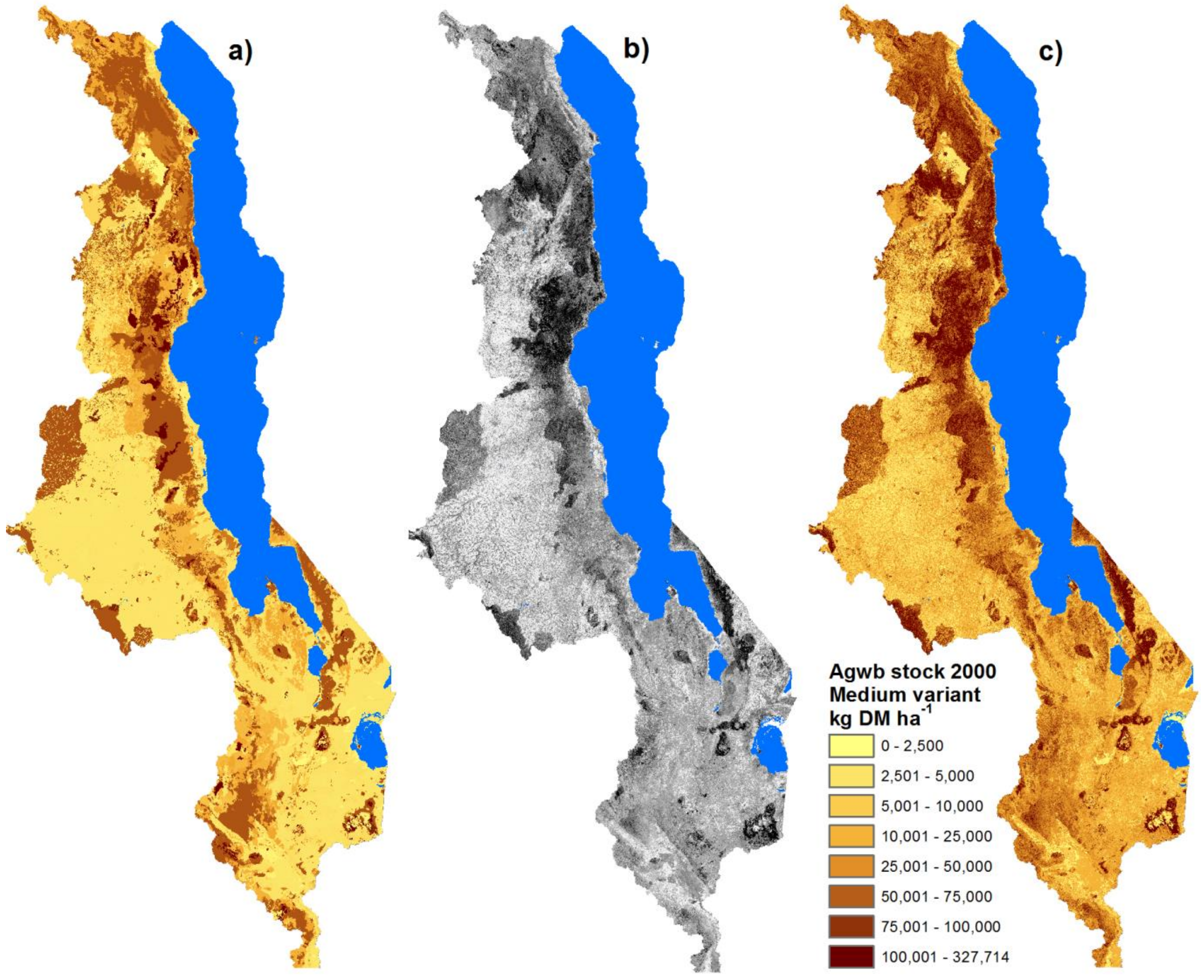
$$agwb_{i,j} = \overline{agwb}_j \left(\frac{agb2000_i}{\overline{agb2000}_j} \right) \quad \text{(Eq. 1)}$$

where

$agwb_{i,j}$ is the stock of agwb of pixel *i* in class *j*, $\overline{agwb}_j$ is the average stock of agwb in class *j*,
$agb2000_i$ is the agb2000 value in pixel *i*, $\overline{agb2000}_j$ is the average agb2000 value in class *j*.

This simple process considerably enhances the spatial distribution of the biomass stock (and improves it if the spatial proxy is reliable) while the mean stock value per strata of the resulting map matches exactly the average stock values per strata used as input. Figure 10 shows the agwb stock map with average class values, the spatial proxy map, and the agwb stock map spatially enhanced.

In order to be consistent with the proxy layer, the spatial enhancement was done on the agwb of year 2000 (using FAO LCCS 2000). Subsequently, the map of stock for year 2010 was produced by adding the changes 2000-2010 and relative stock values to the map of stock 2000.



a) Map with average stock values (1 value per LCCS class); b) Spatial proxy of biomass distribution (agb2000 by Zarin et al. 2016; c) Spatially enhanced map of agwb stock for year 2000.

Figure 10. Spatial Enhancement of agwb Stock Map

PRODUCTIVITY

The sustainable productivity of natural formations is a far less known parameter than the stock, due to the scarcity of permanent sample plots that are the only reliable sources of data for the estimation of the 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. Several equations were produced from available data sources, including the default values proposed by Intergovernmental Panel on Climate Change (IPCC) guidelines covering all ecological regions, a set of observations for broadleaved formations (86 obs.) from a set of international field observations relative to tropical and sub-tropical ecological zones, and studies on dry and wet Miombo formations (Chidumayo, 2013; Chidumayo and Gumbo, 2010) as shown in Figure 11.

Considering that the curve relative to Wet Miombo may be less representative due to the limited number of observations available (as agreed by Professor Chidumayo), it is interesting to note that the "IPCC" curve practically matches the Dry Miombo but with slightly lower MAI values for low stock values.

Finally, two MAI/Stock equations were used to represent the "High MAI" and the "Low MAI" variants—the first based on tropical and subtropical broadleaf formations, yielding higher MAI values, and the second based on the general "IPCC equation", yielding lower MAI values. A third MAI/stock equation was produced on the basis of these two equations, giving intermediate MAI values :

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

High MAI variant: $y = 37.058x^{-0.5879}$ (Eq. 3)

Intermediate MAI variant : $y = 32.136x^{-0.5950}$ (Eq. 4)

where:

y = MAI as percent of stock

x = Aboveground woody biomass stock in tons DM per hectare

Equation 4 (Intermediate MAI variant) was applied to the map of Medium stock to obtain the Medium MAI map contributing to the Medium Variant. Equation 2 (Low MAI variant) was applied to the Minimum stock map and used to develop the High Variant, while the Equation 3 (High MAI variant) was applied to the Maximum stock map and used to develop the Low Variant (see Section 3.4 below for description of chosen scenarios).

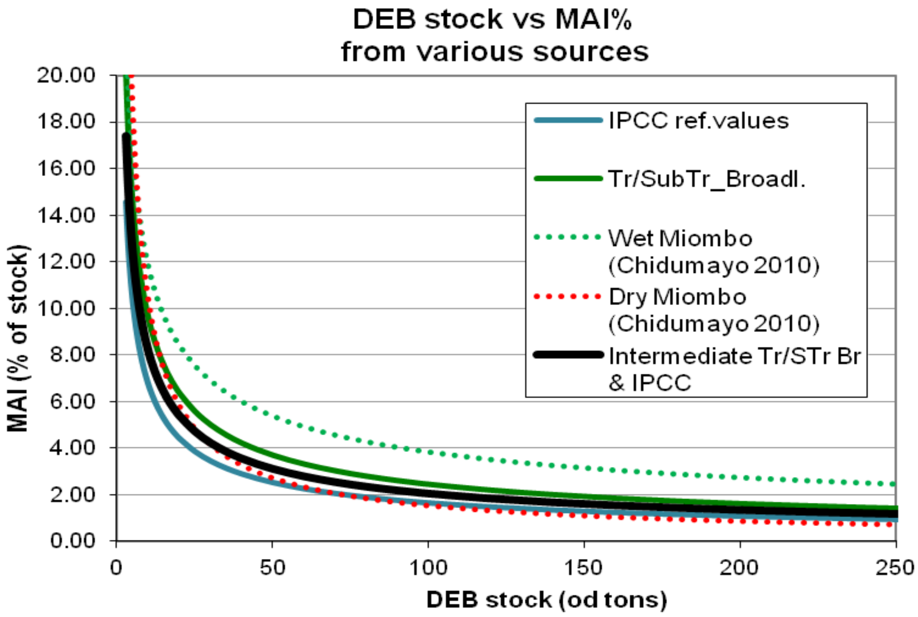


Figure 11. Stock vs. MAI Relations from Standard Equations for Natural Broadleaf Formations

2.3.3 ACCESSIBILITY

In WISDOM analyses, 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 and roads, as well as factors like topographical gradients and other obstacles. The details of each component are discussed below.

LEGAL ACCESSIBILITY

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. Generally, fuelwood harvesting is permitted to local communities living within protected areas for their own use, while commercial fuelwood and charcoal production are always forbidden. In the case of Malawi, according to the 2018 version of the World Database of Protected Areas (WDPA), the categories of Protected Areas are National Parks (International Union for the Conservation of Nature [IUCN] category II) and Wildlife Reserves (IUCN category IV), both of which are, in principle, off-limits to all wood harvesting. Although some limited harvesting is likely to occur in these areas, for the present analysis we assume that these areas are legally inaccessible. The protected areas and the resulting Legal Accessibility Map are presented in Appendix 4.

PHYSICAL ACCESSIBILITY

The estimation of the physical accessibility of biomass resources is based on a woodfuel transport time map covering Malawi following and adapting the procedure described by Nelson (2008) and by Drigo et al. (2014). This map is the result of an accessibility model that considers target locations (in this case accessible features and populated places) and cost, or friction surface, based on several national datasets that represent roads, terrain features (slope, altitude), and land cover.

The subsequent fundamental step for the scope of this study is to convert transport time values (minutes to/from the nearest accessible feature) into an accessibility factor to be applied to the total MAI. 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, the estimate assumes that wood resources (for energy use) that are more than 10 hours of transport time from the nearest accessible feature may be considered as totally inaccessible, and that the accessible fraction decreases in proportion to the increase of travel time.

Details of the transport time map development, data sources, and results are provided in Annex 5.

In this study, 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 based on each major consumption site such as urban centers and densely populated rural areas. In addition to off-road accessibility, this analysis also includes distances along roads to reach the selected consumption sites.

2.3.4 ACCESSIBLE AND AVAILABLE MAI

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 maps of total estimated MAI.

AVAILABLE MAI

Not all accessible MAI can be assumed to be available for fuelwood production or construction material. The main competing use is the industrial roundwood that feeds wood processing industries such as furniture making, wood panels production, electrical poles, building posts, and more.

However, recent information on the annual production of industrial roundwood was not available when collecting data, and the data produced by FAO is considered out of date and a gross overestimation of current production (Department of Forestry [DOF], personal communication). In absence of specific data, we have assumed that the bulk of industrial roundwood comes from existing forest plantations. Consequently, the Available MAI was estimated and mapped by deducting 75% of plantations' MAI[6] from the Accessible 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 potential. 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 construction material.

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

(i) Pixel-level balance, which is the basis of all other balance analyses;
(ii) Balance in a local context, few km around consumption sites, representing the informal self-supply horizon of rural and peri-urban households; and
(iii) Balance based on the "commercial" fraction of the local surplus (resulting from the previous level) considered as source of commercial woodfuel production systems serving distant consumption sites.

2.4.1 PIXEL-LEVEL BALANCE

The supply/demand balance at the level of individual map pixel (or cell) is calculated by subtracting pixel-level consumption from the pixel-level available productivity. The calculation of the supply/demand balance by individual one-hectare cell has a useful accounting function, but 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 12.

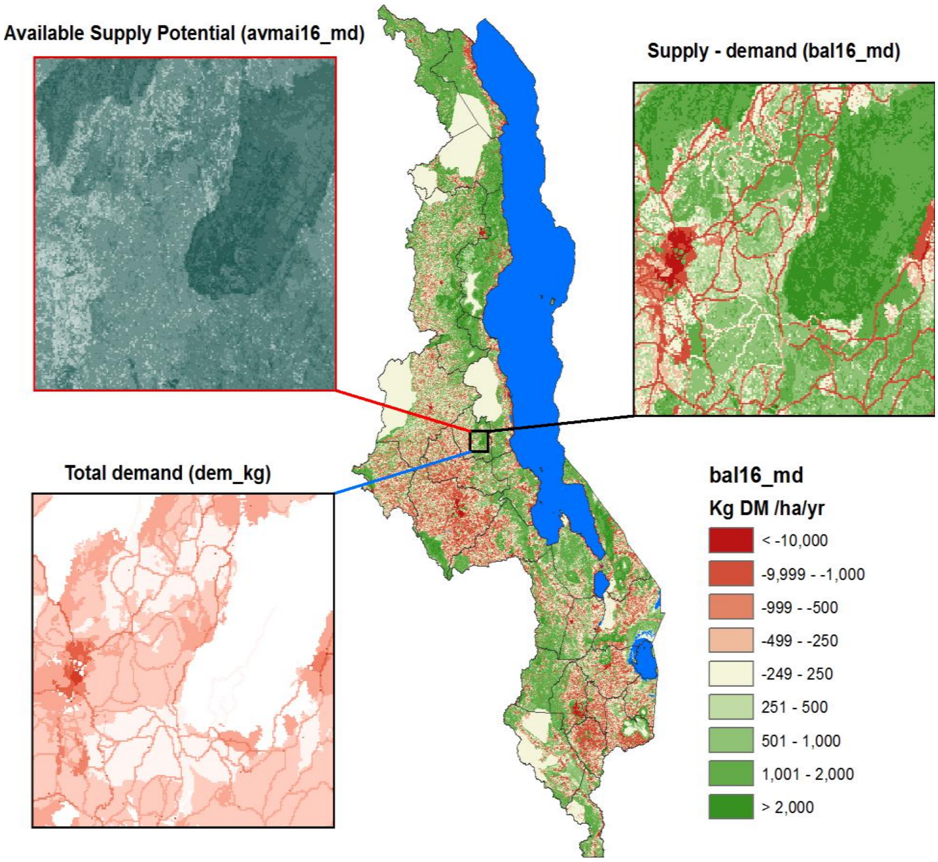


Figure 12. Pixel-Level Supply/Demand Balance

6 It was assumed that 75% of plantations' productivity goes as industrial roundwood while 25% of smaller wood assortments (branches, tree tops) are used as fuelwood.

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 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 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 5km around each pixel.

An example of the balance analysis in a local context is shown in Figure 13 (middle map portion). 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 woodfuel 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 agwb production potential), and then estimating the quantity of remaining agwb that is suitable for commercial utilization (which is limited to the legally and physically accessible resources that may be available and that justify transport and management costs). To assess the commercial surplus, some basic quantitative thresholds related to stock and productivity were defined based on studies carried out in Mozambique (Mancini et al, 2007) as follows:

- One threshold concerned the minimum stocking required for profitable fuelwood production, which is here preliminarily set to 12 tons DM ha^{-1}.
- 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 a condition, the available surplus MAI must exceed 410 kg DM ha^{-1} $year^{-1}$. Consequently, only the accessible areas with a stock above 12 tons DM ha^{-1} and a surplus above 410 kg DM ha^{-1} $year^{-1}$ were considered as potential commercial sources. An example of commercial balance analysis is shown in Figure 13 (right hand map portion).

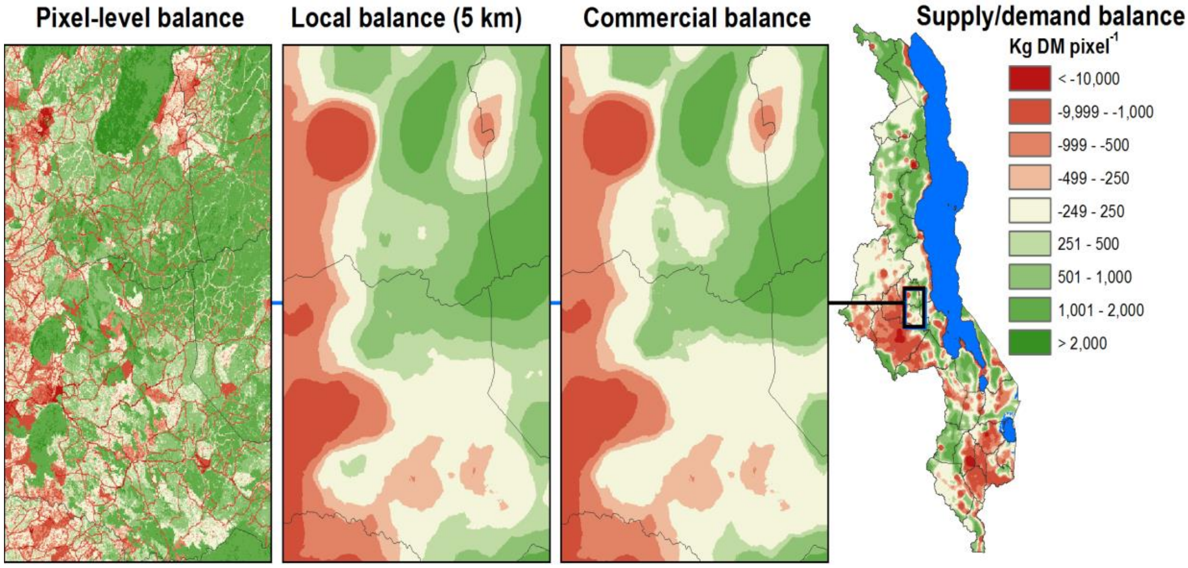


Figure 13. Pixel-Level, Local, and Commercial Balance

At the local level of analysis, it is important and recommended to verify the economic viability of the various situations with local 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.

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 harvesting and how such harvesting impacts available resources.

Keeping 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:

- The ***minimum sustainable woodshed*** that represents what the supply zone should be for the sustainable supply of the needed woody biomass. The minimum sustainable woodshed is defined as the minimum area around the consumption sites in which the cumulative woodfuel 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.
- 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 commercial woodshed is particularly relevant for this study because it produces quantitative and spatially explicit estimates of probable degradation processes due to excessive harvesting.

Figure 14 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*.

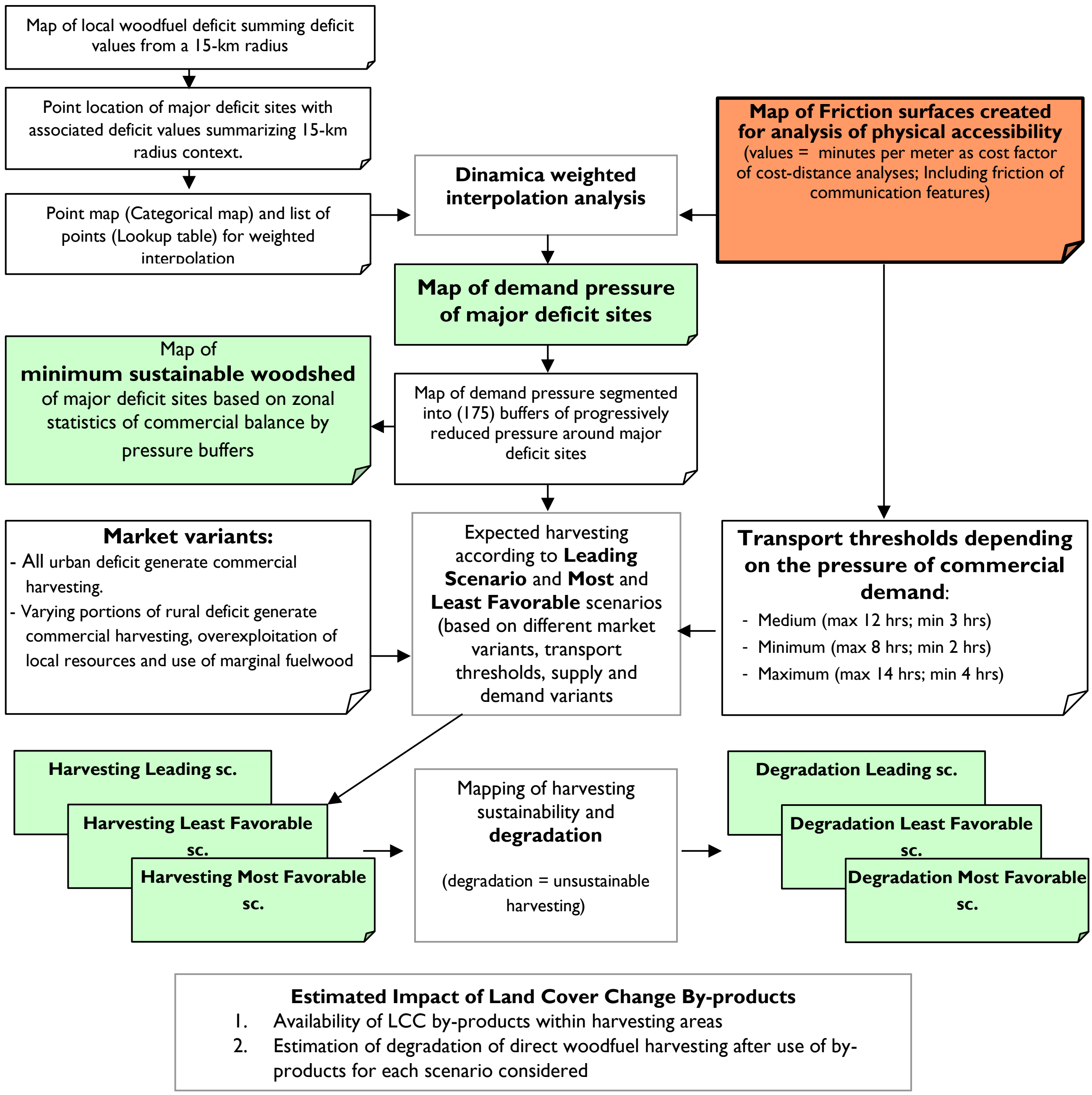


Figure 14. Flowchart Showing the Main Element of Woodshed Analysis

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 the Dinamica EGO processing environment. The model applied considers:

- ***as starting 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 15 km)[7]; and
- ***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.

---

[7] 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, 14 major deficit points were identified.

The model creates an interpolation map for each individual point using the deficit value associated to the point as starting 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 23 in the 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.

2.5.2 DELINEATION OF THE MINIMUM SUSTAINABLE WOODSHED

Once the pressure map is produced, the delineation of the *minimum sustainable woodshed* of the selected deficit sites can be made by calculating the commercial balance of each pressure buffer and progressively expanding the area buffer until the cumulative value of the commercial balance reaches a positive value, indicating that the supply potential (i.e. the commercial surplus) matches the demand within such territory. A minimum sustainable woodshed exists only if the country has a positive commercial balance at the national level. If the overall commercial balance is negative a sustainable woodshed cannot be delineated.

Figure 24 (results section) shows the minimum (theoretical) sustainable woodsheds for 2016 according to the Medium Variant and to worst (High Variant) and best (Low Variant) scenarios. The sustainable woodsheds can be delineated for the Leading and Low Variant because they have positive commercial balances (+0.8 and +3 Mt, respectively) but not for the High Variant, which has a negative commercial balance (-1.9 Mt).

It should be noted, however, that the delineation of the minimum sustainable woodshed, if feasible, is purely theoretical, indicating what *should* be the harvesting area in order to guarantee the sustainable supply of the needed woody biomass, assuming the rational and sustainable resources management system. Such theoretical delineation does not tell what the *actual* harvesting area is, which is the scope of the next section, but provides a revealing 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; and still more 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.

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 the market place would be too high and the exploitation of those distant resources would be uneconomical. 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. We also assume that the acceptable and practiced harvesting distance is not the same throughout the country. A transport distance acceptable for Lilongwe and Blantyre may be far too high for other smaller cities.

Hence, the probable commercial harvesting areas are defined by combining the commercial demand pressure map described in Section 2.5.1 above and transport time from the same deficit sites (see Annex 5 for a description of physical accessibility model).

Three transport thresholds were defined, assuming different pressure thresholds:

- ***Medium transportation threshold:*** Based on a pressure threshold that corresponds to a maximum transport time of approximately 12 hours around Lilongwe and Blantyre and a much lower transport threshold in other areas (3-4 hours).
- ***Minimum transportation threshold:*** With a pressure threshold corresponding to a maximum transport time of approximately 8 hours around Lilongwe and Blantyre, down to 2-3 hours around low-pressure sites.
- ***Maximum transportation threshold:*** With a pressure threshold corresponding to a maximum transport time of approximately 14 hours around Lilongwe and Blantyre and to 4-5 hours around low-pressure sites.

The Medium transportation threshold was used for the Medium Variant. The Minimum threshold, whereby the harvesting is concentrated on a smaller territory was used for the High Variant, and the Maximum threshold was used for the Low Variant. The harvesting areas defined by these three thresholds are shown in Figure 15.

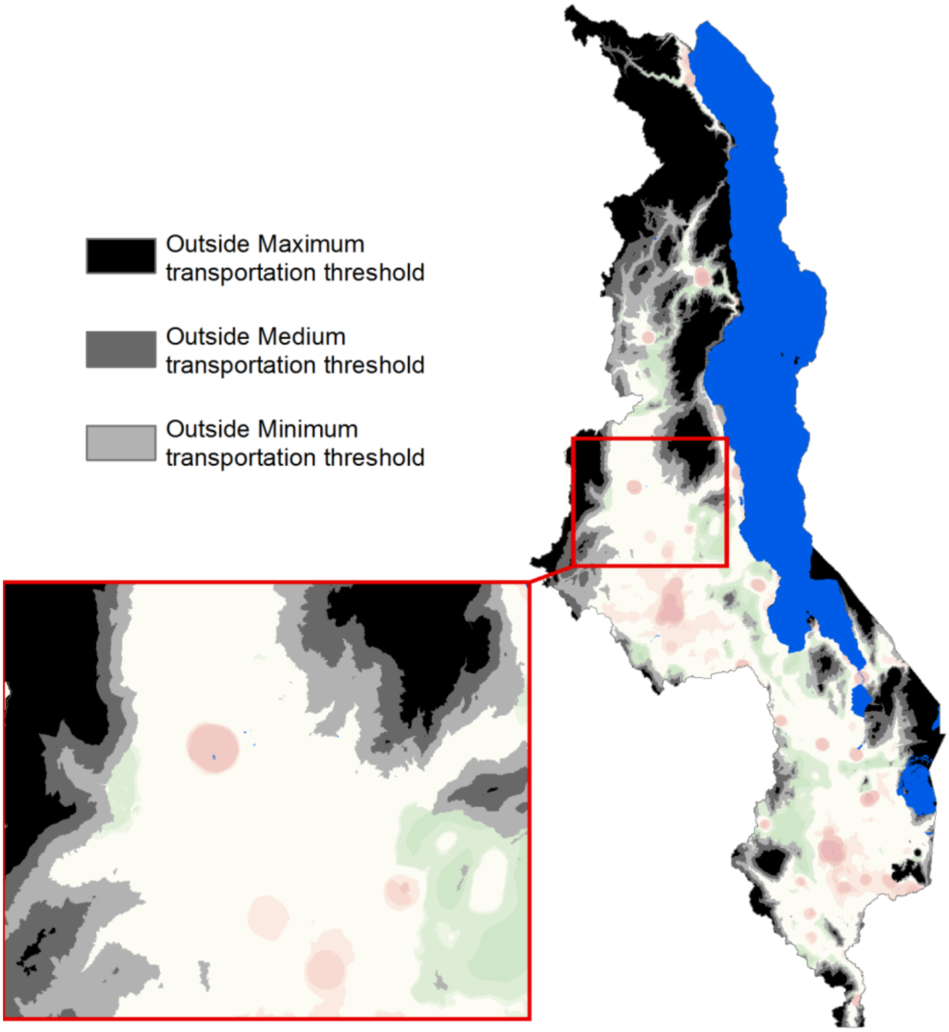


Figure 15. Transportation Thresholds

FROM LOCAL DEFICIT TO COMMERCIAL HARVESTING: MARKET VARIANTS

What fraction of the local deficit converts to commercial harvesting? The demand for woodfuels in urban areas always creates a local deficit; thus, it is safe to assume that urban areas 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 shifting towards non-conventional fuelwood assortments (annual pruning, twigs, etc.) and crop residues; excessive harvesting of the limited resources locally available; or depending on commercial supply.

The extent to which these responses apply to rural Malawi has been revealed by the Rural Firewood Assortments Survey (RFAS), as discussed in the Demand Module, Section 2.2.3. The shift to marginal wood assortments is already considered in estimating the demand for conventional fuelwood in rural deficit areas, for which Medium, Low, and High marginal fuelwood fraction variants are estimated. What remains to be defined is what fraction of the conventional fuelwood consumed in rural deficit areas comes from the unsustainable harvesting of local resources, and what fraction comes from commercial supply. Based on RFAS data, the unsustainable local harvesting fraction and the market-sourced fraction have been estimated for the Medium, Low and High marginal fuelwood variants as follows:

- ***Medium Marginal variant.*** Leading scenario: 36% of the local rural deficit remains on site as unsustainable local harvesting, while the rest of the deficit (64%) generates commercial harvesting.
- ***Low Marginal variant.*** Maximum degradation scenario: 65% of the local rural deficit remains on site as unsustainable local harvesting, while the rest of the deficit (35%) generates commercial harvesting.
- ***High Marginal variant.*** Minimum degradation scenario: 4% of the local rural deficit remains on site as unsustainable local harvesting up, while the rest of the deficit (96%) generates commercial harvesting.

ACCOUNTING FOR LAND COVER CHANGE BY-PRODUCTS

Though not directly linked to woodfuel demand, LCC processes such as deforestation and afforestation 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 firewood, charcoal, timber, and construction material. Similarly, afforestation adds woody biomass equivalent to the MAI of the surrounding land class.

In the absence of recent LCC data at the time of analysis, the quantity of woody biomass by-products annually available was estimated using land cover changes 2000-2010 as estimated by FAO 2014, assuming that the average annual change in woody biomass stock over that decade may still be valid for 2016. Estimated for the Medium stock variant, the by-products annually available are 242 thousand tons DM. With reference to Minimum and Maximum stock estimates, the by-products annually available are 168 kt DM and 329 kt DM, respectively.

Not all deforestation by-products are available as fuelwood, wood for charcoal, or construction material. Out of all woody remains of forest clearing, it is tentatively estimated that 25% are either used as timber or wasted on site; while 75% may be potentially available, the degree to which LCC by-products are actually used as woodfuel is unknown. To accommodate this uncertainty, we explore three possible situations:

- As discussed at the Mid-term WISDOM Workshop[8], the most probable fraction of use of LCC by-products as woodfuels or construction material is 60%.
- Alternative variant whereby 75% of LCC by-products are used (full use of potentially available quantity);
- Alternative variant whereby 45% of LCC by-products are used (minor use of potentially available quantity).

It should 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.

SCENARIOS CONSIDERED

Combined with the Supply and Demand variants, the factors influencing the delineation of commercial woodsheds and harvesting intensity, transport thresholds, etc. give origin to a wide range of scenarios. While some of the assumptions considered are definitely more probable than others, forming what we may call the Medium Variant, the range of results produced by other assumptions provide a measure of the "confidence interval" of leading estimates and, more importantly, provide a clear perception of how much the various assumptions influence the results.

In order to be effective in representing the widest range of conditions/assumptions, we combined them according to their influence on the estimates of woodfuel-induced degradation rates. The most probable variants and assumptions were used to define the Medium Variant. Alternative variants/assumptions appearing least favorable were combined to form the High Variant, while those appearing as most favorable were combined to form the Low Variant (as summarized in Table 3).

Table 3: Scenarios Considered and Relative Data Variants/Assumptions

DATA VARIANTS/ASSUMPTIONS	MEDIUM VARIANT (MOST PROBABLE)	HIGH VARIANT (LEAST FAVORABLE)	LOW VARIANT (MOST FAVORABLE)
agwb stock	Medium stock (mean agwb values)	Minimum stock (mean – 90% CI)	Maximum stock (mean + 90% CI)
agwb MAI	Intermediate MAI equation applied to Med. stock	Low stock/MAI equation applied to Min. stock	High stock/MAI equation applied to Max. stock
Conventional/marginal woodfuel fraction in rural deficit areas	Medium Marginal variant: 42% marginal	Low Marginal variant: 31% marginal	High Marginal variant: 53% marginal
Market supply or unsustainable harvesting of conventional fuelwood in deficit areas	Medium variant: 64% market supply; 36% unsustainable harvesting	Medium variant: 35% market supply; 65% unsustainable harvesting	Medium variant: 96% market supply; 4% unsustainable harvesting
Transportation thresholds	Medium transportation threshold	Minimum transportation threshold	Maximum transportation threshold
Use of LCC by-products for woodfuel or construction material	Medium use: 60%	Minor use: 45%	Full use: 75%

8 Mid-term WISDOM Workshop, Lilongwe, 13 June 2018.

2.5.4 HARVESTING SUSTAINABILITY AND DEGRADATION RATES

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 5:

$$Har_i = w\_s_i * (\sum c\_d / (\sum w\_s) \qquad \text{[Eq. 5]}$$

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.

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

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 (Bailis et al. 2015, Drigo et al. 2014), where statistics on the fraction of forest resources under management plans and forest plantation statistics (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 impacts the stock.

In that study, the SIEF applied to commercial harvesting in Malawi was 0.73, which is a relatively low value due to the limited area under SFM or under forest plantations. In this study, in the absence of other information about "management parameters," and considering that actual plantation area is less than that reported by FAO, we applied a SIEF value of 0.7 to estimate the *expected* unsustainable fraction of commercial harvesting. In order to test the influence of this parameter on the resulting degradation rates, alternative SIEF values of 0.6 and 0.8 were also applied, which indicated that the degradation rate changes with a change of SIEF by a factor of -0.58 (to a SIEF increase of 10% that corresponds a decrease of degradation rate of 5.8%).

2.6 DEMAND, SUPPLY, AND HARVESTING SUSTAINABILITY PROJECTED TO 2021: BAU SCENARIOS

The five-year projection to 2021 of the demand for fuelwood and charcoal (and construction material), the supply potential, and harvesting sustainability is done for business-as-usual (BAU) scenarios in three variants: Medium Variant, High Variant, and Low Variant. The scope of the five-year projection is to estimate the expected situation in 2021 and, most importantly, to reveal the trend of degradation that Malawi faces.

2.6.1 PROJECTED DEMAND TO 2021

PROJECTED RESIDENTIAL SECTOR DEMAND

Residential sector demand was projected to 2021 using the following data and assumptions:

- Population projection estimates by NSO in 2009, just after completion of Census 2008 (projections of rural, urban, and total population to 2021 are shown in Table 6.1 2 in Appendix 1);
- Saturation trends of fuelwood and charcoal in rural and urban areas as evidenced by the sequence of socioeconomic surveys carried out from 1998–2016 that reported on the main cooking and heating fuels in urban and rural areas at various sub-national levels (Figure 16 shows the national summary of the available saturation data and the five-year projections to 2021 based on simple linear regressions, and district-wise saturation values for 2021 are shown in Table 6.1 4 in Appendix 1); and
- In the absence of stove penetration data, a constant proportion of improved to traditional stoves was assumed, and thus constant per capita consumption rates as estimated for year 2016.

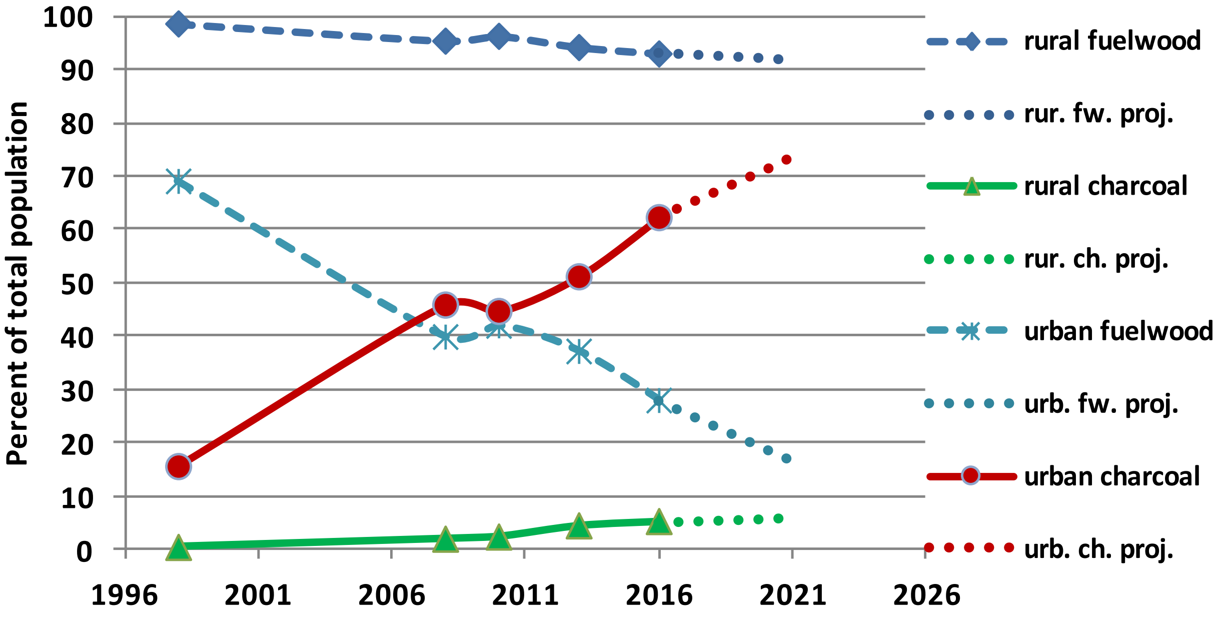


Figure 16. Time Series of Fuelwood and Charcoal Saturation in Rural and Urban Households Based on Socioeconomic Data and Projected to 2021

OTHER SECTORS' PROJECTED DEMAND

Each sector of consumption was projected to 2021 considering primarily population growth, where the consumption is directly determined by number of users or by data time series (where available). Table 4 lists the various sectors of non-residential demand in 2016, the basis of the individual projections, and the estimates of demand in 2021.

Table 4. Projected Non-Residential Woodfuel Demand to 2021

DEMAND SECTOR	BASIS OF PROJECTED DEMAND	DEMAND 2016 (t DM wood equivalent)	DEMAND 2021 (t DM wood equivalent)
Lime production	In the absence of evidence of increase or decrease of lime production the 2016 value is kept.	3,484	3,484
Poultry Industry	Considering that the demand is predominantly urban, the projection is based on the estimated 2021 urban population.	34,787	43,686
Tobacco curing	In the absence of evidence of increase or decrease of tobacco production the 2016 value is kept.	93,106	93,106
Brickmaking	Projection based on population growth 2016-2021, applying the same per capita demand for bricks in urban and rural areas used for 2016.	452,945	555,659
Fish smoking/drying	Projection based on the linear trend of available 2001-2013 data on fish caught and fraction smoked.	63,623	89,709
Boarding schools	Projection based on population growth 2016-2021.	132,942	155,676
Tea drying	Projection based on the linear trend of 2008 (BEST) and 2016 (this study) values.	86,114	93,717
Restaurants and resorts	Projected applying the same fraction (5%) to the 2021 urban household demand.	99,194	128,469
Total Non-HH		966,195	1,163,506

The results of these projections indicate that the non-residential demand will increase from 0.97 Mt DM in 2016 to 1.16 Mt in 2021, with an increment rate of 20% in five years.

Given the scarcity of historical data for most of the sectors considered, these projections are less reliable than residential demand projections and should be taken cautiously. However, the demand of all non-residential sectors is estimated to represents only 8.8% of the total demand in 2021 and, consequently, the probable error of estimation of the individual sectors is not likely to significantly affect the conclusions of this study.

USE OF MARGINAL FUELWOOD BY RURAL HOUSEHOLDS IN 2021

The use of marginal fuelwood in rural areas was estimated following the same procedure used in 2016, but with reference to the increased demand and decreased supply potential estimated for 2021. The proportions of marginal and conventional assortments resulting from the RFAS (Table 2 above) were applied without modifications in consideration that these values, based on the 2018 field survey, might still be representative of 2021 situation.

The fraction of marginal fuelwood in 2021 is estimated to be 3 Mt DM or 22.5% of the total demand for the Medium variant where the Medium Marginal variant is applied to the Medium Supply variant[9].

2.6.2 PROJECTED SUPPLY TO 2021

The projection to 2021 of the supply potential implies the estimation of the changes occurring to the stock of woody biomass in previous years and, from this, the new estimate of annual productivity: total MAI, accessible MAI, and available MAI.

PROJECTED STOCK AND PRODUCTIVITY

The prediction of the sustainable supply potential in 2021 included the following steps of analysis:

- Project the stock map 2010 based on FAO land cover map[10] to 2021 based on:
  - estimated forest area change over the period 2010-2021 based on high resolution global data on forest loss and gain[11] available up to 2017 (Hansen et al, 2013) and projected trend for the period 2018-2021.
  - cumulative degradation for each BAU scenario for the period 2010-2021 using the degradation of year 2016 as "average annual degradation rate."
- Distribute the reduced stock by region, through application of reduction factors to the stock of 2010, since the specific location of deforestation and degradation sites cannot be determined.
- Calculate MAI 2021 based on reduced stock (applying stock/MAI equations to revised stock maps)

The 2021 projection was done for the Medium variant as well as for the Minimum and Maximum supply variants, as for 2016 estimates.

PROJECTED ACCESSIBLE AND AVAILABLE SUPPLY POTENTIAL

The 2021 MAI maps for all three variants were subsequently combined with legal and physical accessibility maps[12] to estimate the accessible MAI for the Medium, Minimum, and Maximum supply variants.

Similarly, the MAI of plantation areas, still derived from 2010 land cover maps, was deducted on the assumption that 75% of plantations' production goes to industrial roundwood rather than woodfuels.

---

[9] In the High Variant, where the Minimum Marginal variant is applied to the Minimum Supply variant, the marginal fuelwood is estimated to be 2.4 Mt DM, or 18% of total demand. In the Low Variant, where the Maximum Marginal variant is applied to the Maximum Supply variant, the marginal fuelwood is estimated to be 3.3 Mt DM, or 25% of total demand.

[10] Since the latest available map was presenting 2010 land cover, that is the year of the produced biomass stock map. Only MAI layers were produced for 2016, by adding to the productivity estimated and mapped for 2010 and six years of change, using as reference the changes reported by land cover data over the period 2000-2010.

[11] Year of gross forest cover loss event (lossyear). Forest loss during the period 2000–2017, defined as a stand-replacement disturbance, or a change from a forest to non-forest state. Encoded as either 0 (no loss) or else a value in the range 1–17, representing loss detected primarily in the year 2001–2017, respectively. Global forest cover gain 2000–2012 (gain): Forest gain during the period 2000–2012, defined as the inverse of loss, or a non-forest to forest change entirely within the study period. Encoded as either 1 (gain) or 0 (no gain). Data downloaded in October 2018 from: http://earthenginepartners.appspot.com/science-2013-global-forest.

