F-you, F-me, fNRB!

Let's talk about modeling woodfuel-landscape dynamics

ETHOSCon Jan 27-28 2024

SEI Stockholm Environment Institute

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C3 Centro de Ciencias de la Complejidad

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Wood harvesting and land cover change

Charcoal awaiting transport to Nairobi

Nearly all landscapes produce a measurable increment of woody biomass. If wood is extracted in excess of that amount, stocks decline and demand is unsustainable.

This is how we define "Non-renewable biomass" (NRB)

The ratio of NRB to consumption is "fNRB"

fNRB helps us estimate CO_2 emissions from woodfuels and quantify ERs from interventions

Leleshwa (T. Camphorata) after harvesting for charcoal (Narok, Kenya)

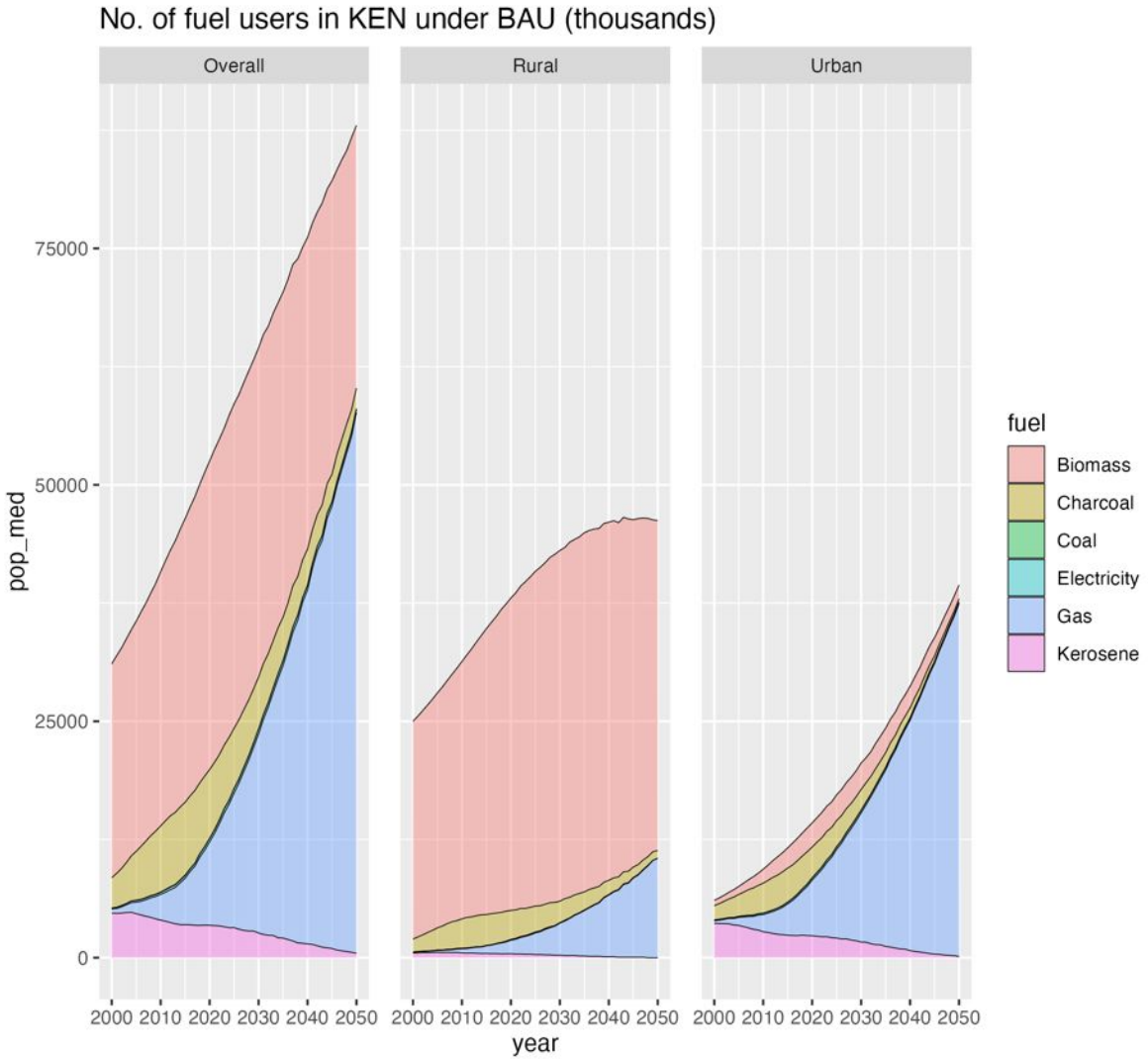
Miombo Forest, Kasungu National Park, Malawi: CC-BY-SA-3.0,2.5,2.0,1.0

How we model fNRB?

We use 3 or 4 key parameters:

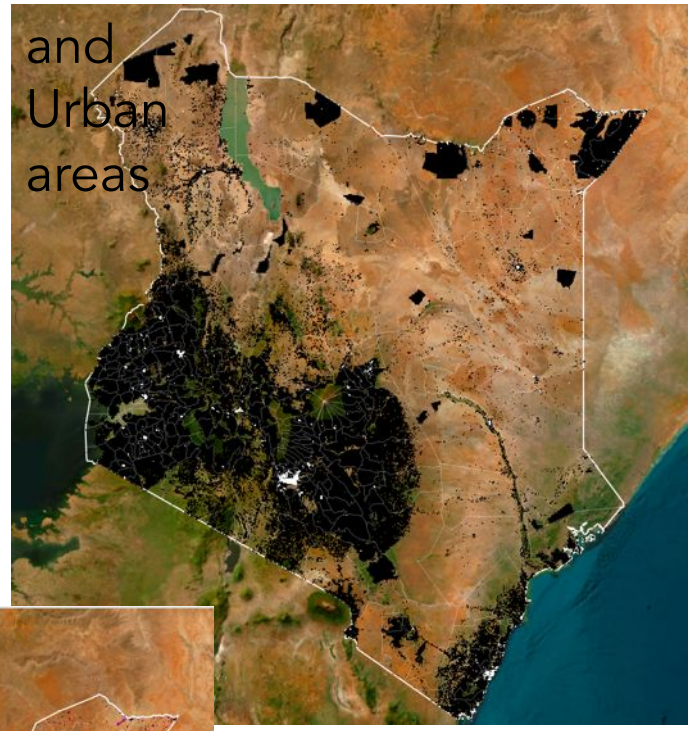
1. Woodfuel consumption
    - Who uses it?
    - Where are they?
    - How much do they use?
2. Tree extent and growth rates
3. Accessibility
4. Other drivers of deforestation, degradation, and tree loss

Who uses which fuel and where?

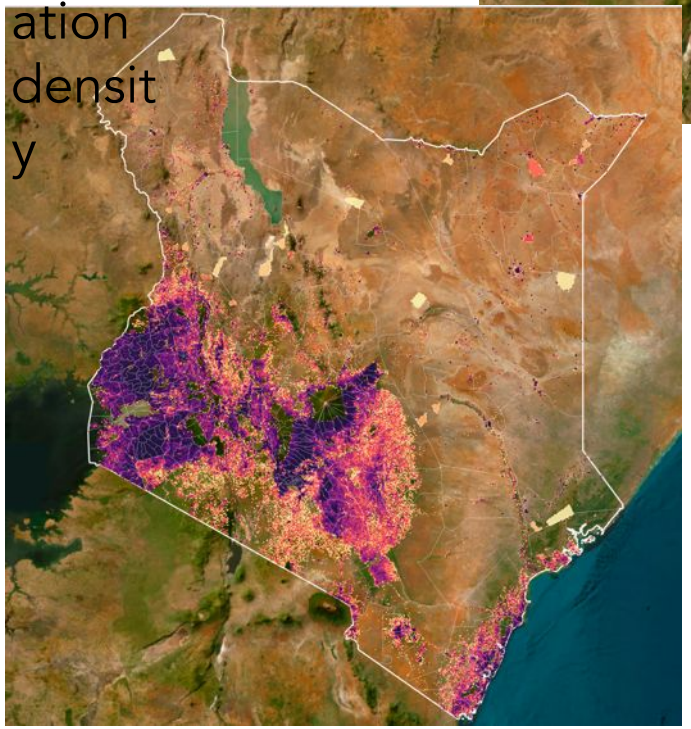


2022 update of WHO Global Household Energy Model from Stoner et al. 2021 and WHO Global Health Observatory

Rural and Urban areas



Population density

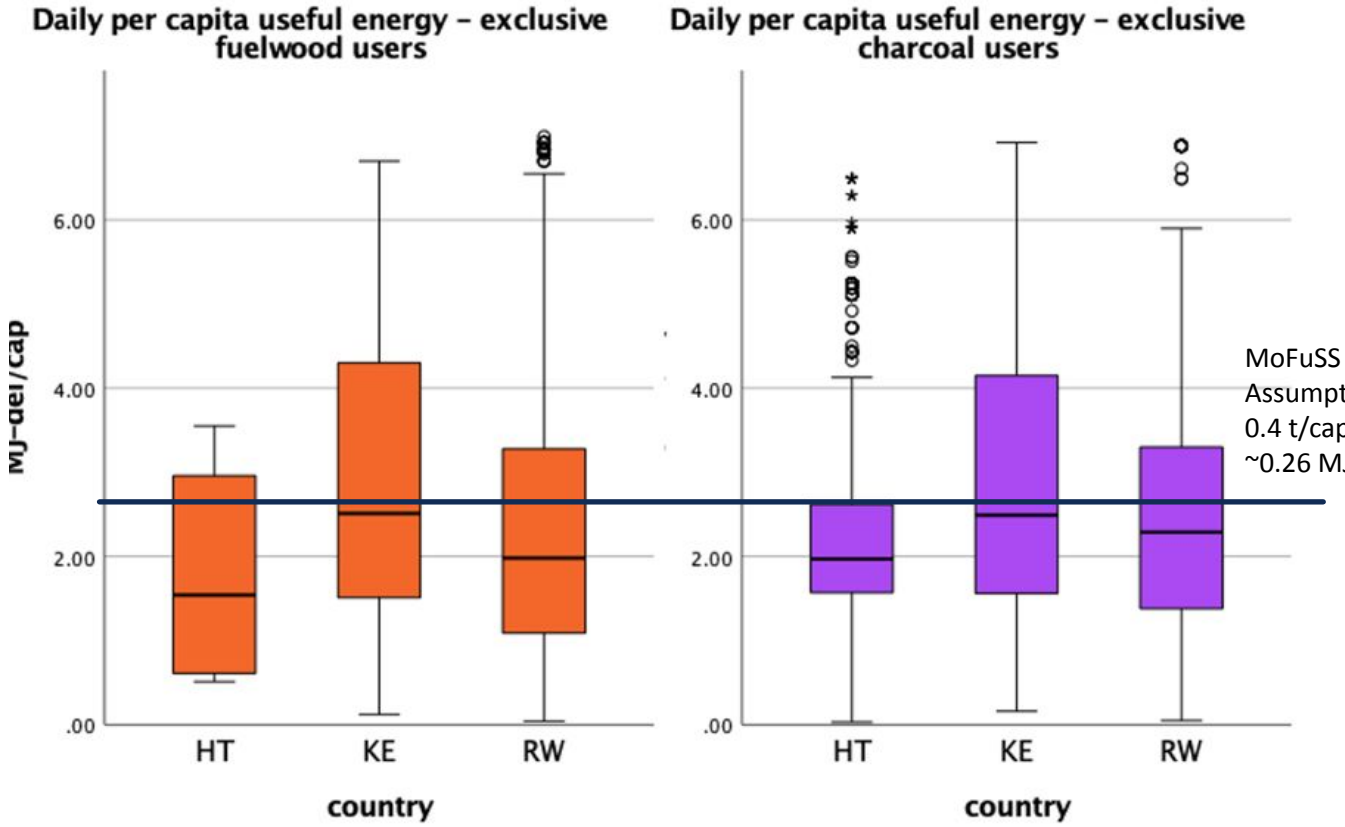


How much fuelwood and charcoal do people use?

Country-specific averages compiled by UNFCCC

	UN and DHS		PDD values	
Region	No.	tpc/yr	No.	tpc/yr
SSA	33	0.59	58	0.87
W Asia & N Africa	1	0.59	0	-
LAC	8	1.10	6	1.11
E Asia & Pacific	7	0.44	10	0.95
South Asia	5	0.57	35	0.40
Eur & Cent Asia	4	0.32	0	-
Total	58	0.62	109	0.74

Moisture content isn't specified, but assume "air dry", so "oven-dry" would be ~20% less

