Appendix: Methodology and Supplementary Data for Global Biomass and Biochar Projections (2050)

1. Dynamic Modelling for Primary Residues

The RPR was dynamically modelled as a function of the predicted dry yield, using a continuous piecewise exponential decay model for primary field residues (wheat straw, maize straw, rice straw, other cereals straw, barley straw, millet straw, sorghum straw). First, the projected dry yield for the target year was converted from kg ha^{-1} to Megagrams per hectare (Mg ha^{-1}) to be compatible with standard empirical baseline parameters. The RPR was then calculated based on established crop-specific empirical coefficients (a and b) using the following piecewise function (Bentsen et al., 2014):

$$RPR = \begin{cases} a.e^{b.Y_{dry,2050}}, & Y_{dry,2050} \leq {}^{-1}/_{b} \\ \frac{-a}{b.e}\frac{1}{Y_{dry,2050}}, & Y_{dry,2050} > {}^{-1}/_{b} \end{cases} \qquad \text{eq.1}$$

- Exponential Decay Phase ($Y_{dry,2050} \leq {}^{-1}/_{b}$): For low to moderate yields, the RPR declines exponentially as the crop yield improves.
- Inverse Linear Phase ($Y_{dry,2050} > {}^{-1}/_{b}$): At very high forecast yields, the exponential decay would continue to drive the RPR to zero, violating biological constraints (since a minimum amount of vegetative biomass is always needed to support the grain). The threshold condition ($Y = -1\ b^{-1}$) enforces a smooth transition of the function to an inverse linear relationship, capping the decay and keeping the RPR at biologically realistic minimums.

2. Static Modelling for Secondary Residues

The dynamic model accounted for primary field residues that depend on the harvest, but some crops produce large secondary processing residues that have constant proportional mass relationships to the harvested grain, regardless of the total yield. Static RPR multipliers were used for these different biomass streams. These separate streams were calculated in parallel and added to the final dataset, to ensure a comprehensive accounting of all available crop residues. These deterministic, scalar multipliers are then used in the analytical model to calculate the total theoretical residue potential, providing a robust biophysical baseline for the study.

3. Derivation of Net Available Biomass via Industrial Competition Modelling

While the Net Available Biomass (NAB) calculated in the preceding step quantifies the volume of biomass theoretically mobilizable beyond conventional agricultural usages (e.g., animal feed, field retention, and burning as fuel), it does not exist within an economic vacuum. As global decarbonization efforts accelerate toward 2050, agricultural residues will become a highly contested feedstock. Specifically, emerging bio-based sectors, namely the sustainable aviation fuel (SAF) industry and the bio-chemicals and plastics sector, are projected to assert significant structural demand on global biomass supplies. Consequently, assessing the true volume of residue accessible for dedicated CDR technologies (specifically biochar) requires the imposition of economic conditions. To prevent the double-counting of feedstocks across overlapping net-zero pathways, this methodology models competitive industrial appropriation by establishing minimum and maximum extraction scenarios based on data aggregated by the Energy Transitions Commission (Energy Transitions Commission, 2021). It provides deterministic projections for the global biomass requirements necessary to decarbonize hard-to-abate sectors by 2050. To translate these global absolute values into proportionate competitive shares, the industrial demands for aviation and the chemicals and plastics sectors are expressed as minimum and maximum proportional shares of the total sustainable biomass envelope defined in ETC's "Prudent Scenario", as detailed in Table 1 and Table 2 outlines projected biomass needs for the year 2050, measured in EJ Year^{-1}.

Table 1. Global sustainable biomass supply potential by feedstock type.

Type of Feedstock	Global Sustainable Biomass Supply (EJ Year^{-1})	
	Min	**Max**
Agricultural Residues	5	12
Forestry Residues	10	20
Total Biomass Available	40	60

Table 2. Projected biomass requirements for prioritized sectors in 2050.