[12] The same maps of legal and physical accessibility were used for the 2016 and 2021 estimates since the change in the layout of National Parks and Wildlife Reserves (basis of legal accessibility) are the same and the changes in the road network during the period are expected to be minimal, and in any case unknown.

2.6.3 PROJECTED SUPPLY/DEMAND BALANCE, LOCAL, AND COMMERCIAL HARVESTING AND EXPECTED DEGRADATION RATES IN 2021

The analysis of supply/demand balance in 2021 and all subsequent steps were carried out following the same processes described above for the 2016 baseline.

Obviously, given the higher demand and the lower supply potential, the results are significantly different, showing a trend of increasing strain on existing resources. This is well represented by the maps of the commercial harvesting areas, which depend primarily on pressure maps. The maps shown in Figure 17 show the expected commercial harvesting areas in 2016 and 2021 based on Medium, Minimum, and Maximum transportation thresholds.

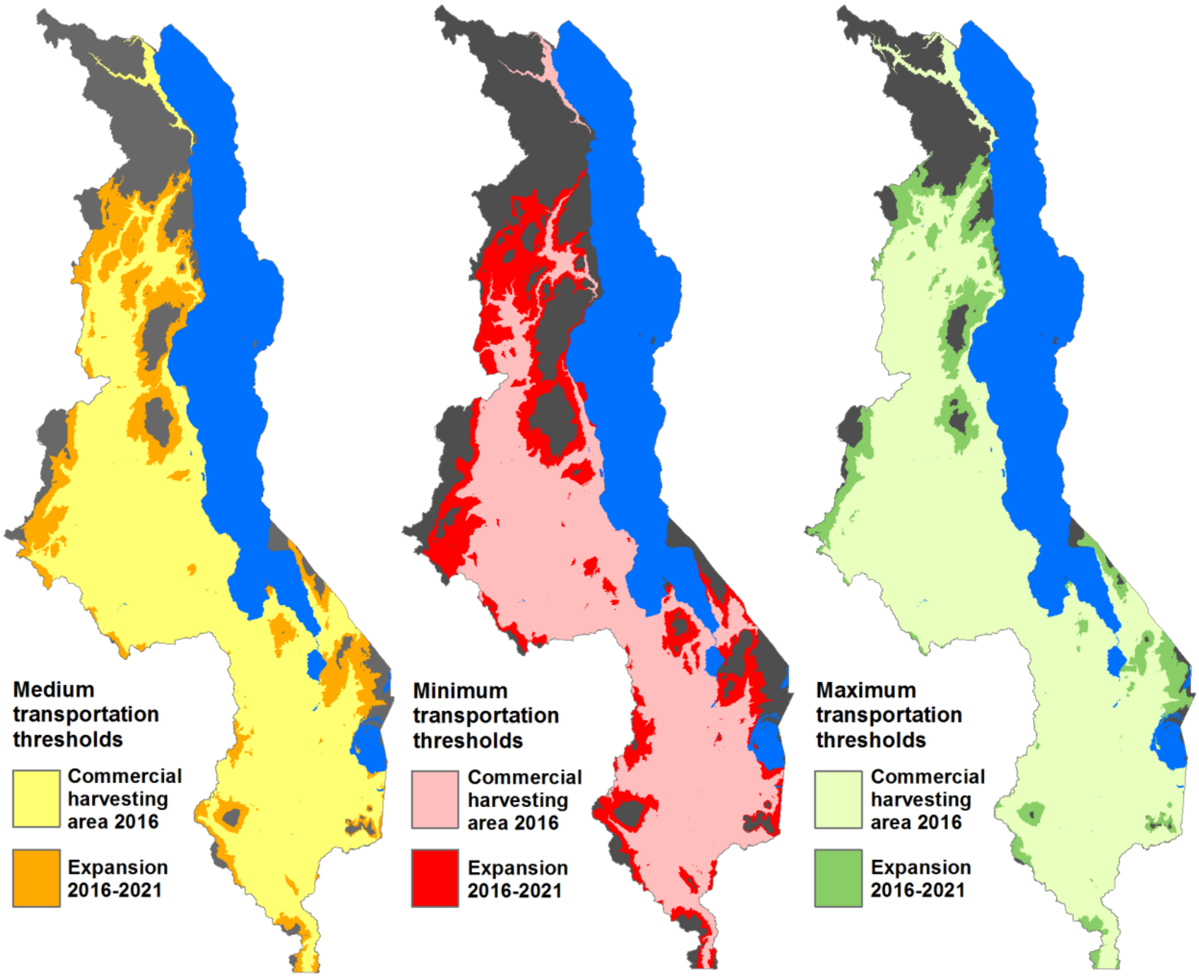


Figure 17. Expected Expansion of Commercial Harvesting Zones between 2016 and 2021

BAU SCENARIOS (2021)

The BAU scenarios for 2021 were defined following the same data variants and assumptions made for 2016, summarized in Table 3 above. As mentioned before, these are all representing BAU conditions and are meant to show the maximum range of values, taking into consideration the most probable data variants and assumptions (Medium Variant) as well as those representing statistical confidence intervals or assumptions that are least (High Variant) or most (Low Variant) favorable.

2.6.4 REPORTING UNITS OF 2021 RESULTS AND 2016-2021 TRENDS

For summarizing and reporting the results of the 2021 projection and the trends from 2016-2021, a lower level of detail was considered appropriate, given that projected estimates are assumed to be less reliable than those referring to year 2016. Thus, districts were aggregated to form geographic areas generally homogeneous in respect of woodfuel demand and supply potential, and respecting regional subdivisions.

Six district groups were created, the list and layout of which are shown in Table 5. The district group North (corresponding to the North Region) has a strong supply potential and limited demand; the groups Centre West and South Middle have strong demand and limited supply potential; the groups Centre East, South East, and South West have significant supply potential but are also under high demand pressure.

Table 5. District Grouping for Reporting 2021 Results and 2016-2021 trends

REGION	DIST. CODE	DISTRICT	DISTRICT GROUP	GROUP CHARACTERISTICS
North	101	Chitipa	**North**	Strong supply potential and limited demand
	102	Karonga		
	103	Nkhata Bay		
	104	Rumphi		
	105	Mzimba		
	106	Likoma		
	107	Mzuzu City		
Centre	201	Kasungu	**Centre West**	Strong demand and limited supply
	203	Ntchisi		
	204	Dowa		
	206	Lilongwe Rural		
	207	Mchinji		
	210	Lilongwe City		
	205	Salima	**Centre East**	Significant supply potential but high demand pressure
	208	Dedza		
	209	Ntcheu		
	202	Nkhotakota		
South	301	Mangochi	**South East**	Significant supply potential but high demand pressure
	302	Machinga		
	303	Zomba	**South Middle**	Strong demand and limited supply
	304	Chiradzulu		
	305	Blantyre Rural		
	307	Thyolo		
	308	Mulanje		
	309	Phalombe		
	314	Zomba City		
	315	Blantyre City		
	312	Balaka		
	306	Mwanza	**South West**	Significant supply potential but high demand pressure
	310	Chikwawa		
	311	Nsanje		
	313	Neno		

3.0 RESULTS

3.1 DEMAND MODULE RESULTS (2016)

The demand in the residential sector in 2016 for fuelwood, charcoal, and small construction material is estimated to be 10.24 Mt DM, as summarized by district in Table 6 by t DM wood-equivalent (weq).

Fuelwood in rural areas covers the greatest share of such demand (67.7%), followed by urban charcoal (14.2%), rural charcoal (11.1%), urban fuelwood (5.2%), and lastly construction material (1.8%).

Table 6. Residential Demand in 2016 (including conventional and marginal fuelwood)

AREA		RURAL CHARCOAL	RURAL FUELWOOD (*)	URBAN CHARCOAL	URBAN FUELWOOD	TOTAL COOKING & HEATING (*)	CONSTRUC-TION MATERIAL	TOTAL RESIDEN-TIAL DEMAND (*)
Code	District	t DM weq	t DM weq	t DM weq	t DM weq	t DM weq	t DM weq	t DM weq
101	Chitipa	9,340	119,110	9,486	3,225	141,161	2,604	**143,765**
102	Karonga	45,581	160,723	26,864	9,132	242,300	3,929	**246,230**
103	Nkhata Bay	4,232	156,495	7,505	2,551	170,784	3,303	**174,087**
104	Rumphi	17,124	107,611	11,523	3,917	140,175	2,477	**142,651**
105	Mzimba	104,000	495,262	13,750	4,674	617,686	11,100	**628,787**
106	Likoma	652	5,021	702	238	6,613	119	**6,732**
107	Mzuzu City	0	0	151,643	24,406	176,049	1,458	**177,507**
201	Kasungu	22,460	454,682	15,686	20,111	512,939	10,142	**523,080**
202	Nkhotakota	43,800	183,305	9,188	11,780	248,073	4,581	**252,654**
203	Ntchisi	8,902	160,387	2,999	3,845	176,133	3,540	**179,673**
204	Dowa	46,315	429,231	1,965	2,519	480,030	9,687	**489,718**
205	Salima	39,507	209,286	10,263	13,158	272,214	5,054	**277,267**
206	Lilongwe Rural	90,317	816,607	0	0	906,924	18,184	**925,108**
207	Mchinji	40,340	320,624	6,894	8,839	376,697	7,306	**384,003**
208	Dedza	17,084	409,643	7,078	9,074	442,879	9,034	**451,913**
209	Ntcheu	52,074	304,043	5,261	6,745	368,123	7,069	**375,192**
210	Lilongwe City	0	0	554,223	175,180	729,403	6,700	**736,103**
301	Mangochi	110,744	446,165	15,128	25,521	597,558	12,531	**610,088**
302	Machinga	36,575	275,463	8,933	15,071	336,041	7,466	**343,507**
303	Zomba	23,557	311,499	0	0	335,056	8,210	**343,266**
304	Chiradzulu	19,572	137,618	762	1,285	159,236	3,920	**163,156**
305	Blantyre Rural	83,024	164,471	0	0	247,495	4,972	**252,468**
306	Mwanza	10,751	39,258	4,649	7,843	62,501	1,193	**63,695**
307	Thyolo	27,457	288,863	5,959	10,053	332,331	7,868	**340,199**
308	Mulanje	79,091	207,718	4,640	7,827	299,276	6,974	**306,250**
309	Phalombe	5,888	148,959	1,735	2,927	159,509	4,638	**164,146**
310	Chikwawa	105,122	224,577	2,551	4,304	336,555	6,645	**343,200**
311	Nsanje	18,152	120,753	7,025	11,852	157,782	3,372	**161,153**
312	Balaka	59,947	163,582	8,425	14,214	246,168	4,812	**250,980**
313	Neno	16,956	69,305	698	1,177	88,136	1,919	**90,055**
314	Zomba City	0	0	48,396	49,633	98,029	897	**98,926**
315	Blantyre City	0	0	512,634	77,191	589,825	5,613	**595,438**
Malawi		1,138,563	6,930,261	1,456,565	528,294	10,053,683	187,318	10,240,997

(*) Including conventional and marginal fuelwood.

The demand in all other non-residential sectors is reported in Table 7, by the specific sector or industrial process for which the demand was considered significant. The total non-residential demand in 2016 is estimated to be 0.97 Mt DM (tentatively, given the scarce data available) of which brickmaking covers the largest share (47%), followed by school catering (14%), commercial demand from restaurants, bakeries, and street vendors (10%), tobacco curing (10%), tea drying (9%), and fish drying (7%). The demand by the poultry and lime industries are relatively small, covering only 3.6% and 0.4% of the non-residential demand, respectively.

Table 7. Non-Residential Woodfuel Demand in 2016

AREA		COMM-ERCIAL	LIME	POULTRY	TOBACCO	BRICKS	FISH DRYING	SCHOOLS	TEA DRYING	TOTAL NON-RES. DEMAND
Code	District	t DM weq	t DM weq	t DM weq	t DM weq	t DM weq	t DM weq	t DM weq	t DM weq	t DM weq
101	Chitipa	635	0	0	1,828	3,909	0	2,338	0	8,710
102	Karonga	1,798	79	0	1,257	8,451	5,398	3,170	0	20,152
103	Nkhata Bay	502	0	0	2,062	4,033	7,985	2,244	7,627	24,454
104	Rumphi	771	0	0	1,546	4,227	1,827	2,037	0	10,409
105	Mzimba	921	0	0	9,644	11,222	183	8,053	0	30,022
106	Likoma	47	0	0	0	233	1,589	133	0	2,002
107	Mzuzu City	8,797	0	0	146	26,232	0	1,748	0	36,923
201	Kasungu	1,788	0	1	7,676	13,422	95	7,435	0	30,416
202	Nkhotakota	1,048	0	0	1,918	6,830	8,642	3,306	277	22,021
203	Ntchisi	342	0	0	2,445	3,783	0	2,549	0	9,120
204	Dowa	224	0	17	4,993	8,069	0	5,786	0	19,089
205	Salima	1,170	0	0	2,614	7,580	5,210	3,237	0	19,812
206	Lilongwe Rural	0	0	19,246	9,032	13,804	435	10,436	0	52,951
207	Mchinji	786	0	4	4,514	8,060	0	4,705	0	18,070
208	Dedza	807	0	0	4,802	9,437	443	5,913	0	21,401
209	Ntcheu	600	1,393	0	4,309	7,280	88	5,047	0	18,716
210	Lilongwe City	36,452	0	933	437	120,522	0	5,790	0	164,135
301	Mangochi	2,032	1,635	0	5,854	15,049	28,789	6,934	9,707	70,001
302	Machinga	1,198	0	5	3,780	8,935	460	5,059	0	19,437
303	Zomba	0	0	7,376	3,463	6,233	802	5,978	265	24,118
304	Chiradzulu	102	0	2,748	1,293	3,254	280	3,083	0	10,760
305	Blantyre Rural	0	53	4,156	1,951	3,778	0	4,070	0	14,008
306	Mwanza	624	0	0	895	2,606	0	1,018	0	5,143
307	Thyolo	800	0	3	2,408	8,151	457	5,956	45,090	62,864
308	Mulanje	623	0	0	2,576	6,992	84	5,788	23,148	39,210
309	Phalombe	233	0	0	1,934	4,156	391	3,455	0	10,169
310	Chikwawa	343	0	1	3,410	5,984	142	4,354	0	14,233
311	Nsanje	943	0	0	1,407	5,130	0	2,368	0	9,848
312	Balaka	1,131	312	3	3,444	6,738	100	3,733	0	15,461
313	Neno	94	12	3	1,333	1,708	0	1,144	0	4,293
314	Zomba City	4,900	0	73	34	16,147	0	916	0	22,071
315	Blantyre City	29,482	0	219	102	100,989	224	5,160	0	136,176
	Malawi	99,194	3,484	34,787	93,106	452,945	63,623	132,943	86,114	966,195

The intensities and spatial distributions of the residential and non-residential demands are shown in Figure 18. The non-residential demand shows a less homogeneous distribution, compared to the residential demand, with greater concentration in or around urban areas.

As final result of the Demand Module, Table 8 reports the Total Demand in 2016, which is estimated to be 11.2 Mt DM, 91% of which is the residential demand and 9% all other non-residential sectors.

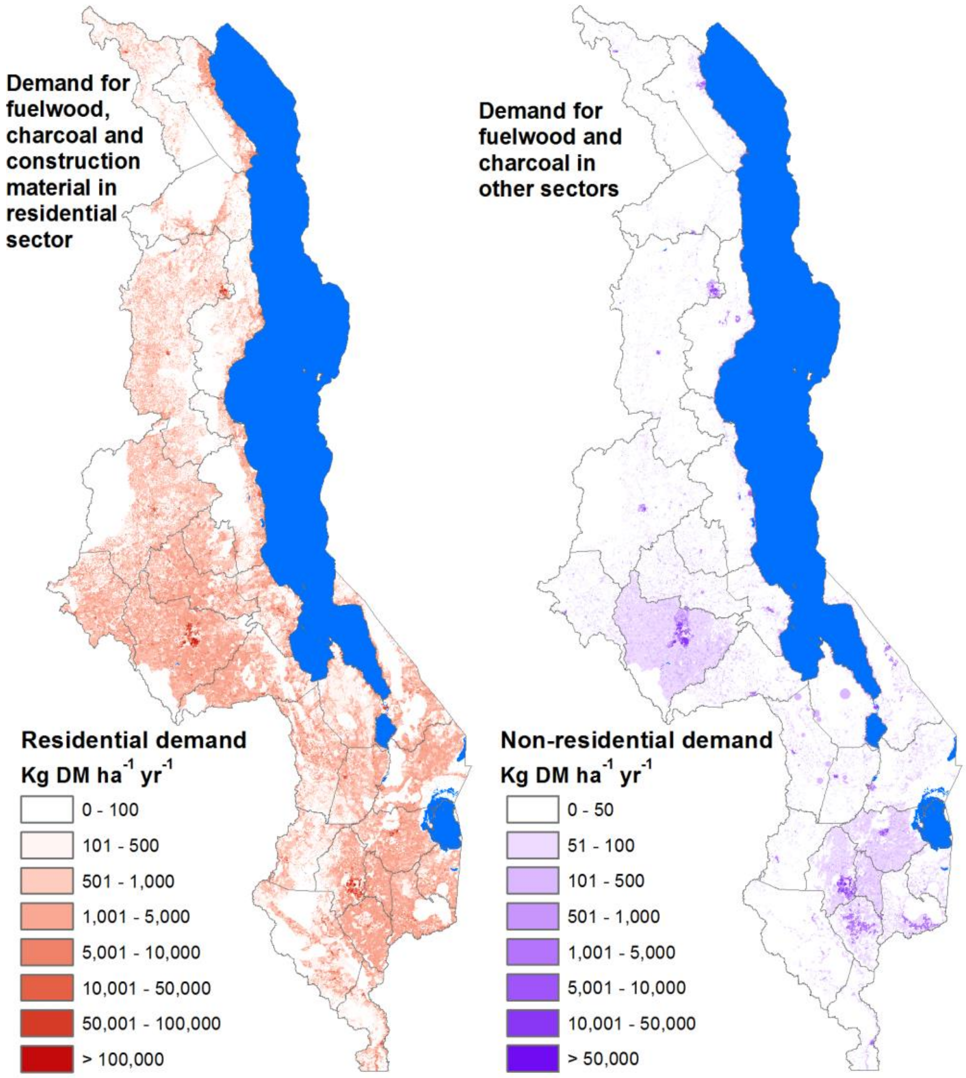


Figure 18. Maps of Residential and Non-Residential Demand in 2016

The Total Demand includes all wood types from all possible sources. The RFAS 2018 revealed that a significant fraction of the fuelwood used in rural areas is not made up of *conventional wood assortments* (branch wood and split-stem wood from felling trees and shrubs) but rather comprises *marginal assortments* (twigs and small branches from annual pruning of farm trees and shrubs). This distinction is extremely relevant for the subsequent phases of analysis because the estimated supply potential refers uniquely to the MAI of conventional wood assortments, while the annual productivity of marginal assortments is not known and not accounted for. Hence, for the consistency of analysis, the marginal fuelwood assortments were estimated and excluded from the Total Demand to define the Conventional Demand, for comparing with the estimated conventional supply potential.

Three estimates of Conventional Demand are produced, applying the range of marginal assortments fractions resulting from the RFAS. According to the Medium Marginal variant, the conventional demand is 8.7 Mt DM, or 77.6% of the total demand; this value becomes 82.7% and 73.6% with reference to the Minimum Marginal variant and to the Maximum Marginal variant, respectively.

Table 8. All Sectors' Demand in 2016 and Estimated Conventional Demand (excluding marginal fuelwood used in rural areas)

AREA		TOTAL DEMAND (including conventional and marginal demand)	CONVENTIONAL DEMAND OF WOODFUELS AND CONSTRUCTION MATERIAL (*)		
			Medium Marginal Variant (**)	Minimum Marginal Variant (**)	Maximum Marginal Variant (**)
Code	District	t DM weq	t DM weq	t DM weq	t DM weq
101	Chitipa	**152,475**	**135,376**	145,783	125,189
102	Karonga	**266,382**	**196,153**	214,287	187,235
103	Nkhata Bay	**198,540**	**168,480**	178,185	156,693
104	Rumphi	**153,060**	**125,790**	132,490	117,093
105	Mzimba	**658,791**	**593,384**	621,101	553,216
106	Likoma	**8,734**	**5,294**	6,608	5,279
107	Mzuzu City	**214,429**	**184,420**	184,545	184,298
201	Kasungu	**553,496**	**441,468**	461,718	409,756
202	Nkhotakota	**274,675**	**206,710**	222,038	194,706
203	Ntchisi	**188,792**	**145,892**	157,113	134,582
204	Dowa	**508,807**	**331,670**	371,042	305,037
205	Salima	**297,079**	**222,239**	239,066	208,758
206	Lilongwe Rural	**978,060**	**718,362**	818,485	673,235
207	Mchinji	**402,073**	**281,414**	304,426	261,048
208	Dedza	**473,315**	**331,360**	363,597	303,969
209	Ntcheu	**393,908**	**311,160**	325,443	290,652
210	Lilongwe City	**900,239**	**740,666**	742,415	738,964
301	Mangochi	**680,080**	**531,789**	563,151	502,180
302	Machinga	**362,926**	**273,369**	289,967	254,340
303	Zomba	**367,384**	**308,871**	332,667	290,870
304	Chiradzulu	**173,917**	**121,592**	137,405	114,648
305	Blantyre Rural	**266,476**	**293,789**	312,723	286,504
306	Mwanza	**68,838**	**58,564**	61,813	55,669
307	Thyolo	**403,064**	**254,691**	292,239	239,594
308	Mulanje	**345,448**	**236,539**	267,348	226,911
309	Phalombe	**174,316**	**126,915**	133,261	117,697
310	Chikwawa	**357,433**	**263,153**	280,982	250,522
311	Nsanje	**171,001**	**130,211**	136,986	122,410
312	Balaka	**266,441**	**219,707**	229,952	209,361
313	Neno	**94,349**	**82,039**	86,861	76,142
314	Zomba City	**120,997**	**55,909**	56,136	55,688
315	Blantyre City	**731,614**	**602,295**	603,175	601,438
Malawi		**11,207,138**	**8,699,271**	**9,273,007**	**8,253,685**

(*) Including conventional fuelwood, construction material and wood used for charcoal. Excluding marginal fuelwood.
(**) Three variants are presented relative to Medium, Minimum and Maximum marginal variants resulting from the RFAS.

The maps in Figure 19 show the distribution of the demand for marginal fuelwood, concentrated primarily on rural deficit areas, and the distribution of the Conventional demand with reference to the Medium Marginal variant and Medium Supply variant.

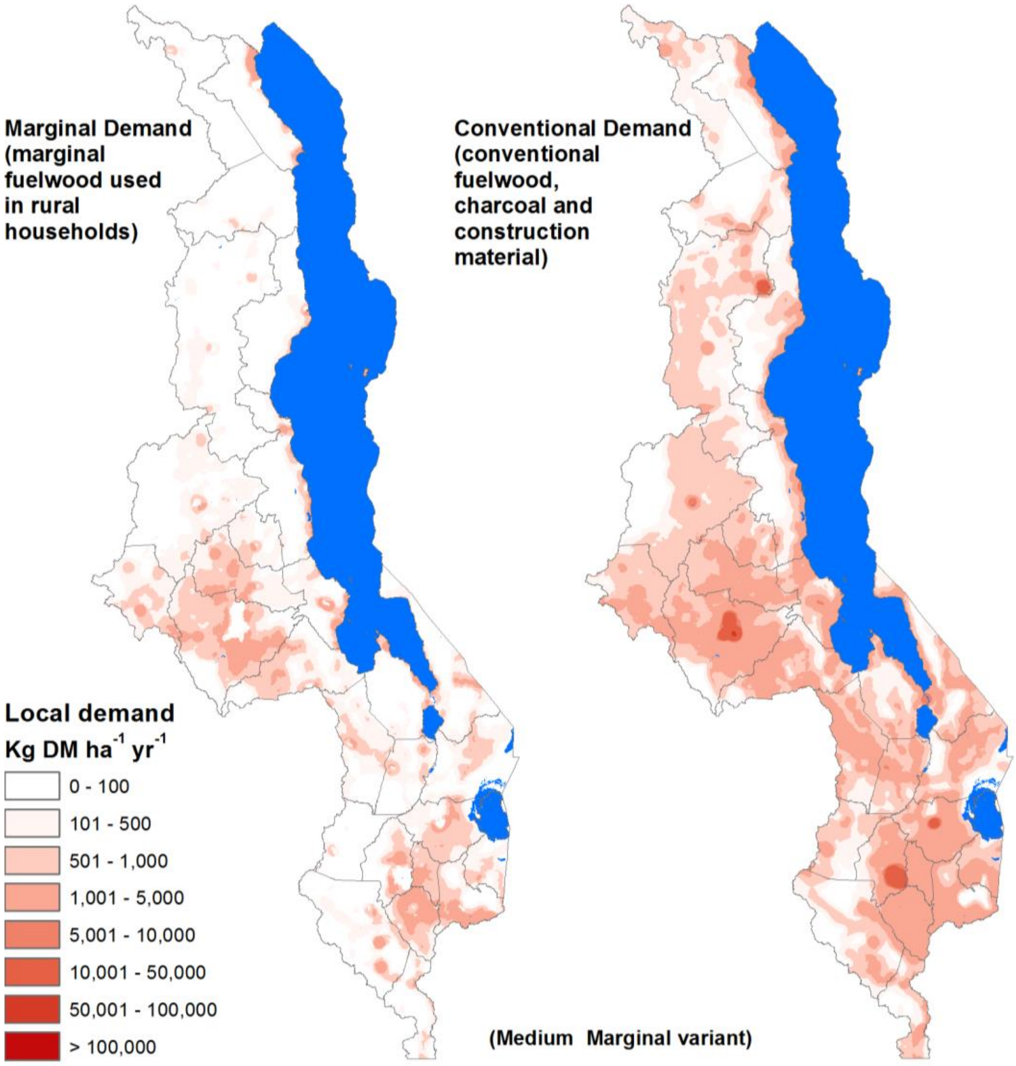


Figure 19. Maps of Marginal and Conventional Demand in 2016 (All Sectors) According to the Medium Marginal (Medium Supply Variants)

Note: These maps show the "local" demand, reporting the pixel-level demand averaged within a context of 5km. Such local context of analysis is necessary in order to estimate what fraction of the rural fuelwood demand is fulfilled by conventional woody resources available locally (within 5 km) and what fraction is fulfilled by marginal fuelwood assortments.

In all subsequent phases of analysis, the "demand" compared to the supply potential is the Conventional Demand (in all three variants) while the Marginal Demand is excluded from further analysis and its sustainability remains undetermined.

3.2 SUPPLY MODULE RESULTS (2016)

The first basic parameters of the supply module were estimated with reference to the latest land cover map available, FAO 2010. Such parameters include estimated stock and MAI of the aboveground woody biomass (agwb), which are summarized in Table 9. For each parameter, three variants were estimated.

The Medium stock variant, based on statistical means of available field data, gives a stock in 2010 of 381 Mt DM. Minimum and Maximum variants based on 90% confidence intervals give 340 and 421 Mt DM, respectively.

Table 9. Stock and Mean Annual Increment (MAI) in 2010

AREA		2010 STOCK ABOVEGROUND WOODY BIOMASS (AGWB)			2010 MAI ABOVEGROUND WOODY BIOMASS MAI (AGWB)		
		Medium Variant	Minimum Variant	Maximum Variant	Medium Variant	Minimum Variant	Maximum Variant
Code	District	kt DM	kt DM	kt DM	t DM yr^{-1}	t DM yr^{-1}	t DM yr^{-1}
101	Chitipa	**25,932**	22,559	29,308	**688,950**	524,133	858,951
102	Karonga	**20,355**	18,154	22,554	**540,842**	414,386	671,598
103	Nkhata Bay	**35,795**	29,003	42,577	**787,361**	580,612	1,002,610
104	Rumphi	**29,737**	24,554	34,908	**739,426**	539,372	940,762
105	Mzimba	**41,741**	38,095	45,391	**1,316,240**	1,037,400	1,602,700
106	Likoma	**40**	26	54	**1,675**	1,119	2,259
107	Mzuzu City	**576**	524	628	**18,576**	14,548	22,768
201	Kasungu	**23,628**	22,228	25,026	**880,630**	701,384	1,064,250
202	Nkhotakota	**25,197**	23,306	27,087	**667,828**	521,790	817,492
203	Ntchisi	**6,206**	5,878	6,531	**213,233**	170,426	256,758
204	Dowa	**6,977**	6,656	7,297	**311,112**	249,998	373,183
205	Salima	**7,988**	6,977	9,004	**280,097**	216,303	345,970
206	Lilongwe Rural	**14,212**	13,352	15,062	**594,464**	475,722	715,221
207	Mchinji	**6,339**	5,960	6,717	**297,053**	237,924	357,645
208	Dedza	**12,336**	11,319	13,350	**444,940**	351,483	540,720
209	Ntcheu	**10,590**	9,381	11,804	**400,580**	311,626	492,389
210	Lilongwe City	**683**	602	763	**36,155**	28,055	44,414
301	Mangochi	**31,761**	29,425	34,101	**911,306**	716,274	1,111,420
302	Machinga	**11,472**	10,595	12,348	**418,391**	329,589	509,715
303	Zomba	**5,890**	5,279	6,500	**252,805**	195,270	309,956
304	Chiradzulu	**1,675**	1,512	1,838	**80,039**	63,348	97,190
305	Blantyre Rural	**5,597**	4,606	6,588	**218,650**	164,721	274,443
306	Mwanza	**3,162**	2,861	3,462	**100,723**	78,524	123,710
307	Thyolo	**4,760**	4,300	5,216	**198,460**	156,246	241,688
308	Mulanje	**7,578**	6,434	8,719	**246,868**	188,919	305,134
309	Phalombe	**3,371**	3,159	3,583	**139,905**	111,317	169,166
310	Chikwawa	**16,675**	14,901	18,450	**604,069**	466,084	745,817
311	Nsanje	**6,574**	6,033	7,116	**239,119**	187,447	292,538
312	Balaka	**5,106**	4,562	5,649	**232,793**	182,707	284,238
313	Neno	**7,772**	7,132	8,416	**241,167**	188,450	295,567
314	Zomba City	**183**	166	200	**5,519**	4,328	6,758
315	Blantyre City	**803**	683	923	**29,232**	22,318	36,502
	Malawi	**380,712**	**340,221**	**421,172**	**12,138,208**	**9,431,823**	**14,913,533**

The total MAI in 2010 was estimated to be 12.1 Mt DM for the Medium variant, with 9.4 and 14.9 Mt DM as Minimum and Maximum MAI variants, respectively.

The relatively wide range between MAI variants is due to the combination of two factors: the stock variant used as reference and the stock/MAI equation applied.

The maps of agwb stock and MAI in 2010, both referring to the Medium variants, are shown in Figure 20.

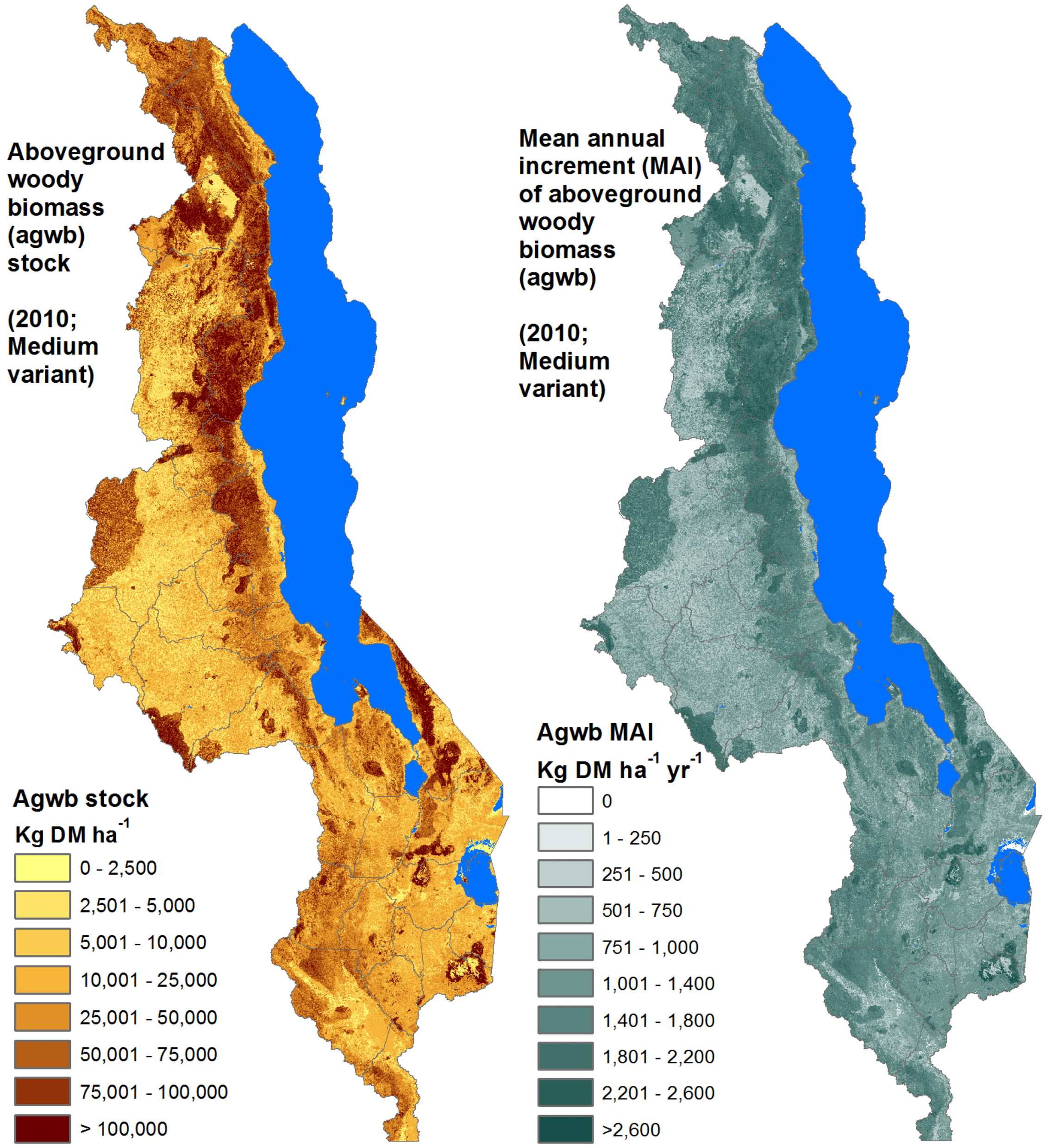


Figure 20. Maps of Stock and Mean Annual Increment in 2010 (Medium Variant)

In order to match the year 2016 for which the demand was estimated, the MAI 2010 data was further elaborated to estimate and map the MAI in 2016 and particularly the fraction that is physically and legally accessible and potentially available for energy use or for small residential construction material. This was done for each MAI variant, and the results are presented in Table 10.

The Available MAI in 2016 for the Medium variant is estimated to be 9.8 Mt DM. This shows a reduction of 18.9% with respect of the total MAI 2010. Such reduction is due to physical accessibility (-6%), legal accessibility (-12%), availability, and six-year projections (-1.8%). The Available MAI in 2016 for the Minimum and Maximum variants is estimated to be 7.7 and 12 Mt DM, respectively.

Table 10. MAI Accessible and Potentially Available in 2016

AREA		2016 AVAILABLE MAI		
		Medium Variant	Minimum Variant	Maximum Variant
Code	District	t DM yr^{-1}	t DM yr^{-1}	t DM yr^{-1}
101	Chitipa	**549,109**	422,133	680,580
102	Karonga	**392,160**	300,913	486,503
103	Nkhata Bay	**603,610**	455,005	757,994
104	Rumphi	**333,424**	252,118	417,814
105	Mzimba	**1,228,140**	972,680	1,490,100
106	Likoma	**1,664**	1,111	2,245
107	Mzuzu City	**18,495**	14,500	22,651
201	Kasungu	**499,557**	401,290	600,051
202	Nkhotakota	**320,489**	248,699	393,715
203	Ntchisi	**209,407**	167,416	252,092
204	Dowa	**310,028**	249,150	371,858
205	Salima	**276,966**	213,873	342,107
206	Lilongwe Rural	**567,101**	455,444	680,495
207	Mchinji	**292,466**	234,627	351,720
208	Dedza	**429,924**	340,142	521,903
209	Ntcheu	**398,928**	310,399	490,292
210	Lilongwe City	**36,161**	28,107	44,367
301	Mangochi	**843,398**	663,286	1,028,150
302	Machinga	**343,438**	271,095	417,765
303	Zomba	**246,116**	190,771	301,073
304	Chiradzulu	**79,778**	63,148	96,864
305	Blantyre Rural	**217,923**	164,245	273,457
306	Mwanza	**98,849**	77,080	121,385
307	Thyolo	**196,363**	154,841	238,865
308	Mulanje	**202,831**	159,698	246,424
309	Phalombe	**134,105**	106,852	161,974
310	Chikwawa	**340,552**	259,573	423,417
311	Nsanje	**178,982**	139,793	219,509
312	Balaka	**229,278**	179,757	280,082
313	Neno	**231,689**	180,971	284,029
314	Zomba City	**5,459**	4,292	6,673
315	Blantyre City	**29,211**	22,318	36,460
	Malawi	**9,845,601**	**7,705,327**	**12,042,613**

Figure 21 shows the MAI in 2016 potentially available for energy use or for small construction material according to the Medium variant, from which the reduced accessibility due to National Parks and Wildlife reserves and due to physical constraints is clearly visible.

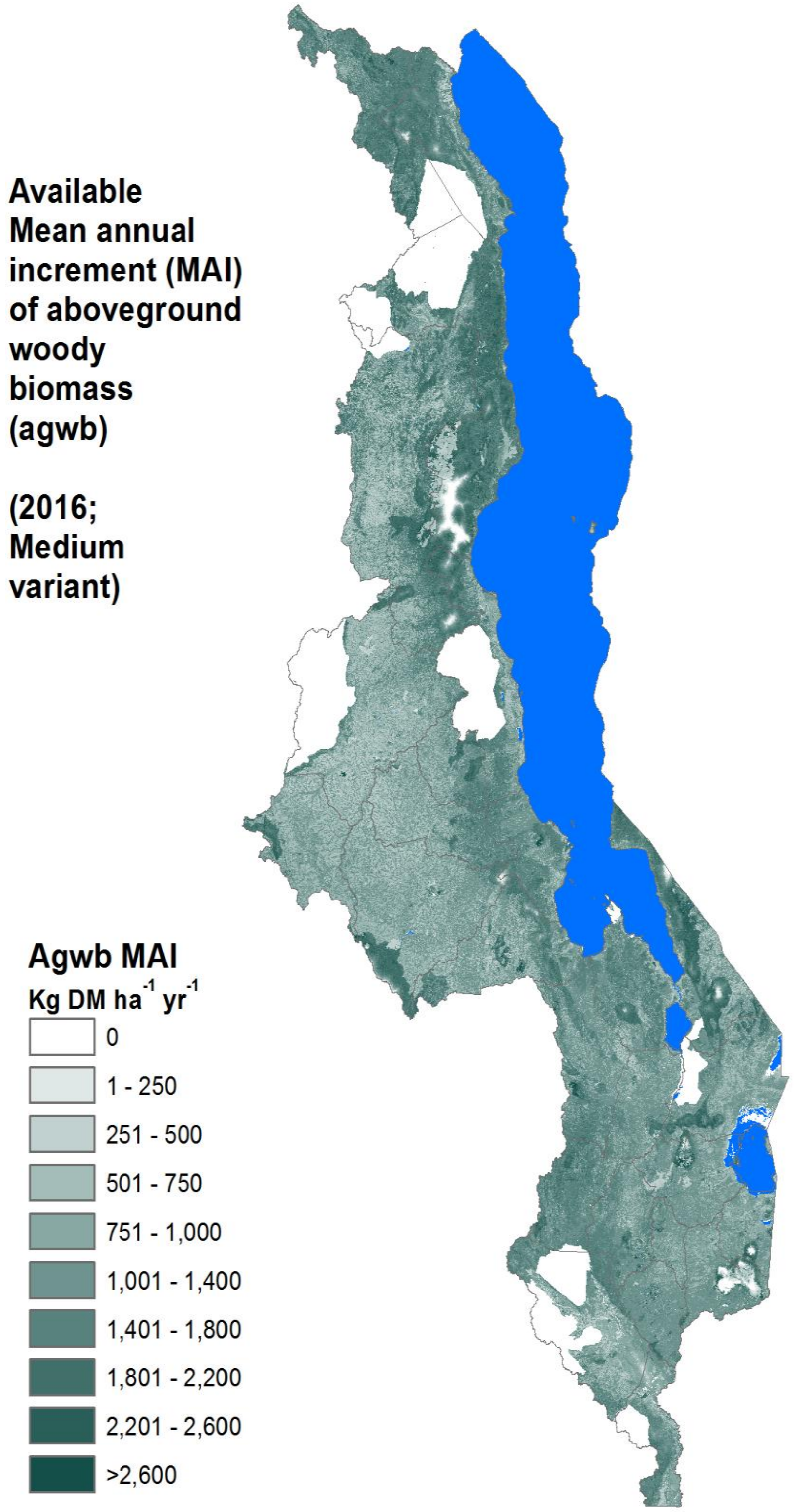


Figure 21. Map of Available Mean Annual Increment in 2016 (Medium Variant)

3.3 INTEGRATION MODULE RESULTS (2016)

Subtracting the Conventional Demand from the available MAI within a 5km local context produces the Local Balance, which tells whether the local resources are greater than the demand (local surplus conditions) or, on the contrary, are less than the demand (local deficit conditions). The Local Balance summary values for the three variants are presented in Table 11 and shown, for the medium variant, in the left-hand map of Figure 22. The Local Balance is useful in mapping the deficit areas and in quantifying the demand that, not being satisfied by the MAI of local resources, will originate: (i) the commercial harvesting of distant resources, and/or (ii) the unsustainable harvesting of local resources.