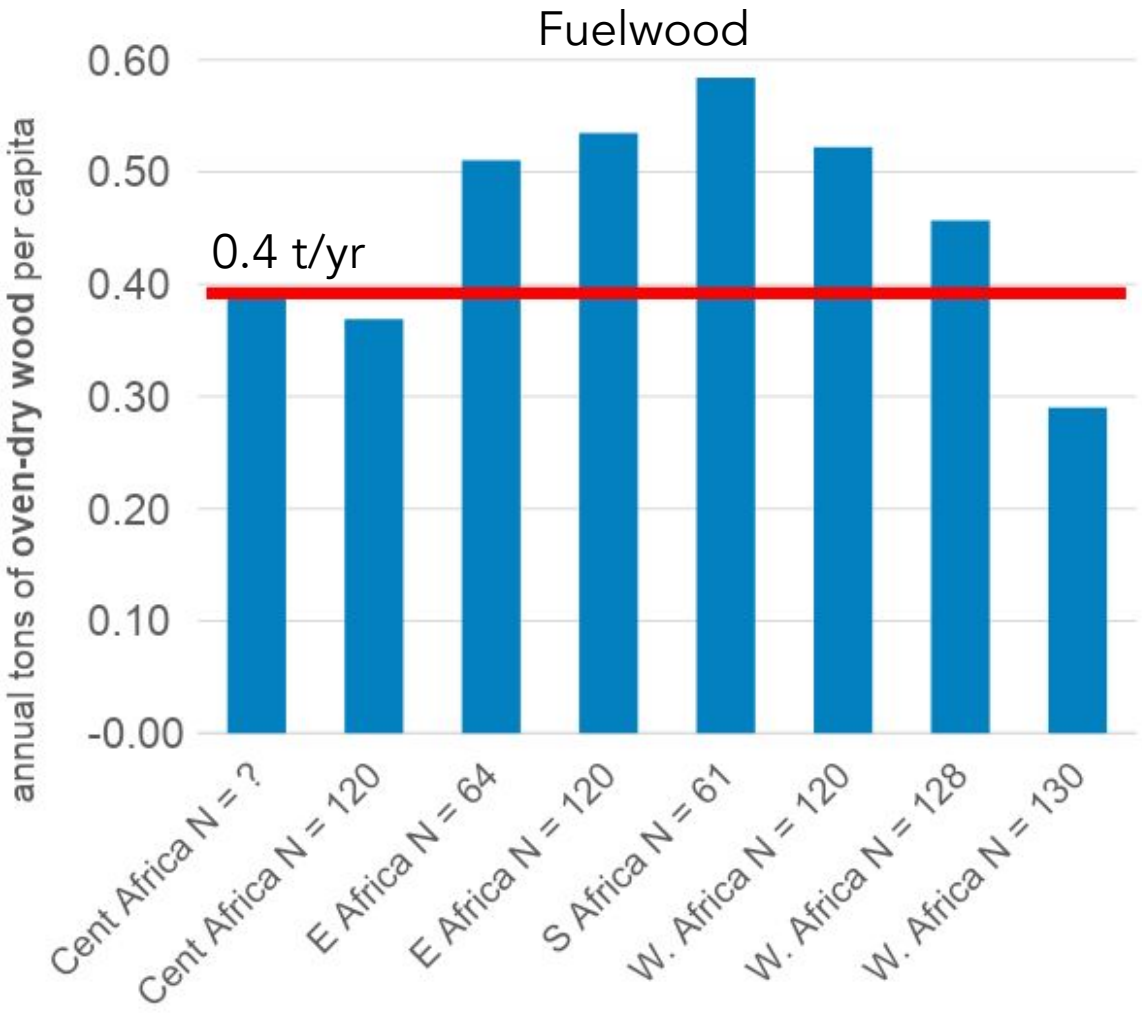


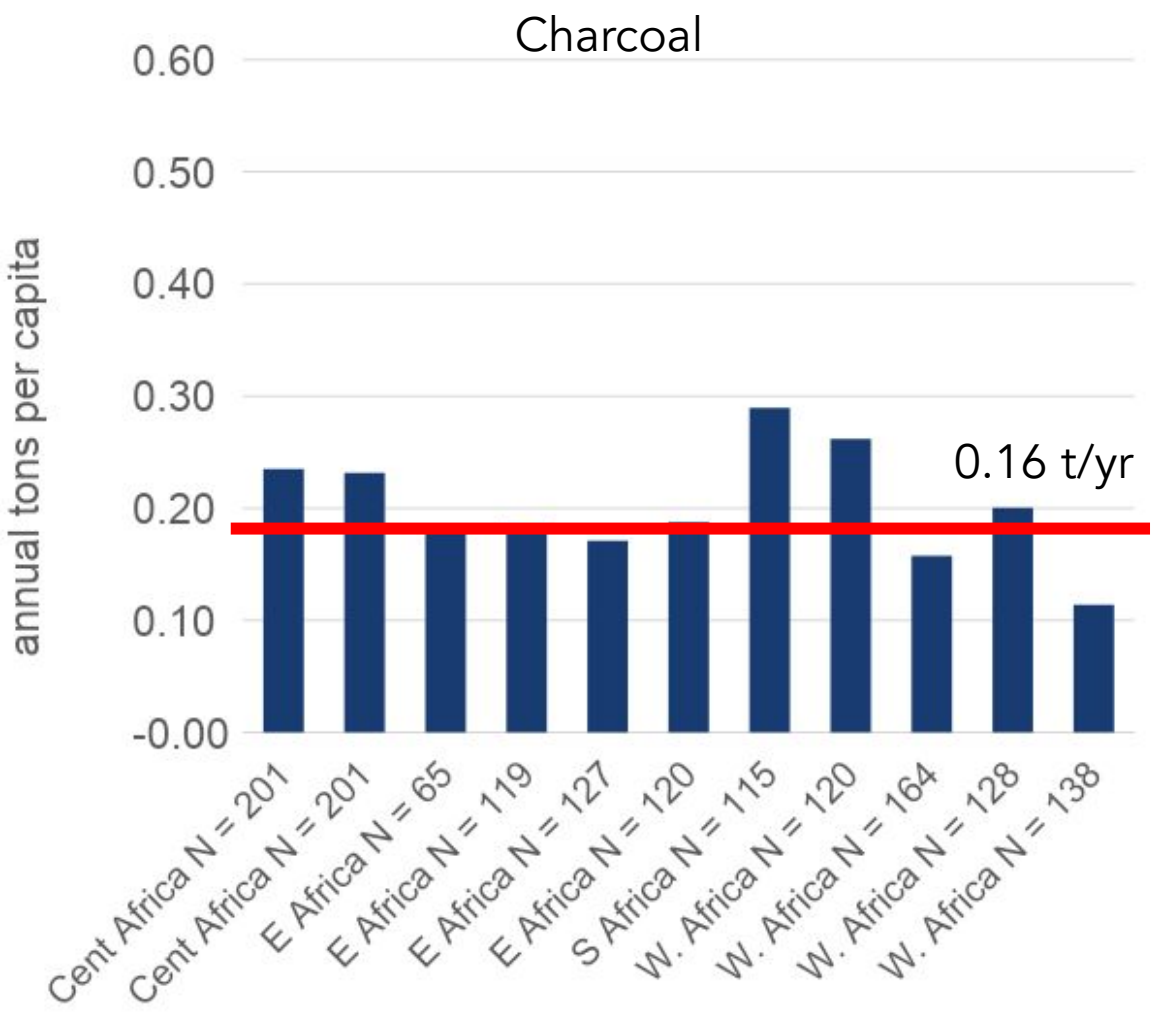
Useful energy equivalent to ~160 kg/cap-year of charcoal

Some public comments requested that we consider alternate values - more on this later

Comparing our assumptions field measurements…

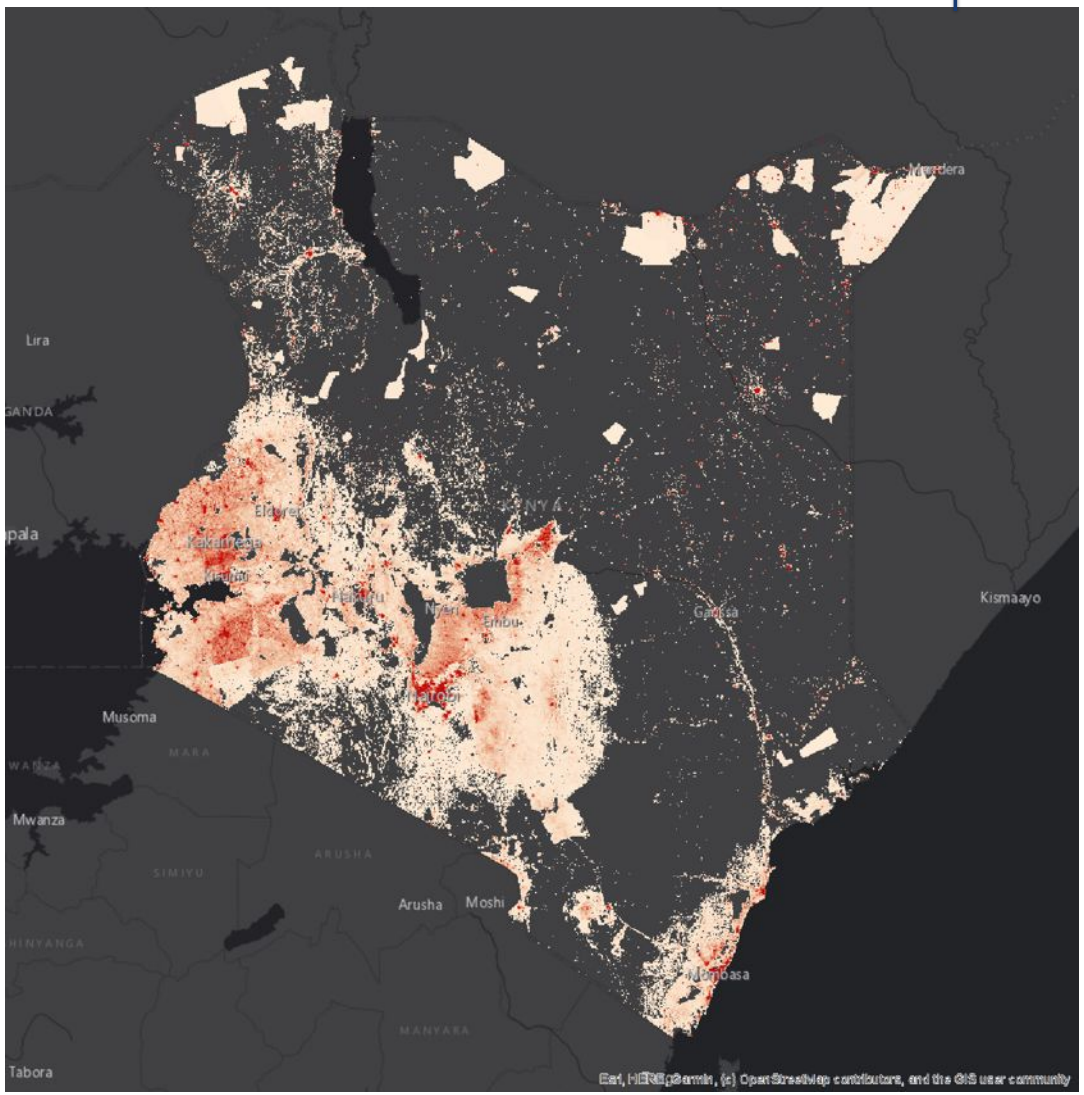
Data from 19 KPT campaigns implemented in 9 SSA countries



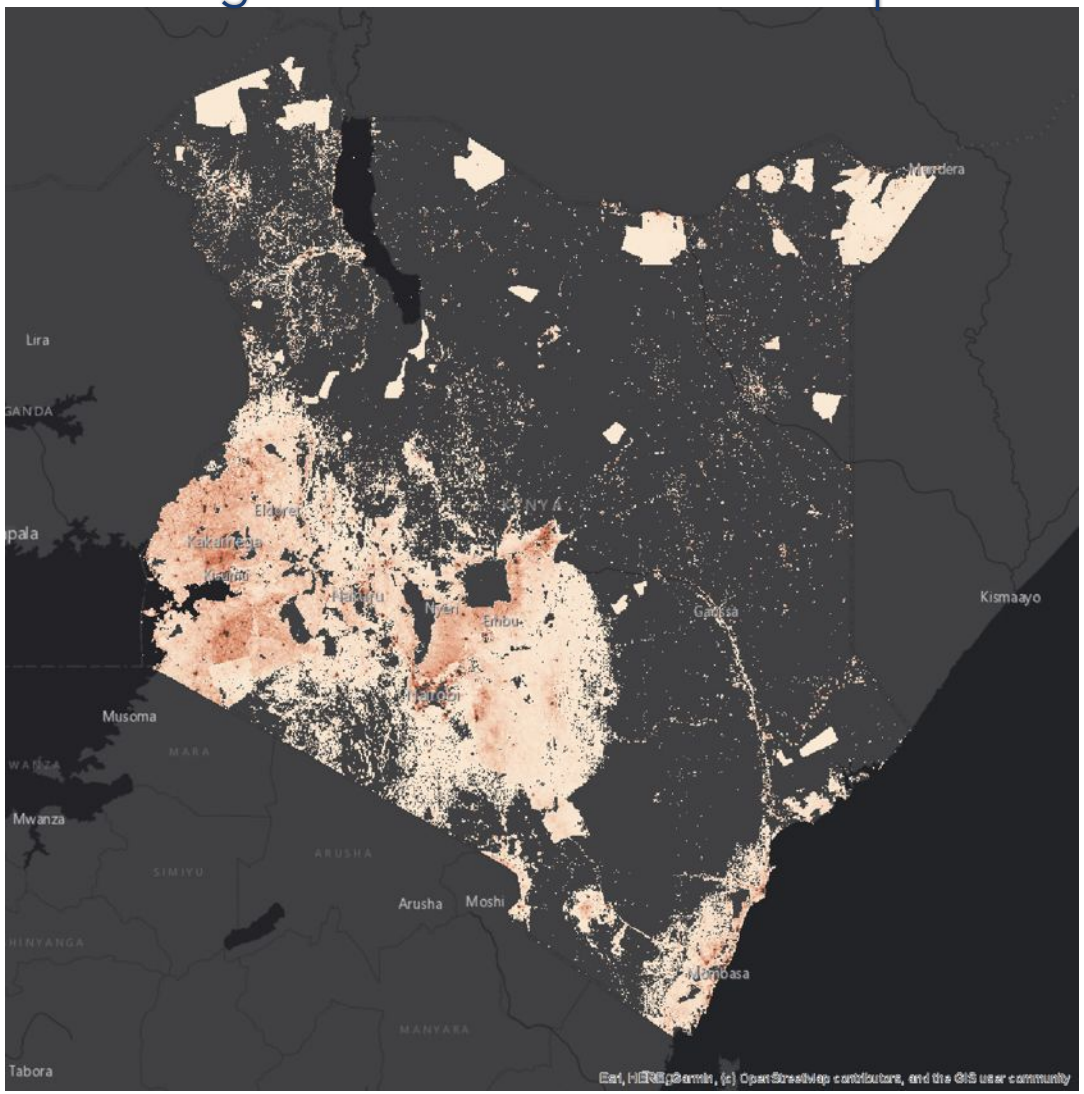


Combined into annual wood and charcoal demand

Marketed fuelwood & charcoal consumption

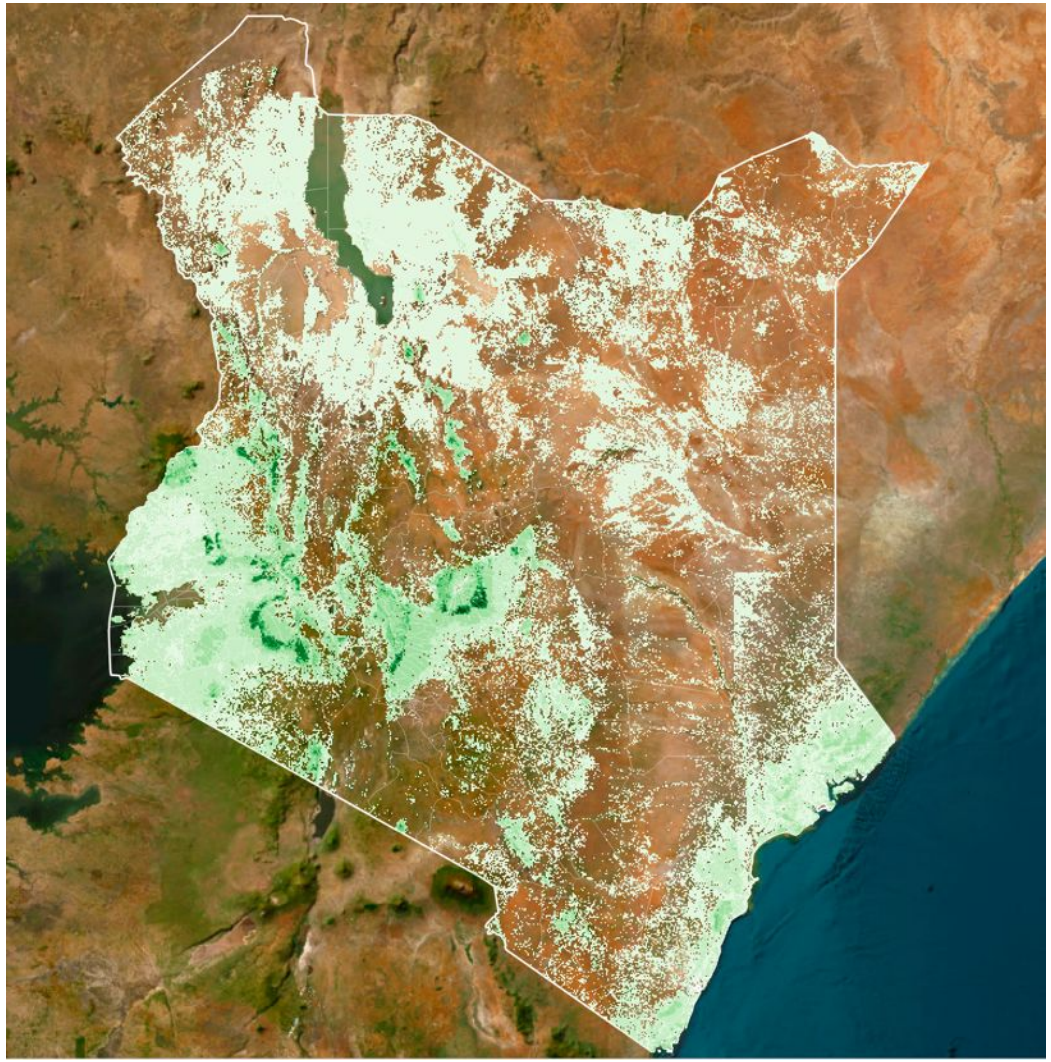


Self gathered fuelwood consumption



Tree extent and growth rates

Woody biomass density



Dry ton/ha

- <= 9
- 9 - 36
- 36 - 72
- 72 - 144
- 144 - 216
- 216 - 264
- 264 - 288
- 288 - 293
- 293 - 329
- > 329