Total Biomass Required for Prioritized Sectors (EJ Year^{-1}) in 2050	Biomass Required (EJ Year^{-1}) in 2050	
	Aviation	**Plastics & Chemicals**
54	15	17

To quantify the ultimate biomass available for biochar production in 2050, the cumulative competitive share (S_{comp}) demanded by the aviation and chemical/plastics sectors must be subtracted from the established Net Available Biomass ($NAB_{c,i,2050}$). Because industrial demand trajectories contain inherent long-term uncertainty, the calculation yields a bounded envelope (a minimum and maximum threshold) rather than a single deterministic point.

The cumulative competitive share is calculated for both the low-competition and high-competition scenarios (Table 3) by summing the respective sector demands:

Low Industrial Competition ($S_{comp,low}$): $Aviation_{min}$ + $Chemicals_{min}$ = $Total_{min}$ eq.2

High Industrial Competition ($S_{comp,high}$): $Aviation_{max}$ + $Chemicals_{max}$ = $Total_{max}$ eq.3

Table 3. Projected share of competing industrial sectors.

Competing Industrial Sector	Projected Share (%)	
	Min	**Max**
Aviation	3.47	5.56
Plastics & Chemicals	4	6.3

Table 4. Wood density of conifer and non-conifer species (saw/veneer logs) by country and continent *.

Country	**Continent**	Wood basic density (dry weight of wood/green m³ wood only) (kg / m³)	
		Conifer	**Non-conifer**
Nigeria	Africa	430	675
South Africa		430	-
China	Asia	420	620
Indonesia		420	540
Malaysia		-	680
Brazil	Latin America	385	500
Chile		405	-
Guyana		-	625
México		450	843
Suriname		-	700
Uruguay		405	783
USA	North America	455	657
New Zealand	Oceania	433	527
Croatia	Europe	371	553
Czechia		434	680
Denmark		390	560
Finland		410	510
France		420	560
Germany		389	563
Ireland		360	-
Lithuania		420	474

Moldova		460	610
Netherlands		440	420
Norway		400	500
Poland		480	614
Portugal		368	-
Russian Fed		517	640
Slovenia		405	570
Spain		436	554
Sweden		415	550
Switzerland		440	625
Ukraine		430	550

* Source: *Forest Product Conversion Factors,* 2020.

Table 5. Wood density of conifer and non-conifer species (pulp logs) by country and continent *.

Continent	Country	Wood basic density (dry weight of wood/green m³ wood only) (kg / m³)	
		Conifer	Non-conifer
Africa	Nigeria	450	550
	South Africa	450	550
Asia	China	410	460
	Indonesia	410	525
Latin America	Brazil	410	460
	Chile	405	625
	Mexico	400	600
	Suriname	-	449
North America	USA	444	471
Oceania	New Zealand	433	-
Europe	Croatia	382	564
	Czechia	434	680
	Denmark	390	560
	Finland	400	490
	France	407	550
	Germany	389	563
	Ireland	360	-
	Lithuania	420	474
	Netherlands	440	420
	Norway	400	500
	Poland	-	614
	Portugal	500	516
	Russian Federation	450	570

	Slovenia	405	570
	Spain	436	620
	Sweden	400	500
	Switzerland	444	625

* Source: *Forest Product Conversion Factors,* 2020.

Table 6. Forestry residue to wood ratios by ecological biome and management method *.

Ecological Biome	Management method		
	Clear Cut Ratio (%)	Selective Cut Ratio (%)	Wood Plantation Ratio (%)
Boreal Forest	69	NA	78
Wooded tundra			
Cool Conifer	71		63
Temperate mixed	53		
Temperate deciduous	47		53
Savanna	39	18	52
Warm mixed			
Tropical woodland			
Tropical Forest			

* Source: Daioglou et al., 2016; Buck, 2013.