Table 11. Local Balance and Commercial Balance in 2016

AREA		LOCAL BALANCE			COMMERCIAL BALANCE -		
		Medium Variant	Minimum Variant	Maximum Variant	Medium Variant	Minimum Variant	Maximum Variant
Code	District	t DM yr^{-1}	t DM yr^{-1}	t DM yr^{-1}	t DM yr^{-1}	t DM yr^{-1}	t DM yr^{-1}
101	Chitipa	**413,789**	276,532	555,308	**405,592**	265,006	545,319
102	Karonga	**200,225**	90,578	303,775	**184,176**	76,773	282,100
103	Nkhata Bay	**439,960**	281,697	606,049	**417,995**	259,309	575,480
104	Rumphi	**206,228**	118,839	298,637	**182,731**	97,566	270,045
105	Mzimba	**627,832**	344,972	929,711	**572,299**	274,703	869,219
106	Likoma	**-3,615**	-5,489	-3,012	**-3,615**	-5,489	-3,012
107	Mzuzu City	**-165,057**	-169,454	-160,487	**-165,063**	-169,458	-160,494
201	Kasungu	**51,741**	-65,459	182,601	**0**	-92,030	79,129
202	Nkhotakota	**138,090**	48,119	226,202	**111,683**	28,061	183,688
203	Ntchisi	**57,231**	5,327	109,888	**51,184**	-2,840	94,672
204	Dowa	**-21,156**	-121,555	67,478	**-28,669**	-127,768	43,437
205	Salima	**58,951**	-21,228	137,838	**49,129**	-30,301	124,199
206	Lilongwe Rural	**-148,926**	-361,198	10,130	**-156,392**	-367,103	-24,600
207	Mchinji	**11,007**	-69,832	90,608	**2,514**	-73,416	48,810
208	Dedza	**97,550**	-24,096	216,534	**86,192**	-32,592	185,047
209	Ntcheu	**88,897**	-14,159	201,025	**74,283**	-25,108	165,394
210	Lilongwe City	**-705,117**	-714,626	-695,537	**-705,117**	-714,626	-695,537
301	Mangochi	**332,742**	122,907	545,391	**306,142**	92,424	504,114
302	Machinga	**71,145**	-17,148	163,755	**53,326**	-34,269	128,945
303	Zomba	**-63,120**	-141,012	8,546	**-72,287**	-144,008	-25,328
304	Chiradzulu	**-41,691**	-74,236	-17,550	**-41,693**	-74,237	-24,491
305	Blantyre Rural	**-75,983**	-148,416	-13,294	**-81,600**	-152,861	-26,757
306	Mwanza	**37,960**	13,607	62,678	**36,222**	7,380	61,665
307	Thyolo	**-58,193**	-137,171	-693	**-59,352**	-137,305	-18,338
308	Mulanje	**-34,746**	-108,533	18,310	**-46,148**	-116,257	-8,037
309	Phalombe	**6,682**	-26,361	43,193	**-685**	-29,911	17,022
310	Chikwawa	**77,501**	-21,434	173,151	**54,805**	-38,372	132,488
311	Nsanje	**51,207**	4,795	99,980	**40,813**	-4,786	79,740
312	Balaka	**7,616**	-51,810	68,478	**-2,693**	-61,733	46,148
313	Neno	**150,668**	94,728	209,326	**145,867**	85,341	205,589
314	Zomba City	**-50,878**	-52,289	-49,473	**-50,878**	-52,289	-49,473
315	Blantyre City	**-572,104**	-579,791	-564,117	**-572,107**	-579,791	-564,121
	Malawi	**1,186,437**	**-1,523,197**	**3,824,429**	**788,655**	**-1,879,987**	**3,042,062**

Note: The results of local balance analyses do not match exactly the supply and demand values presented in previous tables due to the local context of analysis, whereby the value in each pixel is made by the average of the values in the surrounding 5km.

The surplus areas indicate those areas that, having more resources than those locally demanded, may support the commercial harvesting needed to satisfy the demand from deficit areas. But for commercial harvesting, the surplus resources must be above an "economic" minimum to justify the time and cost of woodfuel production and transport to market sites. In order to account for this, the Commercial Balance was produced. The Commercial Balance is derived from the Local Balance by assigning 0 value to *local surplus areas* with sparse resources that are considered not suitable for commercial woodfuel production. The values of all deficit areas as well as surplus areas "suitable" for woodfuel production are exactly the same as the Local Balance. The difference between the Local Balance and the Commercial Balance can be seen in Figure 22 or by comparing the summary totals in Table 11 for the corresponding variants. Such difference, representing the "non-suitable" surplus, represents 10% of the total surplus of the Local Balance, Medium variant.

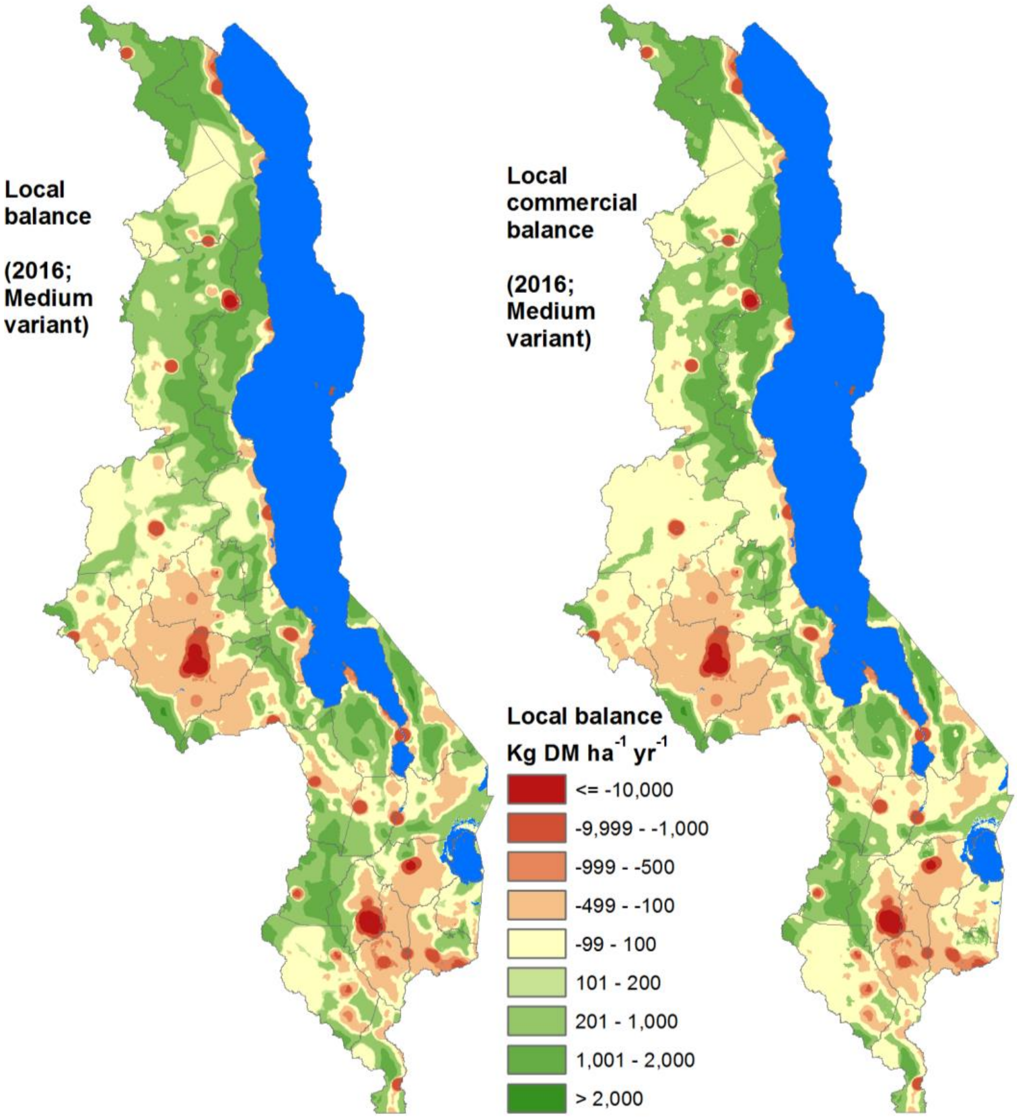


Figure 22. Map of Local Balance and Commercial Balance in 2016 (Medium Variant)

Positive values for the national totals for the Commercial Balance for the Medium variant (+788 kt DM) indicate that, in 2016, the country had sufficient resources to meet the demand. Although the margin is relatively small, the situation could be sustainable in principle if managed under SFM criteria.

According to the Minimum variant, where the national totals are negative, the demand cannot be met, not even if SFM is applied to all resources. The Maximum variant where the national surplus is wide appears to be the more optimistic case, indicating that resources are abundant and adequate to satisfy the demand.

The Commercial Balance provides a more practical representation of deficit and surplus conditions and supports the modeling of commercial harvesting in subsequent steps of analysis.

3.4 WOODSHED ANALYSIS AND EXPECTED DEGRADATION

The scope of the woodshed analysis is to understand how conditions of local deficit, i.e. demand for woodfuel that cannot be met by local resources, translate into commercial harvesting, and how such harvesting impacts the available resources.

As a first step towards this understanding, the map in Figure 23 shows the 14 major deficit sites and the expected commercial harvesting pressure determined by the combined effect of the demand exerted by such sites and the physical accessibility of local surplus areas that represent the resources of woody biomass suitable for commercial harvesting.

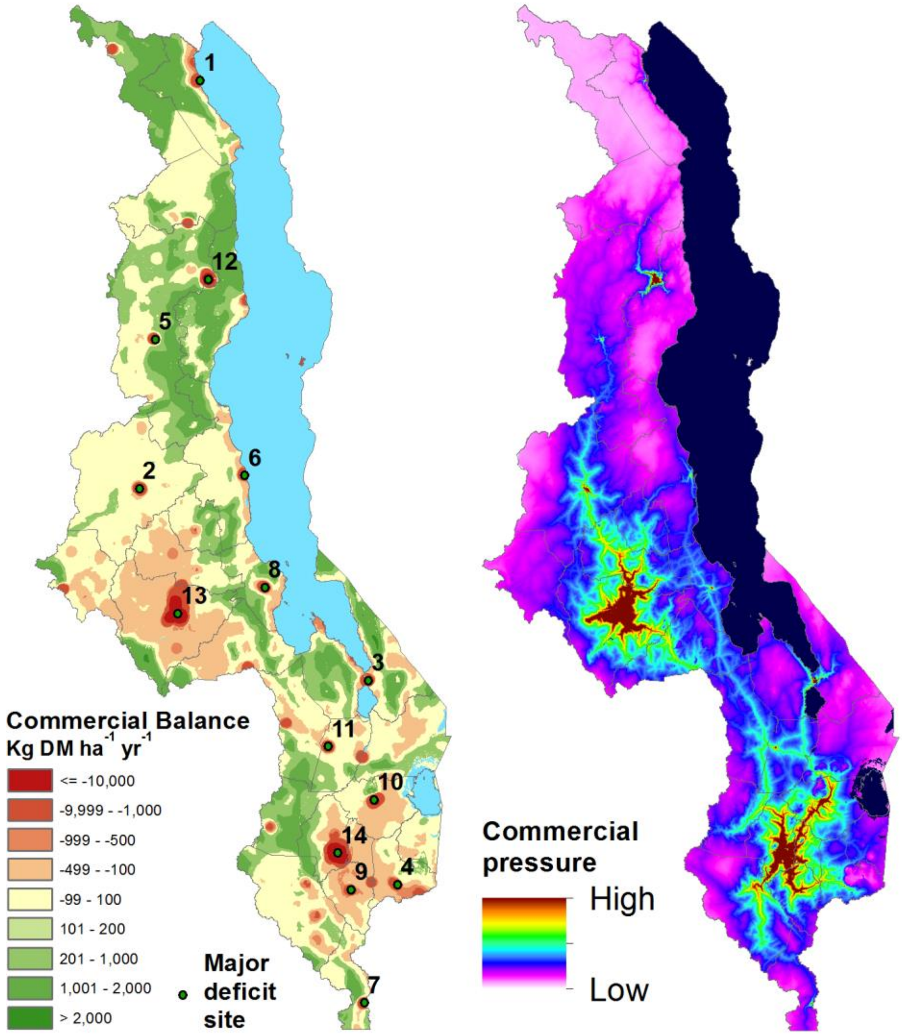


Figure 23. Location of the 14 Major Deficit Sites and Map of Commercial Harvesting Pressure (2016, Medium Variant)

From the map, it appears that the commercial demand is concentrated in the central and southern parts of the country, centered primarily around Lilongwe and Blantyre (Malawi's main woodfuel markets).

BAU SCENARIOS CONSIDERED

In this study, only BAU conditions are considered. However, uncertainties in reference data and alternative assumptions produced varying results that were combined to represent the most probable conditions, as well as the range of potential alternative conditions. The most probable variants and assumptions were used to define the Medium Variant. Alternative variants/assumptions appearing least favorable were combined to form the High Variant (high degradation scenario) while those appearing as most favorable were combined to form the Low Variant (low degradation scenario).

MINIMUM SUSTAINABLE WOODSHEDS

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 management criteria.* The map below (Figure 24) shows that the theoretical sustainable woodshed according to Medium Variant (medium supply and demand variants) is very large, covering almost the entire country.

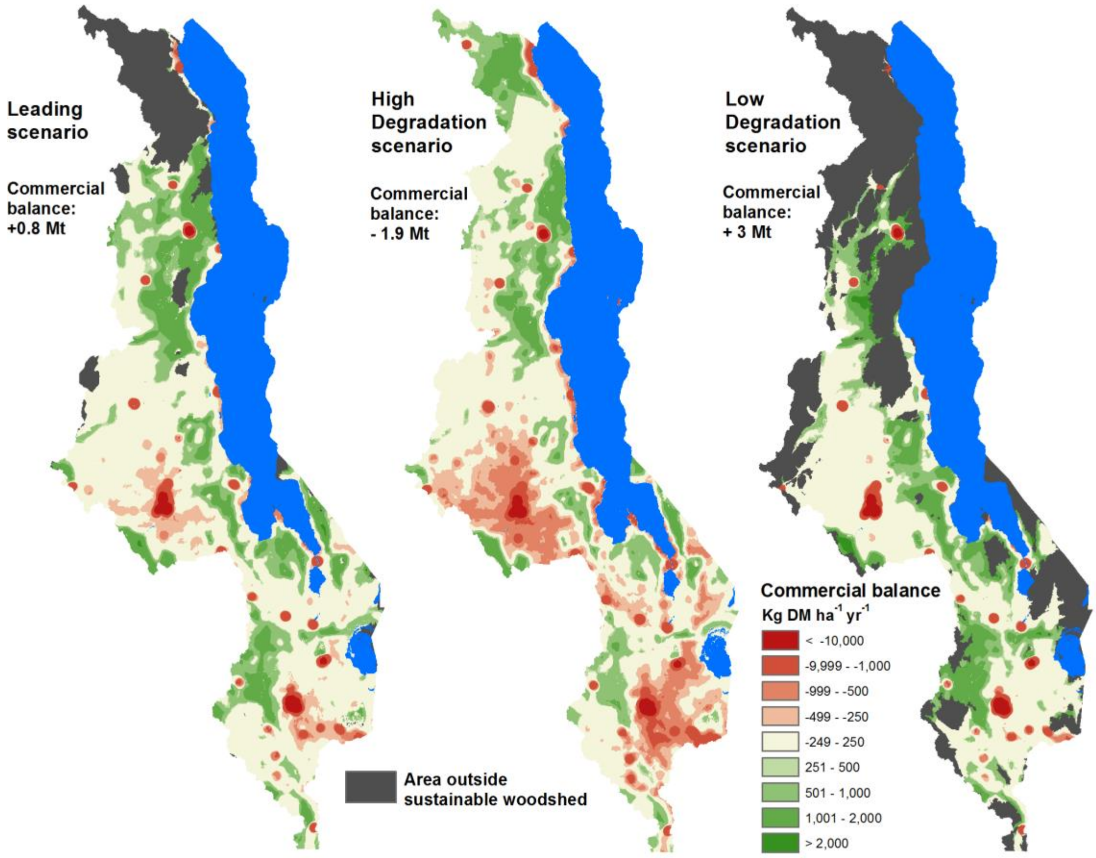


Figure 24. Minimum Sustainable Commercial Woodsheds for 2016 (according to Medium, High, and Low Variants)

The central and right-hand maps show the extremes represented by *least favorable* conditions (High Variant) and by the *most favorable* conditions (Low Variant). The central map, with a negative national commercial balance, shows no woodshed limits because the overall supply potential is smaller than the demand. The second one, with a relatively large commercial surplus, shows a much smaller sustainable woodshed.

These woodsheds are theoretical since they do not represent the actual harvesting areas, but they are important in indicating 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 for all resources, whether forests or otherwise. These areas deserve highest attention in order to prevent forest degradation due to excessive harvesting and guarantee the stable and economical supply of charcoal and wood products to the main market sites.

PROBABLE COMMERCIAL WOODSHEDS & EXPECTED DEGRADATION RATES

Taking a concrete perspective, we assume that current fuelwood harvesting practices are not guided primarily by principles of sustainable resource management. Demand pressure and the 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. Some factors influence the extent of the commercial harvesting area determined by transport constraints; other factors influence the response to local deficit conditions and the creation of commercial supply systems; and still more factors influence the intensity of commercial harvesting, such as the availability of deforestation by-products and overall resource management practices as discussed in detail in Section 2.5.3.

In the absence of statistically defined reference values for several such factors, alternative assumptions were made in this study, with the intent of representing the range of possible conditions. The reference values or assumptions made were hence combined according to their influence on the estimates of woodfuel-induced degradation rates, as discussed in Section 2.5.3.

The results presented hereafter make reference to all woody biomass sources and not only forests, since woodfuels and construction materials are produced from all landscapes with wood resources.

The degradation induced by excessive woodfuel production is here intended to correspond to unsustainable harvesting, and the quantity of woody biomass that is unsustainably harvested is a direct measure of degradation and may be used to estimate net CO_2 emissions. By referring to the whole landscape and not only forest resources, the impact of unsustainable harvesting should be termed *landscape degradation*.

For the sake of synthesis, the results are discussed only briefly and with reference exclusively to the national summary values. It should emphasized, however, that the WISDOM analysis is spatial and sub-national results are available for each and every parameter. In order to represent the spatial resolution of the study, the main results are presented as thematic maps and statistics are summarized at the district level.

EXPECTED DEGRADATION RATE IN 2016 (MEDIUM VARIANT)

The results of woodshed analysis for the Medium Variant are summarized in Table 12. The column "Total Harvesting" shows the distribution of woody biomass harvesting that produces the woodfuels and construction material necessary to satisfy the Conventional Demand (Medium variant). At the national level, total harvesting and total demand match[13], but at the district level (or any other sub-national level), they are different since the spatial distribution of harvesting and consumption are distinct (*cf*: Table 8). The "Sustainable Harvesting" column gives the fraction of total harvesting that is within the annual sustainable increment, which at the national level is 80% of total harvesting.

[13] The slight difference of 23 t DM between the Total Conventional Demand (8,699,271 t DM) and Total harvesting in Table 12 is due to the approximations multi-steps spatial processing.

Table 12. Expected Harvesting and Degradation Rate in 2016 (Medium Variant)

AREA		TOTAL HARVEST-ING	SUSTAIN-ABLE HARVEST ING	UNSUSTAI-NABLE LOCAL HARVEST-ING	UNSUSTAIN-ABLE COMMERCIAL HARVESTING	TOTAL UNSUSTAIN-ABLE HARVESTING	LCC BY-PRODUCT MD (ANNUAL, 2000-2010)	UNSUSTAIN-ABLE DIRECT HARVESTING (BP 60%)
Code	District	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1
101	Chitipa	137,235	126,974	-10,262	0	-10,262	1,536	-9,340
102	Karonga	165,481	152,462	-12,804	-215	-13,019	932	-12,460
103	Nkhata Bay	262,705	206,793	-7,419	-48,494	-55,912	63,223	-17,978
104	Rumphi	129,580	122,774	-3,557	-3,249	-6,806	6,629	-2,828
105	Mzimba	961,823	748,544	-13,087	-200,192	-213,279	75,170	-168,177
106	Likoma	5,294	1,679	-3,615	0	-3,615	0	-3,615
107	Mzuzu City	19,379	19,352	0	-27	-27	1,349	0
201	Kasungu	443,387	408,516	-11,298	-23,573	-34,871	10,664	-28,472
202	Nkhotakota	274,502	215,602	-10,502	-48,398	-58,900	6,281	-55,131
203	Ntchisi	247,807	178,609	-2,609	-66,589	-69,198	0	-69,198
204	Dowa	339,924	296,347	-18,097	-25,480	-43,577	1,186	-42,866
205	Salima	340,494	244,754	-10,250	-85,490	-95,740	221	-95,608
206	Lilongwe Rural	678,503	506,918	-86,834	-84,751	-171,585	7,504	-167,082
207	Mchinji	265,206	247,187	-16,935	-1,084	-18,019	530	-17,701
208	Dedza	483,598	370,363	-12,028	-101,206	-113,235	6,585	-109,284
209	Ntcheu	443,241	353,052	-6,768	-83,421	-90,189	6,669	-86,187
210	Lilongwe City	35,549	35,549	0	0	0	1,262	0
301	Mangochi	683,735	558,206	-27,909	-97,621	-125,529	13,100	-117,669
302	Machinga	332,681	274,243	-9,894	-48,543	-58,438	772	-57,975
303	Zomba	272,926	233,393	-29,506	-10,027	-39,533	4,382	-36,904
304	Chiradzulu	94,805	79,900	-14,905	0	-14,905	0	-14,905
305	Blantyre Rural	309,715	196,810	-47,379	-65,526	-112,905	2,885	-111,174
306	Mwanza	104,281	75,840	-1,678	-26,764	-28,441	0	-28,441
307	Thyolo	216,150	195,212	-20,248	-690	-20,938	895	-20,401
308	Mulanje	206,967	181,901	-20,950	-4,115	-25,066	22,069	-11,824
309	Phalombe	127,944	122,937	-2,466	-2,541	-5,007	0	-5,007
310	Chikwawa	353,014	278,160	-10,295	-64,559	-74,854	1,258	-74,099
311	Nsanje	142,271	123,529	-5,880	-12,862	-18,742	3,861	-16,425
312	Balaka	270,618	205,840	-12,717	-52,062	-64,778	2,477	-63,292
313	Neno	315,214	167,361	0	-147,853	-147,853	0	-147,853
314	Zomba City	5,031	5,031	0	0	0	0	0
315	Blantyre City	30,188	30,188	0	0	0	425	0
	Malawi	8,699,249	6,964,026	-429,891	-1,305,331	-1,735,222	241,862	-1,591,899

The unsustainable harvesting, expressed as negative values, is presented in two components: the "Unsustainable Local Harvesting" (within 5km from consumption sites) totaling -430 kt DM, and the "Unsustainable Commercial Harvesting" (over 5km from consumption sites) totaling -1,305 kt DM. The first represents primarily the impact of excessive fuelwood harvesting for rural households' demand. The second one represents primarily the impact of commercial fuelwood and charcoal production serving distant consumption sites. Combined, these two components give the "Total Unsustainable Harvesting" of -1,725 kt at national level, or 20% of total harvesting. The spatial distribution of the total unsustainable harvesting according to the Leading Scenario is shown in the larger map in Figure 25.

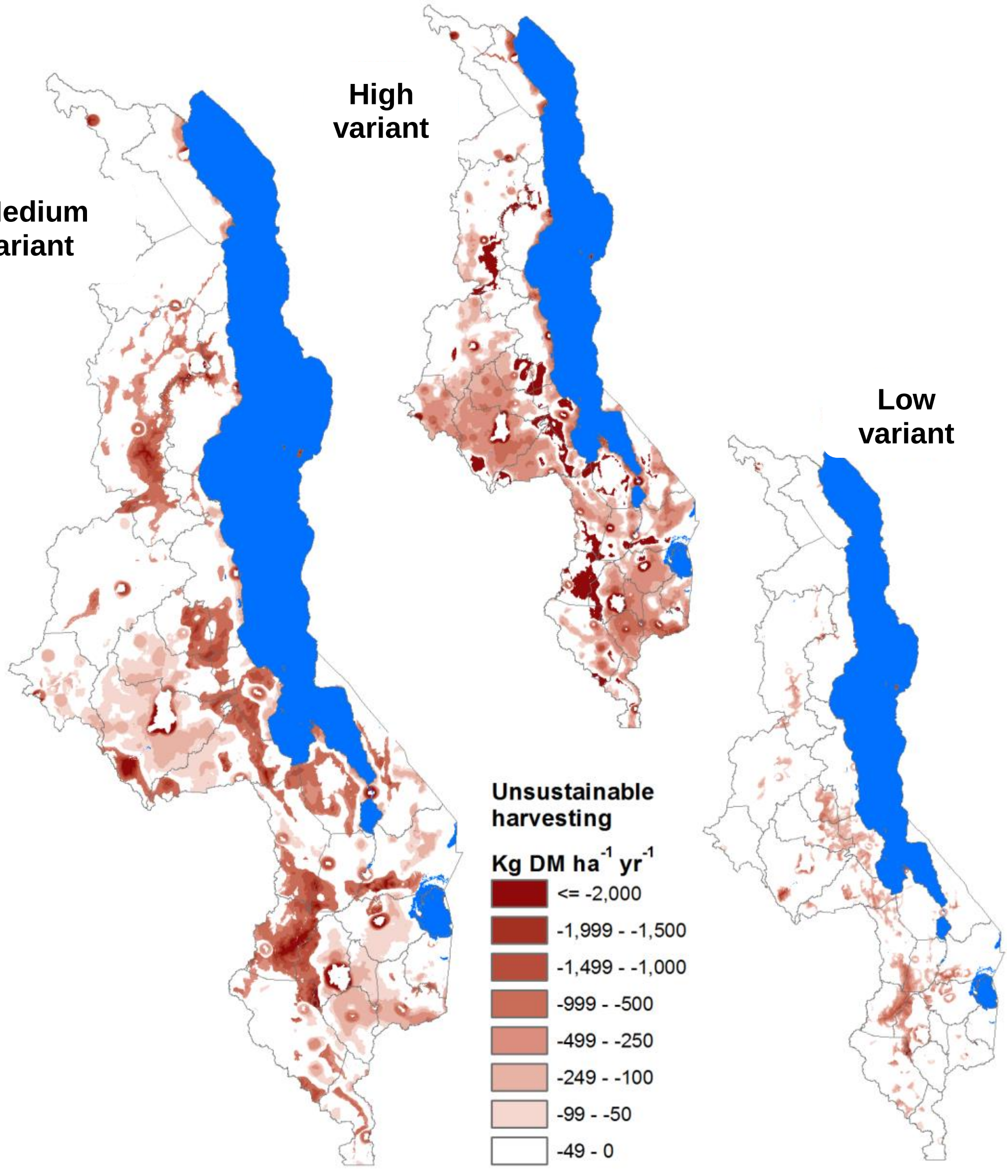


Figure 25. Map of Unsustainable Harvesting in 2016 (according to High, Medium, and Low Variants)

Part of the unsustainable harvesting, however, may be offset by LCC by-products becoming available. It is important to estimate what fraction of the total unsustainable harvesting represents true direct harvesting, and what fraction represents recycling of woody biomass already cut for land clearings for two reasons: (1) to avoid double-counting when reporting emissions from deforestation and forest degradation, and (2) to define the unsustainable direct harvesting that may be reduced by reducing woodfuels demand (the rest being due to land use change and not to excessive wood harvesting). Based on land use changes observed by district between 2000 and 2010, the annual deforestation by-products probably available in 2016 were estimated (second-to-last column) and, assuming that 60% of such woody biomass may be used as woodfuel or as construction material, the unsustainable direct harvesting was estimated for a total of -1,592 kt DM.

RANGE OF 2016 ESTIMATES: HIGH- & LOW-DEGRADATION SCENARIOS

The combination of least favorable data variants and assumptions (see Section 2.5.3) allowed to estimate harvesting intensities and unsustainable harvesting fractions of the High Variant are summarized in Table 13.

Table 13. Expected Harvesting and Degradation Rate in 2016 (High Variant)

AREA		TOTAL HARVEST-ING	SUSTAIN-ABLE HARVEST-ING	UNSUSTAIN-ABLE LOCAL HARVESTING	UNSUSTAIN-ABLE COMMERCIAL HARVESTING	TOTAL UNSUSTAIN-ABLE HARVESTING	LCC BY-PRODUCT MN (ANNUAL, 2000-2010)	UNSUSTAIN-ABLE DIRECT HARVESTING (BP 60%)
Code	District	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1
101	Chitipa	147,057	132,577	-14,026	-454	-14,480	1,442	-13,831
102	Karonga	182,935	130,284	-45,885	-6,766	-52,651	880	-52,255
103	Nkhata Bay	264,288	167,568	-20,973	-75,748	-96,720	45,094	-76,428
104	Rumphi	132,217	118,293	-13,591	-333	-13,924	6,062	-11,197
105	Mzimba	932,035	595,174	-52,401	-284,460	-336,861	56,346	-311,505
106	Likoma	6,608	1,119	-5,489	0	-5,489	0	-5,489
107	Mzuzu City	15,093	15,087	0	-6	-6	1,170	0
201	Kasungu	457,606	355,612	-62,316	-39,678	-101,994	4,575	-99,935
202	Nkhota-kota	304,581	168,246	-43,746	-92,590	-136,335	6,234	-133,530
203	Ntchisi	268,067	143,576	-18,492	-105,999	-124,491	0	-124,491
204	Dowa	344,360	242,202	-85,011	-17,148	-102,158	507	-101,930
205	Salima	398,186	194,287	-40,097	-163,802	-203,899	10	-203,894
206	Lilongwe Rural	823,242	395,030	-242,706	-185,506	-428,212	2,540	-427,069
207	Mchinji	296,859	207,516	-89,331	-12	-89,343	15	-89,337
208	Dedza	526,317	282,702	-66,092	-177,524	-243,615	1,878	-242,770
209	Ntcheu	435,168	275,304	-43,685	-116,179	-159,864	1,716	-159,092
210	Lilongwe City	27,789	27,789	0	0	0	1,052	0
301	Mangochi	642,725	446,925	-91,227	-104,574	-195,800	12,394	-190,223
302	Machinga	365,162	229,714	-52,570	-82,878	-135,448	790	-135,092
303	Zomba	296,596	186,757	-94,659	-15,180	-109,839	487	-109,620
304	Chiradzulu	109,960	63,168	-46,792	0	-46,792	0	-46,792
305	Blantyre Rural	355,512	148,713	-113,158	-93,641	-206,799	1,235	-206,243
306	Mwanza	104,035	57,100	-5,616	-41,319	-46,935	0	-46,935
307	Thyolo	242,238	154,934	-87,304	0	-87,304	311	-87,164
308	Mulanje	229,502	145,818	-79,199	-4,485	-83,684	14,250	-77,271
309	Phalombe	128,789	102,495	-21,893	-4,401	-26,294	0	-26,294
310	Chikwawa	371,307	216,151	-51,804	-103,352	-155,156	1,777	-154,356
311	Nsanje	133,759	98,840	-23,741	-11,179	-34,919	4,120	-33,065
312	Balaka	257,303	165,458	-42,949	-48,896	-91,845	3,003	-90,494
313	Neno	446,478	126,911	-386	-319,181	-319,567	0	-319,567
314	Zomba City	3,846	3,846	0	0	0	0	0
315	Blantyre City	23,384	23,384	0	0	0	108	0
	Malawi	9,273,004	5,622,580	-1,555,136	-2,095,289	-3,650,424	167,994	-3,575,870

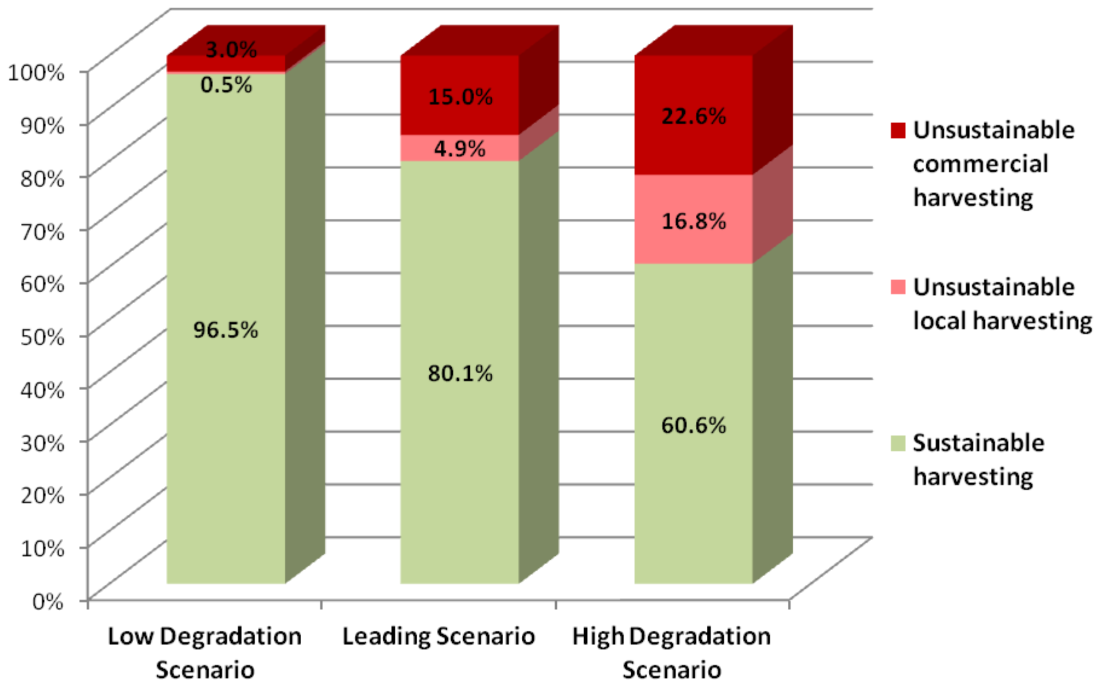
According to this (pessimistic) scenario, only 61% of the total harvesting in 2016 was sustainable and the Total Unsustainable Harvesting was -3,650 kt DM, or 39% of total harvesting, the distribution of which is shown in Figure 26. The direct unsustainable harvesting after deduction of LCC by-products is estimated to be -3,576 kt DM in this scenario.

Based on most favorable data variants and assumptions, the results relative to the Low Variant are summarized in Table 14. According to this (optimistic) scenario, almost 97% of the total harvesting in 2016 was sustainable and the Total Unsustainable Harvesting was only -2886 kt DM, or 3.5 % of total harvesting, the distribution of which is also shown in Figure 26. The direct unsustainable harvesting after deduction of LCC by-products is estimated to be -196 kt DM in this scenario.

Table 14. Expected Harvesting and Degradation Rate in 2016 (Low Variant)

AREA		TOTAL HARVESTING	SUSTAINABLE HARVESTING	UNSUSTAINABLE LOCAL HARVESTING	UNSUSTAINABLE COMMERCIAL HARVESTING	TOTAL UNSUSTAINABLE HARVESTING	LCC BY-PRODUCT MN (ANNUAL, 2000-2010)	UNSUSTAINABLE DIRECT HARVESTING (BP 60%)
Code	District	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1	t DM yr-1
101	Chitipa	125,547	121,581	-3,966	0	-3,966	1,657	-2,724
102	Karonga	162,868	162,023	-845	0	-845	987	-105
103	Nkhata Bay	261,218	256,327	-1,872	-3,019	-4,891	81,422	0
104	Rumphi	141,626	140,681	-944	-1	-945	7,226	0
105	Mzimba	949,441	935,205	-1,153	-13,083	-14,237	95,417	0
106	Likoma	5,279	2,267	-3,012	0	-3,012	0	-3,012
107	Mzuzu City	23,808	23,789	0	-19	-19	1,594	0
201	Kasungu	441,907	434,734	-847	-6,325	-7,173	17,270	0
202	Nkhota-kota	261,793	258,691	-658	-2,444	-3,102	6,420	0
203	Ntchisi	216,769	198,981	-50	-17,738	-17,788	0	-17,788
204	Dowa	343,917	331,236	-530	-12,151	-12,681	1,863	-11,284
205	Salima	302,836	286,873	-662	-15,301	-15,963	2,334	-14,212
206	Lilongwe Rural	608,116	585,832	-7,092	-15,192	-22,284	13,987	-11,794
207	Mchinji	258,629	258,224	-404	0	-405	1,523	0
208	Dedza	437,577	419,560	-185	-17,833	-18,017	12,612	-8,558
209	Ntcheu	412,584	395,490	-259	-16,835	-17,094	13,650	-6,856
210	Lilongwe City	43,427	43,427	0	0	0	1,673	0
301	Mangochi	651,643	644,031	-4,289	-3,323	-7,612	13,869	0
302	Machinga	307,573	294,869	-129	-12,575	-12,704	756	-12,137
303	Zomba	265,970	256,125	-2,190	-7,655	-9,845	9,931	-2,397
304	Chiradzulu	91,131	90,158	-973	0	-973	0	-973
305	Blantyre Rural	267,061	232,024	-4,552	-30,485	-35,037	4,906	-31,358
306	Mwanza	92,683	91,010	-113	-1,561	-1,673	0	-1,673
307	Thyolo	220,936	219,329	-821	-786	-1,607	1,556	-440
308	Mulanje	208,810	206,667	-1,667	-476	-2,143	31,025	0
309	Phalombe	127,121	126,923	-3	-195	-198	0	-198
310	Chikwawa	342,572	325,783	-632	-16,157	-16,789	770	-16,212
311	Nsanje	144,269	142,770	-820	-679	-1,499	3,610	0
312	Balaka	251,755	232,469	-1,031	-18,255	-19,286	2,031	-17,763
313	Neno	241,250	205,074	0	-36,176	-36,176	0	-36,176
314	Zomba City	6,216	6,216	0	0	0	0	0
315	Blantyre City	37,317	37,317	0	0	0	810	0
	Malawi	8,253,648	7,965,681	-39,702	-248,264	-287,966	328,897	-195,661

The national summaries of total harvesting and their sustainable/unsustainable components for the three scenarios considered are shown in the graph in Figure 26.



Note: The total harvesting here represented refers to the Conventional Demand and therefore marginal fuelwood harvesting is excluded.

Figure 26. Total Harvesting in 2016 According to Medium Variant and High- and Low-Degradation Scenarios

3.5 PROJECTION TO 2021 OF WOODFUELS DEMAND, SUPPLY, AND EXPECTED DEGRADATION (BAU SCENARIOS)

The results of the projected analysis to 2021 and the trends from 2016 to 2021 are presented by six broad geo-administrative regions built on aggregations of districts, as described in Section 2.6.4 above.

The demand in the residential and non-residential sectors projected to 2021 vis-à-vis the values estimated for 2016 is shown in Table 15. Urban charcoal demand is growing much faster than any other item, with an annual increase of 9.9%. The decreased urban demand for fuelwood counterbalances this partially, with an annual -5.2%. Charcoal demand in rural areas remains somewhat moderate but, with a 4.2% increase annually and the size of rural population, is likely to dominate national demand trends in the near future. Rural fuelwood demand is expected to increase annually by "only" 3% (slightly less than the annual rural population growth of 3.1% [NSO 2009]), representing a growth in demand by over 1 Mt DM over the five-year period.

The Total Demand, including marginal and conventional wood assortments, increases from 11.2 to 13.3 Mt DM with an annual growth rate of 3.7%.

Table 15. Residential and Non-Residential Demand in 2016 and 2021

AREA		RURAL CHARCOAL		RURAL FUELWOOD		URBAN CHARCOAL		URBAN FUELWOOD	
		2016	2021	2016	2021	2016	2021	2016	2021
Group 1		kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}
10	North	181	220	1,044	1,204	221	340	48	36
21	Centre_west	208	256	2,182	2,557	582	901	210	162
22	Centre_east	152	184	1,106	1,257	32	43	41	28
31	South_east	147	184	722	852	24	34	41	29
32	South_middle	299	348	1,423	1,568	583	841	163	119
33	South_west	151	184	454	524	15	20	25	17
	Malawi	1,139	1,376	6,930	7,963	1,457	2,179	528	392
	Annual % Change		4.2		3.0		9.9		-5.2

AREA		CONSTRUCTION MATERIAL		TOTAL RESIDENTIAL DEMAND		NON-RESIDENTIAL DEMAND		TOTAL DEMAND	
		2016	2021	2016	2021	2016	2021	2016	2021
Group 1		kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}
10	North	25	29	1,520	1,830	133	163	1,652	1,993
21	Centre_west	56	66	3,238	3,942	294	365	3,531	4,307
22	Centre_east	26	29	1,357	1,542	82	95	1,439	1,638
31	South_east	20	24	954	1,123	89	109	1,043	1,231
32	South_middle	48	54	2,515	2,929	335	394	2,850	3,323
33	South_west	13	15	658	760	34	37	692	798
	Malawi	187	218	10,241	12,127	966	1,164	11,207	13,290
	Annual % Change		3.3		3.7		4.1		3.7

The Conventional Demand in 2016 and 2021, obtained by removing the estimated fraction of marginal fuelwood assortments from the Total Demand, is presented in Table 16 for the three variants considered. The marginal fuelwood is estimated to be 23% of the Total Demand for the Medium marginal variant and 18.5 % or 25.6% for the Minimum and Maximum marginal variants, respectively. The Conventional Demand is then combined with supply layers for subsequent phases of analysis.

Table 16. Conventional Demand in 2016 and 2021

AREA		CONVENTIONAL DEMAND					
		Medium Marginal Variant (*)		Minimum Marginal Variant (*)		Maximum Marginal Variant (*)	
		2016	2021	2016	2021	2016	2021
Group 1		kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}
10	North	1,409	1,688	1,483	1,771	1,329	1,618
21	Centre_west	2,659	3,234	2,855	3,431	2,523	3,098
22	Centre_east	1,071	1,192	1,150	1,270	998	1,142
31	South_east	805	923	853	979	757	886
32	South_middle	2,220	2,599	2,365	2,746	2,143	2,562
33	South_west	534	602	567	636	505	584
	Malawi	8,699	10,238	9,273	10,834	8,254	9,891
	Annual % Change		3.5		3.4		4.0

(*) Three variants are presented relative to Medium, Minimum and Maximum marginal variants resulting from the RFAS.

The stock and the potentially available MAI of aboveground woody biomass is presented in Table 17 for three variants. The stock is summarized for year 2010 (year of latest land cover map) and for year 2021, while the available MAI is summarized for 2016 and 2021. The annual change rate for stock resulted to be -0.76% and for the Available MAI -0.8%, both referring to the Medium variant.