Tree recovery in Miombo Woodlands

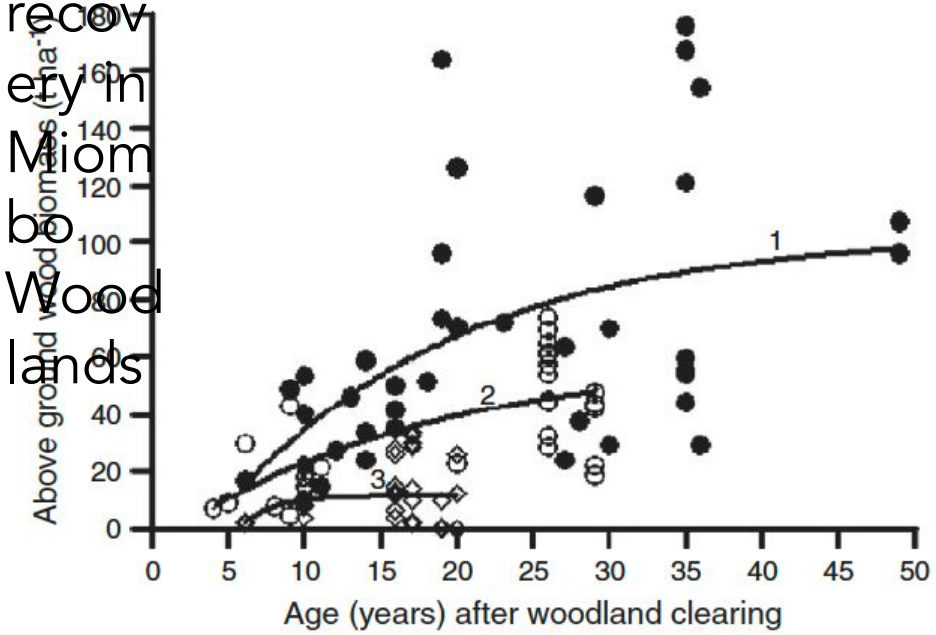
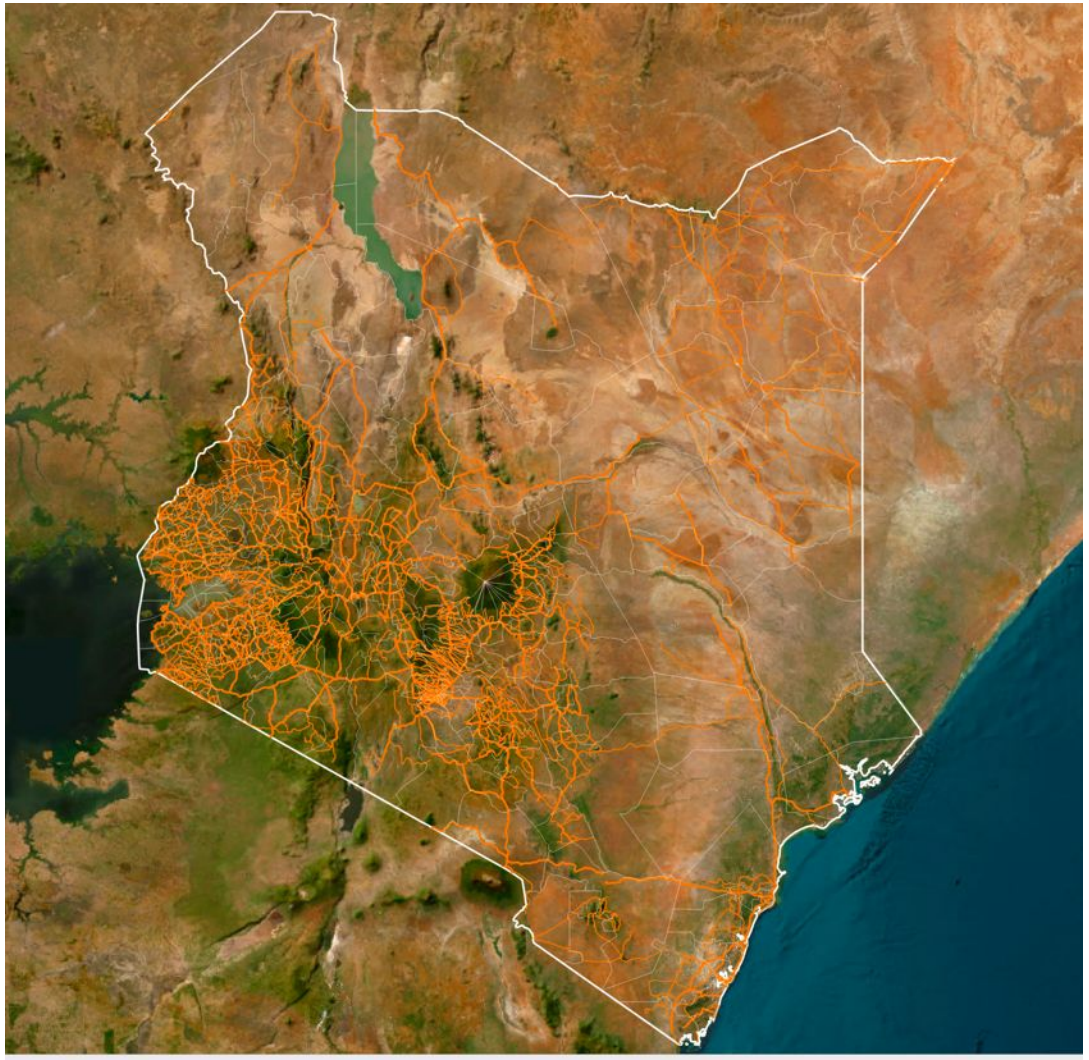


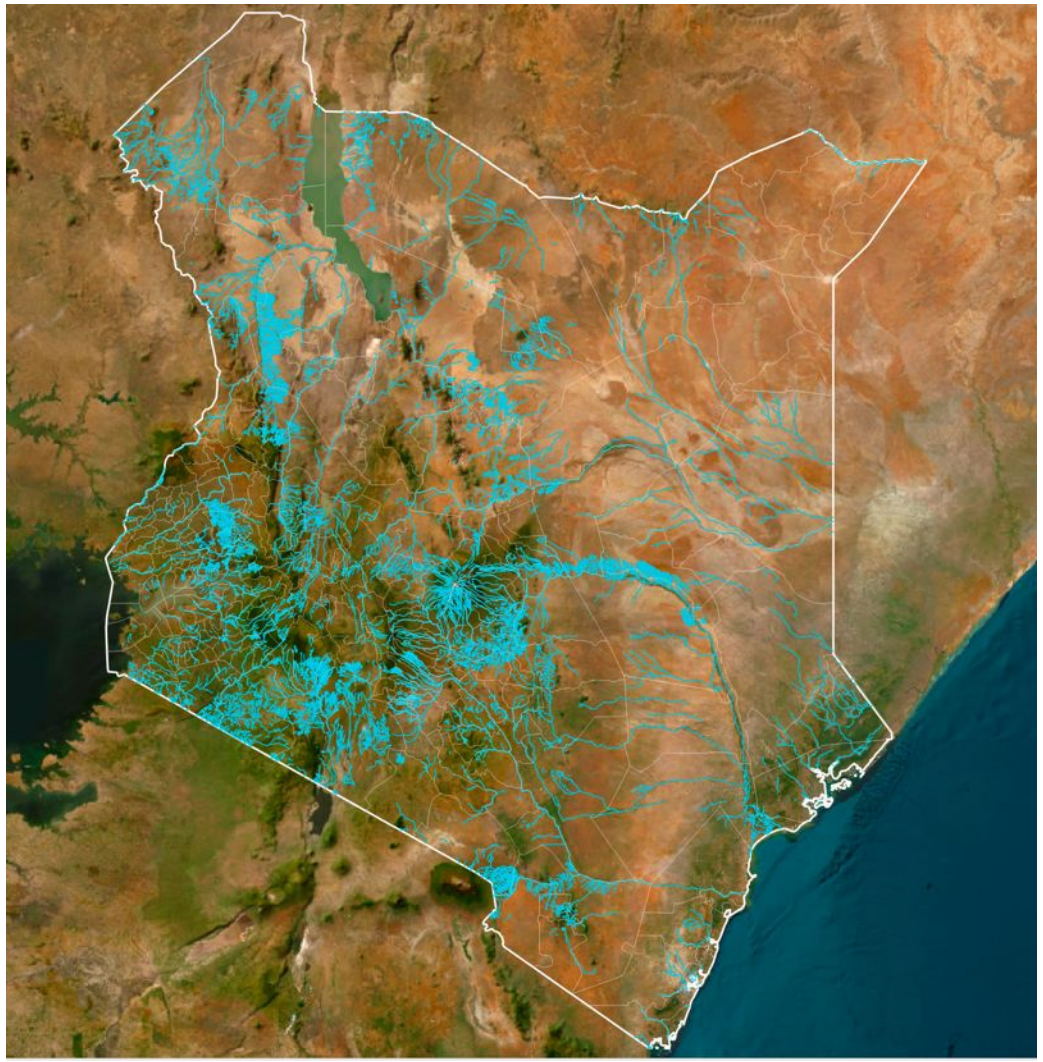
Fig. 3. Wood biomass accumulation in regrowth miombo woodland under different management levels in Zambia: 1 (●) for pre-1980s characterized by good forest management ($y = 103.5 - 129.7 * 0.94x$), 2 (○) for the 1980s characterized by declining forest management ($y = 27.5 * \ln(x) - 37.0$) and 3 (◊) for the 1990s characterized by lack of forest management ($y = 15.7 * \ln(x) - 27.0$).

Chidumayo and Gumbo, 2013

Accessibility



Roads



Rivers

Full list of input data here: https://gitlab.com/mofuss/mofuss/-/wikis/3-Global-datasets-Tier-1-or-Tier-2

Some field validation

Some field validation

What type of wood did you get?

- [ ] Bluegam
- [ ] Tea branches (Makuli)
- [ ] Tea stumps
- [ ] Mango
- [ ] Pears (avocado)
- [ ] Cyndrea
- [ ] Stalks of pigeon peas
- [ ] Stalks of cassava (Nakotongwa)
- [x] Gmelina
- [ ] Kweranyani
- [ ] Bamboo (Nsungwi)
- [ ] Hedges
- [ ] Keisha
- [ ] Mibawa
- [ ] Anaphini
- [ ] Other/Specify

How did you harvest it?

- [ ] Gather deadwood
- [ ] Pruning branches from living trees
- [x] Cut whole living trees
- [ ] Remove dead stumps
- [ ] Other/Specify

How did you bring it back home?

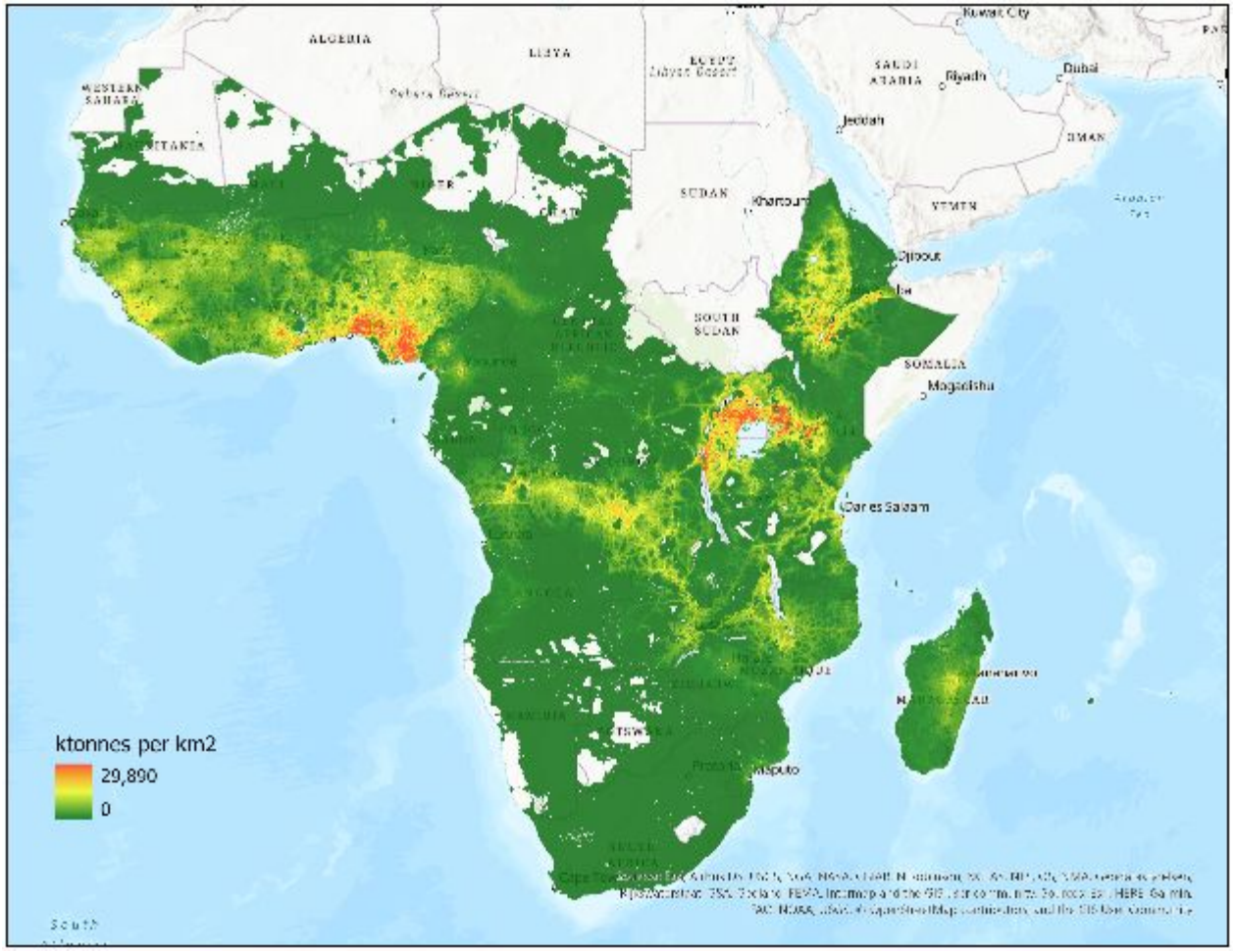
- [ ] Headload
- [ ] Bicycle
- [ ] Motorcycle
- [ ] Vehicle
- [ ] Draft animal
- [ ] Draft animal cart
- [ ] Wheelbarrow
- [x] Other: rolling it