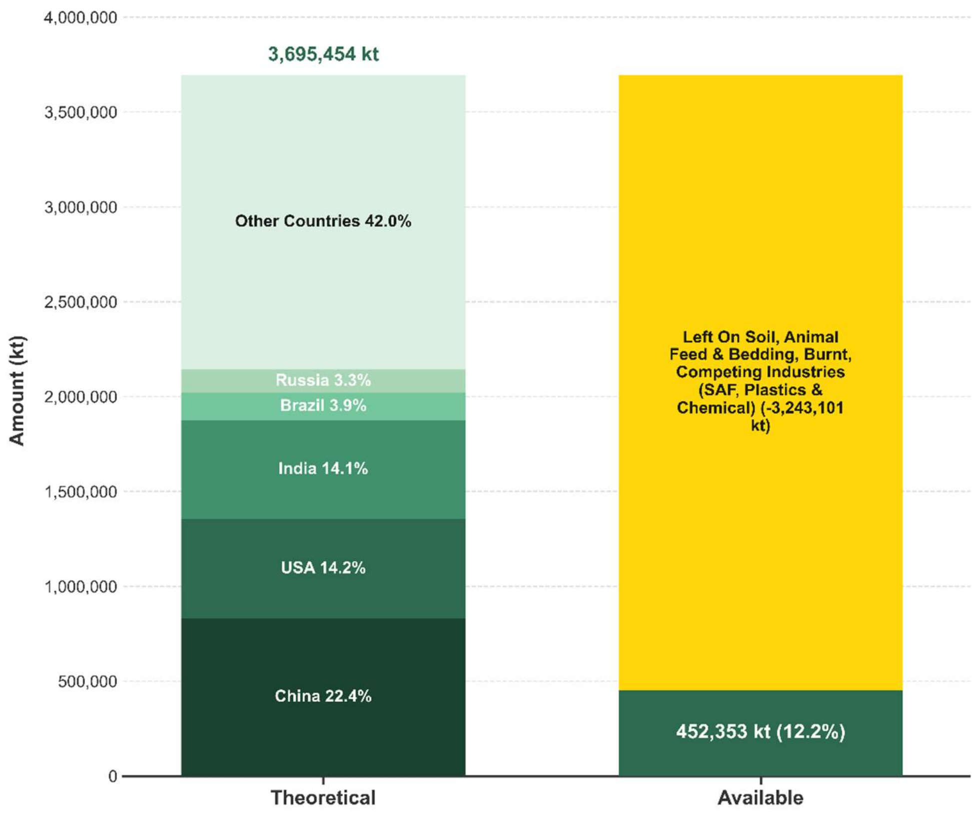

Figure 1. 2050 Global agricultural residue: Theoretical vs. available.

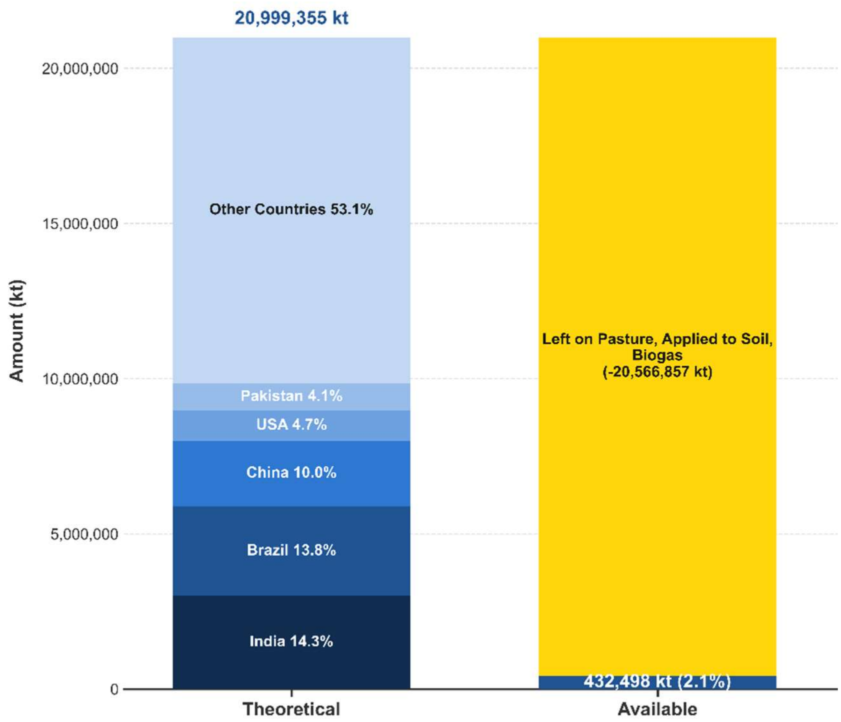

Figure 2. 2050 Global livestock manure: Theoretical vs. available.