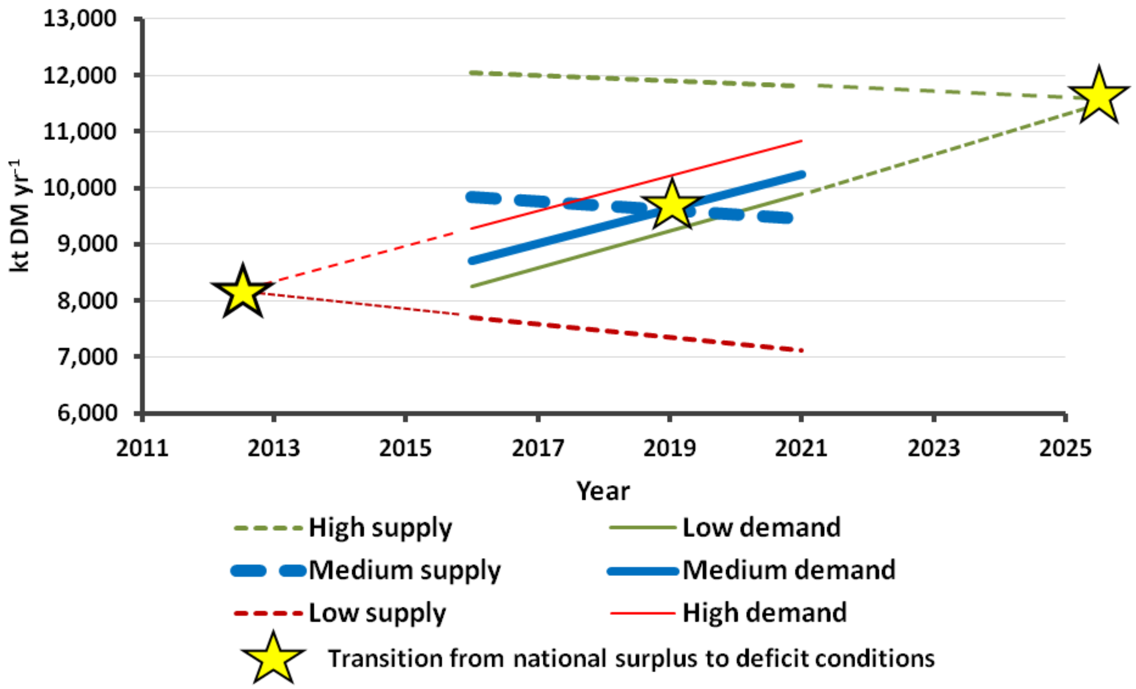
Table 17. Stock (2010-2021) and Available MAI (2016-2021)

AREA		ABOVEGROUND WOODY BIOMASS STOCK					
		Medium Variant		Minimum Variant		Maximum Variant	
		2010	2021	2010	2021	2010	2021
Group I		Mt DM	Mt DM	Mt DM	Mt DM	Mt DM	Mt DM
10	North	154	142	133	121	175	163
21	Centre_west	58	54	55	45	61	60
22	Centre_east	56	51	51	42	61	60
31	South_east	43	40	40	36	46	45
32	South_middle	35	31	31	23	39	37
33	South_west	34	31	31	24	37	36
	Malawi	381	349	340	290	421	401
Annual % Change			-0.76		-1.34		-0.43

AREA		AVAILABLE MAI					
		Medium Variant		Minimum Variant		Maximum Variant	
		2016	2021	2016	2021	2016	2021
Group I		kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}
10	North	3,127	3,015	2,418	2,316	3,858	3,740
21	Centre_west	1,915	1,840	1,536	1,392	2,301	2,271
22	Centre_east	1,426	1,361	1,113	1,008	1,748	1,723
31	South_east	1,187	1,156	934	893	1,446	1,433
32	South_middle	1,341	1,270	1,046	921	1,642	1,604
33	South_west	850	809	657	588	1,048	1,032
	Malawi	9,846	9,451	7,705	7,117	12,043	11,803
Annual % Change			-0.80		-1.53		-0.40

By referring both demand estimates and supply estimates to the same axis, the graph in Figure 27 provides an interesting synopsis of the trends of demand and supply in Malawi. The lines representing the Medium supply and demand variants (Medium Variant, in blue) show how the supply that was greater than demand in 2016 becomes smaller than demand in 2021. The central star indicates the moment of transition from a condition of national surplus to that of deficit, a very crucial transition that appears to happen in 2019. This means that no matter how well Malawi manages the remaining resources, the country cannot entirely meet the growing demand; it also means that, from now on, the impact is likely to worsen rapidly as the gap between the demand and the sustainable supply potential widens.

In order to evaluate alternative scenarios, the supply and demand variants may be combined to estimate the worst conditions (High Variant) and the best conditions (Low Variant). By extending backwards the Low supply and High demand variants we can extrapolate that the transition from national surplus to national deficit in the High Variant has taken place in 2012. On the opposite side, by extending forward the High supply and Low demand variants, we can extrapolate that such transition in the Low Variant is likely to occur in 2025.



Note: The supply lines refer to the Available MAI for the Maximum Variant (High supply), Medium Variant (Medium supply), and Minimum Variant (Low supply) for 2016 and 2021. The Demand lines refer to the Conventional Demand for the Maximum marginal variant (Low demand), Medium marginal variant (Medium demand) and Minimum marginal variant (High demand) for 2016 and 2021.

Figure 27. Trends of Demand and Supply in Malawi

The elaboration of the Local Balance and Commercial Balance gives a detailed estimation and mapping of the change occurring between the available MAI and the Conventional Demand, as summarized in Table 18. Confirming what could be seen in the previous graph for the Medium variant, the Local Balance goes from a national surplus of 1.2 Mt DM in 2016 to a deficit of -0.7 Mt DM in 2021. Slightly worse, the Commercial Balance goes from a surplus of 0.8 Mt DM to a deficit of -1.1 Mt DM. As may be expected, the areas suffering the highest deficit are Centre-West and South-Middle, where the growing urban demand is concentrated.

Table 18. Supply/Demand Balance in 2016 and in 2021

AREA		LOCAL BALANCE MD VARIANT (MEDIUM VARIANT)		COMMERCIAL BALANCE MD VARIANT (MEDIUM VARIANT)	
		2016	2021	2016	2021
Group 1		kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}
10	North	1,719	1,331	1,594	1,203
21	Centre_west	-755	-1,404	-836	-1,461
22	Centre_east	383	198	321	145
31	South_east	404	261	359	221
32	South_middle	-882	-1,330	-927	-1,362
33	South_west	317	208	278	165
Malawi		1,186	-735	789	-1,088

In order to provide a detailed view of the change of the Commercial Balance in Malawi over the period 2016–2021, Figure 28 shows the Commercial Balance maps for 2016 and 2021 for the Medium Variant as well as the map of the differences between the two situations. The map at far right shows various levels of decrease of the Commercial Balance, which represent the deepening of deficit conditions or the reduction of surplus.

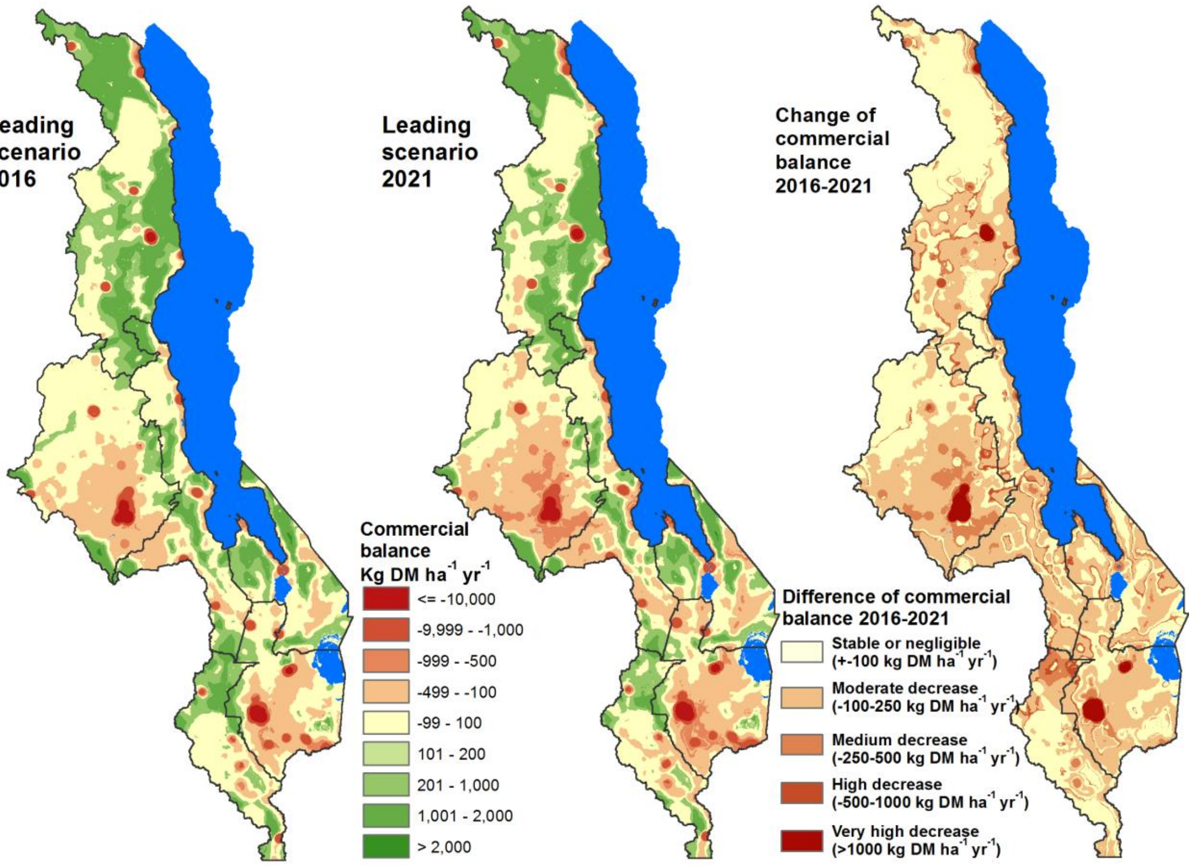


Figure 28. Commercial Balance in 2016 and 2021

A very high decrease is observed in and around major urban sites, mostly as deepening of deficit conditions. Due to the impact of excessive harvesting, the most accessible regions of forests and woodlands show a medium to high decrease, representing a sharp reduction of initial surplus conditions. A moderate decrease is then widely spread over the whole populated landscape simply as the effect of increased local demand due to population growth.

It is important to emphasize once more that the balance tells the relation between the total sustainable supply potential and the demand, and not the actual situation generated by current harvesting practices. In practice, the balance value could be representative of the real situation only if all resources of the country are managed under strict sustainable management criteria. The probable situation and the true impact due to current harvesting practices are modeled through woodshed analysis and an estimation of sustainable and unsustainable harvesting, the latter representing the annual degradation induced by excessive harvesting.

The total unsustainable harvesting for 2016 and 2021 are summarized in Table 19 for the three scenarios considered. In the Medium Variant, the total unsustainable harvesting has increased from 1.7 Mt DM to 2.7 Mt DM in five years.

Table 19. Total Unsustainable Harvesting in 2016 and 2021

AREA		TOTAL UNSUSTAINABLE HARVESTING					
		Medium Variant		High Variant		Low Variant	
		2016	2021	2016	2021	2016	2021
Group 1		kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}
10	North	303	724	520	1,159	28	129
21	Centre_west	337	477	846	1,096	60	158
22	Centre_east	358	495	744	979	54	169
31	South_east	184	309	331	627	20	61
32	South_middle	283	347	653	755	69	114
33	South_west	270	344	557	557	56	130
	Malawi	1,735	2,696	3,650	5,174	288	760
5-year % Change			55.4		41.7		163.8

The distribution of the total unsustainable harvesting and hence of degradation is summarized by district group in the Table 19 and spatially represented in Figure 29, which maps for the Medium Variant the Total unsustainable harvesting in 2016 and 2021 as well as the change between the two.

The unsustainable harvesting appears to increase with particular intensity in the southern part of North Region, where abundant resources are located that are relatively well accessible from the major market sites of the Central Region. The yellow areas, where the unsustainable harvesting appears to be reduced represent the areas where the stock is in good part depleted due to recurrent harvesting.

By comparing the Total Unsustainable harvesting to the Conventional Demand shown in Table 16 above we can estimate the non-renewable biomass fraction (fNRB) relative to the Conventional Demand in Malawi, an important parameter in climate change reporting and in the estimation of GHG emissions. For the Medium Variant the fNRB increase from 20 to 26% between 2016 and 2021. For the High Variant the fNRB values increase from 39 to 48%, while for the Low Variant they increase from 3.5 to 8%.

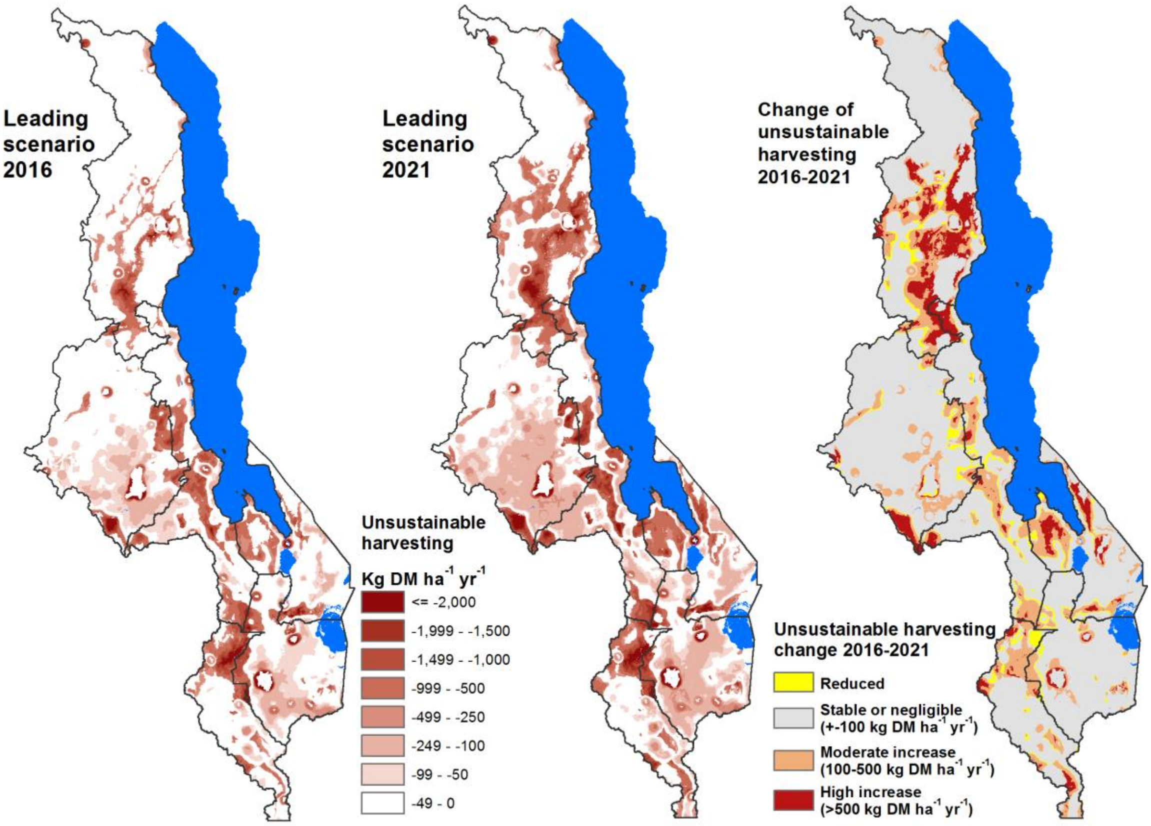


Figure 29. Maps of Unsustainable Harvesting in 2016 and 2021 and Five-Year Change

Table 20 summarizes the fraction of unsustainable harvesting that is estimated to be directly harvested, thus excluding the woody biomass coming from LCC by-products. In the Medium Variant, the direct unsustainable harvesting increased from 1.6 to 1.8 Mt DM between 2016 and 2021[14]. In the High Variant, the direct unsustainable harvesting increased from 3.6 to 4.4 Mt DM, while for the Low Variant the increase is from 196 to 291 kt DM.

Table 20. Direct Unsustainable Harvesting in 2016 and in 2021

AREA		DIRECT UNSUSTAINABLE HARVESTING					
		Medium Variant		High Variant		Low Variant	
		2016	2021	2016	2021	2016	2021
Group 1		kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}	kt DM yr^{-1}
10	North	214	238	471	695	6	4
21	Centre_west	325	400	843	1,044	41	64
22	Centre_east	346	405	739	923	30	74
31	South_east	176	235	325	575	12	0
32	South_middle	264	247	644	691	53	88
33	South_west	267	282	554	515	54	61
	Malawi	1,592	1,807	3,576	4,442	196	291
5-year % Change			13.5		24.2		48.7

[14] In 2021 the difference between Total and Direct unsustainable harvesting (2.7 vs 1.8 Mt DM) is much greater than in 2016 (1.7 vs 1.6 Mt DM) because the annual deforestation rate used for the 2021 analysis (based on Hansen et al, 2018) appears to be much higher than that used for 2016 estimate (based on FAO 2000-2010).

As a final overview, the graph in Figure 30 shows the change in Total Demand, including marginal and conventional wood assortments, the latter divided into sustainable/unsustainable fractions according to the Medium Variant. According to this scenario the conventional demand fraction is relatively stable, being 77.6% of the total demand in 2016 and 77% in 2021. What changes sharply is the unsustainably sourced component of the conventional demand, which grows from 15.5% in 2016 to 20.3% in 2021.

As discussed earlier, the marginal fuelwood was excluded from the analysis of sustainability because the productivity of its sources is not included in the conventional MAI parameters and is largely unknown. Nevertheless, marginal fuelwood represents a significant part of the total demand (22.4% in 2016 and 23% in 2021) and the impact on its sources may be serious although certainly different from that of conventional woodfuels and so far undetermined.

The open questions are: How sustainable is the use of marginal fuelwood in rural areas? What impact has the intensive use marginal of woody biomass for energy on soil fertility and nutrients' cycle?

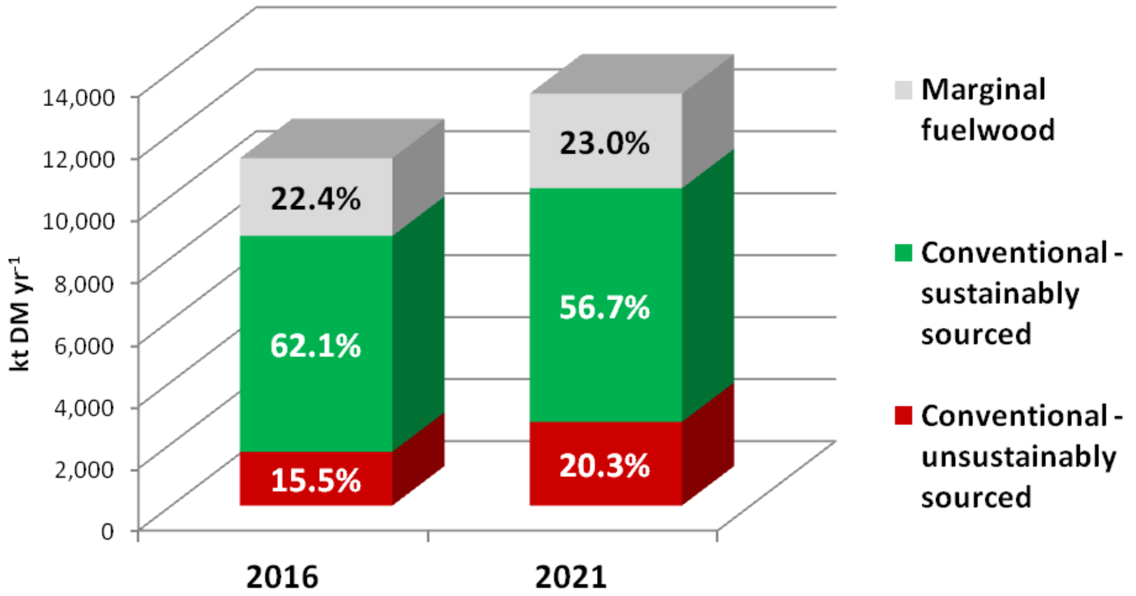


Figure 30. Total Demand in 2016 and 2021 by its Main Components (Medium Variant)

4.0 HOW COULD WISDOM CONTRIBUTE TO PLANNING REMEDIAL ACTIONS TO REDUCE THE GAP AND MITIGATE DEGRADATION?

The statistical and cartographic layers of WISDOM may contribute to formulate remedial strategies and policies and to define the lines of intervention by:

- providing quantitative and geo-referenced *targets* to remedial actions;
- supporting the estimation of the *scope and impact of the lines of intervention*;
- defining the most promising *blend of interventions*; and
- *locally tailoring* remedial actions.

DEFINITION OF TARGET

The analyses at years 2016 and 2021 provide us with several quantitative and spatially explicit parameters relative to various BAU scenarios, with the Medium Variant representing the most probable situation[15]. What year could be taken as reference and which parameter could be used as a target for the definition of remedial policies and strategies? Year 2021 may be preferable, as it allows for taking into account conditions likely to exist by the time policies actually begin to show an impact. The goals of any national sustainability policy can be qualitative or quantitative, and can contain a number of discrete objectives. This study does not attempt to propose a particular metric for measuring woodfuel policy, but it does present several that have not been previously available in Malawi and that provide a more objective measure of the actual impact on the sustainability of the resource. Most simply, we could pick the national deficit of 1.1 Mt DM shown by the 2021 commercial balance (Medium Variant), but bridging that gap would eliminate the degradation only if all resources are managed under strict sustainable management practices, which is an unrealistic assumption in the medium term. A more sensible target might be the 2.7 Mt DM of total unsustainable harvesting estimated in 2021[16]. For the purposes of the following discussion, we take this 2.7 Mt DM as a basis for exploring the cumulative impact of various lines of interventions to meeting this target.

SCOPE AND IMPACT OF INTERVENTIONS

In building the supply and demand modules of WISDOM, all key factors related to per capita consumption, number and distribution of users, stove efficiencies, charcoal yields, biomass stock and productivities, current tree cover, etc. are defined. These same parameters are essential for the estimation of the expected impact of interventions per unit of action, such as fuel replaced, stove upgraded, improved charcoal making, hectares planted or put under SFM, or tree cover increase in farmlands.

When assessing the potential impact of the interventions, it is also necessary to consider the time it takes before benefits are realized. Some actions have an immediate effect, such as fuel replacement or adoption of improved stoves, but other actions need time to show results, such as SFM,

---

15 The High- and Low-Degradation Scenarios represent the estimates due to combination of least and most favorable data variants and assumptions, respectively. The may be considered as pessimistic and optimistic BAU scenarios.

16 The 2.7 Mt of unsustainable harvesting includes the direct harvesting (1.8 Mt) and the use of by-products of deforestation (0.9 Mt) that substitute direct harvesting. It may be assumed, however, that if deforestation is stopped the whole amount would come from unsustainable direct harvesting.

establishment of new plantations, or increasing tree cover in farmlands. For these interventions, 10-15 years may be considered the minimum time needed to obtain tangible results.

BLEND OF INTERVENTIONS

It is evident that such ambitious target cannot be achieved through a single intervention at national level. The remedial strategy will need simultaneous implementation of several lines of intervention.

LOCALLY TAILORING REMEDIAL ACTIONS

Given the diverse situations existing in different parts of the country as evidenced by this spatial analysis, it is essential that the final planning of remedial actions be locally tailored, selecting from the basket of all possible solutions/interventions those that are best adapted to local conditions and needs.

4.1 PRIORITY AREAS OF INTERVENTION

In formulating an operational remedial strategy, each line of intervention must be carefully evaluated in terms of feasibility, cost efficiency, interactions with other interventions, and synergies with ongoing activities. Such thorough evaluation, which is an essential prerequisite for sound policy formulation and strategic planning, is a demanding task that is beyond the scope of this study. This study therefore does not intend to provide any recommendations for specific policy actions.

Nonetheless, it is still a useful exercise to explore how WISDOM data can help to develop and evaluate a hypothetical suite of policies, and to proceed with a preliminary illustrative review of the most promising lines of intervention vis-à-vis a target of avoiding 2.7 Mt DM of annual degradation by 2021.

In the identification of the main lines of intervention, reference is made to the pillars of action identified in the NCS 2017–2027 (Ministry of Natural Resources, Energy, and Mining, 2017). Specifically, the actions considered and their relation to the NCS Pillars are presented in Table 21.

The scope of this section is to review, using WISDOM's analytic context, how these lines of intervention may contribute, individually and in combination, by reducing demand or increasing supply, to prevent the annual degradation of 2.7 Mt DM estimated for year 2021. Keeping this as target of possible actions, the specific interventions in the demand and supply sectors were considered and their individual contributions were preliminarily estimated.

Table 21. Pillars of the National Charcoal Strategy and WISDOM Contributions

NCS PILLARS	WISDOM CONTRIBUTION TO ASSESSING THE IMPACT OF INDIVIDUAL LINES OF INTERVENTION
Actions aiming at REDUCING the DEMAND	
Pillar 1: Promote Alternative Household Cooking Fuels.	Estimate the reduction of the demand for woody biomass resulting from alternative fuel penetration in urban and rural areas, based on WISDOM Demand Module data
Pillar 2: Promote Adoption of Fuel-Efficient (FE) Cookstove Technologies.	Estimate the reduction of the demand resulting from the penetration of Fuel-Efficient Cookstoves, based on WISDOM Demand Module data
Actions aiming at INCREASING the SUSTAINABLE SUPPLY	
Pillar 3: Promote Sustainable Wood Production.	Estimate and map the supply that SFM could produce with current wood resources based on WISDOM supply data.
	Estimate the supply potential of new plantations and woodlots; Geo-referenced criteria (land availability; harvesting pressure and degradation)
	Increase tree cover in farmlands. Estimation of the potential contribution of agro-forestry assuming various tree cover % increases in farmlands based on WISDOM supply module data relative to non-forest areas.
Pillar 5: Regulate Sustainable Charcoal Production.	Improved charcoal making. Estimate the reduction in the use of woody biomass by district or other areas resulting from the adoption of modern kilns, based on WISDOM data on charcoal consumption.
Actions aiming at IMPROVING the REGULATORY, SOCIO-ECONOMIC, and INFORMATION contexts	
Pillar 4: Strengthen Law Enforcement.	A quantitative target cannot be defined in respect to Pillars 4, 6, and 7. WISDOM analysis can nonetheless contribute by providing detailed geo-referenced information on the context of selected areas of action.
Pillar 6: Enhance Livelihoods.	
Pillar 7: Promote Information, Awareness and Behavior-Change Communications.	

In the following review of the main possible lines of intervention, the impact of each action is self-contained, keeping all other factors unchanged. This is meant to facilitate the evaluation of the potential impact and limits of each intervention vis-à-vis the target. Each exploration of interventions below presents some plausible bounds of the scale of the intervention, as well as an estimate of how much of that activity would need to be undertaken to overcome the 2.7 Mt DM target, assuming it were the only intervention available. These are hypothetical discussions meant to illustrate that in all cases, it is likely unreasonable to think that a single intervention can be solely relied on to meet an ambitious national fuelwood sustainability target.

4.1.1 PENETRATION OF ALTERNATIVE COOKING FUELS

Among the woodfuels that may be replaced by alternative fuels, urban charcoal is probably the one that gives the highest potential because it consists of large amounts consumed in relatively small areas and because its replacement, typically by liquid petroleum gas (LPG), is a common sign of economic advancement in urban households. Moreover, charcoal consumption is increasing very fast (+50% in urban areas and +21% in rural areas in five years, against an overall fuelwood increase of +12%) and is likely to have the strongest impact on forest resources.

So far, however, the use of LPG or other alternative fuels seems to be marginal; in the results of the latest IHS 4 (2016), the use of gas (LPG) as main cooking fuel is not reported individually but grouped in the "other fuels" category attaining a mere 0.1% at country level with a peak of 0.6% in the urban South Region.

Unless economic growth boosts LPG adoption radically, which is not very likely in the short term, a rapid and consistent substitution is possible only if subsidized and with the attendant risk of backsliding when subsidies are removed. A typical problem in this case is that when subsidies on LPG cease, the households may revert back to charcoal, a serious risk since LPG is imported and subject to the potential volatility of global commodity prices monetized in hard currency.

Another consideration is that charcoal production (sustainable or unsustainable) is becoming a complementary source of income for a growing share of rural poor households. A massive reduction of charcoal use would have an impact on the income of these vulnerable segments of the population that need to be recognized and assessed.

According to this study, 608,000 urban households and 218,000 rural households will use charcoal as main cooking fuel in 2021, corresponding to 2.2 and 1.4 Mt DM of wood, respectively. For sake of reasoning, we can conclude that meeting the target of 2.7 Mt DM solely through substitution of charcoal with LPG would require a huge effort whereby 76% of all households that use charcoal adopt LPG as cooking fuel. This would involve all 608,000 urban households and over 80,000 rural households.

4.1.2 FURTHER PENETRATION OF IMPROVED COOKSTOVES

Knowing the penetration of fuel-efficient (FE) stoves is difficult because the nation-wide surveys do not collect such information and the knowledge is fragmented among a variety of programs and projects that operated or are currently operating in this sector. From the available information we may summarize the following:

- ***FE Fuelwood stoves in rural areas.*** The Rural Firewood Assortments Survey (RFAS, 2018) indicates that a single three-stone stove is used by 63% of rural HH (29% use a mix of three-stone and other stoves; 8% use only improved stoves [e.g., Chitetezo Mbaula, TLC Rocket Stove and Changu Changu Moto]).
- ***FE Fuelwood stoves in urban areas.*** Fuelwood use in urban areas is decreasing fast (-25% between 2016-2021). FE fuelwood stove use in urban areas is not known but may be assumed higher than in rural areas.
- ***FE Charcoal stoves in rural areas.*** The use of charcoal in rural areas is still very low, but growing. It may be safely assumed that current stoves are almost exclusively poorly efficient versions of Jiko stoves.
- ***FE Charcoal stoves in urban areas.*** Charcoal use is increasing fast but current stoves are almost exclusively poorly efficient versions of Jiko stoves.

The number of households that use fuelwood on three-stone stoves is approximately 2.1 million, with an annual consumption of 5.3 Mt DM, while those that use poorly efficient charcoal stoves are 816,000, for an annual consumption of 3.5 Mt DM weq.

Assuming a wood saving of 23% for FE fuelwood stoves and of 30% for FE charcoal stoves, we can conclude that the target of 2.7 Mt DM cannot be met solely by replacing inefficient stoves, not even if FE stoves are used in all households. In fact, if all three-stone stoves were replaced by FE fuelwood stoves, there would be a wood saving of 1.2 Mt DM; if all charcoal stoves were replaced by FE stoves, the saving would be 1.1 Mt DM weq. Combined, these two would add up to an overall wood saving of 2.3 Mt DM, which represents only 84% of the 2.7 Mt DM target.

It must be emphasized, however, that the adoption of FE stoves brings important benefits other than the reduced consumption of wood and charcoal, including improved indoor air quality and reduced incidence of health problems associated with indoor biomass smoke (such as acute respiratory infections in children and chronic obstructive pulmonary disease in women).

4.1.3 BETTER MANAGEMENT OF EXISTING FORESTS

One of the primary objectives of SFM[17] is to avoid the negative impact of irrational and unsustainable use of resources.

This study indicates a negative supply/demand balance in 2021 of 1.1 Mt DM (Commercial Balance, Medium Variant), which means that the demand exceeds the sustainable supply potential[18] by such amount. At the same time, this study estimates the unsustainable harvesting in 2021 to be 2.7 Mt DM (Medium Variant). We can conclude that the total unsustainable harvesting has two components: one due to the simple lack of resources (1.1 Mt) and one due to the irrational harvesting system or lack of management planning (1.6 Mt). This means that at the best, with optimal and sustainable management of all existing legally accessible wood resources in Malawi, there would be a reduction of the unsustainable harvesting by a maximum of 1.6 Mt DM, with the rest of the gap remaining due to insufficient resources.

Therefore, if implemented on all forest and non-forest woody resources of Malawi, SFM alone could prevent the loss of 1.6 Mt DM, which represents 60% of the target.

4.1.4 ESTABLISHMENT OF NEW PLANTATIONS AND WOODLOTS

The establishment of new plantations and woodlots is certainly an efficient way to increase the supply potential and meet the growing demand for woody biomass in Malawi.

One of the essential elements to be estimated is the availability of land for the creation of new plantations and woodlots. Based on the FAO Land Cover Map of 2010, the Forest Landscape Restoration Opportunities Assessment for Malawi (NFLRA, 2017) indicated a gross area of 753,000 ha potentially available outside National Parks and Wildlife Reserves, with slope above 20% and not used for agriculture. Such area includes mixed land cover types and significant proportions under tree cover, such as open formations and woodlands.

Considering that areas that are already under some tree cover may be best managed by SFM rather than new planting, a more restrictive estimation of the land void of vegetation that may be considered with priority for the establishment of plantations and woodlots was carried out using the same FAO 2010 base map.

The results of this analysis, shown in Table 22, indicate that approximately 200,000 ha are potentially available on lands with slope over 20%, half of which are concentrated in the North Region. Excluding all land with slope below 20% may appear too restrictive, considering also the need to distribute plantations and woodlots in the Centre and South Regions. If we assume that half of the available area with slope <20% may be considered suitable for planting while the remaining half would be kept for farming expansion, we come to a total potential area for plantations and woodlots of 588,000 ha.

---

[17] In this study SFM is intended in the broad sense of sustainable management of woody biomass resources, whether from forest or non-forest areas.

[18] The sustainable supply potential includes the MAI that is physically and legally accessible (thus excluding National Parks and Wildlife Reserves) and that is potentially available for energy use or for construction material (thus excluding industrial roundwood).

Table 22. Land Area Potentially Available for Plantations and Woodlots

AREA	ALL LANDS OUTSIDE NP&WR	LAND AREA POTENTIALLY AVAILABLE* FOR PLANTATIONS AND WOODLOTS IN 2010		
Slope % :	All Slopes ('000 Ha)	0-20 % ('000 Ha)	>20 % ('000 Ha)	All Slopes ('000 Ha)
North	2,293	292	101	393
Centre_west	1,990	172	14	186
Centre_east	1,165	114	20	134
South_east	943	78	25	103
South_middle	1,233	50	29	79
South_west	708	70	11	81
Malawi	8,331	776	200	976

* Land area outside National Parks and Wildlife Reserves that is not under crops nor under tree cover.

Assuming an average yield of 10 m^3 ha^{-1} $year^{-1}$ (corresponding to a MAI of 5.9 t DM), Malawi would need 457k ha of plantations and woodlots to generate the 2.7 Mt DM that is our target. The land area seems to be available, but the task of generating such a large amount of wood in the short term solely by new plantations and woodlots appears extremely demanding, if not impossible.

4.1.5 TREE PLANTING IN FARMLANDS AND AGROFORESTRY

Increasing tree cover in farmlands is a very promising line of intervention. As stated by Nyoka et al, 2016, in their study on Tree-Based Systems (TBS):

> "There is evidence that trees on farms are beneficial to households and communities. They contribute to improved soil fertility, higher crop yields, and increased agricultural production by helping control soil erosion and replenishing soil organic matter and nutrients. Tree-based systems of agriculture help diversify the sources of income and they assist in building household resilience to shocks. When planted at a certain scale, trees can also help reduce runoff and flooding and help recharge groundwater and maintain stream flow."

The presence of trees in farmlands is already increasing despite an overall national reduction of forests and woodlands, as reported by Nyoka et al. It is also likely that, in addition to the other benefits brought by farm trees, farmers already feel the need for more wood resources to be used as fuel and construction material given their rapid reduction, and are likely to respond positively to this line of intervention.

According to the results obtained integrating land cover data and sample data from the TBS survey carried out in five districts, the rain-fed farmlands have a tree cover of 8% on average, with some 15 t DM of stock and a MAI of 1 t DM ha^{-1} yr^{-1} (Medium Supply Variant).

Since rain-fed farmlands cover 4.3 million hectares (FAO 2010), we can roughly estimate that, in order to achieve an additional MAI of 2.7 Mt DM through this line of intervention alone, we should increase the presence of trees in farmlands by 63%, i.e. increasing the tree cover from 8% to 13% (which is a major increment). Again referring to the TBS survey, we can tentatively estimate that such increment would imply the successful planting of some 31 million additional trees, to be subsequently managed on a rotational basis.

4.1.6 MORE EFFICIENT CHARCOAL PRODUCTION

The introduction of efficient kiln systems to reduce the consumption of wood for charcoal making would be effective only if combined with a clear regulatory context and in synergy with SFM planning. However, for sake of reasoning, we consider how improved kiln systems would contribute to such reduction by comparing different yields.

The production of charcoal to satisfy the demand in 2021 is estimated to consume 3.6 Mt DM weq, and the average kiln efficiency assumed for this study is 26.4% dry wood basis, as assumed in BEST 2009. Recent testing indicates the yield of the Half-Orange (HO) kiln at around 38%, dry wood basis (Kawandama Hills Plantation [KHP] Malawi), which implies a reduction of 30.4% of wood compared to the average yield used in the analysis.

A more realistic improved kiln option could be represented by improved earthen kilns that have lower yields but that are far more easily adopted, given the need to move kilns according the availability of feedstock. In absence of clear evidence on the yield of well-tended earth kilns in Malawi, we may take the yield of 31% dry wood basis estimated by Robert Bailis (2005) as the upper range in his survey of earth mound kilns in Kenya. Such yield would imply a wood saving of 15% compared to the average yield used in the analysis.

If all charcoal were produced through high-performing HO kilns, there would be a saving of 1.09 Mt DM of wood (40% of target), while if all charcoal were produced through improved earthen kilns the savings would be 0.539 Mt DM of wood (20% of target).

Both improved systems should be considered. The stable HO kilns should be built in areas where the wood flow is expected to be constant and sustainable based on SFM planning. The improved earthen kiln should be promoted as part of training programs for professional charcoal making and operated where the supply of wood is expected to be less frequent or sporadic.

4.1.7 EXAMPLE OF BLENDING INTERVENTIONS TO MEET THE TARGET

The brief and preliminary review of the main actions shows with sufficient clarity that none of them alone can resolve the growing gap between a diminishing supply potential and a growing demand. Any effective strategy aiming at preventing the processes of degradation due to excessive harvesting would require combined action on several if not all lines of intervention, and a cross-sectoral action involving forestry, energy, and agriculture.

Having determined in general terms the extent to which each intervention can contribute to prevent the degradation, we can now proceed to evaluate how the various actions may be combined to meet the target synergistically.

In the example presented in Table 23 on the following page, each of the seven lines of intervention is assumed to contribute to meet the selected target of 2.7 Mt DM with the same amount (i.e. 14.3% or 385 kt DM), either by reducing the demand or by increasing the supply capacity of the country. While this example is obviously theoretical, it is useful because it allows a comparison of the efforts needed by the various lines of interventions to achieve the same impact.

By assigning a per-unit cost (i.e. LPG subsidy per household, dissemination cost per FE stove, cost of SFM planning and implementation per ha, cost of tree planting and tending per ha, cost of introducing HO and improved earthen kilns), it would be possible to estimate and compare the cost efficiency of each action.

A thorough review of ongoing activities will allow for the modulation/re-sizing and geographical distribution of the action in view of the overall sought target.

By adding knowledge and experience from all sectors involved in the evaluation of the scope of the various lines of intervention, it will be possible to progressively convert this simple example of the integration of activities into a strategic and operational planning tool. This list is not exhaustive; there are other actions, such as the promotion of biogas, that deserve due attention and that in time will grow as true fuel alternatives.

Table 23: Example of Blending of Interventions

INTERVEN-TIONS	BAU CONDITIONS 2021 (MEDIUM VARIANT)			BASIS OF ESTIMATED IMPACT	POSSIBLE BLENDING OF INTERVENTIONS			
					% of Target (2.7 Mt DM)	Impact (t DM yr^{1})	Level of Effort (Remarks) Estimate	Description
Actions on Demand								
Alternative Fuel to Charcoal	No of Households using charcoal :	601,918 urban	213,875 rural	HHs moving to LPG	14.3%	385,160	106,411	= Number of urban HHs moving to LPG
	Charcoal use (t DM weq) :	2,178,666 urban	1,375,742 rural	Reduced charcoal use			17.7%	% of total charcoal in urban areas replaced by LPG.
Fuelwood - Efficient Cookstoves	3-stone Households:	85,372 urban	2,033,345 rural	HHs adopting FE Fuelwood (Fw) stove	14.3%	385,160	678,781	= Number of rural HHs moving from 3-stones to FE Fw stoves
	3-stone t DM:	246,778 urban	5,016,436 rural	Reduced fuelwood use. 23% wood savings per FE Fw stove			7.7%	% of total rural Fw saved by FE Fw stoves; important impact on indoor air quality
Charcoal-Efficient Cookstoves	Jiko Households:	601,918 urban	213,875 rural	HHs adopting FE Ch stove	14.3%	385,160	294,668	= Households adopting high-efficiency charcoal stoves
	t weq DM:	2,178,666 urban	1,375,742 rural	Reduced charcoal use (as weq). 30% wood savings per FE Ch stove			10.8%	% of total charcoal saved by FE Ch stoves
Actions on Supply								
Sustainable Forest Management	Degradation due to lack of SFM (t DM)	1,608,145		% of land area under SFM = % of avoided degradation due to lack of SFM	14.3%	385,160	24.0%	= % of land area under SFM.; consolidation of rural employment; priority to charcoal production areas

INTERVEN-TIONS	BAU CONDITIONS 2021 (MEDIUM VARIANT)			BASIS OF ESTIMATED IMPACT		POSSIBLE BLENDING OF INTERVENTIONS			
						% of Target	Impact	Level of Effort (Remarks)	
						(2.7 Mt DM)	(t DM yr^{1})	Estimate	Description
Plantations and Woodlots				Increased MAI due to increased plantations & woodlots. @ 5.9 t DM /ha/yr of plantation/ woodlot		14.3%	385,160	65,281	= 15 years successful planting (ha). Abundance of potentially available planting areas;
Increased Tree Cover in Farms	Farming area 2010 (ha)	Tree cover % 2016	MAI (t DM/ha/yr)	Increased MAI due to increased tree cover		14.3%	385,160	4.4	= million trees planted in farmlands in 15 years and harvested on rotational basis
	4,291,777	8%	1.0					0.72%	= Increased tree cover percent in farms (+9% of current tree cover)
Improved Earthen Charcoal Kilns	Ch. prod. (t DM weq)	3,554,408		Reduced use of wood	30% savings with HO kiln	14.3%	385,160	17.8%	% of total charcoal made with Half Orange kiln;
					15% savings earthen kiln			36.1%	% of total charcoal made with improved earth mound kiln
Total						**100%**	**2,696,123**		

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 OVERVIEW OF DEMAND, SUPPLY, AND ESTIMATED DEGRADATION

Demand. The national demand for fuelwood, charcoal, and small construction material is projected to increase from 11.2 Mt DM in 2016 to 13.3 Mt DM in 2021. The increase is due primarily to the population growth and continued dependency on woodfuels as an energy source. Most relevant are the changes taking place in urban areas; the rapid increase of charcoal demand (+10% annually) is only partially compensated by the reduction of fuelwood demand (-5% annually).

For the consistency of the analysis, the total demand has been divided into "conventional" demand and "marginal" demand (see Glossary of Main Terms for details). The marginal demand has been estimated but is not included in the analysis of harvesting sustainability due to the total absence of reference data on the productivity of marginal wood sources. The demand for marginal fuelwood is located primarily in rural areas with scarce wood resources. In 2021, according to the Medium Variant, the conventional demand is estimated to cover 77% of the total demand, the remaining 23% being satisfied by marginal fuelwood assortments.

Supply potential. Over the same five-year period, the national supply potential, intended as the MAI physically and legally accessible and potentially available, is estimated to reduce from 9.85 to 9.45 Mt DM (Medium Variant) as the effect of deforestation and accumulated degradation.