Coverage: 90 countries in 16 regions

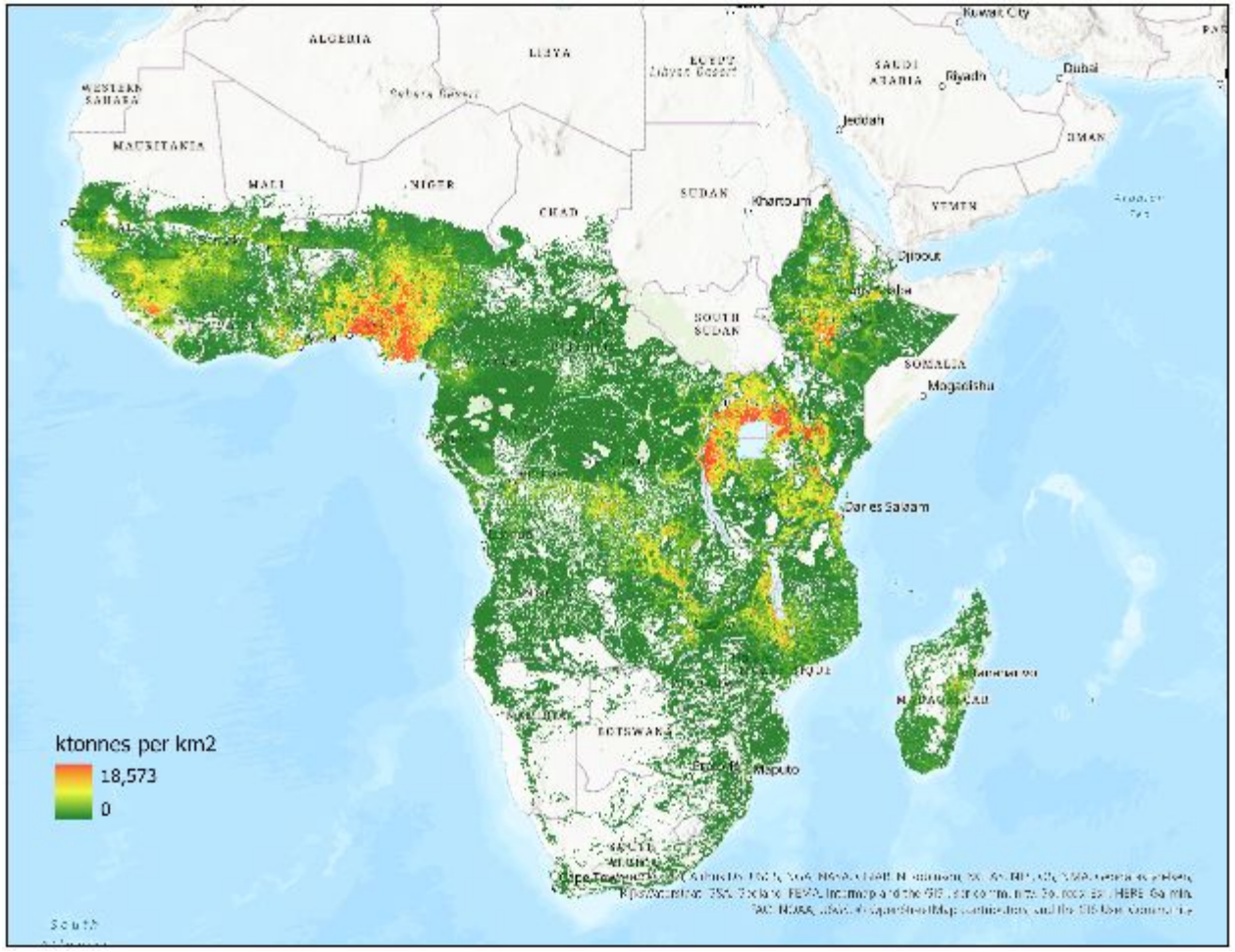
Based on inclusion in key databases (Meta/HDX; WHO)