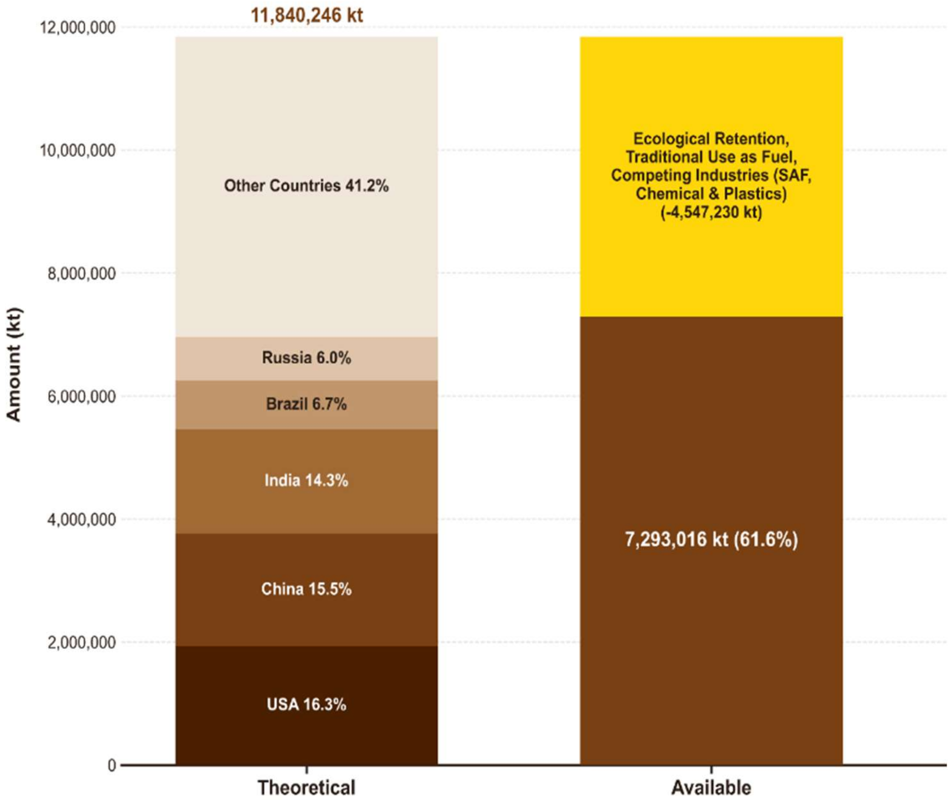

Figure 3. 2050 Global forestry residue: Theoretical vs. available.

Table 7. Biochar yields and temperature ranges by sector and feedstock type.

Sector	Feedstock Type	Temperature Range (°C)	Biochar Yield (%)	Source
Agriculture	Maize Straw	300-684	23-42	Martínez-Gómez et al., 2022
	Barley Straw	460-540	15-22	
	Wheat Straw	300-700	16-47	
	Rice Husk	400-700	44.5-39.1	Dunnigan et al., 2018
	Millet Straw	500	27	Ajikashile et al., 2023
	Sorghum Straw	500	22	
	Maize Cob	450-600	21.80-24.61	Intani et al., 2016
	Rice Straw	400 ± 10	44	Bian et al., 2016
	Other Cereal Straw	-	30	-
Livestock Manure	Cattle (Dairy, non-dairy)	300	70	Hossain et al., 2021
	Chickens	300	66	
	Horses	300	52	
	Goats	300	65	
	Sheep	300	62	
	Buffalo	300	40	
	Swine	500	37	Yoo et al., 2025
Forestry	Forestry residues	450; 550	26-36	Santos et al., 2024

Table 8. Annual growth rate of livestock manure by feedstock type.

Sector	Feedstock Type	Annual growth rate (%)	Source
Livestock manure	Cattle (dairy, non-dairy)	0.6	Alexandratos and Bruinsma, 2012
	Buffalo	0.6	
	Chickens	1.5	
	Horses	0.9	
	Goats	1.0	
	Sheep	1.0	
	Swine	0.5	

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