Supply/demand balance. The integration of supply and demand layers reveals that Malawi stands at a major turning point (from national surplus to deficit condition), which presents serious challenges for the environment as well as for the majority of the population that depend on natural resources for their basic needs

According to the medium data variants and most probable assumptions of the Medium Variant, the supply/demand balance in 2016 was positive by 0.8 Mt DM while in 2021 projections the balance will be negative by 1.1 Mt DM. This indicates that the transition from a condition of surplus to that of deficit is approximately taking place in 2019.

Alternative scenarios based on the least and most favorable variants and assumptions indicate that the moment of transition already happened six years ago (High Variant) or will happen six years from now (Low Variant). This reveals that the situation is seriously compromised, no matter the level of uncertainty characterizing data and assumptions, and that undertaking powerful remedial actions is imperative and urgent.

Unsustainable harvesting. The degradation rate due to unsustainable harvesting of woody biomass is estimated to be 1.7 Mt DM in 2016, increasing to 2.7 Mt DM in 2021 (Medium Variant). The estimated degradation in 2021 is determined in part by insufficient supply potential (1.1 Mt DM) and in part by lack of management (1.6 Mt DM) where wood harvesting insists heavily on certain areas, leaving other areas untapped rather than applying rational rotation systems.

Undetermined impact of marginal fuelwood harvesting. All the results discussed above refer to the supply potential of conventional wood assortments and to the corresponding conventional demand. The impact of marginal fuelwood harvesting on its supply sources is so far undetermined but may be serious (although certainly different from that of harvesting conventional woodfuels).

5.2 ROLE AND CONTRIBUTIONS OF WISDOM ANALYSIS

Despite its technicalities and intricacies, we hope that this analysis contributes to clarifying the challenges ahead and to better defining remedial actions. WISDOM may serve as an integrated planning tool to support ongoing national efforts to resolve the supply/demand gap and to prevent further degradation. As such, WISDOM contributes by defining quantitative and geo-referenced targets for the remedial action, and by supporting the formulation of sound and locally tailored strategies.

The numerous parameters and factors defined for the WISDOM analysis (per capita consumption, number and distribution of users, stove efficiencies, charcoal yields, biomass stock and productivities, current tree cover, etc.) can also contribute to the definition of remedial actions. Specifically, they can contribute to the estimation of the expected impact of interventions per unit of action, such as fuel replaced, stove upgraded, improved charcoal making, hectares planted or put under SFM, tree cover increases in farmlands, etc.

First and foremost, WISDOM contributes by providing a quantitative and geo-referenced estimation of the relation between supply potential and the rate of degradation due to unsustainable harvesting. Such estimates define the problem to be solved and therefore the scope and target of remedial actions.

As an example of evaluation and blending of remedial actions against a well-defined national target, this study provides a preliminary estimation of the scope of the main lines of interventions directly related to the pillars of action of the National Charcoal Strategy. This example of blending actions is purely theoretical, as a real formulation would require thorough knowledge of ongoing efforts and cross-sectoral consultations; however, we hope it may provide a useful hint on how WISDOM data and results can contribute to the formulation of effective remedial strategies.

5.3 MAIN CONCLUSIONS AND RECOMMENDATIONS ON WISDOM DEVELOPMENT

The development of WISDOM Malawi implied several assumptions and some tentative value attributions to fill in for information gaps. In order to improve and consolidate the knowledge base, these assumptions need validation, and tentative estimates should be replaced by solid reference data. The most relevant information gaps to prioritize filling in include the following:

Concerning the Demand Module:

- The RFAS carried out in 2018 in the framework of PERFORM has shed some light on the fraction of the marginal fuelwood assortments used in rural areas. Given its relevance, it is recommended to further study the role and consistency of marginal fuelwood, and to include the distinction between conventional and marginal fuelwood assortments in the questionnaires of censuses and socio-economic surveys that collect data on the preferred fuels used for cooking and heating in Malawi households.
- The fuelwood and charcoal consumption in the non-residential sectors (industrial, commercial, and public sectors) is quite relevant, but available data is old, incomplete, or totally absent. In order to develop a reliable knowledge base, it is recommended to carry out consumption surveys in the various sectors and to request that representatives of major enterprises and reference institutions keep record of the woodfuels annually used.
- Scientific data on current charcoal yields is missing. In order to assess with accuracy the volume of woody biomass currently used in charcoal production and to estimate the benefits of modern carbonization technologies, conducting a survey of current charcoal production is recommended.

Concerning the Supply Module:

- Due to the absence of national references on growth and productivity, estimating the sustainable supply potential was based on generic data relating woody biomass stock and mean annual increment. In order to develop and implement SFM plans, it is essential to proceed with well-designed nationwide inventories of all biomass sources specifically focused on their sustainable growth potential.
- It is generally acknowledged that trees outside the forest (TOF) and agro-forestry in general play an important role in the supply of cooking fuels to rural household, but there is no data on the

role that they play. It is essential to assess the sustainable production potential of TOF and woodlots in farmlands and agro-forestry systems. For this, it is recommended that future forest inventories include a component aiming at farmlands and agro-forestry systems, in order to assess the production potential of "conventional" wood from TOF and woodlots as well as "marginal" wood assortments (twigs, deadwood, annual and periodic pruning of farm trees and shrubs, etc.).

- In view of the high proportion of marginal wood assortments harvested to satisfy rural fuelwood needs, and of the total absence of information on the impact of such practice, it is recommended to study the impact of excessive marginal fuelwood harvesting (soil fertility loss, landscape degradation, etc.).

6.0 REFERENCES

Arnold, M., Köhlin, G., Persson, R., & Shepherd, G. (2003). Fuelwood Revisited: What Has Changed in the Last Decade? Occasional Paper No. 39. Center for International Forestry Research (CIFOR). Bogor Barat, Indonesia.

Bailis, R., Wang, Y., Drigo, R., Ghilardi, A., & Masera, O. (2017). Getting the numbers right: revisiting woodfuel sustainability in the developing world. Special Issue Article in Environmental Research Letters. 12 115002. Retrieved from http://iopscience.iop.org/article/10.1088/1748-9326/aa83ed/meta.

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. Nature Climate Change. doi:10.1038/nclimate2491.

Chidumayo, E.N. & D. J. Gumbo Editors. (2010). The dry forests and woodlands of Africa: Managing for products and services. Earthscan. ISBN: 978-1-84971-131-9.

Chidumayo, E.N. (2013). Forest degradation and recovery in a miombo woodland landscape in Zambia: 22 years of observations on permanent sample plots. Makeni Savanna Research Project, P.O. Box 50323, Ridgeway, Lusaka, Zambia. Forest Ecology and Management, Volume 291, 1 March 2013, Pages 154–161.

DiMiceli, C.M., Carroll, M.L., Sohlberg, R.A., Huang, C., Hansen, M.C., & Townshend, J.R.G. (2011). Annual Global Automated MODIS Vegetation Continuous Fields (MOD44B) at 250 m Spatial Resolution for Data Years Beginning Day 65, 2000-2010, Collection 5 Percent Tree Cover, University of Maryland, College Park, MD, USA.

Drigo, R., Masera, O.R. & Trossero, M.A. (2002). Woodfuel Integrated Supply/Demand Overview Mapping – WISDOM: a geographical representation of woodfuel priority areas. Unasylva Vol. 53 2002/4, pp 36-40. FAO. (Available in English, Spanish and French)
Retrieved from: http://www.fao.org/docrep/005/y4450e/y4450e12.htm

Drigo, R. & Salbitano. F. (2008). WISDOM for Cities. Analysis of wood energy and urbanization aspects using WISDOM methodology. FAO Forestry Department Urban forestry—Wood energy (in English and French). FAO. English version retrieved from:
http://www.fao.org/documents/advanced_s_result.asp?QueryString=wisdom+for+cities&search=Search

Drigo, R., Cuambe, C., Lorenzini, M., Marzoli, A., Macuacua, J., Banze, C., ... Cunhete, D. (2008). WISDOM Mozambique Final Report. Wood energy component of the Consolidation Phase of the project Integrated Assessment of Mozambican Forests. AGRICONSULTING, for the Direcção Nacional de Terras e Florestas, Ministério de Agricultura, Moçambique.
Retrieved from:
http://www.wisdomprojects.net/pdf?file=WISDOM_Mozambique_web_pub.pdf

Drigo, R. (2012). WISDOM Sudan—Spatial analysis of woodfuel supply and demand in Sudan based on WISDOM methodology and new land cover mapping. Activity carried out in the framework of Sudan Institutional Capacity Programme: Food Security Information for Action (SIFSIA) FAO OSRO/SUD/620/MUL. FAO.

Drigo, R., Munyehirwe, A., Nzabanita, V., & A. Munyampundu. (2013). Final report: Update and upgrade of WISDOM Rwanda and Woodfuels value chain analysis as a basis for a Rwanda Supply Master Plan for fuelwood and charcoal. AGRICONSULTING S.p.A., for the Department of Forestry and Nature Conservation (DFNC), Rwanda Natural Resources Authority (RNRA).

Drigo, R., Bailis, R., Masera, O., & Ghilardi, A. (2014). Pan-tropical analysis of woodfuel supply, demand and sustainability. Yale-UNAM NRB Project: Tier I: Final Report. Global Alliance for

Clean Cookstoves (GACC) Project "Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and Beyond."

Drigo, R., Karki, G., & Sharma, S.K. (2014). WISDOM Nepal and contribution to MRV. Consultancy report of project Development of a Measurement, Reporting and Verification (MRV) System for Emissions and Removals. Project implemented by Agriconsulting SpA.

Drigo, R., Bailis, R., Ghilardi, A., & Masera, O. (2015). WISDOM Kenya—Analysis of woodfuel supply, demand and sustainability in Kenya. Tier 2 Report. GACC Yale-UNAM Project Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and Beyond.

Drigo, R. (2016). Data analysis for estimating emissions from forest degradation due to fuelwood harvesting in the context of Nepal's Forest Reference Level (FRL). FAO/UN-REDD Programme Targeted Support (UNJP/GLO/386/UNJ)—Nepal.

Drigo, R. (2017). WISDOM Zambia. Analysis of demand, supply and sustainability of wood products in Zambia Phase II of Integrated Land Use Assessment in the Republic of Zambia GCP/GLO/194/MUL (FIN)—Zambia.

FAO. (2000). Land Cover Classification System (LCCS): Classification Concepts and User Manual. Prepared by A. Di Gregorio and L. J. M. Jansen. Environment and Natural Resources Service, GCP/RAF/287/ITA. FAO, Rome. 2000.

FAO. (2007). Wood-energy supply/demand scenarios in the context of poverty mapping. A WISDOM case study in Southeast Asia for the years 2000 and 2015. Prepared by R. Drigo for the Environment and Natural Resources Service (SDRN) and Forest Product Service (FOPP). Environment and Natural Resources Working Paper 27. ISBN 978-92-5-105710-0. http://www.fao.org/docrep/010/a1106e/a1106e00.htm

FAO. (2002). A guide for woodfuel surveys. Prepared by T. A. Chalico and E. M. Riegelhaupt. EC-FAO Partnership Programme (2000-2002) Sustainable Forest Management Programme. See: http://www.fao.org/docrep/005/Y3779E/Y3779E00.HTM

FAO. (2004). Unified Bioenergy Terminology—UBET. FAO Forestry Department, Wood Energy Programme.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., ... Townshend, J. R.G. (2013). "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Retrieved from: http://earthenginepartners.appspot.com/science-2013-global-forest.

IUCN-WCMC. (2009). World Database of Protected Areas. Released by the International Union for the Conservation of Nature (IUCN) and by the World Conservation Monitoring Centre (WCMC).

Leach, M. & Mearns, R. (1988). Beyond the Woodfuel Crisis: People, Land and Trees in Africa. Earthscan Publications. London.

Mancini, M., Mattioli, E., Morganti, M., Bruschi, P., & Signorini, M.A. (2007). Conhecimento e exploracao de produtos florestais nao madereiros e carvao na zona de Muda, Provincia de Manica (Mocambique). Projecto AIFM.

Masera, O., Bailis, R., Drigo, R., Ghilardi, A. & Ruiz-Mercado, I. (2015). Environmental Burden of Traditional Bioenergy Use. Annual Review of Environment and Resources 11/2015; 40(1). DOI:10.1146/annurev-environ-102014-021318.

Ministry of Natural Resources, Energy, and Mining. (2017). National Charcoal Strategy (2017–2027). Government of Malawi.

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

Nyoka, B., Kundhlande, G., Winterbottom, R., Reytar, K., Ha, K., Behr, D. C. (2016). Taking to Scale Tree-Based Systems that Enhance Food Security, Improve Resilience to Climate Change, and Sequester Carbon in Malawi. Program on Forests PROFOR, World Agroforestry Centre and World Resources Institute.

Zarin, D. J., Harris, N. L., Baccini, A., Aksenov, D., Hansen, M. C., Azevedo-Ramos, C. & Allegretti, A. (2016). Can carbon emissions from tropical deforestation drop by 50% in 5 years? Global change biology, 22(4), 1336-1347.

7.0 APPENDICES

7.1 APPENDIX 1: POPULATION DATA, FUEL SATURATION AND PER CAPITA CONSUMPTION IN RESIDENTIAL SECTOR

Table 7.1 1. Population 2008 and 2016

AREA		CENSUS 2008	PROJ. 2016	PROJ. 2016	PROJ. 2016
Code	District	Total Pop.	Total Pop.	Urban Population	Rural Population
101	Chitipa	178,904	222,769	18,370	204,399
102	Karonga	269,890	348,110	52,024	296,086
103	Nkhata Bay	215,789	277,861	14,534	263,327
104	Rumphi	172,034	214,289	22,314	191,975
105	Mzimba	727,931	922,850	26,628	896,222
106	Likoma	10,414	10,464	1,358	9,106
107	Mzuzu City	133,968	239,008	239,008	0
201	Kasungu	627,467	858,782	54,434	804,348
202	Nkhotakota	303,659	391,575	31,885	359,690
203	Ntchisi	224,872	295,592	10,408	285,184
204	Dowa	558,470	797,426	6,819	790,607
205	Salima	337,895	432,069	35,615	396,454
206	Lilongwe Rural	1,230,834	1,490,641	0	1,490,641
207	Mchinji	456,516	610,781	23,923	586,858
208	Dedza	624,445	752,520	24,561	727,959
209	Ntcheu	471,589	588,038	18,258	569,781
210	Lilongwe City	674,448	1,098,167	1,098,167	0
301	Mangochi	797,061	1,053,585	52,664	1,000,921
302	Machinga	490,579	627,399	31,098	596,301
303	Zomba	579,639	673,178	0	673,178
304	Chiradzulu	288,546	322,646	2,651	319,995
305	Blantyre Rural	340,728	408,019	0	408,019
306	Mwanza	92,947	105,743	16,184	89,559
307	Thyolo	587,053	655,118	20,744	634,374
308	Mulanje	521,391	579,818	16,152	563,666
309	Phalombe	313,129	383,273	6,040	377,233
310	Chikwawa	434,648	549,706	8,882	540,824
311	Nsanje	238,103	288,581	24,457	264,124
312	Balaka	317,324	409,420	29,331	380,089
313	Neno	107,317	158,123	2,430	155,681
314	Zomba City	88,314	147,131	147,131	0
315	Blantyre City	661,256	920,226	920,226	0
	Malawi	13,077,160	16,832,908	2,956,296	13,876,599

Table 7.1 2. Population Projection 2021

AREA		PROJ. 2021	PROJ. 2021	PROJ. 2021
Code	District	Rural Population	Urban Population	Total pop.
101	Chitipa	232,590	20,905	253,495
102	Karonga	345,550	60,715	406,265
103	Nkhata Bay	309,130	17,063	326,193
104	Rumphi	218,621	25,411	244,032
105	Mzimba	1,043,150	30,993	1,074,143
106	Likoma	9,170	1,368	10,538
107	Mzuzu City	0	324,634	324,634
201	Kasungu	974,553	65,955	1,040,508
202	Nkhotakota	421,421	37,357	458,778
203	Ntchisi	336,466	12,280	348,746
204	Dowa	967,816	8,348	976,164
205	Salima	459,383	41,269	500,652
206	Lilongwe Rural	1,684,880	0	1,684,880
207	Mchinji	699,672	28,522	728,194
208	Dedza	817,998	27,598	845,596
209	Ntcheu	650,081	20,829	670,910
210	Lilongwe City	0	1,438,540	1,438,540
301	Mangochi	1,197,790	63,022	1,260,812
302	Machinga	699,600	36,485	736,085
303	Zomba	739,154	0	739,154
304	Chiradzulu	342,439	2,837	345,276
305	Blantyre Rural	457,473	0	457,473
306	Mwanza	96,314	17,404	113,718
307	Thyolo	696,058	22,761	718,819
308	Mulanje	603,509	17,294	620,803
309	Phalombe	431,764	6,913	438,677
310	Chikwawa	628,295	10,319	638,614
311	Nsanje	300,335	27,809	328,144
312	Balaka	447,564	34,538	482,102
313	Neno	195,194	3,046	198,240
314	Zomba City	0	194,976	194,976
315	Blantyre City	0	1,113,280	1,113,280
Malawi		16,005,970	3,712,471	19,718,441

Table 7.1 3. Fuelwood and Charcoal Saturation in Rural and Urban Households In 2016

AREA		URBAN CH	RURAL CH	URBAN FW	RURAL FW
Code	District	% HH	% HH	% HH	% HH
101	Chitipa	58.0	2.8	38.4	97.0
102	Karonga	58.0	9.4	38.4	90.3
103	Nkhata Bay	58.0	1.0	38.4	98.9
104	Rumphi	58.0	5.4	38.4	93.3
105	Mzimba	58.0	7.1	38.4	92.0
106	Likoma	58.0	4.3	38.4	91.8
107	Mzuzu City	71.2	-	22.4	-
201	Kasungu	36.4	2.2	63.7	97.8
202	Nkhotakota	36.4	9.8	63.7	88.1
203	Ntchisi	36.4	2.5	63.7	97.3
204	Dowa	36.4	4.7	63.7	93.9
205	Salima	36.4	8.0	63.7	91.3
206	Lilongwe Rural	36.4	4.9	63.7	94.7
207	Mchinji	36.4	5.5	63.7	94.5
208	Dedza	36.4	1.9	63.7	97.3
209	Ntcheu	36.4	7.3	63.7	92.3
210	Lilongwe City	63.7	-	27.5	-
301	Mangochi	37.6	7.5	61.7	92.5
302	Machinga	37.6	4.2	61.7	95.9
303	Zomba	37.6	2.4	61.7	96.0
304	Chiradzulu	37.6	4.2	61.7	89.2
305	Blantyre Rural	37.6	13.9	61.7	83.6
306	Mwanza	37.6	8.2	61.7	91.0
307	Thyolo	37.6	3.0	61.7	94.5
308	Mulanje	37.6	9.6	61.7	76.5
309	Phalombe	37.6	1.1	61.7	81.9
310	Chikwawa	37.6	13.3	61.7	86.2
311	Nsanje	37.6	4.7	61.7	94.9
312	Balaka	37.6	10.8	61.7	89.3
313	Neno	37.6	7.4	61.7	92.4
314	Zomba City	43.0	-	42.9	-
315	Blantyre City	72.9	-	10.7	-

Table 7.1 4. Fuelwood and Charcoal Saturation in Rural and Urban Households in 2021

AREA		URBAN CH	RURAL CH	URBAN FW	RURAL FW
Code	District	% HH	% HH	% HH	% HH
101	Chitipa	68.8	2.9	22.9	96.5
102	Karonga	68.8	9.8	22.9	89.9
103	Nkhata Bay	68.8	1.0	22.9	98.4
104	Rumphi	68.8	5.7	22.9	92.8
105	Mzimba	68.8	7.4	22.9	91.5
106	Likoma	68.8	4.6	22.9	91.3
107	Mzuzu City	84.5	-	13.3	-
201	Kasungu	43.1	2.3	38.0	97.2
202	Nkhotakota	43.1	10.2	38.0	87.6
203	Ntchisi	43.1	2.6	38.0	96.7
204	Dowa	43.1	4.9	38.0	93.4
205	Salima	43.1	8.4	38.0	90.8
206	Lilongwe Rural	43.1	5.1	38.0	94.2
207	Mchinji	43.1	5.8	38.0	94.0
208	Dedza	43.1	2.0	38.0	96.8
209	Ntcheu	43.1	7.7	38.0	91.8
210	Lilongwe City	75.5	-	16.4	-
301	Mangochi	44.6	7.9	36.8	92.0
302	Machinga	44.6	4.4	36.8	95.3
303	Zomba	44.6	2.5	36.8	95.5
304	Chiradzulu	44.6	4.4	36.8	88.7
305	Blantyre Rural	44.6	14.5	36.8	83.2
306	Mwanza	44.6	8.6	36.8	90.5
307	Thyolo	44.6	3.1	36.8	94.0
308	Mulanje	44.6	10.0	36.8	76.0
309	Phalombe	44.6	1.1	36.8	81.5
310	Chikwawa	44.6	13.9	36.8	85.7
311	Nsanje	44.6	4.9	36.8	94.3
312	Balaka	44.6	11.3	36.8	88.8
313	Neno	44.6	7.8	36.8	91.9
314	Zomba City	51.1	-	25.6	-
315	Blantyre City	86.5	-	6.4	-

Table 7.1 5. General Average per Capita Consumption of Fuelwood & Charcoal in 2008*

REGION	URBAN FUELWOOD	URBAN CHARCOAL	RURAL FUELWOOD	RURAL CHARCOAL
	kg/yr ad	kg/yr	kg/yr ad	kg/yr
Northern	377	52	679	5
Central	328	77	646	6
Southern	244	118	539	9
Weighted Average	293	94	601	7

* Including main users, all users and non-users. Source: BEST 2009**.** Using 2008 population and saturation values, the values above were converted to consumption values by MAIN users.

Table 7.1 6. Average Per Capita Consumption of Main Users (Air-Dry)

REGION	URBAN FUELWOOD	URBAN CHARCOAL	RURAL FUELWOOD	RURAL CHARCOAL
	kg/yr ad	kg/yr	kg/yr ad	kg/yr
Northern	537	236	707	435
Central	683	210	680	329
Southern	924	202	567	388
Weighted Average	721	209	632	371

Table 7.1 7. Average Per Capita Consumption of Main Users (Dry Matter, Wood Equivalent)[19]

REGION	URBAN FUELWOOD	URBAN CHARCOAL	RURAL FUELWOOD	RURAL CHARCOAL
	kg DM/yr	kg DM/yr weq	kg DM/yr	kg DM/yr weq
Northern	457	891	601	1645
Central	580	793	578	1246
Southern	786	764	482	1467
Weighted Average	613	789	537	1404

Note: Assuming constant proportion of improved and traditional stoves, in absence of stove penetration data, these per capita consumption rates were used for year 2016 as well as for year 2021.

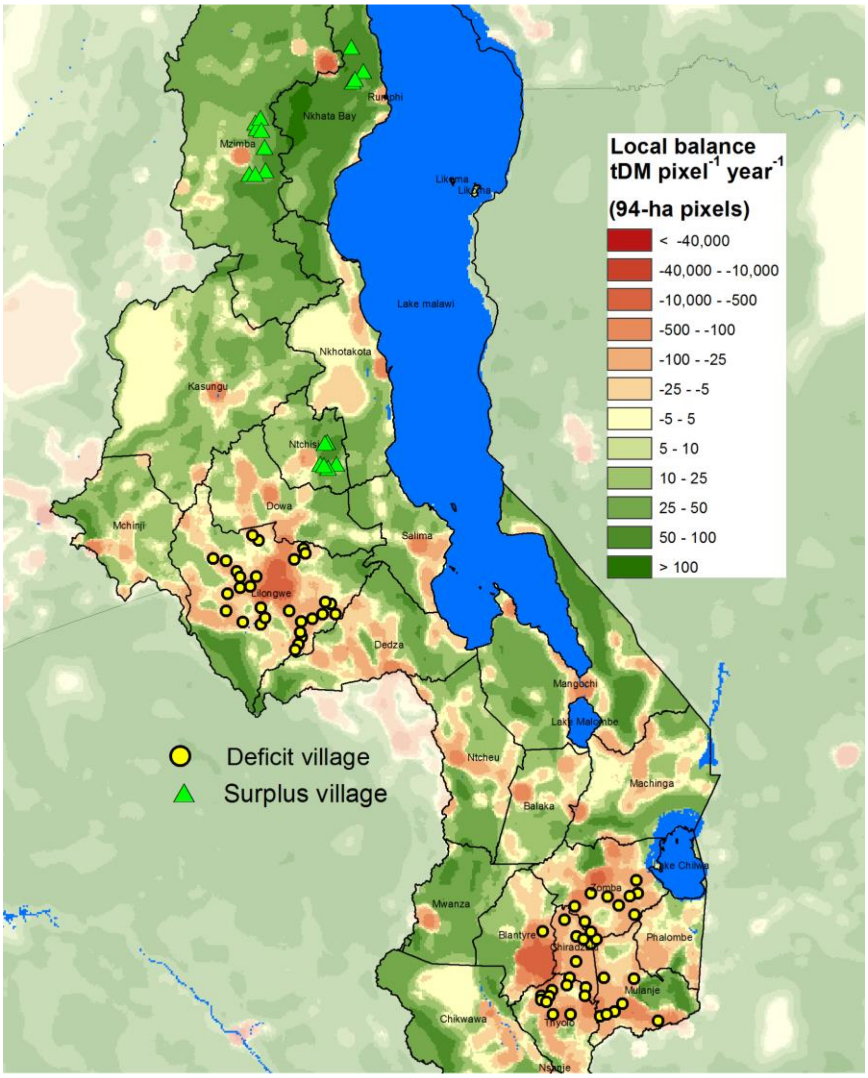
[19] The conversion of charcoal into corresponding woody biomass assumes that 4.45 air-dry tons of wood (15% moisture) are needed for 1 ton of charcoal. This corresponds to 22.5% yield air-dry basis or 26.4% yield dry basis. Source: BEST 2009, based on field testing. FAO standard conversion is 27.8 % dry basis; Bailis et al. (tests in Kenya) gives 24% dry basis (17%-31%).

7.2 APPENDIX 2: RURAL FIREWOOD ASSORTMENTS SURVEY

The Rural Firewood Assortments Survey (RFAS) was carried out in order to provide information on the firewood assortments used by rural households with special attention to the fraction of marginal firewood used in deficit areas (i.e. areas where wood resources within a 5km radius are very limited or absent).

The survey was based on interviews of rural households selected from villages located in areas characterized by *deficit* conditions (within a 5km context, firewood demand much greater than the sustainable supply potential of conventional firewood) or by *surplus* conditions (conventional supply potential greater than demand). The deficit and surplus villages were selected on the basis of a previous pan-tropical WISDOM study (Drigo et al. 2014) that included Malawi providing local supply/demand balance estimates at approximately a 1km resolution (Figure 6.2 1).

A total of 318 households were interviewed, 246 households in 66 deficit villages and 72 households in 18 surplus villages (distributed as shown in Figure 6.2 1).



Source of local balance data: Drigo et al. 2014, Pan-tropical analysis of woodfuel supply, demand and sustainability.

Figure 7.2 1. Selected Deficit and Surplus Villages

The questionnaire used for the interviews is presented in Figure 6.2 2.

Figure 7.2 2: Rural Firewood Assortments Survey: Household Questionnaire

RAPID APPRAISAL OF RURAL FIREWOOD ASSORTMENTS – WISDOM MALAWI

RURAL FIREWOOD ASSORTMENTS SURVEY - HOUSEHOLD QUESTIONNAIRE

Names of enumerator:		
Date of interview	......./........./..........	Interview start at....................

1. Household location and basic details

1.1	Region		1.2	District		
1.3	Village		1.4	TA		
1.5	**X** GPS coordinate		1.6	**Y** GPS coordinate		
1.7	Household # (progressive		1.8	Main activity of HH head		1. Agriculture (own land) 2. Agriculture (rented land) 3. Agriculture (labour work) 4. Livestock farming 5. Handcraft / Trade 7. Others
1.9	Number of dwellers		1.10	Main HH source of income		

2. Household cooking energy

Questions for the head of the household or member in charge of cooking:

What fuel do you use for cooking over the year?			Codes of cooking fuel	
2.1	Main fuel		1. Firewood 2. Charcoal 3. Dung 4. Saw dust 5. Rice/coffee husk	6. Agriculture residues 7. Biogas 8. LPG 9. Electricity 10. Kerosene 11. Others (specify...
2.2	Secondary fuel			
2.3	Tertiary fuel			

If the MAIN fuel is NOT firewood, move to a new household

If the MAIN fuel is firewood, proceed with the interview

3. Household firewood stored

Ask the person in charge of cooking to show the firewood stored.
Take a photo of the firewood stored and save it (add HH number [1.7 above] as note to the picture)
Assess the proportions of the various assortments trying to define the relative sources:

Firewood stored at the household		Propor-tion (%) **	Sources of firewood assortments	
Conventional assortments			Indicate MAIN source	
3.1	stem and split stem wood			**From forests/woodlands** 1. Cut whole trees and shrubs 2. Pruning of trees and shrubs (i.e. cutting branches from the crown, not the main stem) 3. Dead woody material collected from the forest floor **From farmlands, along roads and footpaths, etc.** 4. Whole trees and shrubs cut in farmlands 5. Pruning of trees and shrubs (i.e. cutting branches from the crown, not the main stem) done irregularly, several years apart 6. Pruning of trees and shrubs done regularly every year 7. Woody material collected in the farm 8. Other sources (describe)
3.2	branches diam.>2.5cm			
Marginal assortments				
3.3	thin branches diam.<2.5cm			
3.4	twigs (1-year old shoots)			
3.5	woody agricultural residues *			
3.6	other assortments (describe)*			

*Note: This refers exclusively to woody material. Dry leaves and crop residues are excluded

** Must add to 100

PERFORM 1

4. Weighting of daily firewood consumption

Ask the person in charge of cooking to show how much firewood is consumed per day on average (physically pulling out the wood from the firewood stored)

Weight the daily consumption using a scale, all at once and then separating the various assortments:

Weight the total amount at once

4.1	Total weight of daily consumption (kg)	

Weight the assortments separately

Conventional assortments		
4.2	stem and split stem wood (kg)	
4.3	branches diam.>2.5cm (kg)	
Marginal assortments		
4.4	thin branches diam.<2.5cm (kg)	
4.5	twigs (1-year old branches) (kg)	
4.6	woody agricultural residues * (kg)	
4.7	other assortments (describe)* (kg)	

*Note: This refers exclusively to woody material. Dry leaves and crop residues are excluded

5. Firewood cookstoves used by the household

What are the types of firewood cookstoves you have/use in the household?			What do you use them for?
		Tick	To prepare : daily breakfast (1); daily diner/lunch/supper (2) ; Occasionally, for special food (3) heating water (4) warming room (5)
5.1	Three stones (traditional firewood stove)		
5.2	Double and Triple fixed wood stove		
5.3	Rocket Stove (all mud/brick firewood)		
5.4	Modified Rocket Stove (mud/brick firewood stove, with metal parts)		
5.5	Single movable metal wood stove		
5.6	Saw dust /rice & coffee husk stove		
5.6	Chitetezo Mbaula (clay movable firewood stove)		
5.7	Changu Changu Moto		
5.9	Other(*write them down)* …………		

Note:
If you find another type of stove which is not listed here write its name
Ask to see the cooking stove, and take photos (if new/unique)

Thanks for your participation!!!

7.3 APPENDIX 3: SUPPLY MODULE REFERENCE DATA, STOCK, AND MAI VALUES

Figure 7.3 1. Malawi Land Cover 2010—FAO LCCS Full Resolution

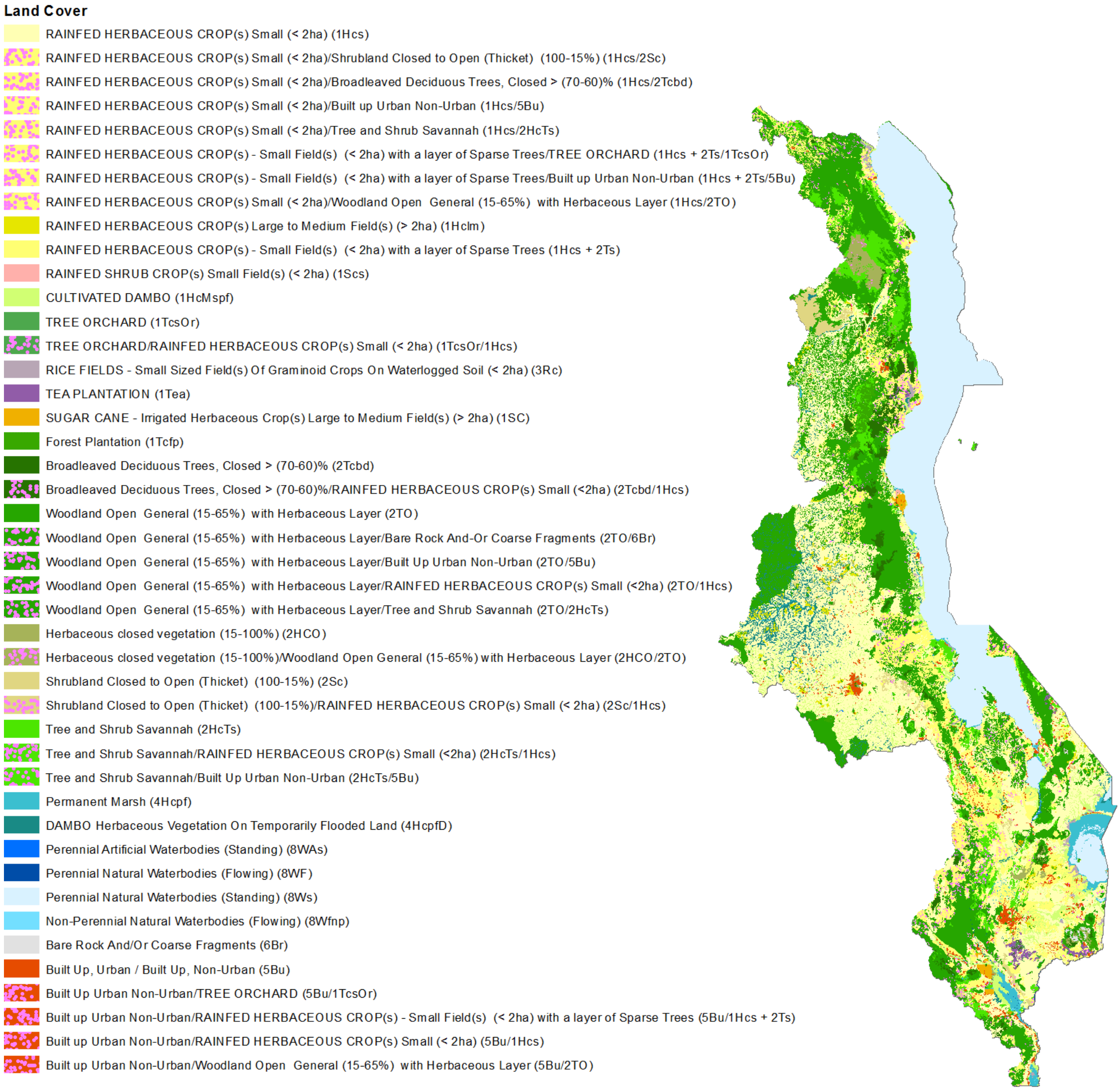


Figure 7.3 2. Forest Inventory Plots and Farmlands Tree Cover Survey Areas

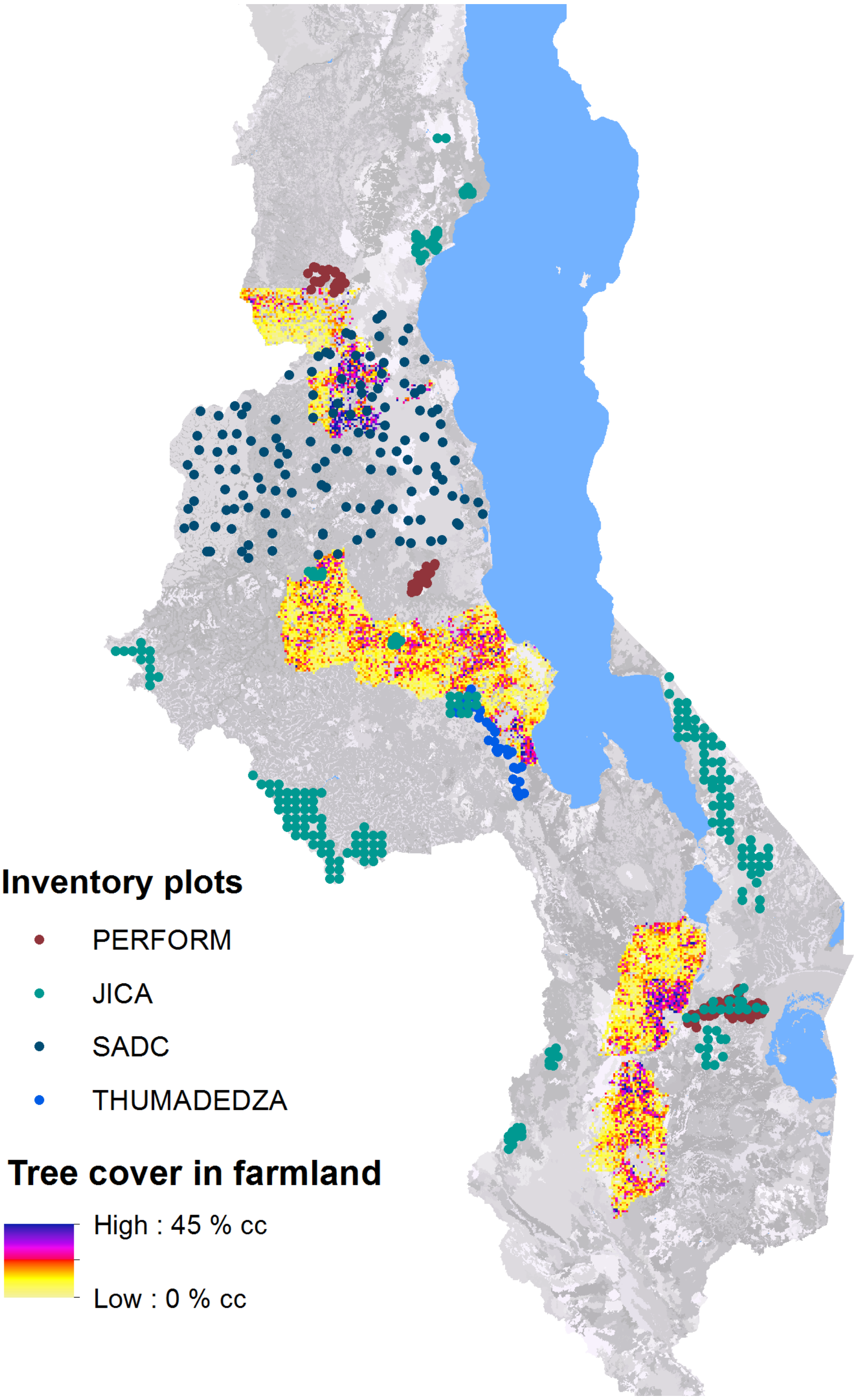


Table 7.3 1. FAO LCCS Classes and Estimated Aboveground Woody Biomass Stock

RASTER CODE	AREA (HA)	LCCS User Label	CLASS DESCRIPTION	FIRST LAYER		SECOND LAYER		MEAN - CI	**MEAN**	MEAN + CI
				av_mg dm ha	*ci_90%*	av_mg dm ha	*ci_90%*	Min agwb tdmha	Mean agwb tdmha	Max agwb tdmha
1	2,704,686	1Hcs	RAINFED HERB CROP(s) Field< 2ha	15.0	*0.3*			14.7	**15.0**	15.3
2	199,395	2Tcbd	Broadl. Decid. Trees, Closed > (70-60)%	104.4	*12.7*			91.7	**104.4**	117.1
3	2,172,501	2TO	Woodland Open General (15-65%) with Herb. Layer	77.8	*4.2*			73.6	**77.8**	82.1
4	263,987	4HcpfD	DAMBO Herb. Veg. On Temp. Flooded Land	13.4	*1.3*			12.1	**13.4**	14.6
5	104,509	1Hcs/2HcTs	RAINFED HERB CROP(s) Field< 2ha/Tree and Shrub Savannah	15.0	*0.3*	65	*30*	22.9	**35.1**	47.4
6	164,214	4Hcpf	Permanent Marsh	14.5	2.2			12.3	**14.5**	16.7
7	746,236	1Hcs/2TO	RAINFED HERB CROP(s) Field< 2ha)/Woodland Open General (15-65%) with Herb. Layer	15.0	*0.3*	78	*4*	38.3	**40.1**	42.0
8	750,032	2TO/1Hcs	Woodland Open General (15-65%) with Herb. Layer/RAINFED HERB. CROP(s) Field< 2ha	77.8	*4.2*	15.0	*0.3*	50.1	**52.7**	55.4
9	91,132	1Hclm	RAINFED HERB. CROP(s) Field> 2ha	12.3	*2.5*			9.8	**12.3**	14.8
10	400,907	1HcMspf	CULTIVATED DAMBO	13.5	*0.9*			12.6	**13.5**	14.4
11	96,913	2Sc	Shrubland Closed to Open (Thicket) (100-15%)	23.5	*3.6*			19.8	**23.5**	27.1
12	400,913	2HcTs	Tree and Shrub Savannah	65.3	*30.1*			35.2	**65.3**	95.4
13	17,116	1Hcs/2Sc	RAINFED HERB CROP(s) Field< 2ha/Shrub Closed to Open (Thicket) (100-15%)	15.0	*0.3*	23	*4*	16.8	**18.4**	20.0
14	85,774	5Bu/1Hcs	Built up Urban Non-Urban/RAINFED HERBACEOUS CROP(s) Small (< 2ha)	22.0	*3.4*	15.0	*0.3*	17.1	**19.2**	21.4
15	20,604	6Br	Bare Rock And/Or Coarse Fragments	11.7	*2.4*			9.3	**11.7**	14.1
16	538,674	1Hcs + 2Ts	RAINFED HERB CROP(s) Field< 2ha with Sparse Trees	18.1	*0.6*			17.5	**18.1**	18.7
17	61,783	5Bu	Built Up, Urban / Built Up, Non-Urban	22.0	*3.4*			18.6	**22.0**	25.4
18	89,947	1Tcfp	Forest Plantation	95.8	*50.2*			45.6	**95.8**	146.0
19	16,485	1Hcs/5Bu	RAINFED HERB CROP(s) Small (< 2ha)/Built up Urban Non-Urban	15.0	*0.3*	22.0	*3.4*	16.3	**17.8**	19.3
20	35,146	2Sc/1Hcs	Shrub Closed to Open (Thicket) (100-15%)/RAINFED HERB CROP(s) Field< 2ha	23.5	*3.6*	15.0	*0.3*	17.8	**20.1**	22.4
21	80,961	2HCO	Herbaceous closed vegetation (15-100%)	3.4	*3.4*			0.1	**3.4**	6.8
22	2,486	2TO/5Bu	Woodland Open General (15-65%) with Herbs Layer/Built Up Urban Non-Urban	77.8	*4.2*	22.0	*3.4*	51.6	**55.5**	59.4
23	4,619	8Wfnp	Non-Perennial Natural Waterbodies (Flowing)	0.0	*0.0*			0.0	**0.0**	0.0
24	434	8WAs	Perennial Artificial Waterbodies (Standing)	0.0	*0.0*			0.0	**0.0**	0.0
25	154,340	8Ws	Perennial Natural Waterbodies (Standing) excl. Lake Malawi	0.0	*0.0*			0.0	**0.0**	0.0
26	8,969	8WF	Perennial Natural Waterbodies (Flowing)	0.0	*0.0*			0.0	**0.0**	0.0
27	120,628	2HcTs/1Hcs	Tree and Shrub Savannah/RAINFED HERB CROP(s) Field< 2ha	65.3	*30.1*	15.0	*0.3*	27.0	**45.2**	63.4
28	5,512	1Hcs/2Tcbd	RAINFED HERB CROP(s) Field< 2ha/Broadl. Decid. Trees, Closed > (70-60%)	15.0	*0.3*	104	*13*	45.5	**50.8**	56.0