Results look something like this at the pixel level…

NRB at pixel level (1km^2) in kt 2010-2050

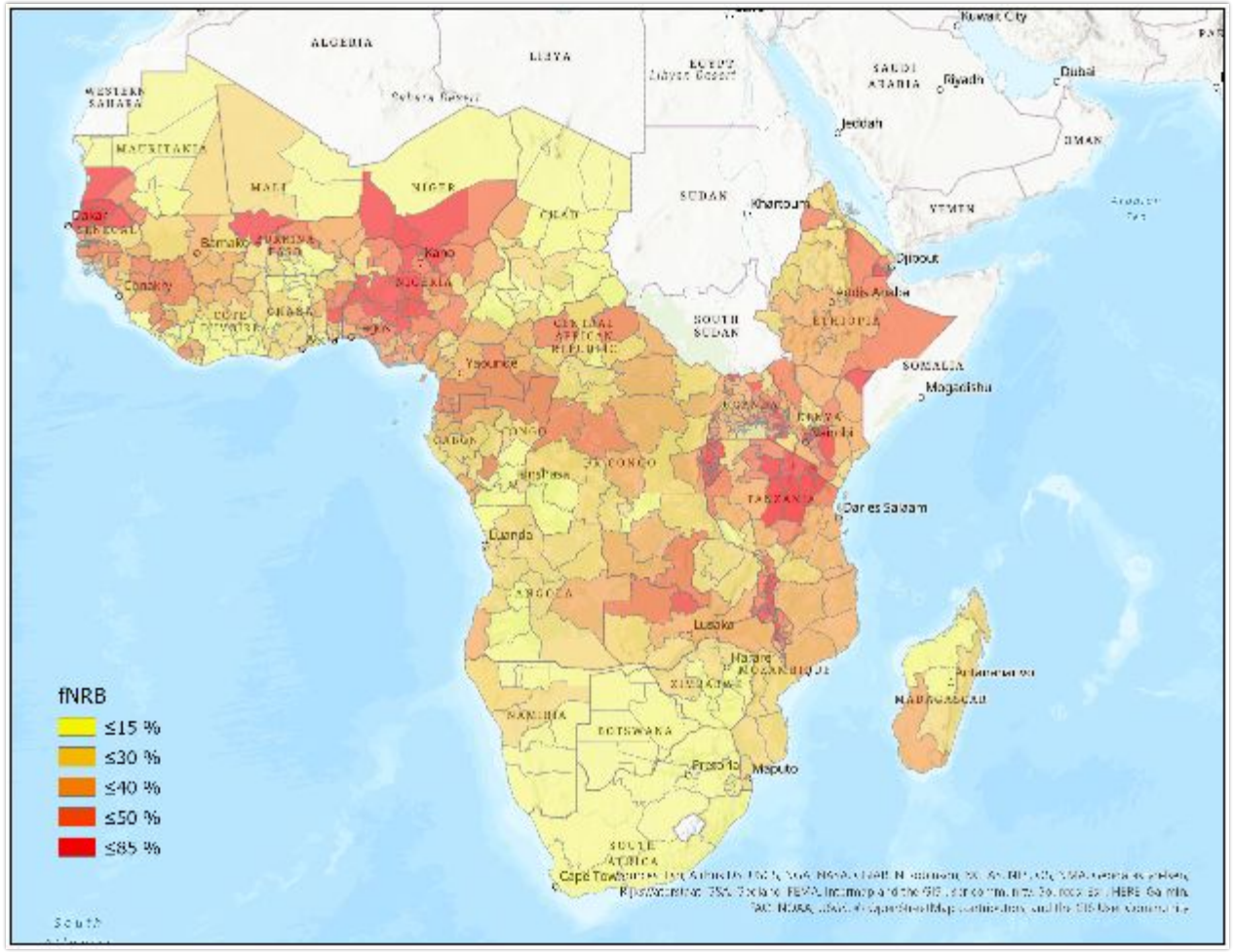


fNRB at pixel level (1km^2) in kt 2010-2050

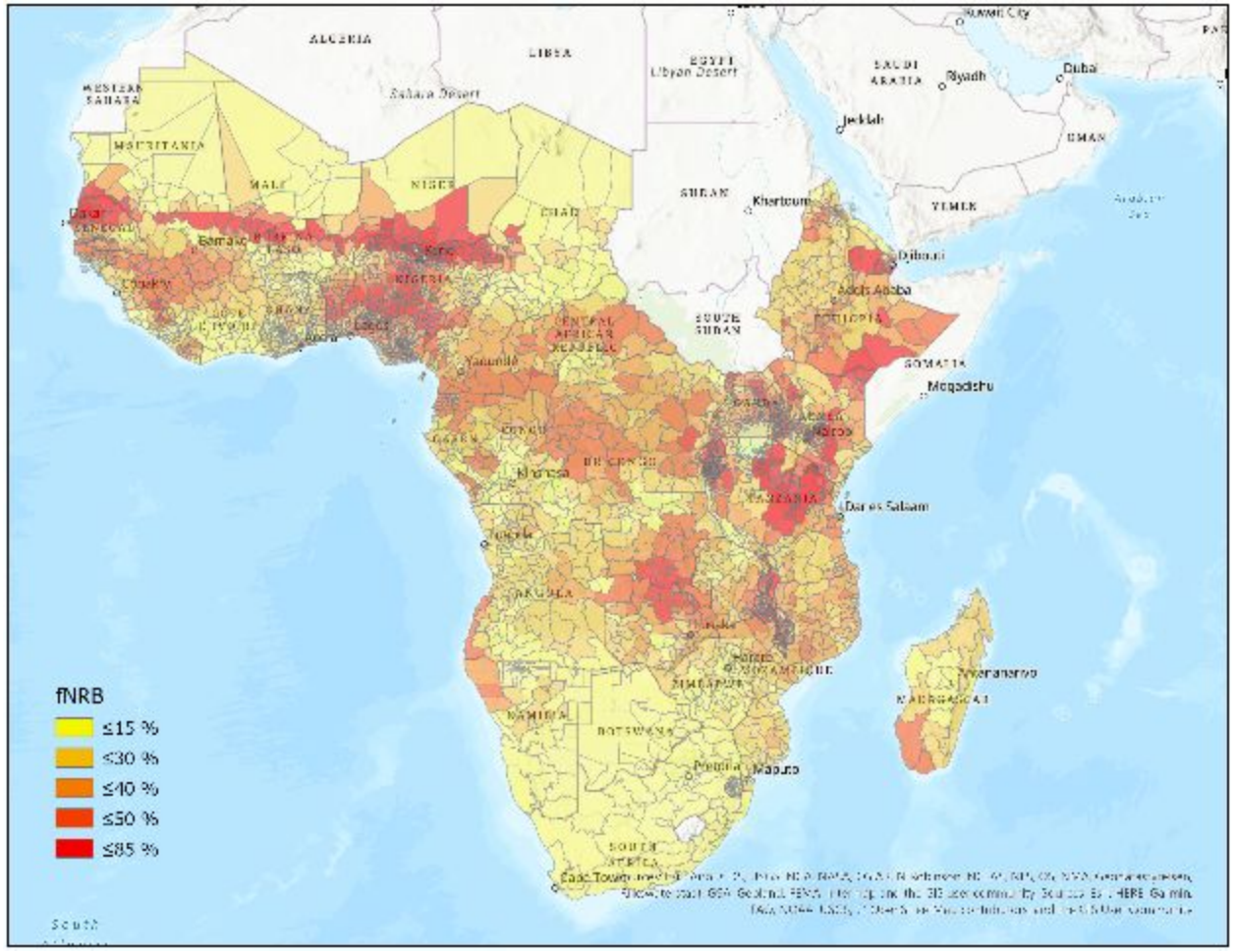


Or in spatially averaged into 1st and 2nd level admin units

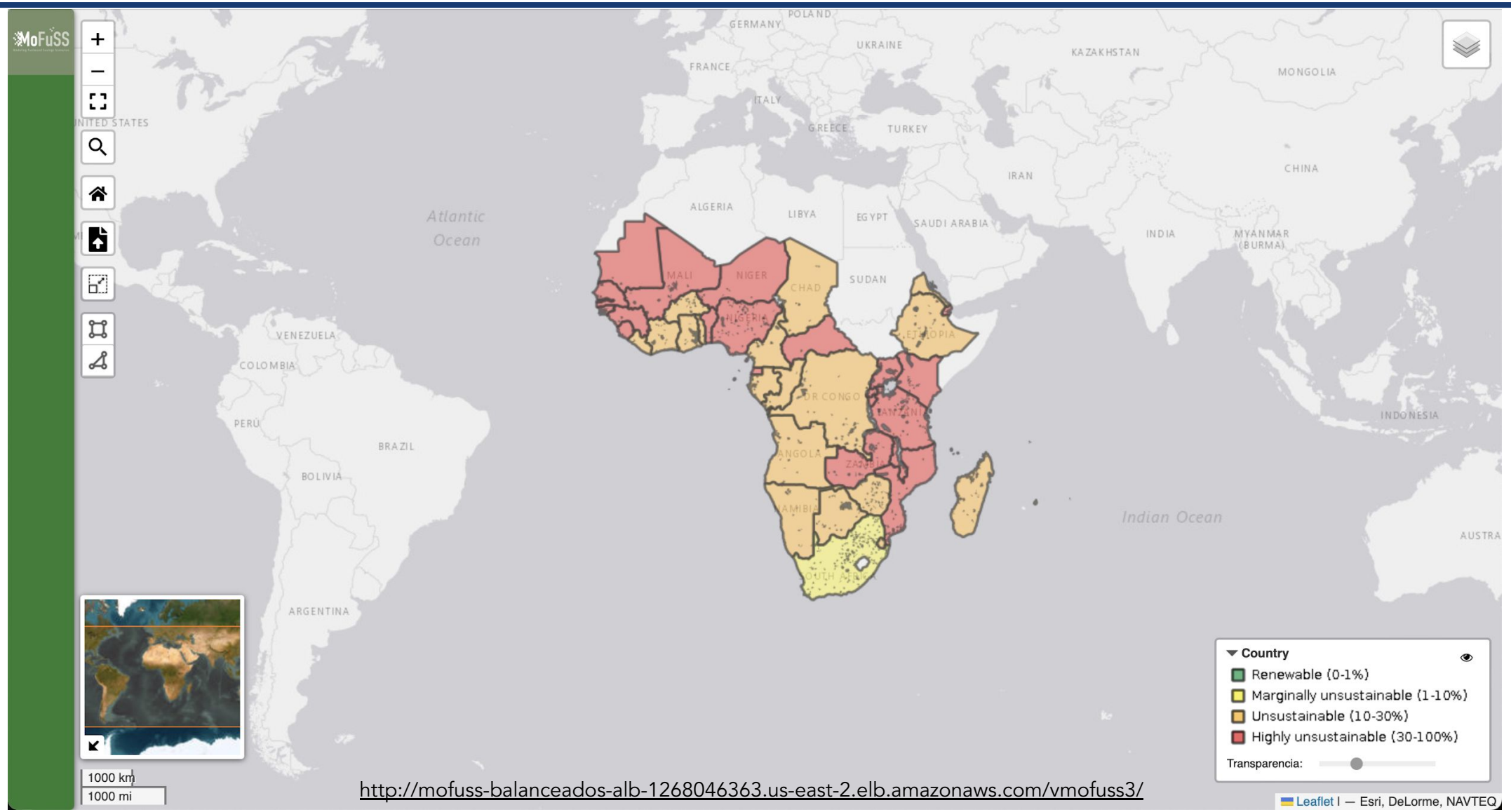
fNRB at sub national 1st admin level



fNRB at sub national 2nd admin level



On the web…



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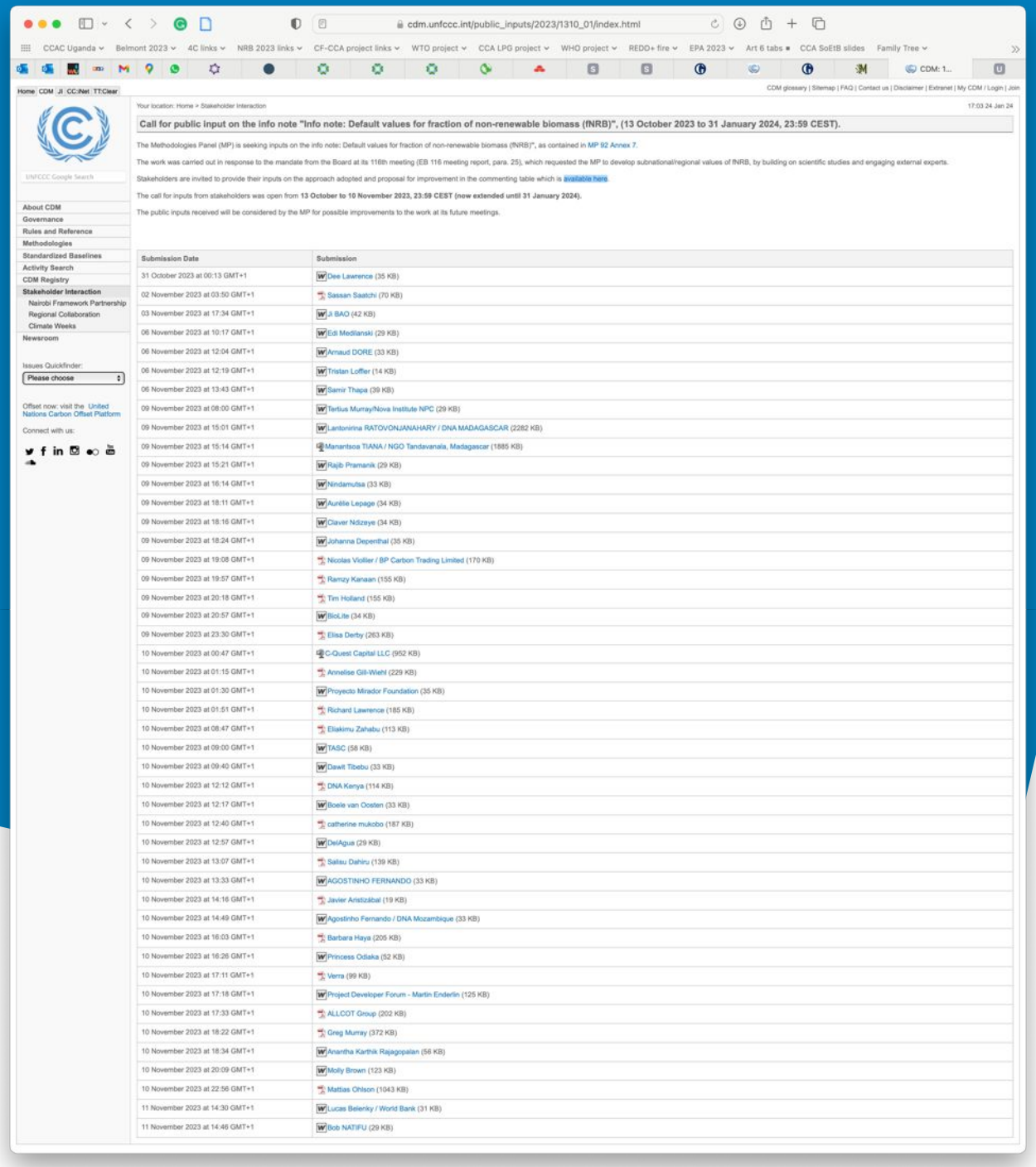


Public comments

46 submissions received to date. Points raised include:

- Accounting for non-residential demand
- Using more country-specific data
  - Fuel consumption
  - Stacking
- Questioned our choice of biomass stock and growth parameters

https://cdm.unfccc.int/public_inputs/2023/1310_01/index.html

Accounting for non-residential demand

- For commercial, institutional, and widespread cottage industries:
  - Impacts are spatially correlated with population distribution
  - Add a multiplier to residential demand
- For tea and tobacco
  - 6 countries – 90% of production in SSA
  - Impacts are localized - not based on popl'n

Non-residential demand

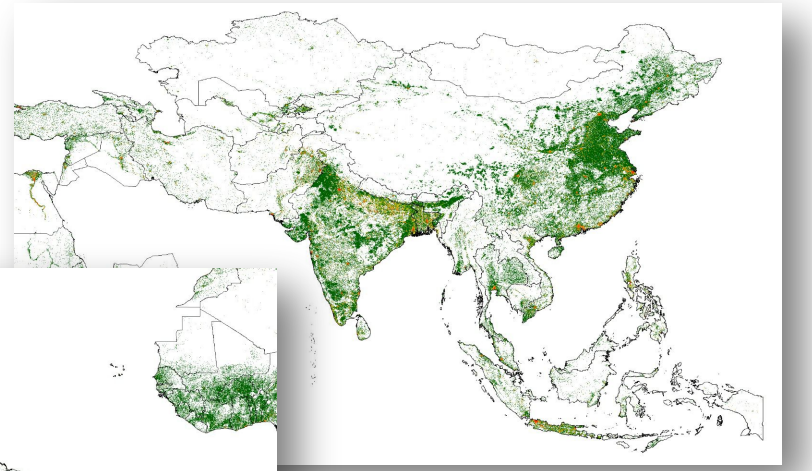
Non-residential woodfuel consumption as a percentage of residential consumption

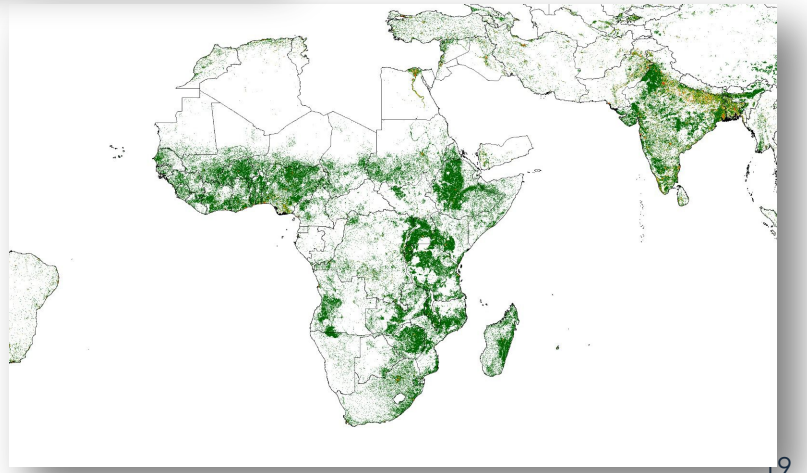
Country	Fuel	Year	Institutions	Food vendors	Inst and restaurants	Tea	Tobacco	Bricks	Other industry	All industry	All non-residential	Source
Rwanda	Wood	2019	11.5%	1.6%	13.2%	0.3%		3.7%		4.0%	17.2%	a
Rwanda	Charcoal	2019	0.8%	58.6%	59.4%						59.4%	a
Uganda	Wood	2020	0.0%	0.0%	1.9%					1.4%	3.3%	b
Uganda	Charcoal	2020	0.0%	0.0%	10.5%						10.5%	b
Kenya	Wood	2018	13.7%	0.0%	13.7%						13.7%	c
Kenya	Charcoal	2018	3.1%	0.0%	3.1%						3.1%	c
Kenya	Wood	2000	0.0%	8.1%	8.1%	1.0%	0.5%	0.4%	1.3%	3.1%	11.3%	d
Kenya	Charcoal	2000	0.0%	19.0%	19.0%	0.0%	0.0%	0.0%	0.0%	0.0%	19.0%	d

a. 2020 Cooking Fuel Energy And Technologies Survey
b. 2020 National Firewood And Agro Residue Survey For Uganda
c. 2018 KOSAP Survey Of Biomass Use In Kenyan Institutions
d. 2000 Moe Study On Kenya's Energy Demand, Supply And Policy Strategy For Households, Small Scale Industries And Service Establishments

Next steps

- Continue reviewing public inputs
- Rerun SSA model for UNFCCC w adjustments
  - Combine sub-regions (still debugging)
  - With commercial and industrial demand
- Run other regions
- Discuss with DNAs
  - UNFCCC-organized webinar next week
  - In-person visits to select countries Q1/2





The 2023/24 MoFuSS team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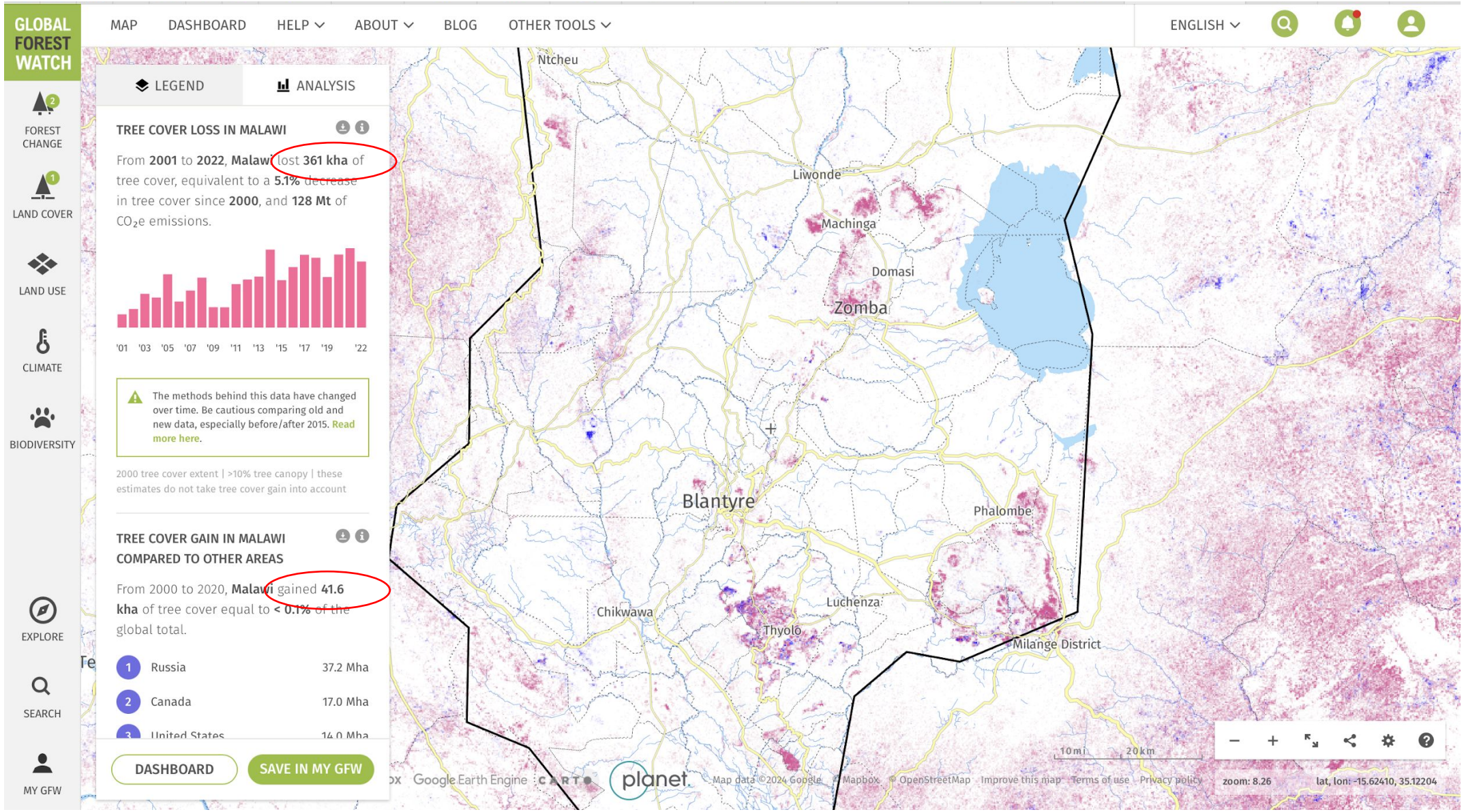
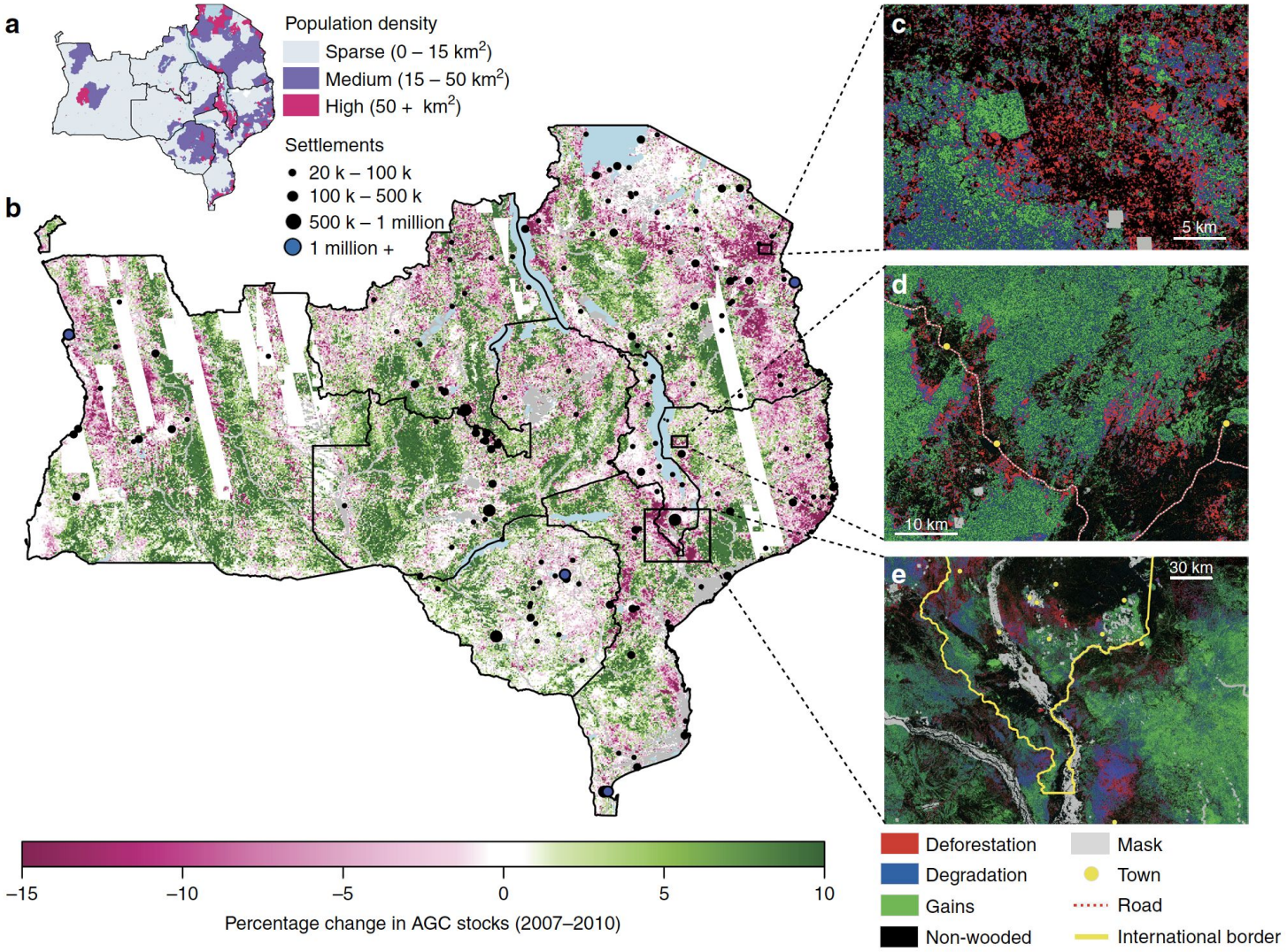
Extra slides