RASTER CODE	AREA (HA)	LCCS User Label	CLASS DESCRIPTION	FIRST LAYER		SECOND LAYER		MEAN - CI	**MEAN**	MEAN + CI
				av_mg dm ha	*ci_90%*	av_mg dm ha	*ci_90%*	Min agwb tdmha	Mean agwb tdmha	Max agwb tdmha
29	4,964	2TO/6Br	Woodland Open General (15-65%) with Herb Layer/Bare Rock And-Or Coarse Fragments	77.8	*4.2*	11.7	*2.4*	47.9	**51.4**	54.9
30	6,639	1TcsOr	TREE ORCHARD	47.9	*25.1*			22.8	**47.9**	73.0
31	4,474	5Bu/2TO	Built up Urban Non-Urban/Woodland Open General (15-65%) with Herbs Layer	22.0	*3.4*	78	*4*	40.6	**44.3**	48.1
32	17,646	5Bu/1TcsOr	Built Up Urban Non-Urban/TREE ORCHARD	22.0	*3.4*	48	*25*	20.3	**32.4**	44.4
33	30,135	1SC	SUGAR CANE - Irrigated Herbaceous Crop(s) Large to Medium Field(s) (> 2ha)	8.4	*6.6*			1.8	**8.4**	14.9
34	37,001	1Tea	TEA PLANTATION	23.5	*3.6*			19.8	**23.5**	27.1
35	42,805	3Rc	RICE FIELDS - Small Sized Field(s) of Graminoid Crops on Waterlogged Soil (< 2ha)	6.2	*3.8*			2.4	**6.2**	9.9
36	1,295	5Bu/1Hcs + 2Ts	Built up Urban Non-Urban/RAINFED HERB CROP(s) Field< 2ha with Sparse Trees	22.0	*3.4*	18.1	*0.6*	18.2	**20.5**	22.7
37	1,167	1TcsOr/1Hcs	TREE ORCHARD/RAINFED HERB CROP(s) Field< 2ha	47.9	*25.1*	15.0	*0.3*	19.6	**34.7**	49.9
38	18,976	2Tcbd/1Hcs	Broadleaved Deciduous Trees, Closed > (70-60%)/RAINFED HERB CROP(s) Field< 2ha	104.4	*12.7*	15.0	*0.3*	60.9	**68.6**	76.4
39	8,346	1Hcs + 2Ts/5Bu	RAINFED HERB CROP(s) Field< 2ha with Sparse Trees/Built up Urban Non-Urban	18.1	*0.6*	22.0	*3.4*	18.0	**19.7**	21.4
40	489	2HcTs/5Bu	Tree and Shrub Savannah/Built Up Urban Non-Urban	65.3	*30.1*	22.0	*3.4*	28.6	**48.0**	67.4
41	11,073	2TO/2HcTs	Woodland Open General (15-65%) with Herb Layer/Tree and Shrub Savannah	77.8	*4.2*	65	*30*	58.2	**72.8**	87.4
42	1,859	1Scs	RAINFED SHRUB CROP(s) Field< 2ha	23.5	*3.6*			19.8	**23.5**	27.1
43	27,710	2HCO/2TO	Herb closed veg (15-100%)/Woodland Open General (15-65%) with Herb Layer	3.4	*3.4*	78	*4*	29.5	**33.2**	36.9
44	21,926	1Hcs + 2Ts/1TcsOr	RAINFED HERB CROP(s) Field< 2ha with Sparse Trees/TREE ORCHARD	18.1	*0.6*	48	*25*	19.6	**30.0**	40.4

Table 7.3 2: FAO LCCS Classes and Estimated Mean Annual Increment of Aboveground Woody Biomass

LC CODE	AREA HA	LCCSUSLB	LOW MAI OF MIN STOCK		MEAN MAI OF MEAN STOCK		HIGH MAI OF MAX STOCK	
			MAI Ha^{-1} agwb t DM ha^{-1} yr^{-1}	Total MAI agwb kt DM yr^{-1}	MAI Ha^{-1} agwb t DM ha^{-1} yr^{-1}	Total MAI agwb kt DM yr^{-1}	MAI Ha^{-1} agwb t DM ha^{-1} yr^{-1}	Total MAI agwb kt DM yr^{-1}
1	2,704,686	1Hcs	0.72	1,949	0.9	2,390	1.05	2,829
2	199,395	2Tcbd	1.59	317	2.1	415	2.60	518
3	2,172,501	2TO	1.45	3,142	1.8	3,979	2.23	4,836
4	263,987	4HcpfD	0.69	182	0.9	230	1.06	281
5	104,509	1Hcs/2HcTs	0.90	94	1.3	137	1.76	184
6	164,214	4Hcpf	0.68	111	0.9	144	1.09	180
7	746,236	1Hcs/2TO	1.09	817	1.4	1,023	1.65	1,234
8	750,032	2TO/1Hcs	1.23	921	1.5	1,159	1.87	1,403
9	91,132	1Hclm	0.60	54	0.8	72	1.00	91
10	400,907	1HcMspf	0.72	287	0.9	359	1.08	433
11	96,913	2Sc	0.86	83	1.1	109	1.41	136
12	400,913	2HcTs	1.07	429	1.7	677	2.34	940
13	17,116	1Hcs/2Sc	0.80	14	1.0	17	1.24	21
14	85,774	5Bu/1Hcs	0.77	66	1.0	84	1.20	103
15	20,604	6Br	0.60	12	0.8	16	1.01	21
16	538,674	1Hcs + 2Ts	0.81	436	1.0	538	1.19	642
17	61,783	5Bu	0.78	48	1.0	62	1.26	78
18	89,947	1Tcfp	1.21	109	2.0	181	2.85	256
19	16,485	1Hcs/5Bu	0.75	12	0.9	16	1.15	19
20	35,146	2Sc/1Hcs	0.83	29	1.1	37	1.30	46
21	80,961	2HCO	0.10	8	0.5	42	0.79	64
22	2,486	2TO/5Bu	1.19	3	1.5	4	1.84	5
23	4,619	8Wfnp	0.00	0	0.0	0	0.00	0
24	434	8WAs	0.00	0	0.0	0	0.00	0
25	154,340	8Ws	0.00	0	0.0	0	0.00	0
26	8,969	8WF	0.00	0	0.0	0	0.00	0
27	120,628	2HcTs/1Hcs	0.95	115	1.4	174	1.96	236
28	5,512	1Hcs/2Tcbd	1.17	6	1.5	8	1.87	10
29	4,964	2TO/6Br	1.20	6	1.5	8	1.85	9
30	6,639	1TcsOr	0.90	6	1.5	10	2.10	14
31	4,474	5Bu/2TO	1.06	5	1.4	6	1.66	7
32	17,646	5Bu/1TcsOr	0.81	14	1.2	21	1.62	29
33	30,135	1SC	0.33	10	0.7	22	1.11	33
34	37,001	1Tea	0.85	31	1.1	41	1.39	51
35	42,805	3Rc	0.37	16	0.6	28	0.92	39
36	1,295	5Bu/1Hcs + 2Ts	0.76	1	1.0	1	1.20	2
37	1,167	1TcsOr/1Hcs	0.82	1	1.3	1	1.74	2
38	18,976	2Tcbd/1Hcs	1.36	26	1.8	33	2.18	41
39	8,346	1Hcs + 2Ts/5Bu	0.82	7	1.0	9	1.26	11
40	489	2HcTs/5Bu	0.96	0	1.5	1	1.98	1
41	11,073	2TO/2HcTs	1.33	15	1.8	20	2.31	26
42	1,859	1Scs	0.86	2	1.1	2	1.40	3
43	27,710	2HCO/2TO	1.02	28	1.3	36	1.62	45
44	21,926	1Hcs + 2Ts/1TcsOr	0.84	18	1.2	27	1.63	36
Total Malawi				9,369		12,053		14,805

7.4 APPENDIX 4: LEGAL ACCESSIBILITY OF BIOMASS RESOURCES

Preliminarily, we assume all woody biomass is legally accessible with the exception of resources found within protected areas, which face some restrictions. In reality, national parks and other conservation areas present various restrictions on the exploitation of forest resources. In order to account for these legal constraints, an accessibility factor was allocated to the protected areas on the basis of IUCN definitions of Protected Area Management Categories and on national experts' opinions on the access rates (percent accessible) of biomass resources to local communities and to commercial operators in each protection category. The map of protected areas of Malawi (file MalawiProtectedAreas.shp) is more detailed and more complete than the dataset published in the 2018 edition of the WDPA and is therefore used as main reference.

The location and extent of the Protected Areas of Malawi are shown in Figure 6.4 1. The IUCN categories of Malawi Protected areas are National Parks and Wildlife Reserves, categories that exclude fuelwood harvesting for both local and commercial use.   Accordingly, all protected areas are assumed to be 0% accessible for commercial and local woodfuel production.

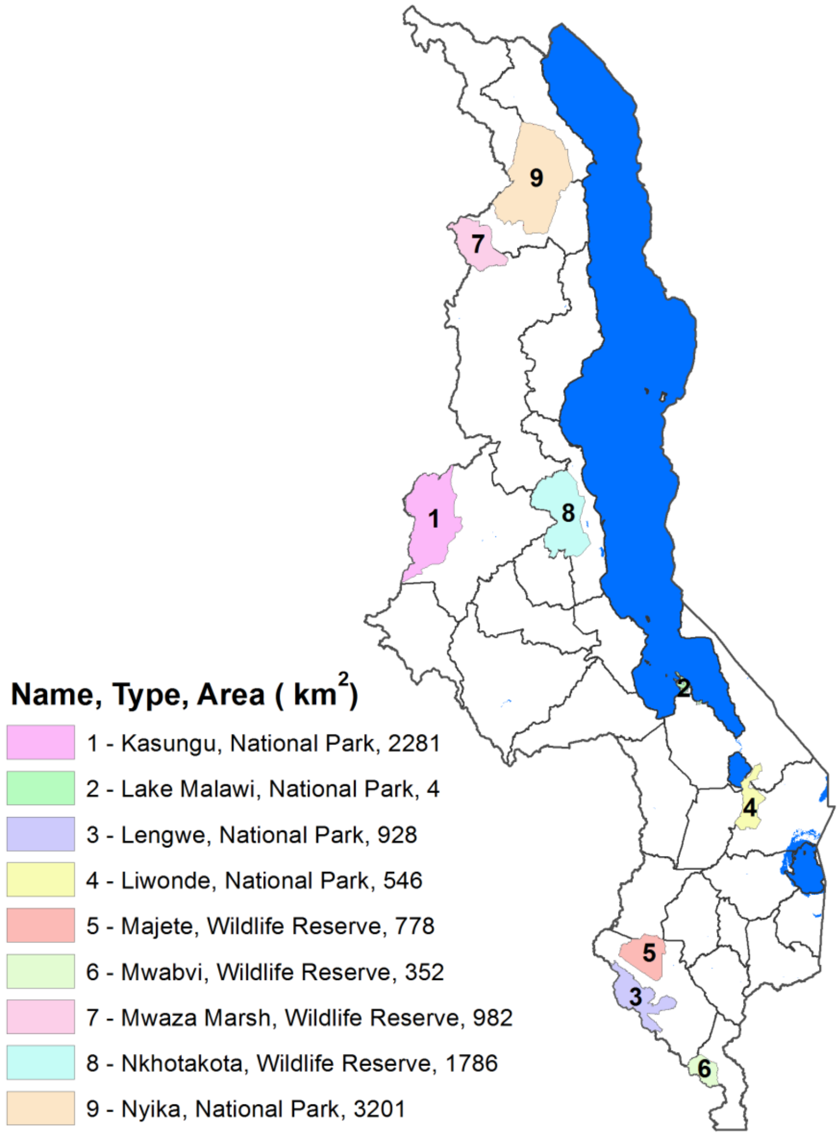


Figure 7.4 1. Protected Areas of Malawi

7.5 APPENDIX 5: PHYSICAL ACCESSIBILITY OF BIOMASS RESOURCES

Off-Road Accessibility: Transport 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; the contribution of railway seems to be negligible) or that are close to populated places (urban centers, villages, and densely populated rural areas) have the highest level of accessibility, it may be assumed that the accessibility of the resources located far from such features is inversely proportional to the time (or effort) necessary to reach them (considering here the time needed to go and return loaded with fuelwood or charcoal).

In order to associate a parameter of physical accessibility to the legally accessible woody biomass resources, a *woodfuel transport time map* is produced following and adapting the procedure described by Nelson[20] and by Drigo[21] .

Target locations. The target locations are all accessible areas, including:

1. Populated places:
    - Urban and built-up areas derived from land cover 2010 (classes with built up as primary component). Map name builtup.
    - Village locations derived from point map villages_iltsi_utm_wgs84.shp. Map name village_prnk1.
    - School locations. Map name sch_pop_rnk02.
2. Communication features:
    - Road network derived from shapefile Roads_Tracks.shp. Map name rd_mn2.

The target locations (or source features of cost-distance analysis) is composed by the layers described above, merged into a single map. Map name target_0.

Friction surface components:

1. ***Land cover friction.*** The base friction values applied to land cover classes and communication features, intended as transport speed in minutes per km assuming flat terrain and altitude below 2000 meters above sea level (msl) are reported in Table 6.5 1. On this basis, the friction map of land cover classes was generated. Map name fric_lc_mnkm.
2. ***Elevation factor.*** A speed reduction factor is normally applied to higher elevation starting from elevations greater than 2000 msl, as done by Nelson. In case of Malawi, the area above 2000 msl is very limited and mostly located within Nyika National Park and therefore already inaccessible for legal reasons. A small "non-protected" high altitude area is located in the southeast of the country, covered by grasses and barren lands with negligible woody vegetation. High altitude areas appear irrelevant for this study and therefore the elevation factor has not been considered.

[20] 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. Retrieved from http://bioval.jrc.ec.europa.eu/products/gam/index.htm.

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

Table 7.5 1. Friction Values (Minutes / Km Return Trip) Applied to Land Cover Classes and Communication Features, Assuming Flat Terrain

RASTER CODE	LCCSUSLB *	AGGR_2011	GOING MIN/KM	LOADED FACTOR	RETURN LOADED	TOT RETURN TRIP MIN/KM
17	5Bu	URB	4	1.0	4	**8**
14	5Bu/1Hcs	URB/AG	8	1.5	12	**20**
32	5Bu/1TcsOr	URB/AG	8	1.5	12	**20**
36	5Bu/1Hcs + 2Ts	URB/AG	8	1.5	12	**20**
31	5Bu/2TO	URB/TCO	8	1.5	12	**20**
19	1Hcs/5Bu	AG/URB	12	1.5	18	**30**
22	2TO/5Bu	TCO/URB	12	1.5	18	**30**
39	1Hcs + 2Ts/5Bu	AG/URB	12	1.5	18	**30**
40	2HcTs/5Bu	HCO/URB	12	1.5	18	**30**
10	1HcMspf	AG	16	1.5	24	**40**
33	1SC	AG	16	1.5	24	**40**
35	3Rc	AG	16	1.5	24	**40**
1	1Hcs	AG	16	1.5	24	**40**
9	1Hclm	AG	16	1.5	24	**40**
16	1Hcs + 2Ts	AG	16	1.5	24	**40**
34	1Tea	AG	16	1.5	24	**40**
37	1TcsOr/1Hcs	AG/AG	16	1.5	24	**40**
42	1Scs	AG	16	1.5	24	**40**
44	1Hcs + 2Ts/1TcsOr	AG/AG	16	1.5	24	**40**
5	1Hcs/2HcTs	AG/HCO	20	1.5	30	**50**
7	1Hcs/2TO	AG/TCO	20	1.5	30	**50**
13	1Hcs/2Sc	AG/SCO	20	1.5	30	**50**
28	1Hcs/2Tcbd	AG/TCO	20	1.5	30	**50**
30	1TcsOr	AG	20	1.5	30	**50**
21	2HCO	HCO	20	1.5	30	**50**
43	2HCO/2TO	HCO/TCO	22	1.5	33	**55**
8	2TO/1Hcs	TCO/AG	24	1.5	36	**60**
20	2Sc/1Hcs	SCO/AG	24	1.5	36	**60**
27	2HcTs/1Hcs	HCO/AG	24	1.5	36	**60**
38	2Tcbd/1Hcs	TCO/AG	24	1.5	36	**60**
12	2HcTs	HCO	24	1.5	36	**60**
3	2TO	TCO	26	1.5	39	**65**
11	2Sc	SCO	26	1.5	39	**65**
29	2TO/6Br	TCO/BS	26	1.5	39	**65**
41	2TO/2HcTs	TCO/HCO	26	1.5	39	**65**
2	2Tcbd	TCO	30	1.5	45	**75**
4	4HcpfD	HCO	30	1.5	45	**75**
15	6Br	BS	30	1.5	45	**75**
18	1Tcfp	TP	30	1.5	45	**75**
6	4Hcpf	HCO	40	1.5	60	**100**
23	8Wfnp	WAT	60	1.2	72	**132**
24	8WAs	WAT	120	1.0	120	**240**
25	8Ws	WAT	120	1.0	120	**240**
26	8WF	WAT	120	1.0	120	**240**
Communication features						
	Main road		1	1	1	**2**
	District road		2	1	2	**4**
	Secondary_road		3	1	3	**6**
	Tertiary road		5	1.2	6	**11**
	Other road (tracks/ paths)		12	1.5	18	**30**

* See Table 6.3 1 in Appendix 3 for full class names.

Slope Factor

The slope map was produced on the basis of the Digital Elevation Model of 90m spatial resolution (source: ASTER). The effect of slope on travel speed is estimated following Nelson's approach, which was based on van Wagtendonk and Benedict (1980)[22] 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 Malawi 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 = slope_fac). The estimated effect of slope on off-road speed and on crossing time are shown in Table 6.5 2.

Table 7.5 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
15	0.15	1.62	0.48
20	0.2	1.90	0.38
25	0.25	2.24	0.30
30	0.3	2.63	0.23
35	0.35	3.09	0.18
40	0.4	3.62	0.14
45	0.45	4.26	0.11
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
90	0.9	18.12	0.01
100	1	25.00	0.01
200	2	625.00	0.00

The slope factor, applied to the map of nominal friction values (fric_lc_mnkm), generated the map of friction of land cover classes in minutes per km considering slope. Map name : friclcslp_mkm.

The friction map of roads (rd_mn2) is then superimposed to the slope-affected friction of land cover classes (friclcslp_mkm) to generate the comprehensive friction map expressed as minutes per kilometer. Map name: friction_mkm. This map is then converted to minutes per meter, generating map fric1m_m, shown in Figure 6.5 1.

Cost-Distance Analysis

Cost-distance analysis using the map target_0 as target and the map fric1_m_m as cost factor, generated the map cd_min, expressing the cumulative transport time (in minutes) necessary to reach any point in Malawi from the nearest road, village or city.

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

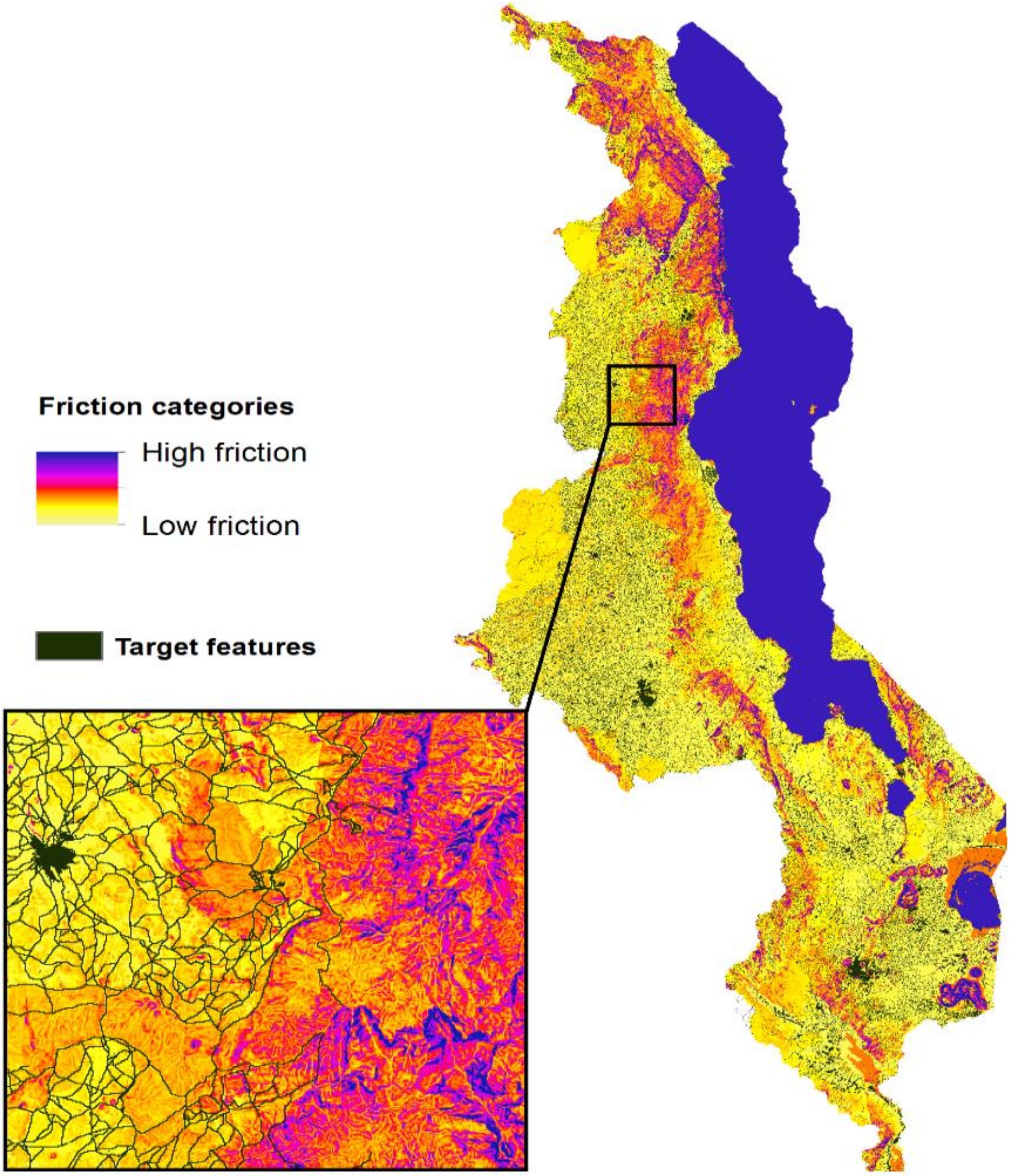


Figure 7.5 1. Friction and Target Features

The result of the analysis is presented in Figure 6.5 2 that shows the map of travel time to nearest accessible feature (hours of transport, return trip).

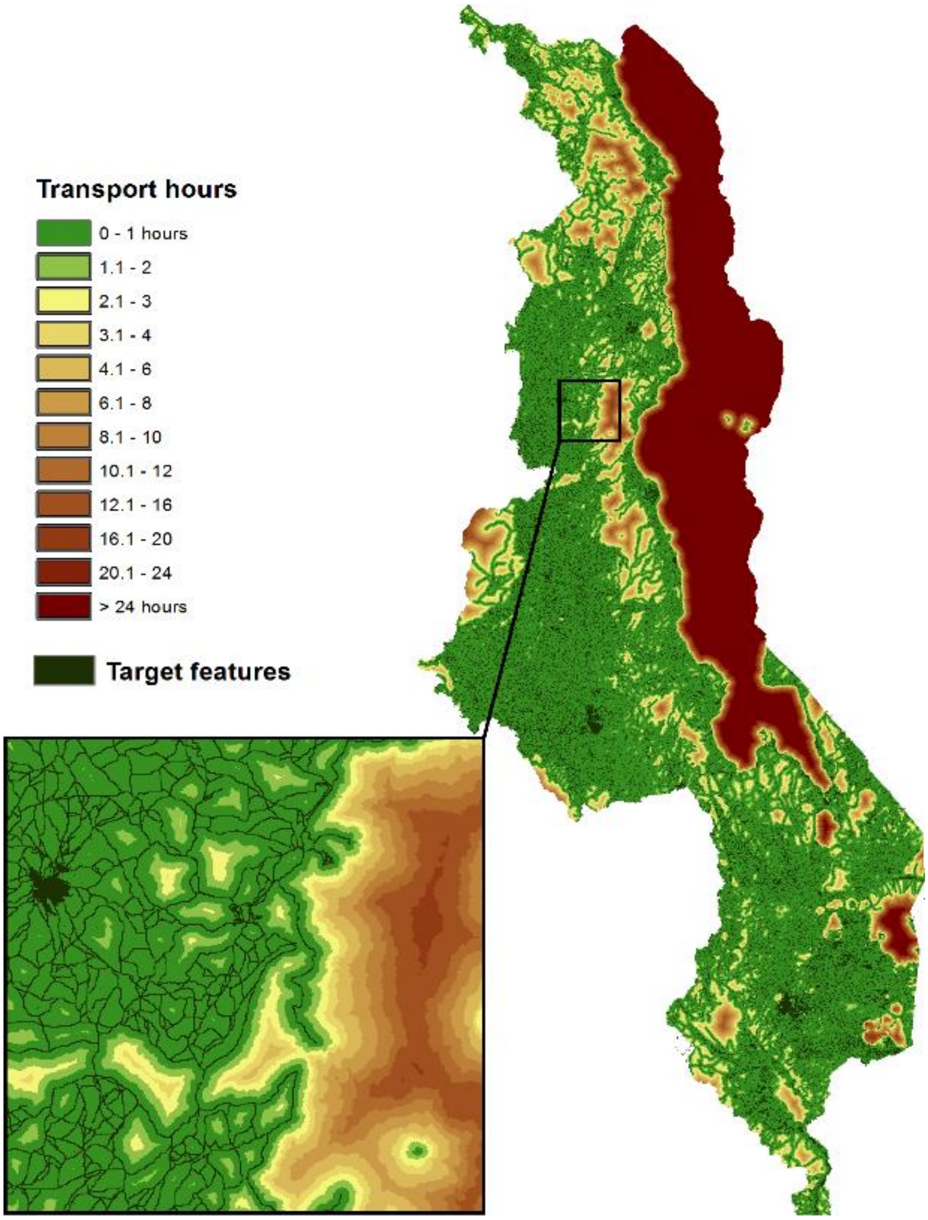


Figure 7.5 2. Transport Time Map (Hours from the Nearest Target Feature)

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 6.5 3 presents the hypothesis of conversion of travel time into percent of accessibility applied, by which 94% of all resources are physically accessible and 6% inaccessible.

Table 7.5 3. Accessibility Factors Applied to Estimated MAI Based on Travel Time

TRANSPORT TIME FROM NEAREST TARGET FEATURE				TOTAL MAI	ACCESSIBILITY PERCENTAGES		ACCESSIBLE MAI
cd2_20	Minutes	Hours	Work Days	kt dm	Access loss (%)	% Accessible	kt dm
1	60	1	0.1	7,930		**100**	**7,930**
2	120	2	0.3	1,484	2.0	**98**	**1,454**
3	180	3	0.4	809	3.0	**95**	**769**
4	240	4	0.5	522	4.0	**91**	**475**
5	300	5	0.6	352	6.0	**85**	**299**
6	360	6	0.8	255	8.0	**77**	**197**
7	420	7	0.9	193	10.0	**67**	**130**
8	480	8	1.0	145	12.0	**55**	**80**
9	540	9	1.1	113	14.0	**41**	**47**
10	600	10	1.3	91	16.0	**25**	**23**
11	720	12	1.5	125	18.0	**7**	**9**
12	840	14	1.8	68	7.0	**0**	**0**
13	960	16	2.0	35	0.0	**0**	**0**
14	1,080	18	2.3	12	0	**0**	**0**
15	1,200	20	2.5	2	0	**0**	**0**
16	1,440	24	3.0	0	0	**0**	**0**
17	1,800	30	3.8	0	0	**0**	**0**
18	2,160	36	4.5	0	0	**0**	**0**
19	2,880	48	6.0	0	0	**0**	**0**
20	> 2,880	> 48	> 6	0	0	**0**	**0**
Totals				**12,138**			**11,411**

Non-accessible MAI (%) : **6**

Accessible MAI (%) : **94**

7.6 APPENDIX 6: DESCRIPTION OF MAPS AND ANALYTICAL STEPS

All maps are raster unless otherwise specified as vector map or point map.
All raster maps are at 100 meters resolution, unless otherwise specified.
Map projection: WGS 1984 UTM 36S (single projection for whole country)

MODULE/FILENAME	DESCRIPTION
Cartographic base	
Administrative layout	
ea_p08_orig	Vector map. Original map derived from population_2008.shp from ILTSI archive, with Enumeration Areas (EA) units (12666) and population, households data from census 2008. The maps has many gaps and overlaps and 21 EA are repeated (and pop data doubled!) In Personal Geodatabase EA.mdb
ea_cod_01	Preliminary raster of ea_p08 on EACODE (presenting no-data pixels)
ea_08	Clean raster version of Enumeration Areas 2008 (ea_cod_01) with gaps filled using majority value from surrounding cells. Value = EA code (version of Census 2008).
dist_08	District map derived from ea_08
ea_msk1	Mask of Malawi based on EA map (value 1). Lake Malawi is excluded.
msk0	Mask (val 0) of Malawi based on EA map. Lake Malawi is included
land1_water0	Land mask based on lccs_2010 and msk0 Map used to clip local balance maps on land areas.
ea08_from_rast2 ea08_mult	Vector map. Ea map (EA codes) from raster ea_08 and dissolved. Total units 12,642 Includes TA, District and Region codes and names, HH and pop 2008 data, urb/rur areas ea08_mult = Dissolve ea08_from_rast2 on EA code (multipart map with unique EA code) Added attributes from ea_p08_orig. In Personal Geodatabase EA.mdb Total pop 13,028,909 (census 08 13,077,160) Rural pop 11,058,521 (census 08 11,073,851) Urban pop 1,970,388 (census 08 2,003,309)
ta08_tmp (singlepart) ta08_multipart	Vector map. Traditional Areas (from ea_08) with TA codes derived from EA codes (which differ from TA codes originally given in the file!). Includes district and Region codes and names, HH and pop 2008 data. Total 364 units In Personal Geodatabase EA.mdb
Land cover data (LCCS 2010 [1990 & 2000] dataset)	
fao_ful_res	Vector map. Original full resolution national LCCS stored in in geodatabase fao_ful_res.mdb It shows lccs at 2010 and changes 1990-2000 and 2000-2010 44 land cover classes or class combinations
lccs2010	raster 100m on field LCCSUSLB of fao_ful_res The extent of this map doesn't match that of ea_msk1
lccs2010_exp*	focal maps (circle, majority) produced to fill the gaps along the borders between lccs2010 and ea_msk1.
lccs2010_mos1	Mosaic of lccs2010 and lccs2010_exp* to produce a single expanded map without gaps
lccs_2010	Land cover 2010 Lccs2010_mos1 map clipped on ea_msk1 (Lake Malawi excluded) "lccs2010_mos1" * "ea_msk1"
changed_1990_2000	Vector map of changed polygons 1990-2000
changed_2000_2010	Vector map of changed polygons 2000-2010
lccs2k_patch	Areas changed over the period 2000-2010 reporting 2000 codes
lccs_2000	Lccs 2000 Created mosaicing lccs2k_patch on lccs_2010

MODULE/FILENAME	DESCRIPTION
lc2010_chngd lc2010_chnged	Changes in land cover occurring between 2000-2010 lc2010_chngd = Con("lccs_2000" == "lccs_2010",0,"lccs_2010") lc2010_chnged = Con("lc2010_chngd" > 0, "lc2010_chngd") (to remove 0 values)
dist_lc_2010	District and land cover combined (dist code+lccscode) "dist_08" * 100 + "lccs_2010"
reg_lc_2010	Region and land cover combined (reg code+lccscode) Int("dist_08" / 100) * 100 + "lccs_2010" zst_reg_lc_2010_ tbs10haplots.dbf
Forest mask(s)	
forest_msk_1	Possible definition of forest area 2010 based on aggregations of LCCS classes Forest mask 01: 1:Tree cover 2: Agric. Trees 3: Shrub 4: Agric. Shrubs 0: Other classes recl_lccs_2010_forest_msk_1.txt
Potential plantation areas	
pot_pl_pc	Possible definition of potentially available plantation area based on estimated fraction of LCCS 2010 classes that may be available for forest plantations. Value= percent available. \GIS\LC\recl_lccs_2010_pot_pl_pc.txt
pot_pl_stat2	potential plantation area in areas outside National Parks and Wildlife Reserves by district, by district group, percent potentially available and slope categories Con("legac" == 100,"dist_08" * 100000 + "dist_08_gr1" * 1000 +"pot_pl_pc" * 10 + "slp_cat_4",0)
Accessibility maps	
Physical accessibility	
m_slp_buf2k	Slope (percent rise) based on (corrected) strm90 with 2km buffer around national border
slp100_b2k	m_slp_buf2k resampled to 100m
slp100	Slope map (float, 32 bits) clipped on msk1 Con("msk1_lake0" == 1,"slp100_b2k",0)
slp_cat_4	Slope categories map Codes: water 0 0-20 1 20-30 2 30-45 3 >45 4
Target features	
rd_mn2	Road network as target feature (but with values giving transport time in minutes per kilometer) Generated by reclass of road map rd_pop_rnk03 (used for population mapping) recl_rd_pop_rnk03_rd_mn1.txt Original class 0 reclassed to NoData
builtup	Target features from land cover Derived from fric_lc_mnkm selecting only classes of build-up classes (value <=20)
sch_pop_rnk02	Schools as target (but with values giving pop ranking values)
village_prnk1	Villages as target feature (but with values giving pop ranking values) from field pop_rank of villages_iltsi_utm_wgs84.shp
target_0	Target features (accessible features including built-up areas, villages, schools and roads) Model "build target_0"
Friction elements	
Land cover friction	
fric_lc_mnkm	Friction of land cover classes in minutes per km considering round trip (return trip

MODULE/FILENAME	DESCRIPTION
	loaded) on flat terrain. Reclass recl_lccs_2010_fric_lc_mnkm.txt
Slope factor	
slope_fac	Slope factor Power(5,2 * ("slp100" / 100))
friclcslp_mkm	Friction of land cover classes (no roads and paths) in minutes per km considering round trip (return trip loaded) considering slope. = "fric_lc_mnkm" * "slope_fac"
rd_mn2	Friction of roads, tracks and footpaths in min/km (return trip loaded)
rd_mn2_fl rd_mn2_fl0	= float (rd_mn2) mosaic with msk0
fr_lcslprdmkm friction_mkm	Friction of land cover classes (considering slope) and roads, tracks and footpaths in minutes per km (round trip with return loaded) [Float] Con("rd_mn2_fl0" == 0,"friclcslp_mkm",Con("rd_mn2_fl0" < "friclcslp_mkm","rd_mn2_fl0","friclcslp_mkm")) Float("msk0" + 240) = msk240_fl produced to fill the NoData with lake friction (val 240) = mosaic to new raster (msk240_fl; frlcslprdmkm) last
fric1_m_m	Friction as minutes per meter (including land cover and all roads but NOT railways) "friction_mkm" / 1000
Cost distance	
cd_min	Cost-distance map (minutes from nearest target feature) cost distance (target_0; fric1_m_m)
cd_20	Reclass cdmin into 20 classes
ph_acc01	Percent accessible map based on elaboration of cd_20 recl_cd_20_ph_acc01.txt
Legal accessibility	
Nat_Parks_Wildlife_Res_DOFdata	National Parks and Wildlife Reserved extracted from MalawiProtectedAreas.shp According to WDPA these areas are IUCN categories II and IV, all in theory excluded from exploitation, either for commercial and local use.
legac_0	Conversion to raster based on field perc_acces
legac	Legal accessibility map Mosaic of msk100 and legac_0
Supply Module	
lccs_2010	Land cover base map (see above)
DEB stock	
	Preliminary estimates based on Pantropical aboveground live biomass map produced at 30 m resolution representing the biomass stock for the year 2000 in (Mg/ha). (Zarin et al., 2016)
agb2k agb_2k	Malawi aboveground live biomass map resampled to 100m and clipped on mask (values assumed to be tDM/ha. (based on Zarin et al., 2016). agb2k has data gaps (mainly rivers/river beds, lakes but also other classes). Gaps were replaced with 0 values (agb_2k). zst_lccs_2000_agb_2k.dbf
TOF tree cover % data from TBS study	
All_districts_pct_tree cover	1-km raster with tree cover % in farmland areas
pct_treecover_pnt	Point map of the centre of All_districts_pct_treecover with % tree cover value (grid_code)
tbs10haplots	Raster of pct_treecover_pnt on grid_code. 100m cell, snap to msk zst_reg_lc_2010_ tbs10haplots.dbf
tbs10ha_pl	TBS plot areas (approximate, 3 x 3 pixels around center points) statistics of tree cover mean, sd by lccs_2010 classes: zst_lccs_2010_tbs10ha_pl.dbf
	Stock estimated based on field plot data from various forest inventories
plots_v4	Point map. Recalculated plot agb from original tree parameters (May 2018) Shapefile based on unit.summary.csv (received by Ben on 8th May)

MODULE/FILENAME	DESCRIPTION
plot_mgha495	raster of plots_v4.shp on field Mg_p_ha (abg tonnes DM/ha)
stk_kgha_md	Aboveground woody biomass (agwb) in 2010 (kg DM/ha) Preliminari map. Single value per class, without variations within classes recl_lccs_2010_stk_kgha_md.txt
	Spatial distribution of stk values within LCCS classes agb_2k by (Zarin et al., 2016) is used as spatial proxy for the distribution of stock (estimated above) within lccs classes. Since agb_2k refers to year 2000, the stock distribution is done first on lccs_2000 mapa nd then the changes 2000-2010 with their respective 2010 stock values are superimposed to the spatialized 2000 stk map to obtain the 2010 stk map
Medium stock	
m_stk2kkghamd stk2k_kgha_md	Phase 1: create 2000 pixel values Recl_lccs_2000_mult_agb_2k_stk2k_kgha_md.txt (reclass file of lccs_2000 to create the multiplier map that, applied to agb2k in t obtains the stk map 2000 in kg DM/ha "agb_2k" * "m_stk2kkghamd" zst_lccs_2000_stk2k_kgha_md.dbf
stk2010chg_md	Phase 2: add 2010 stk values for the lc classes that changed 2000-2010 (c2010_chnged) Reclass lc2010_chnged using recl_lccs_2010_stk_kgha_md.txt
stk10_kgha_md stk10kg_md	Phase 3: Mosaic 2010 stk values for the lc classes that changed 2000-2010 on the spatialized stock 2000 to obtain the stk 2010. Mosaic to new raster (stk2k_kgha_md; stk2010chg_md; last) Convert to float : Float(stk10_kgha_md)
Minimum stock	
m_stk2kkghamn stk2k_kgha_mn	Phase 1: create 2000 pixel values Recl_lccs_2000_mult_agb_2k_stk2k_kgha_mn.txt (reclass file of lccs_2000 to create the multiplier map that, applied to agb2k in t obtains the stk map 2000 in kg DM/ha "agb_2k" * "m_stk2kkghamn" zst_lccs_2000_stk2k_kgha_mn.dbf
stk2010chg_mn	Phase 2: add 2010 stk values for the lc classes that changed 2000-2010 (c2010_chnged) Reclass lc2010_chnged using recl_lccs_2010_stk_kgha_mn.txt
stk10kg_mn	Phase 3: Mosaic 2010 stk values for the lc classes that changed 2000-2010 on the spatialized stock 2000 to obtain the stk 2010. Mosaic to new raster (stk2k_kgha_mn; stk2010chg_mn; last; select float 32 format)
Maximum stock	
m_stk2kkghamx stk2k_kgha_mx	Phase 1: create 2000 pixel values Recl_lccs_2000_mult_agb_2k_stk2k_kgha_mx.txt (reclass file of lccs_2000 to create the multiplier map that, applied to agb2k in t obtains the stk map 2000 in kg DM/ha "agb_2k" * "m_stk2kkghamx" zst_lccs_2000_stk2k_kgha_mx.dbf
stk2010chg_mx	Phase 2: add 2010 stk values for the lc classes that changed 2000-2010 (c2010_chnged) Reclass lc2010_chnged using recl_lccs_2010_stk_kgha_mx.txt
stk10kg_mx	Phase 3: Mosaic 2010 stk values for the lc classes that changed 2000-2010 on the spatialized stock 2000 to obtain the stk 2010. Mosaic to new raster (stk2k_kgha_mx; stk2010chg_mx; last; select float 32 format)
bp_yr_md bp_yr_mn bp_yr_mx	***Estimated annual deforestation by-products*** (from lccs, period 2000-2010). Limited to negative changes. md = Con(("%stk10kg_md%" - "%stk2k_kgha_md%") <= 0,("%stk10kg_md%" - "%stk2k_kgha_md%") / 10,0) zst_dist_08_bp_yr_md.dbf mn = Con(("%stk10kg_mn%" - "%stk2k_kgha_mn%") <= 0,("%stk10kg_mn%" - "%stk2k_kgha_mn%") / 10,0)

MODULE/FILENAME	DESCRIPTION
	zst_dist_08_bp_yr_mn.dbf mx = Con(("%stk10kg_mx%" - "%stk2k_kgha_mx%") <= 0,("%stk10kg_mx%" - "%stk2k_kgha_mx%") / 10,0) zst_dist_08_bp_yr_mx.dbf
DEB MAI - Mean MAI variant of MEAN stock	
mai10_kg_md	Calculate Mean MAI variant of MEAN stock applying the equation: Intermediate: $y = 32.136x^{-0.595}$ where x= stock in t DM and y= MAI as % of stock and converting MAI% into MAI kg DM ha^{-1} yr^{-1} Con("stk10kg_md" <= 1, "stk10kg_md" * 0.33,(Power("stk10kg_md" / 1000, - 0.595) * 32.136) * "stk10kg_md" / 100) zst_lccs_2010_mai10_kg_md
phacmai_md	Physically accessible MAI md Int("mai10_kg_md" * "ph_acc01" / 100 + 0.5)
acmai_md	Physically and legally accessible MAI md = Int("phacmai_md" * "legac" / 100 + 0.5)
DEB MAI - Low MAI variant of Minimum stock	
mai10_kg_mn	Calculate Low MAI variant of Minimum stock applying the equation: Low MAI variant: $y = 27.221x^{-0.6061}$ where x= stock in t DM and y= MAI as % of stock and converting MAI% into MAI kg DM ha^{-1} yr^{-1} Con("stk10kg_mn" <= 1, "stk10kg_mn" * 0.33,(Power("stk10kg_mn" / 1000, - 0.6061) * 27.221) * "stk10kg_mn" / 100) zst_lccs_2010_mai10_kg_mn.dbf
phacmai_mn	Physically accessible MAI mn Int("mai10_kg_mn" * "ph_acc01" / 100 + 0.5)
acmai_mn	Physically and legally accessible MAI mn Int("phacmai_mn" * "legac" / 100 + 0.5)
DEB MAI - High MAI variant of Maximum stock	
mai10_kg_mx	Calculate High MAI variant of Maximum stock applying the equation: High MAI variant: $y = 37.058x^{-0.5879}$ where x= stock in t DM and y= MAI as % of stock and converting MAI% into MAI kg DM ha^{-1} yr^{-1} Con("stk10kg_mx" <= 1, "stk10kg_mx" * 0.33,(Power("stk10kg_mx" / 1000, - 0.5879) * 37.058) * "stk10kg_mx" / 100) zst_lccs_2010_mai10_kg_mx.dbf
phacmai_mx	Physically accessible MAI mn Int("mai10_kg_mx" * "ph_acc01" / 100 + 0.5)
acmai_mx	Physically and legally accessible MAI mx Int("phacmai_mx" * "legac" / 100 + 0.5)
avmai_md	Available MAI (medium variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations' accessible MAI) Con("lccs_2010" == 18,"acmai_md" * 0.25,"acmai_md")
avmai_mn	Available MAI (minimum variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations' accessible MAI) Con("lccs_2010" == 18,"acmai_mn" * 0.25,"acmai_mn")
avmai_mx	Available MAI (maximum variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations' accessible MAI) Con("lccs_2010" == 18,"acmai_mx" * 0.25,"acmai_mx")
Estimation of MAI 2016 based on MAI 2010 + 6 * annual MAI change 2000-2010	
avmai16_md	***Model MAI_2016_md*** stk2kkgha_mdf = Float("%stk2k_kgha_md%") mai_2k_md = Con("%stk2kkgha_mdf%" <= 1, "%stk2kkgha_mdf%" * 0.33,(Power("%stk2kkgha_mdf%" / 1000, - 0.595) * 32.136) * "%stk2kkgha_mdf%" / 100) acmai2k_md = Int(("%MAI_2k_md%" * "%ph_acc01%" / 100) * "%legac%" / 100 + 0.5)

MODULE/FILENAME	DESCRIPTION
	Available MAI (medium variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations' accessible MAI) avmai2k_md = Con("%lccs_2000%" == 18,"%acmai2k_md%" * 0.25,"%acmai2k_md%") y_avmai_ch_md = ("%avmai_md%" - "%avmai2k_md%") / 10 avmai16_md = "%avmai_md%" + "%y_avmai_ch_md%" * 6
avmai16_mn	***Model MAI_2016_mn*** stk2kkgha_mnf = Float("%stk2k_kgha_mn%") mai_2k_mn = Con("%stk2kkgha_mnf%" <= 1, "%stk2kkgha_mnf%" * 0.33,(Power("%stk2kkgha_mnf%" / 1000, - 0.6061) * 27.221) * "%stk2kkgha_mnf%" / 100) acmai2k_mn = Int(("%MAI_2k_mn%" * "%ph_acc01%" / 100) * "%legac%" / 100 + 0.5) Available MAI (minimum variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations' accessible MAI) avmai2k_mn = Con("%lccs_2000%" == 18,"%acmai2k_mn%" * 0.25,"%acmai2k_mn%") y_avmai_ch_mn = ("%avmai_mn%" - "%avmai2k_mn%") / 10 avmai16_mn= "%avmai_mn%" + "%y_avmai_ch_mn%" * 6
avmai16_mx	***Model MAI_2016_mx*** stk2kkgha_mxf = Float("%stk2k_kgha_mx%") mai_2k_mx = Con("%stk2kkgha_mxf%" <= 1, "%stk2kkgha_mxf%" * 0.33,(Power("%stk2kkgha_mxf%" / 1000, - 0.5879) * 37.058) * "%stk2kkgha_mxf%" / 100) acmai2k_mx = Int(("%MAI_2k_mx%" * "%ph_acc01%" / 100) * "%legac%" / 100 + 0.5) Available MAI (maximum variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations' accessible MAI) avmai2k_mx = Con("%lccs_2000%" == 18,"%acmai2k_mx%" * 0.25,"%acmai2k_mx%") y_avmai_ch_mx = ("%avmai_mx%" - "%avmai2k_mx%") / 10 avmai16_mx = "%avmai_mx%" + "%y_avmai_ch_mx%" * 6
Estimated local stock relative to the avmai16_* , needed to establish the maximum fraction of the stock that can be annually removed in overexploited rural deficit areas	
l_stk16_t_md	***Local stock – Medium variant*** $y = 16.537x^{2.4715}$ Stk (t DM) = 16.537 * avmai16 / 1000 ^ 2.4715 Model : calc stk from MAI & local stk stk16_t_md : Power("%avmai16_md%" / 1000,2.4715) * 16.537 stk16t_f5k_md : focal mean (stk16_t_md ; circle ; 50 ; mean) l_stk16_t_md : "%stk16t_f5k_md%" * "land1_water0" Note: this is a conservative estimation of the local stock (5km focalmean) based on the MAI/stk equation using available MAI2016 as input. Useful for the estimation of the maximum harvestable stock fraction but NOT to estimate the actual stock
l_stk16_t_mn	***Local stock – Minimum variant*** $y = 27.203x^{2.5387}$ Stk (t DM) = 27.203 * avmai16 / 1000 ^ 2.5387 Model : calc stk from MAI & local stk stk16_t_mn : Power("%avmai16_mn%" / 1000,2.5387) * 27.203 stk16t_f5k_mn : focal mean (stk16_t_mn ; circle ; 50 ; mean) l_stk16_t_mn : "%stk16t_f5k_mn%" * "%land1_water0%" Note: this is a conservative estimation of the local stock (5km focalmean) based on the MAI/stk equation using available MAI2016 as input. Useful for the estimation of the maximum harvestable stock fraction but NOT to estimate the actual stock
l_stk16_t_mx	***Local stock – Maximum variant*** $y = 11.121x^{2.4266}$ Stk (t DM) = 11.121 * avmai16 / 1000 ^ 2.4266

MODULE/FILENAME	DESCRIPTION
	Model : calc stk from MAI & local stk stk16_t_mx : Power("%avmai16_mx%" / 1000, 2.4266) * 11.121 stk16t_f5k_mx : focal mean (stk16_t_mx ; circle ; 50 ; mean) l_stk16_t_mx : "%stk16t_f5k_mx%" * "land1_water0" Note: this is a conservative estimation of the local stock (5km focalmean) based on the MAI/stk equation using available MAI2016 as input. Useful for the estimation of the maximum harvestable stock fraction but NOT to estimate the actual stock
Demand Module	
Population mapping	
carr_rank_01	Population carrying capacity related to land cover classes recl_lccs_2010_pop_carr_rank.txt
rd_pop_rnk02 rd_pop_rnk03 (on 0-msk)	Population carrying capacity related to roads from field pop_rank of Road_Tracks.shp population carrying capacity ranking applied: Main road : 20 District road : 15 Secondary road : 10 Tertiary road : 8 Other road : 6
sch_pop_rnk02 sch_pop_rnk03 (on 0-msk)	Population carrying capacity related to schools From field pop_rank of prim_&_sec_schools_utm_wgs84.shp Population carrying capacity ranking applied: > 2000 students: 100 1000-2000 : 50 500-999 : 30 200-499 : 20 <200 : 10
p_rnk_lc_rd	Ierarchy of rank maps Con("carr_rank_01" > "rd_pop_rnk03","carr_rank_01","rd_pop_rnk03")
p_rnk_all_01	Preliminary Ranking of probable population distribution Con("p_rnk_lc_rd" > "sch_pop_rnk03","p_rnk_lc_rd","sch_pop_rnk03") Note: 27 EAs have no pop proxies! More spatial features are needed
village_prnk1 villag2_prnk1	Population carrying capacity ranking of villages • from field pop_rank of villages_iltsi_utm_wgs84.shp (village_prnk1) for whole country • from field pop_rank of village_cnt_filling_gaps.shp (villag2_prnk1) only for ea without pop proxies population carrying capacity ranking applied: All villages : 100
p_rnk_all_02	Ranking of probable population distribution based on: • Land cover • Roads • Villages (villages_iltsi_utm_wgs84 snd selectd village_cnt) • schools Mosaic of p_rnk_all_01, village_prnk1, villag2_prnk1
Population 2016	
pop16_mult	Multiplier map of pop 2016 reclass file: recl_ea_08_pop16_mult.txt
pop2016	2016 Population distribution. Value= pop per 1ha pixel * 1000 "pop16_mult" * "p_rnk_all_02"
pop_urb_2016	Urban population 2016 Value= pop per 1ha pixel * 1000 Con("urb1_rur2" == 1,"pop2016",0)
pop_rur_2016	Rural population 2016 Value= pop per 1ha pixel * 1000

MODULE/FILENAME	DESCRIPTION
	Con("urb1_rur2" == 2,"pop2016",0)
pop16_rur_fl	Float("pop_rur_2016")
pop16_urb_fl	Float("pop_urb_2016")
Household demand 2016	
m_rur_ch	Multiplier of pop_rur_2016 (to obtain rural charcoal consumption) recl_dist_08_m_rur_ch.txt
m_rur_fw	Multiplier of pop_rur_2016 (to obtain rural fuelwood consumption) recl_dist_08_m_rur_fw.txt
m_urb_ch	Multiplier of pop_urb_2016 (to obtain urban charcoal consumption) recl_dist_08_m_urb_ch.txt
m_urb_fw	Multiplier of pop_urb_2016 (to obtain urban fuelwood consumption) recl_dist_08_m_urb_fw.txt
rurhh_chkg	Rural households' demand for charcoal Int("pop16_rur_fl" * "m_rur_ch" / 1000000 + 0.5)
rurhh_fwkg	Rural households' demand for fuelwood Int("pop16_rur_fl" * "m_rur_fw" / 1000000 + 0.5)
urbhh_chkg	Urban households' demand for charcoal Int("pop16_urb_fl" * "m_urb_ch" / 1000000 + 0.5)
urbhh_fwkg	Urban households' demand for fuelwood Int("pop16_urb_fl" * "m_urb_fw" / 1000000 + 0.5)
const_mat	Construction material consumed by rural and urban householda Int(("pop16_rur_fl" * 12.2 + "pop16_urb_fl" * 6.1) / 1000 + 0.5)
hh_dem_kg	Households' demand "rurhh_chkg" + "rurhh_fwkg" + "urbhh_chkg" + "urbhh_fwkg" + "const_mat"
NON-Household demand	
comm_dem_kg	Commercial demand (tent. estimated as 5% of urban hh demand) Int(("urbhh_fwkg" + "urbhh_chkg") / 20 + 0.5)
sch_dem_kg	School consumption map_stud_0 "map_stud_0" * 28.88
lime_area_0	Lime mine area sel_lime_mine
lime_dem_kg	Lime demand "lime_area_0" * 162.83
poult_dem_kg	Poultry industry demand poult_dem_0 "poult_dem_0" * 42.66
tobac_dem_kg	Tobacco curing demand "cropland" * 19.999
brick_dem_kg	Brick making demand ("pop_rur_2016" * 9.26 + "pop_urb_2016" * 109.75) / 1000
tea_dem_kg	Tea drying demand tea_area_0 = Con("lccs_2010" == 34,1,0) "tea_area_0" * 2327.35
fish_d_dem_kg	Firewood consumption for fish smoking/drying (spatial proxy: populating within 500m from lake shore) all_lakes1_0 lake_shore500 = ("lakes_exp5" - "all_lakes1_0") * "msk1" Shore500_0 = mosaic msk0; lake_shore500 shore_pop_0 = "Shore500_0" * "pop2016" fish_d_dem_kg = "shore_pop_0" * 0.163
nonhh_dem_kg	Non-residential demand "comm_dem_kg" + "sch_dem_kg" + "lime_dem_kg" + "poult_dem_kg" + "tobac_dem_kg" + "brick_dem_kg" + "tea_dem_kg" + "fish_d_dem_kg"
dem_kg	Total woodfuel demand in all sectors (hh and non-hh). Kg DM/ha "nonhh_dem_kg" + "hh_dem_kg"
l_dem_kg	local demand

MODULE/FILENAME	DESCRIPTION
	= focalmean dem_kg, circle, 50
Revision of fuelwood consumption in rural deficit areas	
	A distinction is made between the rural use of "conventional" fuelwood (solid wood pieces from stems and branches) and of "marginal" fuelwood (twigs produced through annual/ periodic pruning of trees and shrubs on farmlands). According to the Rural Firewood Assortments Survey (RFAS), in rural DEFICIT areas (less than 90% of the demanded fuelwood available within 5 km context) an average of 40% of the supply is made of marginal assortments and 60% is made of conventional assortments (46% collected and 14% purchased). Also according to the RFAS, in rural SURPLUS areas an average of 14% of the supply is made of marginal assortments and 86% is made of conventional assortments (85% collected and 1% purchased). Procedure: Compare local fuelwood demand in rural areas with local balance values (lbal16_md / l_rhh_fw * 100) to estimate what percent of the rural hh demand for fw is not fulfilled by the local sustainable supply potential.
l_rhh_fw	Rural HH fuelwood demand for 2016 averaged within a 5km radius = focalmean rurhh_fwkg, circle, 50
Map produced for the analysis of percentage fulfilled in rural areas	
r_fulf2_md	Recalculation made in order to eliminate odd values where the demand is below 10kg/ha/yr. Con("urb1_rur2" == 2,Con("l_rhh_fw" <= 10,0,Int("lbal16_md" / "l_rhh_fw" * 100 + 0.5)),0)
r_fulf1_0_md	Rural deficit (1) and surplus (0) areas. Md supply variant Con("r_fulf2_md" < 0,1,0)
r_fulf2_mn	Recalculation made in order to eliminate odd values where the demand is below 10kg/ha/yr. Con("%urb1_rur2%" == 2,Con("%l_rhh_fw%" <= 10,0,Int("%lbal16_mn%" / "%l_rhh_fw%" * 100 + 0.5)),0)
r_fulf1_0_mn	Rural deficit (1) and surplus (0) areas. Mn supply variant Con("r_fulf2_mn" < 0,1,0)
r_fulf2_mx	Recalculation made in order to eliminate odd values where the demand is below 10kg/ha/yr. Con("%urb1_rur2%" == 2,Con("%l_rhh_fw%" <= 10,0,Int("%lbal16_mx%" / "%l_rhh_fw%" * 100 + 0.5)),0)
r_fulf1_0_mx	Rural deficit (1) and surplus (0) areas. Mx supply variant Con("r_fulf2_mx" < 0,1,0)
Revised local demand considering only the conventional fuelwood demand in rural areas based on percent fulfilled and on RFAS results. In the resulting demand maps marginal fuelwood assortments are excluded.	
lrhfw_md lrhfw_md_marg	***Local rural conventional fuelwood demand for Leading scenario*** ***Med supply variant – Med marginal fraction*** lrhfw_md = Con("r_fulf2_md" > 0,"l_rhh_fw" * 0.87,Con("r_fulf2_md" <= -90,"l_rhh_fw" / 4,"l_rhh_fw" + ("l_rhh_fw" * ("r_fulf2_md" - 13) / 150))) lrhfw_md_marg (marginal fw %) = ("l_rhh_fw" - "lrhfw_md") / "l_rhh_fw" * 100 zst_r_fulf1_0_md_lrhfw_md_marg.dbf mean marginal fw in deficit areas: 41.7 % (RFAS: 41.6%) mean marginal fw in surplus areas: 12.3 % (RFAS: 13 %)
lrhfw_mn lrhfw_mn_marg	***Local conventional fuelwood demand for least favorable scenario*** ***Min supply variant – Minimum marginal fraction*** lrhfw_mn = Con("r_fulf2_mn" > 0,"l_rhh_fw" * 0.95,Con("r_fulf2_mn" < -90,"l_rhh_fw" * 0.52,"l_rhh_fw" + ("l_rhh_fw" * ("r_fulf2_mn" - 5) / 200))) lrhfw_mn_marg (marginal fw %) = ("l_rhh_fw" - "lrhfw_mn") / "l_rhh_fw" * 100 zst_ r_fulf1_0_mn_irhfw_mn_marg.dbf = mean marginal fw in deficit areas: 30.5 % (RFAS: 30%) mean marginal fw in surplus areas: 4.5 % (RFAS: 5%)
lrhfw_mx	***Local conventional fuelwood demand for most favorable scenario*** ***Max supply variant – Maximum marginal fraction***

MODULE/FILENAME	DESCRIPTION
lrhfw_mx_marg	lrhfw_mx = Con("r_fulf2_mx" > 0,"l_rhh_fw" * 0.78,Con("r_fulf2_mx" < -90,"l_rhh_fw" * 0.25,"l_rhh_fw" + ("l_rhh_fw" * ("r_fulf2_md" - 22) / 150))) lrhfw_mx_marg (marginal fw %) = ("l_rhh_fw" - "lrhfw_mx") / "l_rhh_fw" * 100 zst_ r_fulf1_0_mx_irhfw_mx_marg.dbf = mean marginal fw in deficit areas: 52.9 % (RFAS: 52 %) mean marginal fw in surplus areas: 21.1% (RFAS: 22 %)
l_demr_md	Total demand in a local 5km context – Md variant l_dem_kg - l_rhh_fw + lrhfw_md
l_demr_mn	Total demand in a local 5km context – Mn variant l_dem_kg - l_rhh_fw + lrhfw_mn
l_demr_mx	Total demand in a local 5km context – Mx variant l_dem_kg - l_rhh_fw + lrhfw_mx
Integration Module	
Supply / Demand balance assuming TOTAL Demand (including marginal and conventional fuelwood)	
Pixel-level balance (2016) assuming total demand (including marginal and conventional fuelwood)	
bal16_md	Pixel-level balance (2016) Medium variant "avmai16_md" - "dem_kg"
bal16_mn	Pixel-level balance (2016) Minimum variant "avmai16_mn" - "dem_kg"
bal16_mx	Pixel-level balance (2016) Maximum variant "avmai16_mx" - "dem_kg"
Local balance (2016) assuming total demand (including marginal and conventional fuelwood)	
lbal16_md	Local balance on a 5 km harvesting horizon md variant) = focalmean bal16_md, circle, 50 ; clipped on land1_water0
lbal16_mn	Local balance on a 5 km harvesting horizon mn variant) = focalmean bal16_mn, circle, 50 ; clipped on land1_water0
lbal16_mx	Local balance on a 5 km harvesting horizon mx variant) = focalmean bal16_mx, circle, 50 ; clipped on land1_water0
ldef_md	Local deficit Total demand – Md supply Con("lbal16_md" < 0,"lbal16_md",0)
Local-level commercial balance assuming total demand (including marginal and conventional fuelwood) based on 410 od kg/ha/yr surplus threshold, the stock on a 30-years rotation expected to be > 12 od t /ha (IUCN Protected Areas are already excluded).	
combal_md	Model for Commercial balance « combal_Malawi »: 1: Combal_tmp1 = Con("lbal16_md" < 410, Con("lbal16_md" >=0,0, "lbal16_md"), "lbal16_md") 2: Combal_md = Con("%combal_tmp1%">0, Con("avmai16_md" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%")
combal_mn	Model for Commercial balance « combal_Malawi »: 1: Combal_tmp1 = Con("%lbal16_mn%" < 410, Con("%lbal16_mn%" >=0,0, "%lbal16_mn%"), "%lbal16_mn%") 2: Combal_mn = Con("%combal_tmp1%">0, Con("avmai16_mn" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%")
combal_mx	Model for Commercial balance « combal_Malawi »: 1: Combal_tmp1 = Con("lbal16_mx" < 410, Con("lbal16_mx" >=0,0, "lbal16_mx"), "lbal16_mx") 2: Combal_mx = Con("%combal_tmp1%">0, Con("avmai16_mx" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%")
Supply / Demand balance assuming CONVENTIONAL Demand (including only conventional fuelwood and excluding marginal fuelwood assortments used by rural HH)	
Local balance (2016) assuming conventional demand (including only conventional fuelwood and excluding marginal fuelwood assortments used by rural HH)	
lbal16r_md	Recalculation of local balance to exclude marginal fuelwood. Md variant "lbal16_md" + "l_rhh_fw" - "lrhfw_md"
lbal16r_mn	Recalculation of local balance to exclude marginal fuelwood. Mn variant "lbal16_mn" + "l_rhh_fw" - "lrhfw_mn"
lbal16r_mx	Recalculation of local balance to exclude marginal fuelwood. Mx variant

MODULE/FILENAME	DESCRIPTION
	"lbal16_mx" + "l_rhh_fw" - "lrhfw_mx"
lsur16r_md	Local surplus – Md var Con("lbal16r_md" > 0,"lbal16r_md",0)
lsur16r_mn	Local surplus – Mn var Con("lbal16r_mn" > 0,"lbal16r_mn",0)
lsur16r_mx	Local surplus – Mx var Con("lbal16r_mx" > 0,"lbal16r_mx",0)
Local-level commercial balance assuming conventional demand (including only conventional fuelwood and excluding marginal fuelwood assortments used by rural HH) and including commercial surplus only. Commercial surplus based on 410 od kg/ha/yr surplus threshold, the stock on a 30-years rotation expected to be > 12 od t /ha (IUCN Protected Areas are already excluded).	
combalr_md	Commercial balance – Medium variant Based on editing of model "combalr_Malawi": 1: Combal_tmp1 = Con("lbal16r_md" < 410, Con("lbal16r_md" >=0,0, "lbal16r_md"),"lbal16r_md") 2: Combalr_md = Con("%combal_tmp1%">0, Con("avmai16_md" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%") (Remember to delete intermediate data!)
combalr_mn	Commercial balance – Minimum variant Based on editing of model "combalr_Malawi": 1: Combal_tmp1 = Con("%lbal16r_mn%" < 410, Con("%lbal16r_mn%" >=0,0, "%lbal16_mn%"), "%lbal16r_mn%") 2: Combalr_mn = Con("%combal_tmp1%">0, Con("avmai16_mn" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%") (Remember to delete intermediate data!)
combalr_mx	Commercial balance – Maximum variant Based on editing of model "combalr_Malawi": 1: Combal_tmp1 = Con("lbal16r_mx" < 410, Con("lbal16r_mx" >=0,0, "lbal16r_mx"), "lbal16r_mx") 2: Combal_mx = Con("%combal_tmp1%">0, Con("avmai16_mx" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%") (Remember to delete intermediate data!)
Woodshed analysis	
Local deficit and peak deficit locations	
Deficit_pnts_14	Point map. Main deficit points (must be point feature, not multipoint)
	Local deficit- Leading scenario: Conventional demand Medium marginal fraction – Medium Supply variant Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_md
ldefr_md	Local deficit within 5 km radius: = Con("lbal16r_md" <= 0,"lbal16r_md",0)
defsumr15_md	Major deficit areas SUMMARIZING the deficit within a 15 km radius. = focalSUM ("ldefr_md", circle, 150, SUM)
pnts14_defsumr15_md	Point map. Map of 14 points marking peak deficit locations based on 15 KM deficit map with assigned deficit value from defsumr15_md (RASTERVALU field) and defined Pnt_ID code, that represent the major consumption sites to be used as point values in IDW Dinamica analysis. The sum of deficit in RASTERVALU is converted to positive values in field defsum15km.
	Local deficit – High degradation scenario (Least favorable variants/assumptions): Conventional demand Minimum marginal fraction - Min supply variant Folder E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mn
ldefr_mn	Local deficit within 5 km radius : = Con("lbal16r_mn" <= 0,"lbal16r_mn",0)
defsumr15_mn	Major deficit areas SUMMARIZING the deficit within a 15 km radius – Conventional demand Minimum marginal fraction – Minimum supply variant = focalSUM ("ldefr_mn", circle, 150)

MODULE/FILENAME	DESCRIPTION
pnts14_defsumr15_mn	Point map. Map of 14 points marking peak deficit locations based on 15 KM deficit map with assigned deficit value from defsumr15_mn (Extract value to point; RASTERVALU field) and defined Pnt_ID code, that represent the major consumption sites to be used as point values in IDW Dinamica analysis. The sum of deficit in RASTERVALU is converted to positive values in field defsum15km.
	Local deficit – Low degradation scenario (Most favorable variants / assumptions): Conventional demand Maximum marginal fraction – MaximumSupply variant Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mx
ldefr_mx	Local deficit within 5 km radius : = Con("lbal16r_mx" <= 0,"lbal16r_mx",0)
defsumr15_mx	Major deficit areas SUMMARIZING the deficit within 15 km radius Conventional demand Maximum marginal fraction – Maximum supply variant = focalSUM ("ldefr_mx", circle, 150)
pnts14_defsumr15_mx	Point map. Map of 14 points marking peak deficit locations based on 15 KM deficit map with assigned deficit value from defsumr15_mx(RASTERVALU field) and defined Pnt_ID code, that represent the major consumption sites to be used as point values in IDW Dinamica analysis. The sum of deficit in RASTERVALU is converted to positive values in field defsum15km.
Mapping commercial harvesting pressure based on Dinamica EGO	
fric1_m_m.tif	***Friction map*** = Export fric1_m_m in tiff format
pnt_id.tif	***Categorical map*** With ID of major deficit points map extent to matching that of fric1_m_m.tif = PointToRaster pnts14_defsumr15_md.shp ; pnt_ID; MOST_FREQUENT; NONE; snap to fric1_m_m.tif
Harvesting pressure- Leading scenario: Conventional demand Medium marginal fraction – Medium Supply variant Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_md	
	Lookup Tables With ID points (fieldname: key) and deficit values (fieldname: value; positive)
id_defsr_md.csv	Values from pnts14_defsumr15_md.shp
	wcd_defr_md_prec2.egoml : (Conventional Demand Medium marginal fraction – Med supply) Precision 2 (2 iterations) Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_md
wcd_defr_md0.tif	Final cumulative map of all individual points interpolation maps (weighted cost distance) cost##.tif : Individual point interpolation map (temporary, not saved on disk) sumcost##.tif : Progressively cumulative maps of individual points interpolation maps (temporary, saved on disk in folder woodsheds\wcd_r_md) . Last map= sumcost**.tif
wcd_defr_md	Final grid version of weighted cost distance maps with gaps at point locations filled in and clipped Model "focal_mosaic_clip" focalmean (wcd_defr_md0.tif ; circle, 1) to fill the NoData at point position (wcd_defr_mdf1.tif) Mosaic to wcd_defr_md_tmp.tif and clipped on msk1_lake0
wcd_md_cat1	Weight to be used to distribute pressure on surplus resources Segmentation of wcd_defr_md into 174 classes reflecting the weighted cost distance values (weighted on wcd values) recl_wcd_defr_md_value_w_cat_01.txt (note: same class intervals applied to all wcd_defr maps)

MODULE/FILENAME	DESCRIPTION
Harvesting pressure- High degradation scenario: Conventional demand Minimum marginal fraction – Minimum Supply variant Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mn	
	Lookup Tables With ID points (fieldname: key) and deficit values (fieldname: value; positive)
id_defsr_mn.csv	Values from pnts14_defsumr15_mn.shp
	wcd_defr_mn_prec2.egoml : (Conventional demand Minimum marginal fraction – Minimum Supply variant) Precision 2 (2 iterations) Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mn
wcd_defr_mn0.tif	Final cumulative map of all individual points interpolation maps (weighted cost distance) cost##.tif : Individual point interpolation map (temporary, not saved on disk) sumcost##.tif : Progressively cumulative maps of individual points interpolation maps (temporary, saved on disk in folder woodsheds\wcd_r_mn) . Last map= sumcost**.tif
wcd_defr_mn	Final grid version of weighted cost distance maps with gaps at point locations filled in and clipped Model "focal_mosaic_clip" focalmean (wcd_defr_mn0.tif ; circle, 1) to fill the NoData at point position (wcd_defr_mnf1.tif) Mosaic to wcd_defr_mn_tmp.tif and clipped on msk1_lake0
wcd_mn_cat1	Weight to be used to distribute pressure on surplus resources Segmentation of wcd_defr_mn into 174 classes reflecting the weighted cost distance values (weighted on wcd values) recl_wcd_defr_mn_value_w_cat_01.txt (note: same class intervals applied to all wcd_defr maps)
Harvesting pressure- Low degradation scenario: Conventional demand Maximum marginal fraction – Maximum Supply variant Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mx	
	Lookup Tables With ID points (fieldname: key) and deficit values (fieldname: value; positive)
id_defsr_mx.csv	Values from pnts14_defsumr15_mx.shp
	wcd_defr_mx_prec2.egoml : (Conventional demand Maximum marginal fraction – Maximum Supply variant) Precision 2 (2 iterations) Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mx
wcd_defr_mx0.tif	Final cumulative map of all individual points interpolation maps (weighted cost distance) cost##.tif : Individual point interpolation map (temporary, not saved on disk) sumcost##.tif : Progressively cumulative maps of individual points interpolation maps (temporary, saved on disk in folder woodsheds\wcd_r_mx) . Last map= sumcost**.tif
wcd_defr_mx	Final grid version of weighted cost distance maps with gaps at point locations filled in and clipped Model "focal_mosaic_clip" focalmean (wcd_defr_mx0.tif ; circle, 1) to fill the NoData at point position (wcd_defr_mxf1.tif) Mosaic to wcd_defr_mx_tmp.tif and clipped on msk1_lake0
wcd_mx_cat1	Weight to be used to distribute pressure on surplus resources Segmentation of wcd_defr_mx into 174 classes reflecting the weighted cost distance values (weighted on wcd values) recl_wcd_defr_mx_value_w_cat_01.txt (note: same class intervals applied to all wcd_defr maps)
Travel time from major deficit sites	
time_pnts_14	Transport time (going and back) from major deficit points. Values in minutes cost distance (Deficit_pnts_14; fric1_m_m)
hours_pnts_14	Transport time (going and back) from major deficit points. Values in hours "time_pnts_14" / 60

MODULE/FILENAME	DESCRIPTION
tt_md	***Medium Transport threshold assumed variable depending on the pressure of commercial demand and minimum transport time from nearest site (3 hours).*** <u>Medium transportation threshold:</u> Based on wcd_defr_md, applying a pressure threshold of 1,500,000 results a maximum transport time of approx. 10 hours around Lilongwe and Blantyre and much lower transport threshold in other areas with a minimum of 3 hours. Model transport threshold : wcd_1500k = Con("%wcd_defr_md%" >= 1500000,1,0) hrs_3 = Con("%hours_pnts_14%" <= 3,1,0) tt_md = Con("%hrs_3%" + "%wcd_1500k%" == 0,0,1)
tt_mn	***Minimum Transport threshold assumed variable depending on the pressure of commercial demand and minimum transport time from nearest site (2.5 hours).*** <u>Minimum transportation threshold:</u> Based on wcd_defr_mn, applying a pressure threshold of 2,000,000 results a maximum transport time of approx. 8 hours around Lilongwe and Blantyre and much lower transport threshold in other areas with a minimum of 2.5 hours. Model transport threshold : wcd_2000k = Con("%wcd_defr_mn%" >= 2000000,1,0) hrs_2_5 = Con("%hours_pnts_14%" <= 2.5,1,0) tt_mn = Con("%hrs_2_5%" + "%wcd_2000k%" == 0,0,1)
tt_mx	***Maximum Transport threshold assumed variable depending on the pressure of commercial demand and minimum transport time from nearest site (4 hours).*** <u>Maximum transportation threshold:</u> Based on wcd_defr_mx, applying a pressure threshold of 1,200,000 results a maximum transport time of approx. 12 hours around Lilongwe and Blantyre and much lower transport threshold in other areas with a minimum of 4 hours. Model transport threshold : wcd_1200k = Con("%wcd_defr_mx%" >= 1200000,1,0) hrs_4 = Con("%hours_pnts_14%" <= 4,1,0) tt_mx = Con("%hrs_4%" + "%wcd_1200k%" == 0,0,1)
Harvesting – Leading scenario assumptions: Conventional demand Md marg. fraction – Medium Supply variant (Md) – Partial Market (Md27%-30pc stk) – Transport threshold tt_md – Md use of LCCbp 60% Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_md	
lh_md	***Rural and minor urban deficit generating unsustainable local harvesting*** ***36%*** of the local rural deficit (within tt_md zone) remains on site as unsustainable local harvesting up to a maximum of 30% of the local stock, while the rest of the deficit generates commercial harvesting. Outside the transport threshold zone (tt_md = 0), the deficit remains entirely on site as unsustainable harvesting Con("lbal16r_md" < 0,Con("tt_md" == 1,Con("r_fulf1_0_md" == 1,Con(- "lbal16r_md" * 0.36 <= ("l_stk16_t_md" * 1000 * 0.3),"lbal16r_md" * 0.36, - ("l_stk16_t_md" * 1000 * 0.3)),0),"lbal16r_md"),0) zst_dist_08_lh_md.dbf = ***-429,891,336 kgDM***
c_def_md	Commercial deficit including total urban deficit and the fraction of the rural deficit within tt_md from major deficit sites that is not harvested locally. Con("tt_md" == 1,Con("combalr_md" < 0,"combalr_md" - "lh_md",0),0) zst_ dist_08_c_def_md.dbf Tot commercial deficit: ***-2,315,530,085 kg DM***
wcsur_md	Creation of the weighted commercial surplus value (surplus * pressure level) within the woodshed zone tt_md around major deficit points for the distribution of the commercial deficit as harvesting . Con("tt_md" == 1,Con("combalr_md" > 0,"combalr_md" *"wcd_md_cat1",0),0) zst_dist_08_wcsur_md.dbf total weighted surplus : ***148,022,728,160***
ch_md	Commercial harvesting by pixel : tot deficit (sum c_def_md) 2,315,530,085 / total weighted surplus (sum wcsur_md) 148,022,728,160 = 0.015643071 (multiplier of wcsur_md) "wcsur_md" * 0.015643071

MODULE/FILENAME	DESCRIPTION
h_md	***Total harvesting***, including: • sustainable local demand (local harvesting within local supply potential) = sus_demr16md= Con("lbal16r_md" >= 0,"l_demr_md","l_demr_md" + "lbal16r_md") • Rural and minor urban deficit generating unsustainable local harvesting (lh_md) • Commercial harvesting (ch_md) "sus_demr16md" + "ch_md" - "lh_md"
Unsustainable (non-renewable) harvesting – commercial, local, and total (see Model "calc non-renewable harvesting")	
chs_md_70	Commercial harvesting sustainability assuming a ***SIEF of 0.7*** Con("ch_md" > 0,"combalr_md" * 0.7 - "ch_md",0)
nrch_md_70	Non-Renewable commercial harvesting within tt_md from major deficit sites assuming a SIEF of 0.7 Unsustainable fuelwood extraction in kg DM = measure of (forest) degradation Con("chs_md_70"<0, "chs_md_70",0) zst_dist_08_nrch_md_70.dbf = ***-1,305,330,943 kg DM***
tnrh_md_70	TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_md) and unsustainable commercial harvesting (nrch_md_70) "nrch_md_70" + "lh_md" (both negatives) zst_dist_08_tnrh_md_70.dbf = ***-1,735,222,239 kg DM***
tnrhmd70_for1	TOTAL Non-renewable harvesting within Forest area For forest_msk_1 = 1 zst_dist_08_tnrhmd70_for1.dbf= ***-679,549,651 kg DM***
Alternative SIEF for sensitivity analysis	
chs_md_60	Commercial harvesting sustainability assuming a ***SIEF of 0.6*** Con("ch_md" > 0,"combalr_md" * 0.6 - "ch_md",0)
nrch_md_60	Non-Renewable commercial harvesting within tt_md from major deficit sites assuming a SIEF of 0.6 Unsustainable fuelwood extraction in kg DM = measure of (forest) degradation Con("chs_md_60"<0, "chs_md_60",0)
tnrh_md_60	TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_md) and unsustainable commercial harvesting (nrch_md_60) "nrch_md_60" + "lh_md" (both negatives) zst_ dist_08_tnrh_md_60.dbf = ***-1,878,178,576 kg DM***
chs_md_80	Commercial harvesting sustainability assuming a ***SIEF of 0.8*** Con("ch_md" > 0,"combalr_md" * 0.8 - "ch_md",0)
nrch_md_80	Non-Renewable commercial harvesting within tt_md from major deficit sites assuming a SIEF of 0.8 Unsustainable fuelwood extraction in kg DM = measure of (forest) degradation Con("chs_md_80"<0, "chs_md_80",0)
tnrh_md_80	TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_md) and unsustainable commercial harvesting (nrch_md_80) "nrch_md_80" + "lh_md" (both negatives) zst_ dist_08_tnrh_md_80.dbf = ***-1,592,674,393 kg DM***
	Recommended further processing: Total <u>direct</u> harvesting and unsustainable direct harvesting after use of 60% of land cover change (LCC) by-products should be estimated/mapped when detailed LCC data become available.
Harvesting – High degradation scenario assumptions: Conventional demand Mn marg. fraction – Minimum Supply variant (Mn) – Partial Market (Mn31%-30pc stk) – Transport threshold tt_mn – Mn use of LCCbp 45% Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mn	
lh_mn	***Rural and minor urban deficit generating unsustainable local harvesting*** 65 % of the local rural deficit (within tt_mn zone) remains on site as unsustainable local harvesting up to a maximum of 30% of the local stock, while the rest of the deficit generates commercial harvesting. Outside the transport threshold zone (tt_mn = 0), the deficit remains entirely on site as unsustainable harvesting

MODULE/FILENAME	DESCRIPTION
	Con("lbal16r_mn" < 0,Con("tt_mn" == 1,Con("r_fulf1_0_mn" == 1,Con(-"lbal16r_mn" * 0.65 <= ("l_stk16_t_mn" * 1000 * 0.3),"lbal16r_mn" * 0.65, -("l_stk16_t_mn" * 1000 * 0.3)),0),"lbal16r_mn"),0) zst_dist_08_lh_mn2.dbf = ***-1,555,135,556 kg DM***
c_def_mn	Commercial deficit including total urban deficit and the fraction of the rural deficit within tt_mn from major deficit sites that is not harvested locally. Con("tt_mn" == 1,Con("combalr_mn" < 0,"combalr_mn" - "lh_mn",0),0) zst_ dist_08_c_def_mn.dbf Tot commercial deficit: ***-2,414,020,842 kg DM***
wcsur_mn	Creation of the weighted commercial surplus value (surplus * pressure level) within the woodshed zone tt_mn around major deficit points for the distribution of the commercial deficit as harvesting. Con("tt_mn" == 1,Con("combalr_mn" > 0,"combalr_mn" *"wcd_mn_cat1",0),0) zst_dist_08_wcsur_mn.dbf total weighted surplus: ***56,131,753,536***
ch_mn	Commercial harvesting by pixel : tot deficit (sum c_def_mn) 2,414,020,842 / total weighted surplus (sum wcsur_mn) 56,131,753,536= 0.043006332 (multiplier of wcsur_mn) "wcsur_mn" * 0.043006332
h_mn	***Total harvesting,*** including: • sustainable local demand (local harvesting within local supply potential) = sus_demr16mn= Con("lbal16r_mn" >= 0,"%l_demr_md%","l_demr_mn" + "lbal16r_mn") • Rural and minor urban deficit generating unsustainable local harvesting (lh_mn) • Commercial harvesting (ch_mn) "sus_demr16mn" + "ch_mn" - "lh_mn"
Unsustainable (non-renewable) harvesting – commercial, local and total (see Model “calc non-renewable harvesting”)	
chs_mn_70	Commercial harvesting sustainability assuming a ***SIEF of 0.7*** Con("ch_mn" > 0,"combalr_mn" * 0.7 - "ch_mn",0)
nrch_mn_70	Non-Renewable commercial harvesting within tt_mn from major deficit sites assuming a SIEF of 0.7 Unsustainable fuelwood extraction in kg DM = measure of (forest) degradation Con("chs_mn_70"<0, "chs_mn_70",0) zst_dist_08_nrch_mn_70.dbf = ***-2,095,289,268 kg DM***
tnrh_mn_70	TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_mn) and unsustainable commercial harvesting (nrch_mn_70) "nrch_mn_70" + "lh_mn" (both negatives) zst_ dist_08_tnrh_mn_70.dbf = ***-3,650,424,305 kg DM***
tnrhmn70_for1	TOTAL Non-renewable harvesting within Forest area For forest_msk_1 = 1 zst_dist_08_tnrhmn70_for1.dbf = ***-1,306,643,542 kg DM***
Harvesting – Low degradation scenario assumptions: Conventional demand Mx marg. fraction – Maximum Supply variant (Mx) – Partial Market (Mx31%-30pc stk) – Transport threshold tt_mx – Mx use of LCCbp 75% Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mx	
lh_mx	***Rural and minor urban deficit generating unsustainable local harvesting*** 4 % of the local rural deficit (within tt_mx zone) remains on site as unsustainable local harvesting up to a maximum of 30% of the local stock, while the rest of the deficit generates commercial harvesting. Outside the transport threshold zone (tt_mx = 0), the deficit remains entirely on site as unsustainable harvesting Con("lbal16r_mx" < 0,Con("tt_mx" == 1,Con("r_fulf1_0_mx" == 1,Con(-"lbal16r_mx" * 0.04 <= ("l_stk16_t_mx" * 1000 * 0.3),"lbal16r_mx" * 0.04, -("l_stk16_t_mx" * 1000 * 0.3)),0),"lbal16r_mx"),0) zst_dist_08_lh_mx.dbf = ***-39,702,487 kgDM***
c_def_mx	Commercial deficit including total urban deficit and the fraction of the rural deficit within tt_mx from major deficit sites that is not harvested locally.