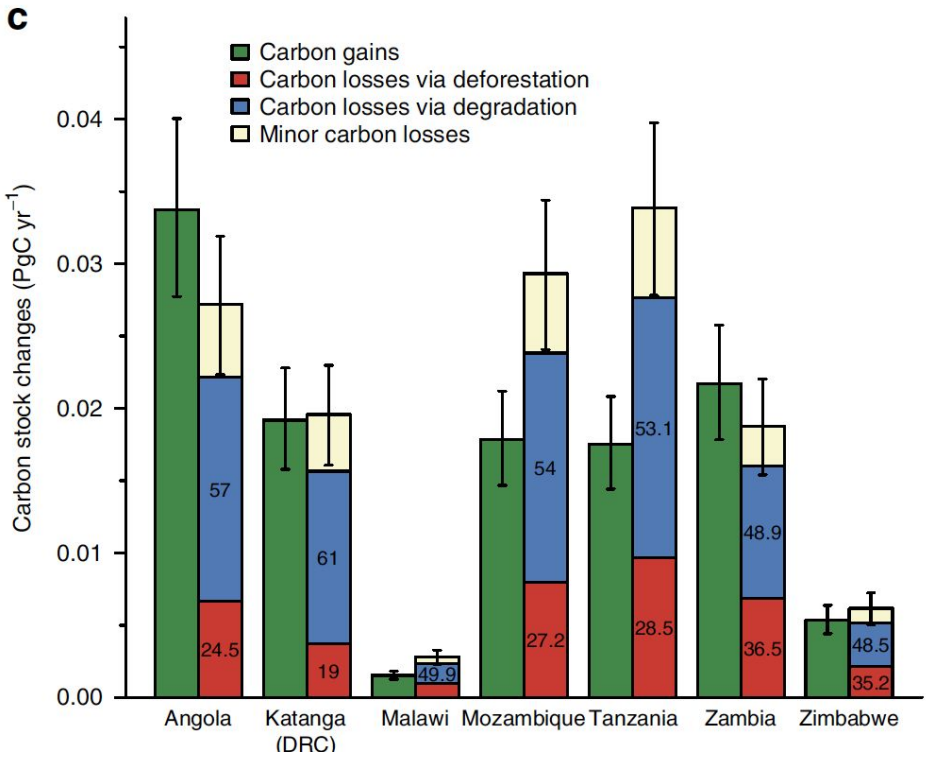
Yes, trees grow in SSA (data from LANDSAT)



https://www.globalforestwatch.org/map/country/MWI/

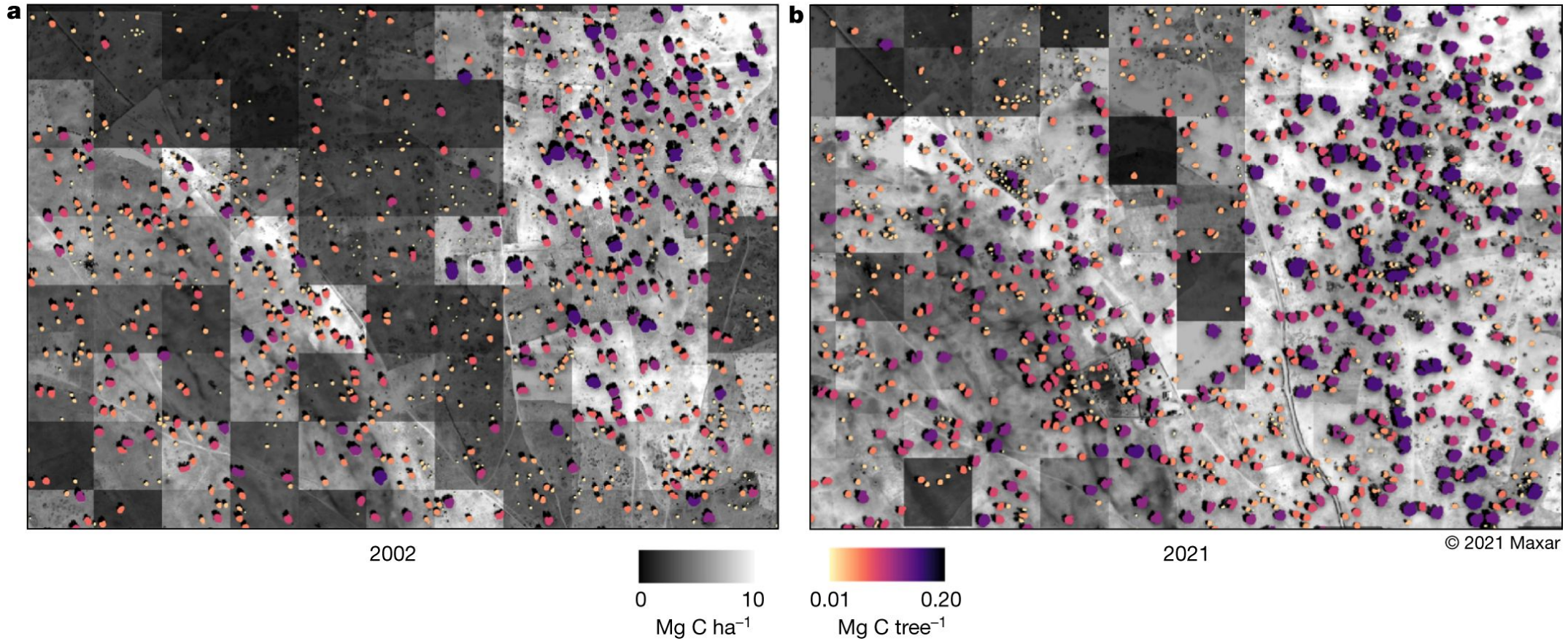
Yes, trees grow in SSA (data from ALOS-PALSAR)





Carbon stock changes due to deforestation, degradation and (re)growth, with the values is the losses bar showing the percentage contribution of deforestation and degradation to the total carbon losses . Error bars show the 95% confidence intervals (CIs) and represent for the total error on each bar (from https://www.nature.com/articles/s41467-018-05386-z).

Yes, trees grow in SSA (data from MAXAR analyzed with AI



A 50-cm-scale image from 2002 (**a**) and a 50-cm-scale satellite image from 2021 (**b**) showing an agroforestry area at the same location. Tree cover has increased between 2002 and 2021 and the average carbon density of both areas was calculated and increased from 6 to 10 Mg ha^{-1}. A large number of trees grow on farmlands, keeping the soils fertile and reducing the need for fallow periods. The greyscale of the background images indicates the carbon density per hectare, whereas the colour scale shows the carbon content of individual trees. This is a good example of the tree restoration monitoring potential in our study area (from https://www.nature.com/articles/s41586-022-05653-6)

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

Today

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

Next year

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

Two years from now

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

3 years from now

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

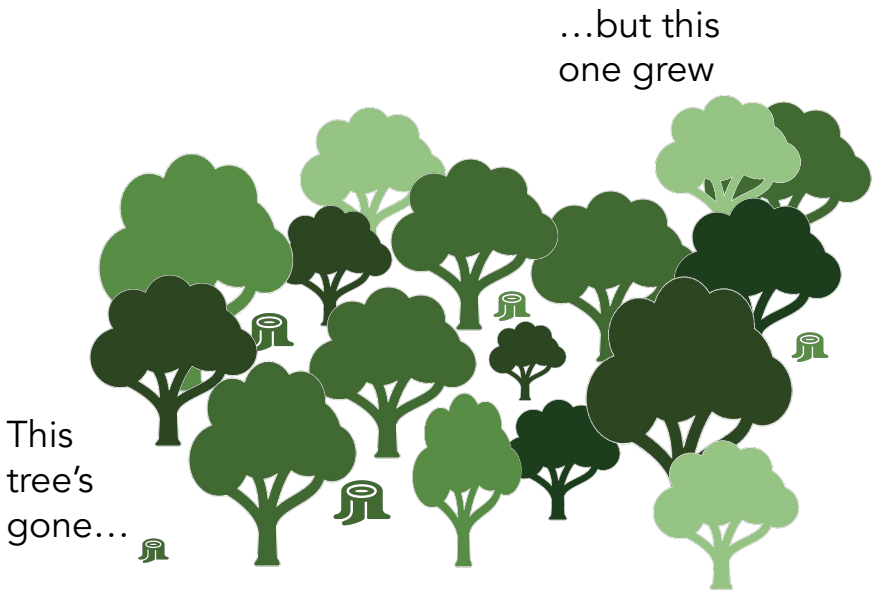
What happens if we start harvesting wood at the equivalent of 1 tree mid-sized per year?

3 years from now

What is fNRB?

Conceptually, it's straightforward:

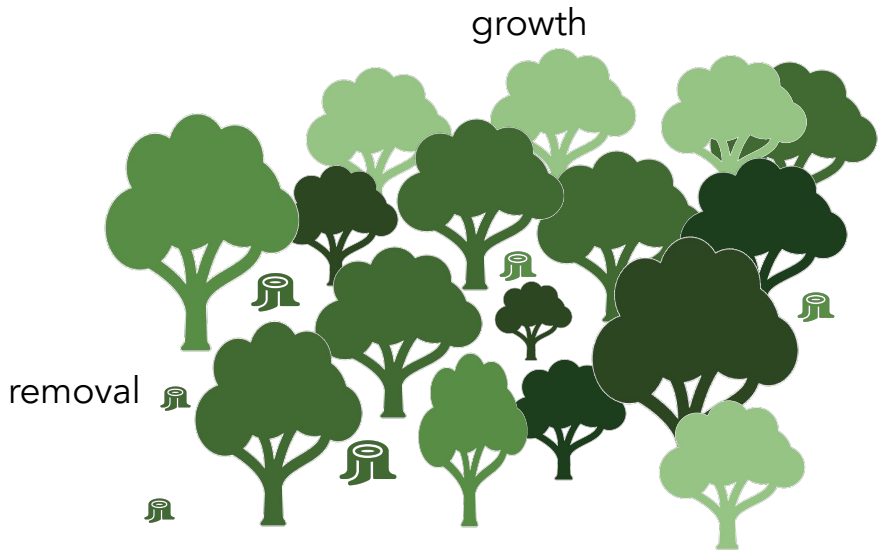
- Imagine we have 1 hectare of healthy woodland
- Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree
- New growth matches our harvest, so there's no net loss.



What is fNRB?

Conceptually, it's straightforward:

- Imagine we have 1 hectare of healthy woodland
- Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree
- This can continue for years…



What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

This can continue for years…

6 years from now

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

But what happens if we double our harvest?

6 years from now

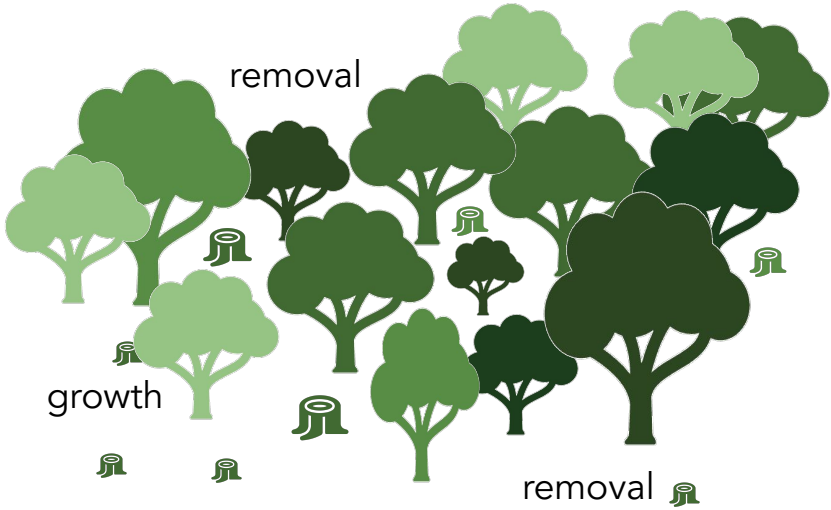
What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

We start seeing slow degradation…



7 years from now

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

Degradation continues…

8 years from now

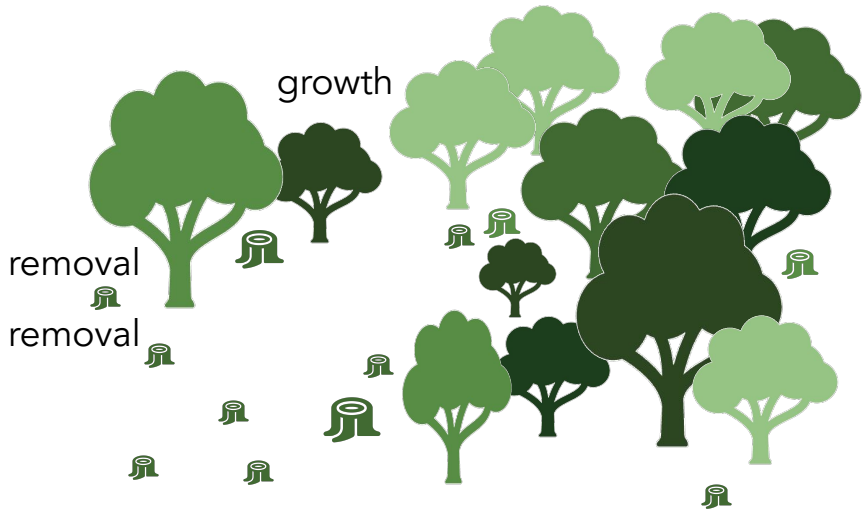
What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

Degradation continues…



9 years from now

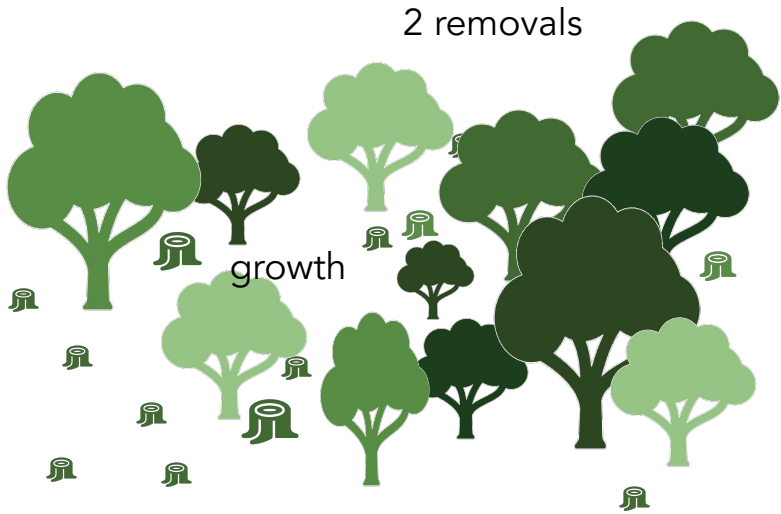
What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

Degradation continues…



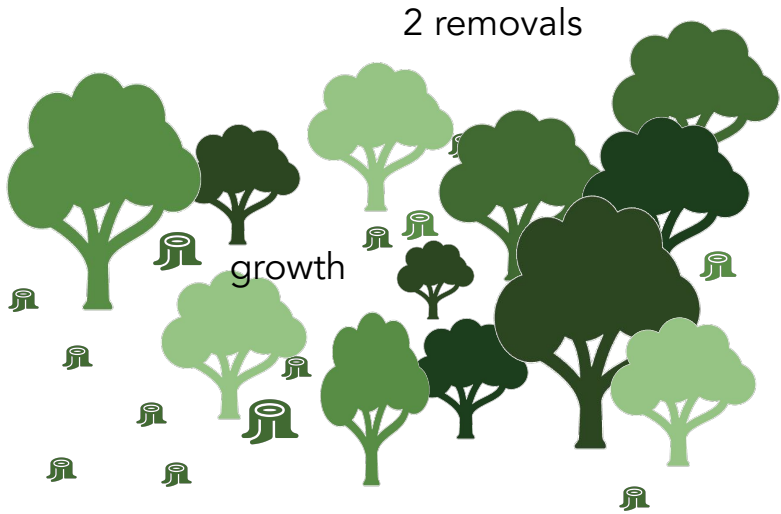
What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

Now jump ahead 5 years…



What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

Now jump ahead 5 years…

…we see a net loss of 5 trees

15 years from now

What is fNRB?

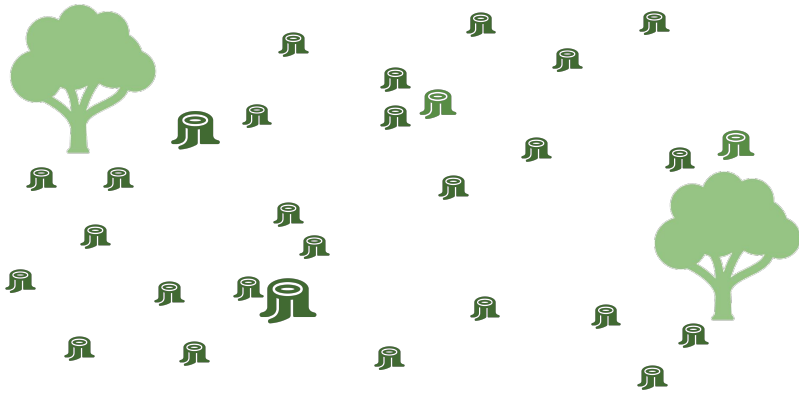
Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

So in just 5 more years…

…trees are nearly gone



20 years from now

What is fNRB?

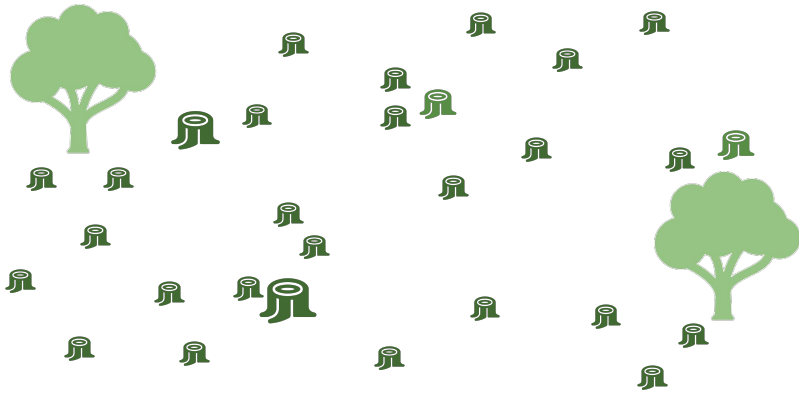
Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

So in just 5 more years…

…and we won't meet demand the next year.

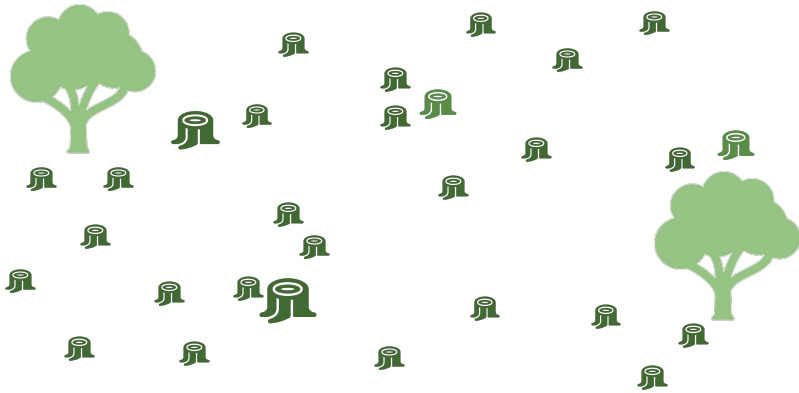


20 years from now

What is fNRB?

Conceptually, it's straightforward:

- Imagine we have 1 hectare of healthy woodland
- Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree
- What is fNRB in this example?



20 years from now

What is fNRB?

Conceptually, it's straightforward:

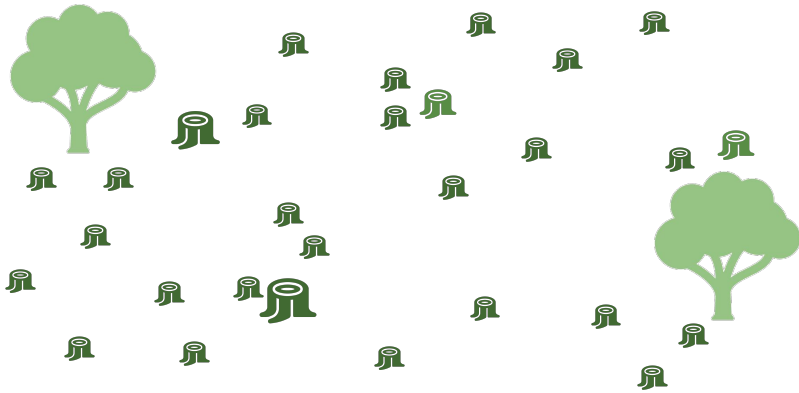
Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

What is fNRB in this example?

In one year, the landscape produces 

And we harvest +  



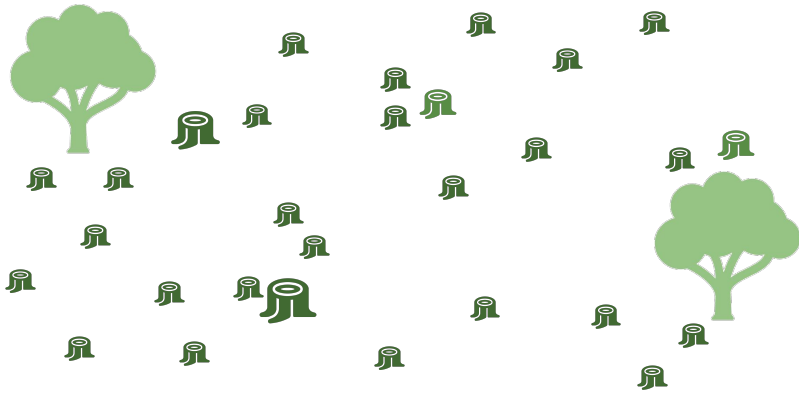
20 years from now

What is fNRB?

Conceptually, it's straightforward:

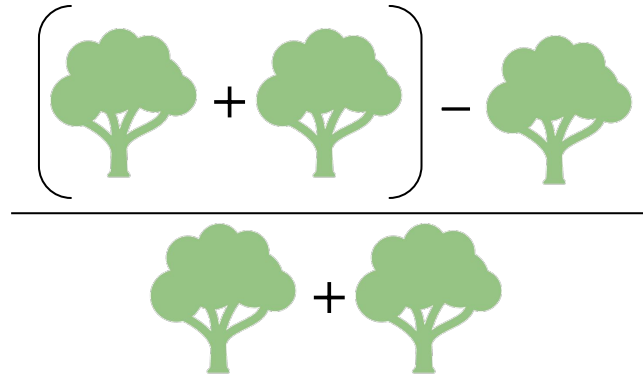
Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree



So fNRB is…

$$fNRB = \frac{Harvest - Growth}{Harvest} =$$



20 years from now

$$= 50\%$$

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

What happens if we go back to "Year-6" and start harvesting trees at a rate that leads to fNRB of 90% rather than 50%?

6 years from now

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

What happens if we go back to "Year-6" and start harvesting trees at a rate that leads to fNRB of 90% rather than 50%?

6 years from now

What is the annual harvest if fNRB = 90% ?

What is fNRB?

Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

What happens if we go back to "Year-6" and start harvesting trees at a rate that leads to fNRB of 90% rather than 50%?

We need to go back to our definition…

$$fNRB = 90\% = \frac{Harvest - Growth}{Harvest}$$

and solve for "Harvest"

6 years from now (alternate universe)

What is fNRB?

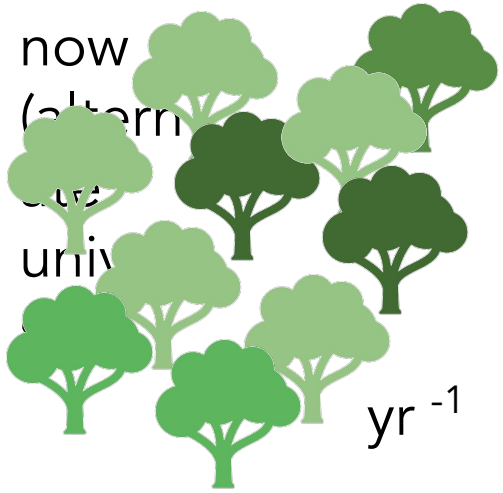
Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

What would happen if we go back to "year 6" and start harvesting trees at a rate that leads to fNRB of 90% rather than 50%?

6 years from now (altern… uni…



$$90\% = \frac{Harvest - Growth}{Harvest} \therefore Harvest = 10 \times Growth = \text{…} \; yr^{-1}$$

What is fNRB?

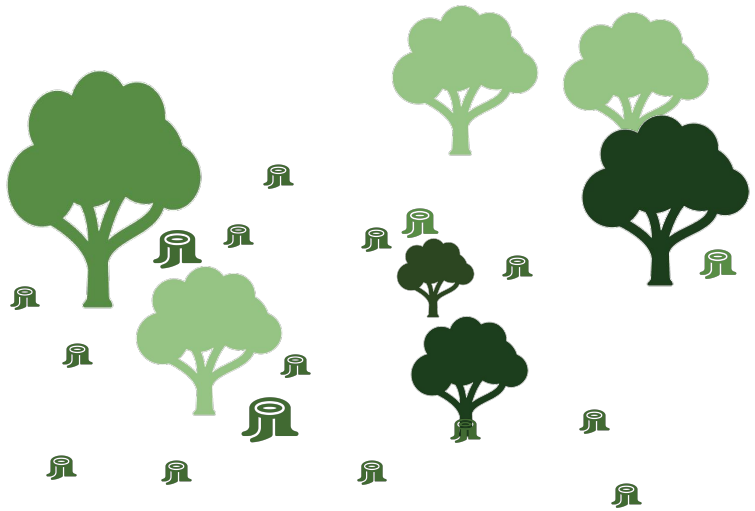
Conceptually, it's straightforward:

Imagine we have 1 hectare of healthy woodland

Trees growth at an annual rate that is equivalent to the woody biomass of 1 mid-sized tree

When fNRB = 90%

- each year there's a net loss of 9 trees
- in this case, stock is depleted in < 2 years
- by Year-8 we can't meet demand



7 years from now (alternate universe)

Summing up

50% fNRB

- Harvest is 2x the "sustainable" yield
- Harvest can continue for 15 years in our "model" *
  - Starting to harvest in Year-6, depletes stock in Year-21

90% fNRB

- Harvest is 10x the "sustainable" yield
- Harvest can only be sustained for ~2 yrs
  - Starting to harvest in Year-6, depletes stock by Year-8

* Depends on initial stock

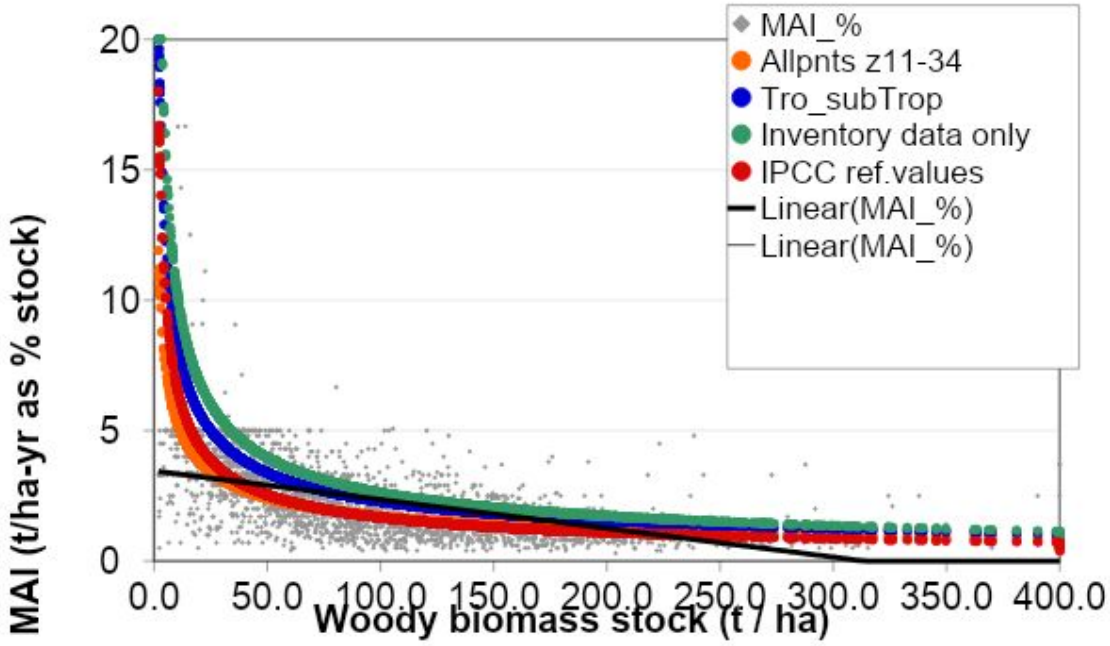
Some issues with this

Growth rate depends on stock

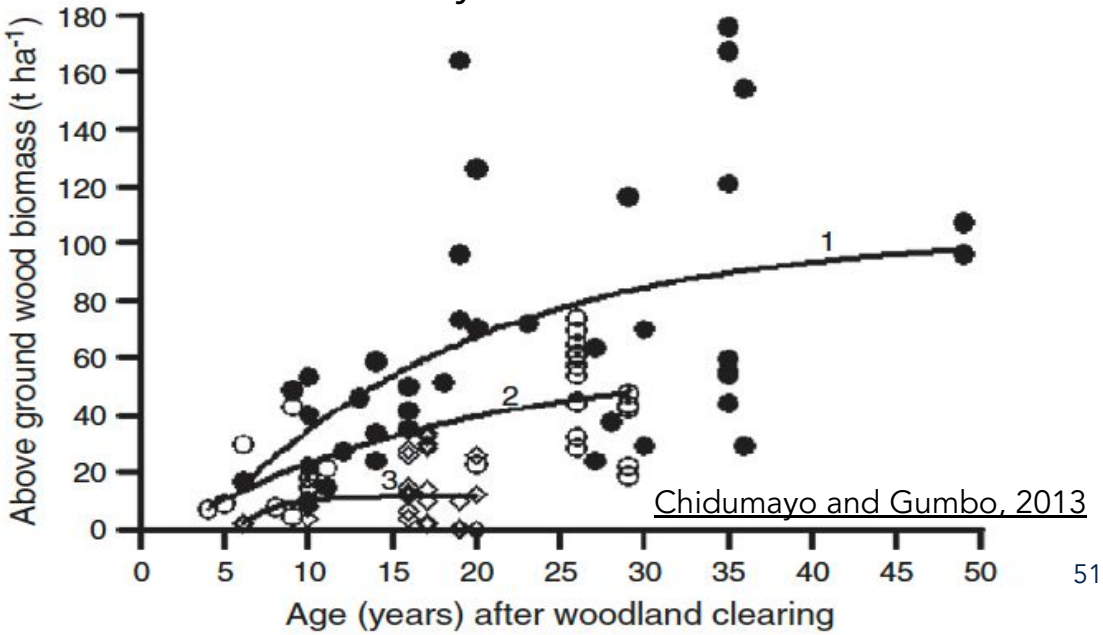
- It's not constant
  - Closer to an inverse power relationship (Growth $\propto$ Stock $^{-\text{constant between zero and one}}$)
- Growth typically increases with minor disturbance

  Less competition for water, light, & nutrients
- Trees are often pruned or coppiced

  Regrow faster than from seeds or rootstock



Tree recovery in Miombo Woodlands



Chidumayo and Gumbo, 2013

Challenges using Tool30 – misleading or ambiguous data sources

From FAO's "2000 Global Forest Resource Assessment"

Table 14. Distribution of total forest area by ecological zone				Tropical					
Country/area	Total land area	Total forest area	% forest	rain forest	Moist	Dry	Shrub	Desert	Mountain
	1000 ha	1000 ha		%	%	%	%	%	%
Angola	124670	69756	56.0%	9	65	25	1	n.s.	n.s.
Benin	11063	2650	24.0%	5	66	29			
Botswana	56673	12427	21.9%			73	27		
Burkina Faso	27360	7089	25.9%		9	90	1		
Burundi	2568	94	3.7%						100
Cameroon	46540	23858	51.3%	81	16	2	n.s.		1
Central African Republic	62297	22907	36.8%	23	53	24			
Chad	125920	12692	10.1%		10	88	2		
Congo	34150	22060	64.6%	95		5			
Côte d'Ivoire	31800	7117	22.4%	63	37				n.s.
Dem. Rep. of the Congo	226705	135207	59.6%	82	15	n.s.			3
Equatorial Guinea	2805	1752	62.5%	100					
Eritrea	11759	1585	13.5%				75	7	18
Ethiopia	110430	4593	4.2%		3	39	30	n.s.	29
Gabon	25767	21826	84.7%	99		1			
Gambia	1000	481	48.1%		24	76			
Ghana	22754	6335	27.8%	47	32	21			
Guinea	24572	6929	28.2%	28	71				1
Guinea-Bissau	3612	2187	60.5%	23	77				
Kenya	56915	17096	30.0%	1	18	1	28		53
Liberia	11137	3481	31.3%	99	1				n.s.
Madagascar	58154	11727	20.2%	34	9		38		18
Malawi	9409	2562	27.2%		48	37			15
Mali	122019	13186	10.8%		17	81	3		
Mauritania	102522	317	0.3%				100		
Mauritius	202	16	7.9%		100				
Mozambique	78409	30601	39.0%	1	18	81			n.s.
Namibia	82329	8040	9.8%			53	43	1	3
Niger	126670	1328	1.0%			99	1		
Nigeria	91077	13517	14.8%	22	36	38	2		2
Rwanda	2466	307	12.4%						100
Senegal	19252	6205	32.2%		20	70	10		

Data / Parameter table 5.

Data / Parameter:	$MAI_{forest,i}$, $MAI_{other,i}$
Data unit:	tonnes/ha/yr
Description:	Mean Annual Increment of woody biomass growth per hectare in sub-category *i* of forest areas in the relevant period Mean Annual Increment of woody biomass growth per hectare in sub-category *i* of other land areas in the relevant period
Source of data:	The following data source may be used: (a) Global Forest Resources Assessment 2000 by the FAO for "Distribution of total forest area by ecological zone" (Table 14); and/or (b) 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for "Above-ground biomass growth rates for different ecological zones" (Chapter 4, Table 4.9). Use a weighted average based on the forest area of three categories (i.e. primary forests, above and below 20 years secondary forests), if such data is available. Otherwise, use a simple average of the two age categories of secondary forests or a simple average of the three categories if primary forests exist; (c) Global Forest Resources Assessment (e.g. Table 17 "Net annual increment in forest 1990-2015" in 2015 version); (d) National studies or government data or official statistics. The most recent available data shall be used. However, the vintage of the above data shall not be before year 2000. It is required to determine MAI values for different sub-categories of forest areas and other land areas. However, in the absence of the local data in the country, global data (such as 2019 Refinement to 2006 IPCC Guidelines) or data of similar ecological zones in other regions may be used with due justification. Further, if the MAI value for other land areas is not available in a country while only the MAI value for forest areas exits, the MAI value for forest areas may be used as the MAI value for other land areas with due justification

e.g. FAO's GFRA only identifies a small area of Montane Forest in Rwanda as a potential source of wood, but 75% of Rwandans who collect fuelwood obtain it from private land and 88% travel less than 2km (MININFRA, 2020)

Challenges using Tool30 – misleading or ambiguous data sources

From IPCC's "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories"

TABLE 4.9 (UPDATED)
ABOVE-GROUND NET BIOMASS GROWTH IN NATURAL FORESTS[1,2,3,4] (TONNES D.M. HA^{-1} YR^{-1})

Domain	Ecological Zone[4]	Continent	Status/ Condition	Aboveground biomass growth [tonnes d.m. ha^{-1} yr^{-1}]	Uncertainty	Uncertainty type	References
	Tropical rainforest	Africa	Primary	1.3	3.5	SD	1, 2
			Secondary> 20 years	3.5	3.3	SD	3-8
			Secondary≤ 20 years	7.6	5.9	SD	3-7, 9
		North and South America	Primary	1.0	2.0	SD	2, 10, 11
			Secondary> 20 years	2.3	1.1	SD	3, 4, 12-15
			Secondary≤ 20 years	5.9	2.5	SD	3, 4, 6, 12-14
		Asia	Primary	0.7	2.2	SD	2, 16
			Secondary> 20 years	2.7	3.1	SD	3, 4, 17
			Secondary≤ 20 years	3.4	3.9	SD	3, 4, 17-19

Real data from *miombo* woodlands show (re)growth rates that are:

- Not constant
  - Higher in young stands
  - Very variable

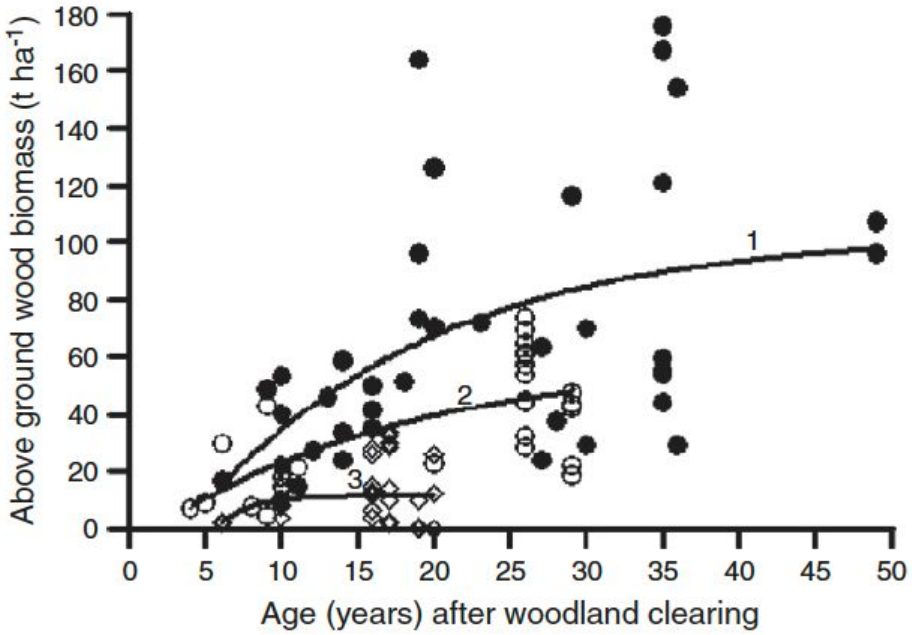


Fig. 3. Wood biomass accumulation in regrowth miombo woodland under different management levels in Zambia: 1 (●) for pre-1980s characterized by good forest management ($y = 103.5 - 129.7 * 0.94x$), 2 (○) for the 1980s characterized by declining forest management ($y = 27.5 * \ln(x) - 37.0$) and 3 (◊) for the 1990s characterized by lack of forest management ($y = 15.7 * \ln(x) - 27.0$).

Challenges using Tool30 – misleading or ambiguous data sources

From FAO's "2015 Global Forest Resource Assessment"

Net annual increment (m3 per hectare and year)	Total					contrib from conifers	contrib from broadleaf
	1990	2000	2005	2010	2015	2015	2015
Burkina Faso		1.2					
Equatorial Guinea	7.5	7.6	7.4	7.8	7.6	0	7.6
Ghana	4						
Kenya	3.5	3.4	3.3	2.8	3.3	2	1.3
Mali	0.9	0.9	0.9	0.9	0.9		
Mauritania					1.8	0	1.8
Swaziland	4.5	5.2	5.2	5	5.4	5.8	4.9
United Republic of Tanzania	2.5	2.5	2.5	2.5	2		

Take Kenya as an example:

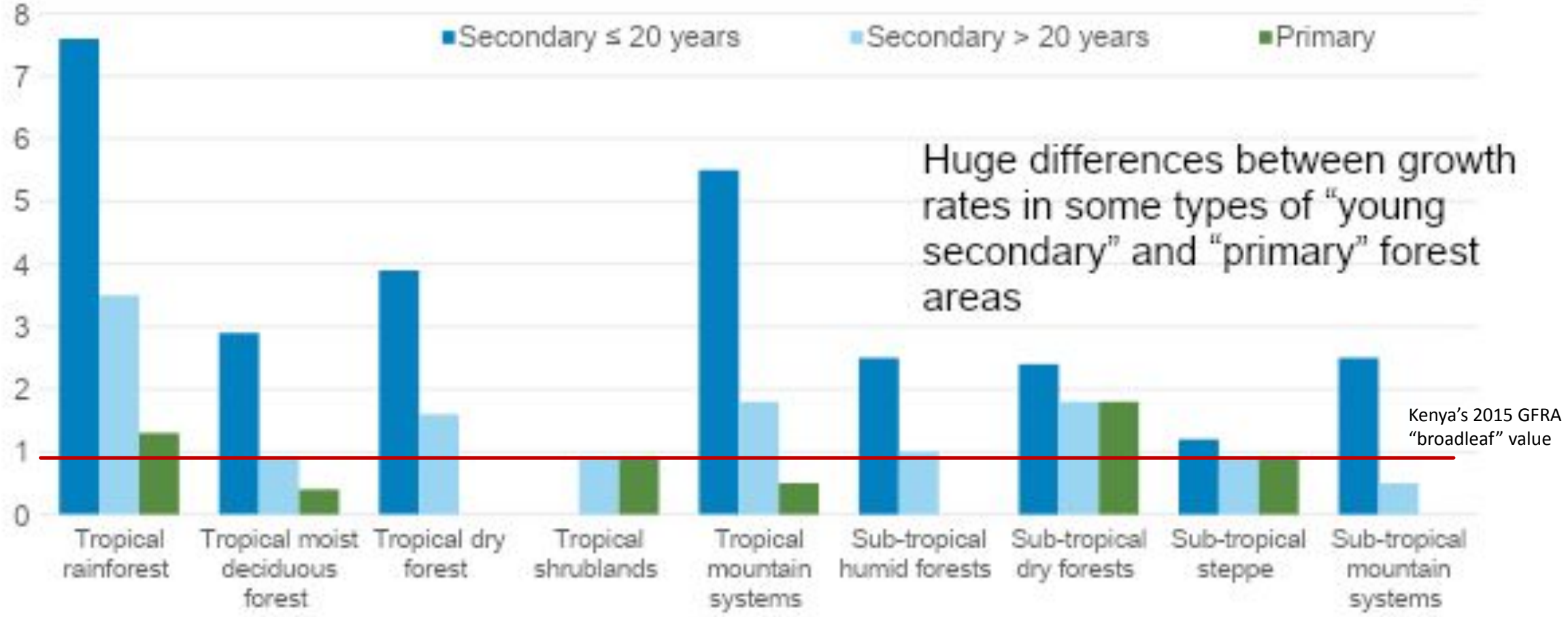
- 1.3 m^3/ha-yr for broadleaf forests
  < Mauritania ?!?!
- 0.9 dry-tons/ha-yr
- lower than most IPCC data

Other sources have very limited coverage. E.g. FAO's 2015 GFRA:

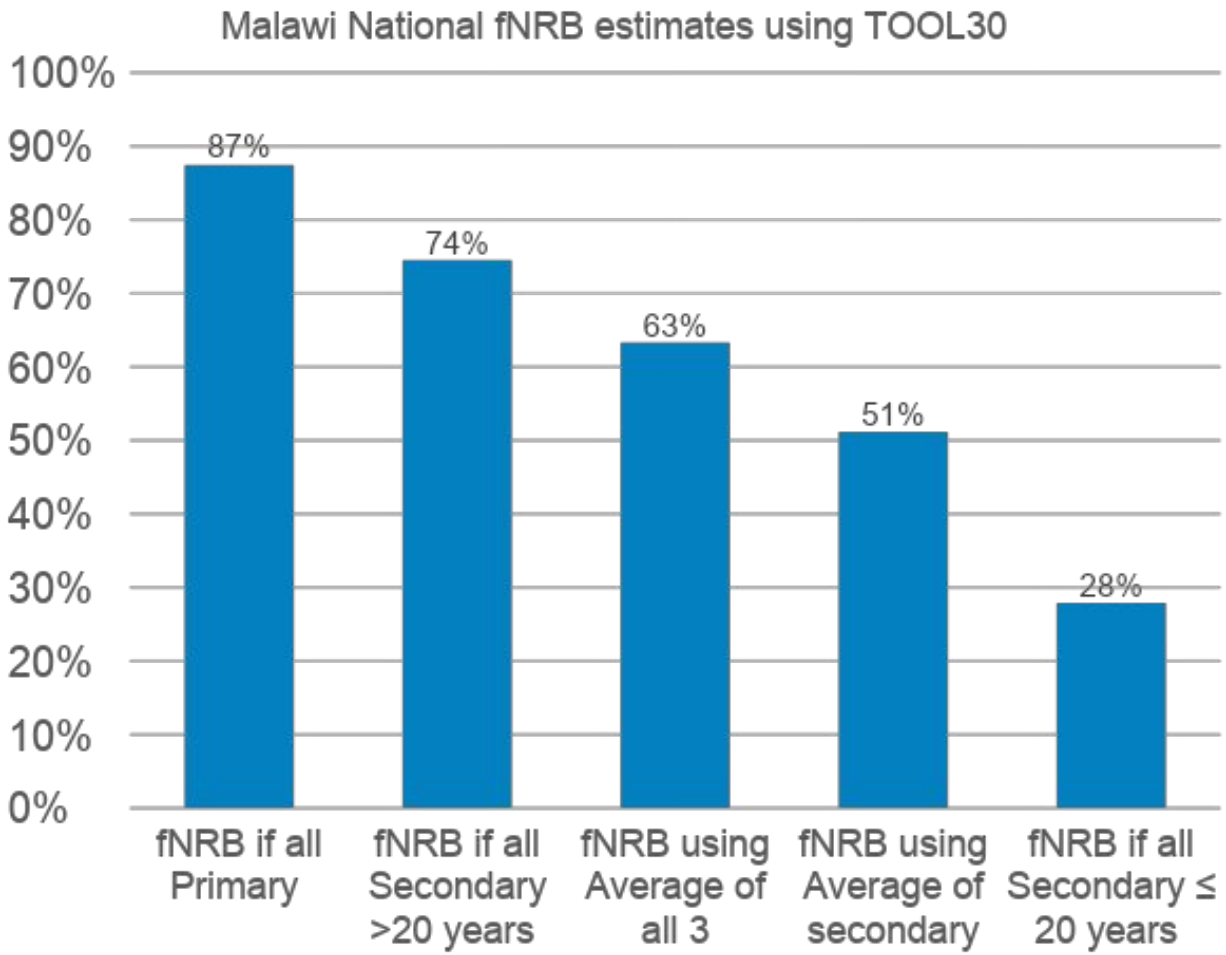
- Only includes 11 countries in SSA
- Has no breakdown by forest type
  - Only conifer / broadleaf
  - Inconsistent presentation of data
  - No scientific sources cited
  - No uncertainty provided

Challenges using Tool30 – misleading or ambiguous data sources

IPCC (2019) default growth rates for forest types in Africa



Challenges using Tool30 – misleading or ambiguous data sources



Example from Malawi using inputs recommended by TOOL30 including:

- Forest areas from FAO's 2000 GFRA
- MAI's from IPCC 2019 guidelines
- Consumption from a registered PDD

fNRB varies from 87% to 28%