MODULE/FILENAME	DESCRIPTION
	Con("tt_mx" == 1,Con("combalr_mx" < 0,"combalr_mx" - "lh_mx",0),0) zst_ dist_08_c_def_mx.dbf Tot commercial deficit: ***-2,205,138,635 kg DM***
wcsur_mx	Creation of the weighted commercial surplus value (surplus * pressure level) within the woodshed zone tt_mx around major deficit points for the distribution of the commercial deficit as harvesting . Con("tt_mx" == 1,Con("combalr_mx" > 0,"combalr_mx" *"wcd_mx_cat1",0),0) zst_dist_08_wcsur_mx.dbf total weighted surplus: ***293,216,370,480***
ch_mx	Commercial harvesting by pixel : tot deficit (sum c_def_mx) 2,205,138,635 / total weighted surplus (sum wcsur_mx) 293,216,370,480 = 0.00752051678 (multiplier of wcsur_mx) "wcsur_mx" * 0.00752051678
h_mx	Total harvesting, including: • sustainable local demand (local harvesting within local supply potential) = sus_demr16mx= Con("lbal16r_mx" >= 0,"l_demr_mx","l_demr_mx" + "lbal16r_mx") • Rural and minor urban deficit generating unsustainable local harvesting (lh_mx) • Commercial harvesting (ch_mx) "sus_demr16mx" + "ch_mx" - "lh_mx"
Unsustainable (non-renewable) harvesting – commercial, local and total (see Model “calc non-renewable harvesting”)	
chs_mx_70	Commercial harvesting sustainability assuming a ***SIEF of 0.7*** Con("ch_mx" > 0,"combalr_mx" * 0.7 - "ch_mx",0)
nrch_mx_70	Non-Renewable commercial harvesting within tt_mx from major deficit sites assuming a SIEF of 0.7 Unsustainable fuelwood extraction in kg DM = measure of (forest) degradation Con("chs_mx_70"<0, "chs_mx_70",0) zst_dist_08_nrch_mx_70.dbf = -248,263,683 kg DM
tnrh_mx_70	TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_mx) and unsustainable commercial harvesting (nrch_mx_70) "nrch_mx_70" + "lh_mx" (both negatives) zst_ dist_08_tnrh_mx_70.dbf = -287,966,240 kg DM
tnrhmx70_for1	TOTAL Non-renewable harvesting within Forest area For forest_msk_1 = 1 zst_dist_08_tnrhmx70_for1.dbf = -112,930,099 kg DM
Projection to 2021	
Projected population 2021	
m_urb_21	Multiplier of mapped pop urb 2016 to obtain pop urb 2021 recl_dist_08_m_urb_21.txt
m_rur_21	Multiplier of pop rur 2016 to obtain pop rur 2021 recl_dist_08_m_rur_21.txt
pop_urb_21_fl	Urban pop 2021 "pop16_urb_fl" * "m_urb_21" / 100000 zst_dist_08_pop_urb_21_fl
pop_rur_21_fl	Rural pop 2021 "pop16_rur_fl" * "m_rur_21" / 100000 zst_dist_08_pop_rur_21_fl.dbf
Household demand 2021	
m_rur_ch21	Multiplier of pop16_rur_fl (to obtain rural charcoal consumption in 2021) recl_dist_08_m_rur_ch21.txt
m_rur_fw21	Multiplier of pop16_rur_fl (to obtain rural fuelwood consumption in 2021) recl_dist_08_m_rur_fw21.txt
m_urb_ch21	Multiplier of pop16_urb_fl (to obtain urban charcoal consumption in 2021) recl_dist_08_m_urb_ch21.txt
m_urb_fw21	Multiplier of pop16_urb_fl (to obtain urban fuelwood consumption in 2021)

MODULE/FILENAME	DESCRIPTION
	recl_dist_08_m_urb_fw21.txt
rurhh_chkg21	Rural household demand for charcoal 2021 Int("pop16_rur_fl" * "m_rur_ch21" / 1000000 + 0.5)
rurhh_fwkg21	Rural household demand for fuelwood 2021 Int("pop16_rur_fl" * "m_rur_fw21" / 1000000 + 0.5)
urbhh_chkg21	Urban household demand for charcoal 2021 Int("pop16_urb_fl" * "m_urb_ch21" / 1000000 + 0.5)
urbhh_fwkg21	Urban household demand for fuelwood 2021 Int("pop16_urb_fl" * "m_urb_fw21" / 1000000 + 0.5)
const_mat21	Construction material consumed by rural and urban households in 2021 Int(("pop_rur_21_fl" * 12.2 + "pop_urb_21_fl" * 6.1) / 1000 + 0.5)
hh_dem_kg21	Total residential (hh) demand "rurhh_chkg21" + "rurhh_fwkg21" + "urbhh_chkg21" + "urbhh_fwkg21" + "const_mat21"
NON-Household demand 2021	
comm_dem_kg21	(projected based on 2021 urban population) Commercial demand (tent. estimated as 5% of 2021 urban hh demand) Int(("urbhh_fwkg21" + "urbhh_chkg21") / 20 + 0.5)
sch_dem_kg21	School consumption Projected from 2016 to 2021 based on estimated population growth [*1.171]. From pop projections, it appears the school age growth is equal to tot pop growth. "sch_dem_kg" * 1.171 zst_dist_08_sch_dem_kg21.dbf
brick_demkg21	Brick making (projected on 2021 rur and urb pop and assuming the same per capita consumption in urban and rural areas) ("pop_rur_21_fl" * 9.26 + "pop_urb_21_fl" * 109.75) / 1000
lime_dem_kg	Fuelwood used for lime production Due to lack of evidence of increasing lime production from the scarse data available, the value is assumed constant for 2016 and 2021.
poult_dem21	Poultry industry Consumption projected to 2021 based on the increase of urban population (* 1.25581) "poult_dem_kg" * 1.25581
tobac_dem_kg	Tobacco curing Due to lack of evidence on the probable slight reduction of tobacco production, the value is assumed constant for 2016 and 2021
fish_d_dem21	Fish drying consumption Projected from to 2021 based on 2001-2013 fish production trend. Growth factor applied to 2016 fish drying consumption map: 1.410 "fish_d_dem_kg" * 1.41
tea_dem_kg21	Tea drying Projected from to 2021 based on 2008-2016 tea production trend. Growth factor applied to 2016 tea drying consumption map: 1.08829 "tea_dem_kg" * 1.08829
nonhh_dem_21	Total non-residential demand "comm_dem_kg21" + "sch_dem_kg21" + "lime_dem_kg" + "poult_dem21" + "tobac_dem_kg" + "brick_demkg21" + "tea_dem_kg21" + "fish_d_dem21"
dem_kg21	Total woodfuel demand in all sectors (hh and non-hh). Kg DM/ha "nonhh_dem_21" + "hh_dem_kg21"
l_dem_kg21	Local demand = focalmean dem_kg21, circle, 50
Projected supply potential in 2021	
los2k_17_clip.tif	Merging of Hansen's forest lossyear 2001 – 2017 clipped on district08 map. Pix size 27.7m
gain2k_12_clip.tif	Merging of Hansen's forest gain 2001 – 2012 clipped on district08 map. Pix size 27.7m
Estimated deforested stock – based on 2010-2017 forest loss (Hansen 2018) and stock 2010 Model: calc stk of Hansen def 2010_17	

MODULE/FILENAME	DESCRIPTION
….GIS\Hansen_change\ def17_stkmd	Stock of sites deforested in 2010-2017. Medium stock variant Con("%los2k_17_clip.tif%" >= 10,("%los2k_17_clip.tif%" * 0 + 1) * "%stk10kg_md%") projection_2021\supply_21\zst_dist_08_gr1_def17_stkmd.dbf
def17_stkmn	Stock of sites deforested in 2010-2017. Minimum stock variant Con("%los2k_17_clip.tif%" >= 10,("%los2k_17_clip.tif%" * 0 + 1) * "%stk10kg_mn%") projection_2021\supply_21\zst_dist_08_gr1_def17_stkmn.dbf
def17_stkmx	Stock of sites deforested in 2010-2017. Maximum stock variant Con("%los2k_17_clip.tif%" >= 10,("%los2k_17_clip.tif%" * 0 + 1) * "%stk10kg_mx%") projection_2021\supply_21\zst_dist_08_gr1_def17_stkmx.dbf
Calculation of agwb stock loss due to forest area changes (as per Hansen 2001-2017) and degradation rate due to direct harvesting (WISDOM 2016) by district: Map calc: Model "calc stock 2021 from 2010 on dist8 factors"	
stk21_md	Stock 2021 Medium variant f21_d8_md_stk = Recl_dist_08_f21_d8_md_stk.txt (factor * 100,000 in order to be integer) stk21_md = "%stk10kg_md%" * "f21_d8_md_stk" / 100000
stk21_mn	Stock 2021 Minimum variant f21_d8_mn_stk = Recl_dist_08_f21_d8_mn_stk.txt (factor * 100,000 in order to be integer) stk21_mn = "%stk10kg_mn%" * "f21_d8_mn_stk" / 100000
stk21_mx	Stock 2021 Maximum variant f21_d8_mx_stk = Recl_dist_08_f21_d8_mx_stk.txt (factor * 100,000 in order to be integer) stk21_mx = "%stk10kg_mx%" * "f21_d8_mx_stk" / 100000
l_stk21_md	Local stock 2021- Medium variant Model focal & clip on land1_water0 Focal Mean stk21_md; circle; 50) = stk21_md_f50 (temporary) & clip on "land1_water0
l_stk21_mn	Local stock 2021- Minimum variant Model focal & clip on land1_water0 Focal Mean stk21_mn; circle; 50) = stk21_mn_f50 (temporary) & clip on "land1_water0
l_stk21_mx	Local stock 2021- Maximum variant Model focal & clip on land1_water0 Focal Mean stk21_mx; circle; 50) = stk21_mx_f50 (temporary) & clip on "land1_water0
Agwb MAI Md 2021- Mean MAI variant of MEAN agwb stock 2021	
mai21_md	Calculate Mean MAI variant of MEAN stock applying the equation: Intermediate: $y = 32.136x^{-0.595}$ where x= stock in t DM and y= MAI as % of stock and converting MAI% into MAI kg DM ha^{-1} yr^{-1} Con("stk21_md" <= 1, "stk21_md" * 0.33,(Power("stk21_md" / 1000, - 0.595) * 32.136) * "stk21_md" / 100)
phacmai21_md acmai21_md avmai21_md	Model to estimate Accessible and available MAI Md : "calc phacmai21_md acmai21_md avmai21_md" Physically accessible MAI md phacmai21_md = "mai21_md" * "ph_acc01" / 100 Physically and legally accessible MAI md acmai21_md = "phacmai21_md" * "legac" / 100 Available MAI (medium variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations' accessible MAI) avmai21_md = Con("lccs_2010" == 18,"acmai21_md" * 0.25,"acmai21_md")
avmai_dif_md	Difference "avmai21_md" - "avmai16_md"
Agwb MAI mn 2021- Low MAI variant of Minimum agwb stock 2021	
mai21_mn	Calculate Low MAI variant of Minimum stock applying the equation:

MODULE/FILENAME	DESCRIPTION
	Low MAI variant: $y = 27.221x^{-0.6061}$ where x= stock in t DM and y= MAI as % of stock and converting MAI% into MAI kg DM ha^{-1} yr^{-1} Con("stk21_mn" <= 1, "stk21_mn" * 0.33,(Power("stk21_mn" / 1000, - 0.6061) * 27.221) * "stk21_mn" / 100)
phacmai21_mn acmai21_mn avmai21_mn	Model to estimate Accessible and available MAI Mn : “calc phacmai21_mn acmai21_mn avmai21_mn” Physically accessible MAI mn phacmai21_mn = "mai21_mn" * "ph_acc01" / 100 Physically and legally accessible MAI mn acmai21_mn = "phacmai21_mn" * "legac" / 100 Available MAI (medium variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations’ accessible MAI) avmai21_mn = Con("lccs_2010" == 18,"acmai21_mn" * 0.25,"acmai21_mn")
Agwb MAI mx 2021 - High MAI variant of Maximum agwb stock 2021	
mai21_mx	Calculate High MAI variant of Maximum stock applying the equation: High MAI variant: $y = 37.058x^{-0.5879}$ where x= stock in t DM and y= MAI as % of stock and converting MAI% into MAI kg DM ha^{-1} yr^{-1} Con("stk21_mx" <= 1, "stk21_mx" * 0.33,(Power("stk21_mx" / 1000, -0.5879) * 37.058) * "stk21_mx" / 100)
phacmai21_mx acmai21_mx avmai21_mx	Model to estimate Accessible and available MAI Mx : “calc phacmai21_mx acmai21_mx avmai21_mx” Physically accessible MAI mx phacmai21_mx = "mai21_mx" * "ph_acc01" / 100 Physically and legally accessible MAI mx acmai21_mx = "phacmai21_mx" * "legac" / 100 Available MAI (medium variant) after deduction of plantation industrial roundwood (estimated as 75% of plantations’ accessible MAI) avmai21_mx = Con("lccs_2010" == 18,"acmai21_mx" * 0.25,"acmai21_mx")
	Revision of 2021 fuelwood consumption in rural areas A distinction is made between the rural use of "conventional" fuelwood (solid wood pieces from stems and branches) and of "marginal" fuelwood (twigs produced through annual/ periodic pruning of trees and shrubs on farmlands). For the projection to 2021 it is assumed that the results of the Rural Firewood Assortments Survey (RFAS) carried out in 2018 are still valid. According to the RFAS, in rural DEFICIT areas (less than 90% of the demanded fuelwood available within 5 km context) an average of 40% of the supply is made of marginal assortments and 60% is made of conventional assortments (46% collected and 14% purchased). Also according to the RFAS, in rural SURPLUS areas an average of 14% of the supply is made of marginal assortments and 86% is made of conventional assortments (85% collected and 1% purchased). Procedure: Compare local fuelwood demand in rural areas with local balance values (lbal21_md / l_rhh_fw21 * 100) to estimate what percent of the rural hh demand for fw is not fulfilled by the local sustainable supply potential.
l_rhh_fw21	Rural HH fuelwood demand for 2021 averaged within a 5km radius = focalmean rurhh_fwkg21, circle, 50 zst_dist_08_lrhfw21_md.dbf
Map produced for the analysis of percentage fulfilled in rural areas in 2021	
r_f21_md	Recalculation made in order to eliminate odd values where the demand is below 10kg/ha/yr. Con("urb1_rur2" == 2,Con("l_rhh_fw21" <= 10,0,Int("lbal21_md" / "l_rhh_fw21" * 100 + 0.5)),0)
r_f21_1_0_md	Rural deficit (1) and surplus (0) areas. Md supply variant Con("r_f21_md" < 0,1,0)

MODULE/FILENAME	DESCRIPTION
r_f21_mn	Recalculation made in order to eliminate odd values where the demand is below 10kg/ha/yr. Con("urb1_rur2" == 2,Con("l_rhh_fw21" <= 10,0,Int("lbal21_mn" / "l_rhh_fw21" * 100 + 0.5)),0)
r_f21_1_0_mn	Rural deficit (1) and surplus (0) areas. Mn supply variant Con("r_f21_mn" < 0,1,0)
r_f21_mx	Recalculation made in order to eliminate odd values where the demand is below 10kg/ha/yr. Con("urb1_rur2" == 2,Con("l_rhh_fw21" <= 10,0,Int("%lbal21_mx" / "l_rhh_fw21" * 100 + 0.5)),0)
r_f21_1_0_mx	Rural deficit (1) and surplus (0) areas. Mx supply variant Con("r_f21_mx" < 0,1,0)
Revised local demand in 2021 considering only the conventional fuelwood demand in rural areas based on percent fulfilled and on RFAS results. In the resulting demand maps marginal fuelwood assortments are excluded.	
lrhfw21_md3 lrhfw21md_mg3	***Local rural conventional fuelwood demand 2021 for Leading scenario*** Med supply variant – Med marginal fraction Using the same factors resulting from RFAS 2018 lrhfw21_md3 = Con("r_f21_md" > 0,"l_rhh_fw21" * 0.87,Con("r_f21_md" <= -90,"l_rhh_fw21" / 4,"l_rhh_fw21" + ("l_rhh_fw21" * ("r_f21_md" - 13) / 170))) zst_dist_08_lrhfw21_md3.dbf (conv= 62 % of tot demand (2016: 64.5 %)) lrhfw21md_mg3 (marginal fw %) = ("l_rhh_fw21" - "lrhfw21_md3") / "l_rhh_fw21" * 100 zst_r_f21_1_0_md_lrhfw21_md_mg3.dbf mean marginal fw in deficit areas: 41.6 % (RFAS 2016: 41.6%) mean marginal fw in surplus areas: 12.0 % (RFAS 2016: 13 %)
lrhfw21_mn lrhfw21mn_mg	***Local conventional fuelwood demand for least favorable scenario*** Min supply variant – Minimum marginal fraction lrhfw21_mn = Con("r_f21_mn" > 0,"l_rhh_fw21" * 0.95,Con("r_f21_mn" <= -90,"l_rhh_fw21" * 0.52,"l_rhh_fw21" + ("l_rhh_fw21" * ("r_f21_mn" - 5) / 220))) zst_dist_08_lrhfw21_mn.dbf (conv= 70 % of tot demand (2016: 72.9%)) lrhfw21mn_mg (marginal fw %) = ("l_rhh_fw21" - "lrhfw21_mn") / "l_rhh_fw21" * 100 zst_ r_fulf1_0_mn_irhfw21mn_mg.dbf = mean marginal fw in deficit areas: 31.8 % (RFAS: 30%) mean marginal fw in surplus areas: 4.4 % (RFAS: 5%)
lrhfw21_mx3 lrhfw21mx_mg3	***Local conventional fuelwood demand for most favorable scenario*** Max supply variant – Maximum marginal fraction lrhfw21_mx3 = Con("r_f21_mx" > 0,"l_rhh_fw21" * 0.78,Con("r_f21_mx" <= -90,"l_rhh_fw21" * 0.25,"l_rhh_fw21" + ("l_rhh_fw21" * ("r_f21_mx" - 22) / 145))) zst_dist_08_lrhfw21_mx3.dbf (conv= 58 % of tot demand (2016: 58.1%)) lrhfw21mx_mg3 (marginal fw %) = ("l_rhh_fw21" - "lrhfw21_mx3") / "l_rhh_fw21" * 100 zst_ r_fulf1_0_mx_irhfw21mx_mg3.dbf = mean marginal fw in deficit areas: 48 % (RFAS: 52 %) mean marginal fw in surplus areas: 21 % (RFAS: 22 %)
l_demr21_md	Total demand in a local 5km context – Md variant "l_dem_kg21" - "l_rhh_fw21" + "lrhfw21_md3"
l_demr21_mn	Total demand in a local 5km context – Mn variant "l_dem_kg21" - "l_rhh_fw21" + "lrhfw21_mn"
l_demr21_mx	Total demand in a local 5km context – Mx variant "l_dem_kg21" - "l_rhh_fw21" + "lrhfw21_mx3"
dem_diff_md	Difference of conventional demand 2016 – 2021 (Md variant) "l_demr21_md" - "l_demr_md"
Integration Module	
Supply / Demand balance 2021 assuming TOTAL Demand (including marginal and conventional fuelwood)	

MODULE/FILENAME	DESCRIPTION
Pixel-level balance (2021) assuming total demand (including marginal and conventional fuelwood)	
bal21_md	Pixel balance 2021 – Medium variant "avmai21_md" - "dem_kg21"
bal21_mn	Pixel balance 2021 – Minimum variant "avmai21_mn" - "dem_kg21"
bal21_mx	Pixel balance 2021 – Maximum variant "avmai21_mx" - "dem_kg21"
Local balance (2021) assuming total demand (including marginal and conventional fuelwood)	
lbal21_md	Local balance on a 5 km harvesting horizon md variant) = focalmean bal21_md, circle, 50 ; clipped on land1_water0
lbal21_mn	Local balance on a 5 km harvesting horizon mn variant) = focalmean bal21_mn, circle, 50 ; clipped on land1_water0
lbal21_mx	Local balance on a 5 km harvesting horizon mx variant) = focalmean bal21_mx, circle, 50 ; clipped on land1_water0
2021 Supply / Demand balance assuming CONVENTIONAL Demand (including only conventional fuelwood and excluding marginal fuelwood assortments used by rural HH)	
Local balance (2021) assuming conventional demand (including only conventional fuelwood and excluding marginal fuelwood assortments used by rural HH)	
lbal21r_md	Recalculation of 2021 local balance to exclude marginal fuelwood. Md variant "lbal21_md" + "l_rhh_fw21" - "lrhfw21_md3"
lbal21r_mn	Recalculation of 2021 local balance to exclude marginal fuelwood. Mn variant "lbal21_mn" + "l_rhh_fw21" - "lrhfw21_mn"
lbal21r_mx	Recalculation of 2021 local balance to exclude marginal fuelwood. Mx variant "lbal21_mx" + "l_rhh_fw21" - "lrhfw21_mx3"
2021 Local-level commercial balance assuming conventional demand (including only conventional fuelwood and excluding marginal fuelwood assortments used by rural HH) and including commercial surplus only. Commercial surplus based on 410 od kg/ha/yr surplus threshold, the stock on a 30-years rotation expected to be > 12 od t /ha (IUCN Protected Areas are already excluded).	
combalr21_md	2021 Commercial balance – Medium variant Based on editing of model "combalr_Malawi": 1: Combal_tmp1 = Con("lbal21r_md" < 410, Con("lbal21r_md" >=0,0, "lbal21r_md"),"lbal21r_md") 2: Combalr21_md = Con("%combal_tmp1%">0, Con("avmai21_md" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%") (Remember to delete intermediate data!)
combalr21_mn	2021 Commercial balance – Minimum variant Based on editing of model "combalr_Malawi": 1: Combal_tmp1 = Con("%lbal21r_mn%" < 410, Con("%lbal21r_mn%" >=0,0, "%lbal21r_mn%"), "%lbal21r_mn%") 2: Combalr21_mn = Con("%combal_tmp1%">0, Con("avmai21_mn" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%") (Remember to delete intermediate data!)
combalr21_mx	2021 Commercial balance – Maximum variant Based on editing of model "combalr_Malawi": 1: Combal_tmp1 = Con("lbal21r_mx" < 410, Con("lbal21r_mx" >=0,0, "lbal21r_mx"), "lbal21r_mx") 2: Combalr21_mx = Con("%combal_tmp1%">0, Con("avmai21_mx" * 30 > 12000, "%combal_tmp1%",0), "%combal_tmp1%") (Remember to delete intermediate data!)
cbalr_dif_md	Difference between commercial balance maps 2016 and 2021 "combalr_md" - "combalr21_md"
2021 Woodshed Analysis	
2021 Local deficit and peak deficit locations	
Deficit_pnts_14	Main deficit points (same points used for 2016 analysis)
2021 Local deficit- Leading scenario: Conventional demand Medium marginal fraction – Medium Supply variant Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_md	

MODULE/FILENAME	DESCRIPTION
ldef21r_md	Local deficit within 5 km radius: = Con("lbal21r_md" <= 0,"lbal21r_md",0)
defsum21r15md	Major deficit areas SUMMARIZING the deficit within a 15 km radius. = focalSUM ("ldef21r_md", circle, 150, SUM)
pnts14_defsum21r15_md	Point map (14 points in total) marking peak deficit locations based on 15 KM deficit map with assigned deficit value from defsum21r15md (RASTERVALU field) and defined Pnt_ID code, that represent the major consumption sites to be used as point values in IDW Dinamica analysis. The sum of deficit in RASTERVALU is converted to positive values in field defsum15km.
2021 Local deficit – High degradation scenario (Least favorable variants/assumptions): Conventional demand Minimum marginal fraction - Min supply variant Folder E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mn	
ldef21r_mn	Local deficit within 5 km radius : = Con("lbal21r_mn" <= 0,"lbal21r_mn",0)
defsum21r15mn	Major deficit areas SUMMARIZING the deficit within a 15 km radius – Conventional demand Minimum marginal fraction – Minimum supply variant = focalSUM ("ldef21r_mn", circle, 150)
pnts14_defsum21r15_mn	Point map (14 points in total) marking peak deficit locations based on 15 KM deficit map with assigned deficit value from defsum21r15mn (Extract value to point; RASTERVALU field) and defined Pnt_ID code, that represent the major consumption sites to be used as point values in IDW Dinamica analysis. The sum of deficit in RASTERVALU is converted to positive values in field defsum15km.
2021 Local deficit – Low degradation scenario (Most favorable variants / assumptions): Conventional demand Maximum marginal fraction – MaximumSupply variant Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mx	
ldef21r_mx	Local deficit within 5 km radius : = Con("lbal21r_mx" <= 0,"lbal21r_mx",0)
defsum21r15mx	Major deficit areas SUMMARIZING the deficit within 15 km radius Conventional demand Maximum marginal fraction – Maximum supply variant = focalSUM ("ldef21r_mx", circle, 150)
pnts14_defsum21r15_mx	Point map (14 points in total) marking peak deficit locations based on 15 KM deficit map with assigned deficit value from defsum21r15mx(RASTERVALU field) and defined Pnt_ID code, that represent the major consumption sites to be used as point values in IDW Dinamica analysis. The sum of deficit in RASTERVALU is converted to positive values in field defsum15km.
Mapping of 2021 commercial harvesting pressure based on Dinamica EGO	
fric1_m_m.tif	Friction map (same one used for the 2016 analysis)
pnt_id.tif	Categorical map with ID of major deficit points (same one used for the 2016 analysis)
2021 Harvesting pressure- Leading scenario: Conventional demand Medium marginal fraction – Medium Supply variant Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_md	
	Lookup Tables With ID points (fieldname: key) and deficit values (fieldname: value; positive)
id_defs21r_md.csv	Values from pnts14_defsum21r15_md.shp
	wcd_def21r_md_prec2.egoml : (Conventional Demand Medium marginal fraction – Med supply) Precision 2 (2 iterations) Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_md
wcd_def21r_md0.tif	Final cumulative map of all individual points interpolation maps (weighted cost distance) cost##.tif : Individual point interpolation map (temporary, not saved on disk) sumcost##.tif : Progressively cumulative maps of individual points interpolation maps (temporary, saved on disk in folder

MODULE/FILENAME	DESCRIPTION
	:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_md) . Last map= sumcost**.tif
wcd_def21r_md	Final grid version of weighted cost distance maps with gaps at point locations filled in and clipped Model "focal_mosaic_clip" focalmean (wcd_def21r_md0.tif ; circle, 1) to fill the NoData at point position (wcd_def21r_mdf1.tif) Mosaic to wcd_def21r_md_tmp.tif and clipped on msk1_lake0
wcd21_md_cat1	Weight to be used to distribute pressure on surplus resources Segmentation of wcd_def21r_md into 174 classes reflecting the weighted cost distance values (weighted on wcd values) recl_wcd_def21r_value_w_cat_01.txt (note: same class intervals applied to all wcd_def21r maps)
2021 Harvesting pressure- High degradation scenario: Conventional demand Minimum marginal fraction – Minimum Supply variant Folder: Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mn	
	Lookup Tables With ID points (fieldname: key) and deficit values (fieldname: value; positive)
id_defs21r_mn.csv	Values from pnts14_defsum21r15_mn.shp
	wcd_def21r_mn_prec2.egoml : (Conventional demand Minimum marginal fraction – Minimum Supply variant) Precision 2 (2 iterations) Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mn
wcd_def21r_mn0.tif	Final cumulative map of all individual points interpolation maps (weighted cost distance) cost##.tif : Individual point interpolation map (temporary, not saved on disk) sumcost##.tif : Progressively cumulative maps of individual points interpolation maps (temporary, saved on disk in folder :\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mn) . Last map= sumcost**.tif
wcd_def21r_mn	Final grid version of weighted cost distance maps with gaps at point locations filled in and clipped Model "focal_mosaic_clip" focalmean (wcd_def21r_mn0.tif ; circle, 1) to fill the NoData at point position (wcd_def21r_mnf1.tif) Mosaic to wcd_def21r_mn_tmp.tif and clipped on msk1_lake0
wcd21_mn_cat1	Weight to be used to distribute pressure on surplus resources Segmentation of wcd_def21r_mn into 174 classes reflecting the weighted cost distance values (weighted on wcd values) recl_wcd_def21r_value_w_cat_01.txt (note: same class intervals applied to all wcd_defr maps)
2021 Harvesting pressure- Low degradation scenario: Conventional demand Maximum marginal fraction – Maximum Supply variant Folder: Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mx	
	Lookup Tables With ID points (fieldname: key) and deficit values (fieldname: value; positive)
id_defs21r_mx.csv	Values from pnts14_defsum21r15_mx.shp
	wcd_def21r_mx_prec2.egoml: (Conventional demand Maximum marginal fraction – Maximum Supply variant) Precision 2 (2 iterations) Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mx
wcd_def21r_mx0.tif	Final cumulative map of all individual points interpolation maps (weighted cost distance) cost##.tif : Individual point interpolation map (temporary, not saved on disk) sumcost##.tif : Progressively cumulative maps of individual points interpolation maps (temporary, saved on disk in folder

MODULE/FILENAME	DESCRIPTION
	:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mx) . Last map= sumcost**.tif
wcd_def21r_mx	Final grid version of weighted cost distance maps with gaps at point locations filled in and clipped Model "focal_mosaic_clip" focalmean (wcd_def21r_mx0.tif ; circle, 1) to fill the NoData at point position (wcd_def21r_mxf1.tif) Mosaic to wcd_def21r_mx_tmp.tif and clipped on msk1_lake0
wcd21_mx_cat1	Weight to be used to distribute pressure on surplus resources Segmentation of wcd_def21r_mx into 174 classes reflecting the weighted cost distance values (weighted on wcd values) recl_wcd_def21r_value_w_cat_01.txt (note: same class intervals applied to all wcd_defr maps)
2021 Travel time from major deficit sites	
time_pnts_14	Transport time (going and back) from major deficit points. Same points used for 2016 analysis Values in minutes
hours_pnts_14	Transport time (going and back) from major deficit points. Same used for 2016 analysis Values in hours
tt21_md	***2021 Medium Transport threshold assumed variable depending on the pressure of commercial demand and minimum transport time from nearest site (3 hours).*** Medium transportation threshold: Based on wcd_def21r_md, applying a pressure threshold of 1,500,000 results a maximum transport time of approx. 10 hours around Lilongwe and Blantyre and much lower transport threshold in other areas with a minimum of 3 hours. Model transport threshold 21 : wcd_1500k (temporary)= Con("wcd_def21r_md" >= 1500000,1,0) hrs_3 (temporary) = Con("%hours_pnts_14%" <= 3,1,0) tt21_md = Con("%hrs_3%" + "%wcd_1500k%" == 0,0,1)
tt21_mn	***2021 Minimum Transport threshold assumed variable depending on the pressure of commercial demand and minimum transport time from nearest site (2.5 hours).*** Minimum transportation threshold: Based on wcd_def21r_mn, applying a pressure threshold of 2,000,000 results a maximum transport time of approx. 8 hours around Lilongwe and Blantyre and much lower transport threshold in other areas with a minimum of 2.5 hours. Model transport threshold : wcd21_2000k = Con("%wcd_def21r_mn%" >= 2000000,1,0) hrs_2_5 = Con("%hours_pnts_14%" <= 2.5,1,0) tt21_mn = Con("%hrs_2_5%" + "%wcd21_2000k%" == 0,0,1)
tt21_mx	***2021 Maximum Transport threshold assumed variable depending on the pressure of commercial demand and minimum transport time from nearest site (4 hours).*** Maximum transportation threshold: Based on wcd_def21r_mx, applying a pressure threshold of 1,200,000 results a maximum transport time of approx. 12 hours around Lilongwe and Blantyre and much lower transport threshold in other areas with a minimum of 4 hours. Model transport threshold : wcd21_1200k = Con("%wcd_def21r_mx%" >= 1200000,1,0) hrs_4 = Con("%hours_pnts_14%" <= 4,1,0) tt21_mx = Con("%hrs_4%" + "%wcd21_1200k%" == 0,0,1)
2021 Harvesting – Leading scenario assumptions: Conventional demand Md marg. fraction – Medium Supply variant (Md) – Partial Market (Md27%-30pc stk) – Transport threshold tt21_md – Md use of LCCbp 60% Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_md	
lh_21md	***2021 Rural and minor urban deficit generating unsustainable local harvesting***

MODULE/FILENAME	DESCRIPTION
	36% of the local rural deficit (within tt_md zone) remains on site as unsustainable local harvesting up to a maximum of 30% of the local stock, while the rest of the deficit generates commercial harvesting. Outside the transport threshold zone (tt21_md = 0), the deficit remains entirely on site as unsustainable harvesting Con("lbal21r_md" < 0,Con("tt21_md" == 1,Con("r_f21_1_0_md " == 1,Con(-"lbal21r_md" * 0.36 <= ("l_stk21_md" * 0.3),"lbal21r_md" * 0.36, - ("l_stk21_md" * 0.3)),0),"lbal21r_md"),0) zst_dist_08_lh_21md.dbf = -662,160,273 kgDM
c_def_21md	2021 Commercial deficit including total urban deficit and the fraction of the rural deficit within tt_md from major deficit sites that is not harvested locally. Con("tt21_md" == 1,Con("combalr21_md" < 0," combalr21_md" - "lh_21md",0),0) zst_ dist_08_c_def_21md.dbf Tot commercial deficit: -3,378,637,295 kg DM
wcsur_21md	2021 - Creation of the weighted commercial surplus value (surplus * pressure level) within the woodshed zone tt21_md around major deficit points for the distribution of the commercial deficit as harvesting. Con("tt21_md" == 1,Con("combalr21_md" > 0,"combalr21_md" * "wcd21_md_cat1",0),0) zst_dist_08_wcsur_21md.dbf total weighted surplus: 219,799,455,377
ch_21md	2021 Commercial harvesting by pixel : tot deficit (sum c_def_21md) 3,378,637,295 / total weighted surplus (sum wcsur_21md) 219,799,455,377 = 0.015371454 (multiplier of wcsur_21md) "wcsur_21md" * 0.015371454
sus_demr21md h_21md	2021 Total harvesting, including: • sustainable local demand (local harvesting within local supply potential) = sus_demr21md = Con("lbal21r_md" >= 0,"l_demr21_md","l_demr21_md" + "lbal21r_md") • Rural and minor urban deficit generating unsustainable local harvesting (lh_21md) • Commercial harvesting (ch_21md) h_21md = "sus_demr21md" + "ch_21md" - "lh_21md"
h16_21md	Difference of total harvesting between 2016 and 2021 "h_21md" - "h_md"
2021 Unsustainable harvesting – commercial, local and total (see Model "calc non-renewable harvesting")	
chs_21md_70	2021 Commercial harvesting sustainability assuming a SIEF of 0.7 Con("ch_21md" > 0,"combalr21_md" * 0.7 - "ch_21md",0)
nrch_21md_70	2021 Non-Renewable commercial harvesting within tt21_md from major deficit sites assuming a SIEF of 0.7 Unsustainable fuelwood extraction in kg DM = measure of (forest) degradation Con("chs_21md_70"<0, "chs_21md_70",0) zst_dist_08_nrch_21md_70.dbf = -2,033,964,309 kg DM
tnrh_21md_70	2021 TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_21md) and unsustainable commercial harvesting (nrch_21md_70) "nrch_21md_70" + "lh_21md" (both negatives) zst_dist_08_tnrh_21md_70.dbf = -2,696,123,378 kg DM
tnrh16_21md70	Difference of non renewable harvesting between 2016 and 2021 "tnrh_md_70" - "tnrh_21md_70"
tnrh21md70_fl	2021 TOTAL Non-renewable harvesting within Forest area Con(forest_msk_1 == 1, tnrh_21md_70) zst_dist_08_tnrh21md70_fl.dbf= -1,166,775,670 kg DM
2021 Harvesting – High degradation scenario assumptions: Conventional demand Mn marg. fraction – Minimum Supply variant (Mn) – Partial Market (Mn31%-30pc stk) – Transport threshold tt_mn – Mn use of LCCbp 45% Folder: E:\Winrock_Malawi\GIS\projection_2021\woodsheds21\wcd_21r_mn	
lh_21mn	2021 Rural and minor urban deficit generating unsustainable local harvesting **65%** of the local rural deficit (within tt_mn zone) remains on site as unsustainable local harvesting up to a maximum of 30% of the local stock, while the rest of the

MODULE/FILENAME	DESCRIPTION
	deficit generates commercial harvesting. Outside the transport threshold zone (tt21_mn = 0), the deficit remains entirely on site as unsustainable harvesting Con("lbal21r_mn" < 0,Con("tt21_mn" == 1,Con("r_f21_1_0_mn " == 1,Con(-"lbal21r_mn" * 0.36 <= ("l_stk21_mn" * 0.3),"lbal21r_mn" * 0.65, - ("l_stk21_mn" * 0.3)),0),"lbal21r_mn"),0) zst_dist_08_lh_21mn.dbf = -2,139,943,570 kgDM
c_def_21mn	2021 Commercial deficit including total urban deficit and the fraction of the rural deficit within tt_mn from major deficit sites that is not harvested locally. Con("tt21_mn" == 1,Con("combalr21_mn" < 0," combalr21_mn" - "lh_21mn",0),0) zst_ dist_08_c_def_21mn.dbf Tot commercial deficit: -3,456,823,790 kg DM
wcsur_21mn	2021 - Creation of the weighted commercial surplus value (surplus * pressure level) within the woodshed zone tt21_mn around major deficit points for the distribution of the commercial deficit as harvesting . Con("tt21_mn" == 1,Con("combalr21_mn" > 0,"combalr21_mn" * "wcd21_mn_cat1",0),0) zst_dist_08_wcsur_21mn.dbf total weighted surplus : 80,334,017,500
ch_21mn	2021 Commercial harvesting by pixel : tot deficit (sum c_def_21mn) 3,456,823,790 / total weighted surplus (sum wcsur_21mn) 80,334,017,500 = 0.043030635 (multiplier of wcsur_21mn) "wcsur_21mn" * 0.043030635
sus_demr21mn h_21mn	2021 Total harvesting, including: • sustainable local demand (local harvesting within local supply potential) = sus_demr21mn = Con("lbal21r_mn" >= 0,"l_demr21_mn","l_demr21_mn" + "lbal21r_mn") • Rural and minor urban deficit generating unsustainable local harvesting (lh_21mn) • Commercial harvesting (ch_21mn) h_21mn = "sus_demr21mn" + "ch_21mn" - "lh_21mn"
2021 Unsustainable (non-renewable) harvesting – commercial, local and total (see Model "calc non-renewable harvesting")	
chs_21mn_70	2021 Commercial harvesting sustainability assuming a SIEF of 0.7 Con("ch_21mn" > 0,"combalr21_mn" * 0.7 - "ch_21mn",0)
nrch_21mn_70	2021 Non-Renewable commercial harvesting within tt21_mn from major deficit sites assuming a SIEF of 0.7 Unsustainable fuelwood extraction in kg DM = measure of (forest) degradation Con("chs_21mn_70"<0, "chs_21mn_70",0) zst_dist_08_nrch_21mn_70.dbf = -3,033,759,020 kg DM
tnrh_21mn_70	2021 TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_21mn) and unsustainable commercial harvesting (nrch_21mn_70) "nrch_21mn_70" + "lh_21mn" (both negatives) zst_dist_08_tnrh_21mn_70.dbf = -5,173,704,260 kg DM
tnrh21mn70_f1	2021 TOTAL Non-renewable harvesting within Forest area Con(forest_msk_1 == 1, tnrh_21mn_70) zst_dist_08_tnrh21mn70_f1.dbf= -2,084,027,420kg DM
2021 Harvesting – Low degradation scenario assumptions: Conventional demand Mx marg. fraction – Maximum Supply variant (Mx) – Partial Market (Mx31%-30pc stk) – Transport threshold tt_mx – Mx use of LCCbp 75% Folder: E:\Winrock_Malawi\GIS\woodsheds\wcd_r_mx	
lh_21mx	2021 Rural and minor urban deficit generating unsustainable local harvesting **4%** of the local rural deficit (within tt_mx zone) remains on site as unsustainable local harvesting up to a maximum of 30% of the local stock, while the rest of the deficit generates commercial harvesting. Outside the transport threshold zone (tt21_mx = 0), the deficit remains entirely on site as unsustainable harvesting Con("lbal21r_mx" < 0,Con("tt21_mx" == 1,Con("r_f21_1_0_mx " == 1,Con(-"lbal21r_mx" * 0.36 <= ("l_stk21_mx" * 0.3),"lbal21r_mx" * 0.04, - ("l_stk21_mx" * 0.3)),0),"lbal21r_mx"),0)

MODULE/FILENAME	DESCRIPTION
	zst_dist_08_lh_21mx.dbf = -76,289,793 kgDM
c_def_21mx	2021 Commercial deficit including total urban deficit and the fraction of the rural deficit within tt_mx from major deficit sites that is not harvested locally. Con("tt21_mx" == 1,Con("combalr21_mx" < 0," combalr21_mx" - "lh_21mx",0),0) zst_ dist_08_c_def_21mx.dbf Tot commercial deficit: -3,091,568,098 kg DM
wcsur_21mx	2021 - Creation of the weighted commercial surplus value (surplus * pressure level) within the woodshed zone tt21_mx around major deficit points for the distribution of the commercial deficit as harvesting . Con("tt21_mx" == 1,Con("combalr21_mx" > 0,"combalr21_mx" * "wcd21_mx_cat1",0),0) zst_dist_08_wcsur_21mx.dbf total weighted surplus : 398,057,268,300 ….
ch_21mx	2021 Commercial harvesting by pixel : tot deficit (sum c_def_21mx) 3,091,568,098 / total weighted surplus (sum wcsur_21mx) 398,057,268,300 = 0.007766641. (multiplier of wcsur_21mx) "wcsur_21mx" * 0.007766641
sus_demr21mx h_21mx	2021 Total harvesting, including: • sustainable local demand (local harvesting within local supply potential) = sus_demr21mx= Con("lbal21r_mx" >= 0,"l_demr21_mx","l_demr21_mx" + "lbal21r_mx") • Rural and minor urban deficit generating unsustainable local harvesting (lh_21mx) • Commercial harvesting (ch_21mx) h_21mx = "sus_demr21mx" + "ch_21mx" - "lh_21mx"
2021 Unsustainable (non-renewable) harvesting – commercial, local, and total (see Model "calc non-renewable harvesting")	
chs_21mx_70	2021 Commercial harvesting sustainability assuming a SIEF of 0.7 Con("ch_21mx" > 0,"combalr21_mx" * 0.7 - "ch_21mx",0)
nrch_21mx_70	2021 Non-Renewable commercial harvesting within tt21_mx from major deficit sites assuming a SIEF of 0.7 Unsustainable fuelwood extraction in kg DM = measure of (forest) degradation Con("chs_21mx_70"<0, "chs_21mx_70",0) zst_dist_08_nrch_21mx_70.dbf = - 683,285,704 kg DM
tnrh_21mx_70	2021 TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_21mx) and unsustainable commercial harvesting (nrch_21mx_70) "nrch_21mx_70" + "lh_21mx" (both negatives) zst_dist_08_tnrh_21mx_70.dbf = -759,575,310 kg DM
tnrh21mx70_f1	2021 TOTAL Non-renewable harvesting within Forest area Con(forest_msk_1 == 1, tnrh_21mx_70) zst_dist_08_tnrh21mx70_f1.dbf= -321,683,885 kg DM

U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov