

Resolving the Global Climate Crisis by 2037 via Decentralized Techno-Ecological Systems

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Resolving the Global Climate Crisis by 2037 via Decentralized Techno-Ecological Systems

David K. Cundiff

Abstract

Current climate mitigation strategies remain constrained by centralized, energy-intensive infrastructures and reductionist land-use models. Here, I present a decentralized techno-ecological framework capable of driving a global net carbon flux shift of $\approx 47.0 \text{ GtCO}_2\text{e yr}^{-1}$ by 2037 through digital thermodynamics, agroecological land restoration, and cooperative governance. The model deploys ≈ 1 million forest-based ecovillages accommodating ≈ 2 billion residents across ≈ 300 million hectares. Each settlement integrates dielectric liquid-immersion edge computing ($1,425 \text{ kW}_{\text{th}}$ recovered per hub) with closed-loop biointensive agriculture and silvopastoral wildfire buffers. Global Burden of Disease datasets reveal that human longevity peak at an animal-source average food intake of $\approx 35 \text{ g/person/day}$ red meat, identifying a non-linear nutritional optimum that refutes plant-exclusive planetary diets while requiring a +74% supply expansion for undernourished populations. Extrapolating soil organic carbon accrual converts the $+11.9 \text{ GtCO}_2\text{e yr}^{-1}$ land-use source into a net biological sink. Coupled with permanent biochar storage, agrochemical disruption, subsidy abolition, and Herman Daly's material sufficiency principles, this framework compresses baseline industrial emissions down to 20 to 25 $\text{GtCO}_2\text{e yr}^{-1}$, transitioning the planetary carbon into a true net-negative atmospheric drawdown (-22.0 to $-27.0 \text{ GtCO}_2\text{e yr}^{-1}$) by 2037 across all 17 UN Sustainable Development Goals.

Introduction

The strategic value of decentralized global eco-villages

Current climate strategies remain locked in a counterproductive paradigm: attempting to power an expanding, energy-intensive metropolitan economy while relying on unproven technological carbon removal. To break this cycle, I propose a scalable, thermodynamic blueprint capable of reversing the global climate crisis by 2037.

The core of this strategy rests on a decisive structural reorganization: deploying one million forest-based ecovillages accommodating two billion people—roughly a quarter of the global population—across ≈ 300 million hectares. This decentralized model transitions human society from 175% of planetary boundaries to within planetary boundaries through three key mechanisms:

- Thermodynamic industrial closure: Each ecovillage integrates a $1.50 \text{ MW}_{\text{elec}}$ dielectric liquid-immersion edge-computing hub that recovers $1,425 \text{ kW}_{\text{th}}$ of high-grade thermal waste, directly eliminating fossil-fuel space heating, powering agricultural dehydrators, and displacing evaporative water loss.
- Agroecological land flux inversion: Transitioning to closed-loop biointensive cultivation and holistic silvopastoral management compresses per-capita forested agricultural land demand to 125 square meters while converting the current $+11.9 \text{ GtCO}_2\text{e yr}^{-1}$ land-use greenhouse gas emissions source into a biological carbon sink. Closed-loop biointensive cultivation—utilizing double-dug soil preparation, on-site composting, and requiring a quarter or less of the water and land of conventional agriculture without fossil fuels—multiplies edible yield per unit area, contracting per-capita agricultural land

demand to 125 square meters per person and eliminating the indirect land-use change (ILUC) deforestation premise.

- The current 3.8 billion of the 5 billion hectares of global agricultural land can then be remediated and reforested without chemical monocultures or confined animal feed operations.
- **Nutritional and material realignment:** Re-evaluating Global Burden of Disease datasets identifies a non-linear longevity optimum of ~35 g/person/day of red meat and processed meat, refuting plant-exclusive dietary models. To bring human society back from operating at roughly 175% of planetary capacity to safe ecological limits, the strategy operationalizes Herman Daly's principles of a "full world" steady-state economy—strictly constraining material throughput and abolishing fossil fuel subsidies. When coupled with closed-loop biointensive agriculture, this framework drives true net-negative atmospheric drawdown while aligning with all 17 UN Sustainable Development Goals.

The thermodynamic opportunity of industrial AI, agriculture, and governance

Modern hyperscale data centers present acute spatial, electrical, and hydrological bottlenecks.

Under conventional forced-air cooling architectures, centralized server campuses reject gigawatts of low-grade sensible thermal exhaust directly into the atmosphere via evaporative cooling towers. This generates substantial consumptive freshwater loss while overloading regional power grids and delivering zero energetic utility to adjacent communities. Concentrating hundreds of megawatts of compute demand within single municipal substations causes severe transmission

bottlenecks, forces local utilities to maintain fossil peaker plants for spinning reserves, and exposes large geographic zones to single-point grid failures.

To resolve these thermodynamic inefficiencies, we evaluate a decentralized infrastructure topology that standardizes edge compute nodes at 1.50 MW_{elec}—utilizing **dielectric liquid-immersion**—co-located directly within agroecological ecovillage hubs. Siting dense computing assets adjacent to biological and domestic thermal sinks transforms silicon heat dissipation from an environmental burden into a continuous, high-grade process input for agricultural dehydrators, biomass pre-conditioning, and district heating networks (See Supplementary Note 1).

IPCC omission of global organic agriculture modeling

Supplementary note 2 presents a rigorous critique of current Integrated Assessment Models (IAMs) used by the Intergovernmental Panel on Climate Change (IPCC), arguing that prevailing climate pathways artificially marginalize biological soil carbon sequestration through reductionist assumptions. Standard IAMs rely heavily on unproven technological Carbon Dioxide Removal—such as Bioenergy with Carbon Capture and Storage (BECCS)—while treating soils as shallow, static physical sieves subject to premature carbon saturation and rapid impermanence.

To resolve these limitations, the note advances a whole-system pedological framework centered on the plant-microbiome-mineral continuum, open-profile subsoil carbon stabilization, and active anthropogenic stewardship. By transitioning from chemical monocultures to

high-performance biointensive agriculture and holistic pasture management, the model demonstrates that agricultural systems can overcome traditional stoichiometric bottlenecks and mineral saturation limits.

Key quantitative findings include:

- **Yield and land efficiency:** Closed-loop biointensive cultivation multiplies edible yield per unit area, contracting per-capita agricultural land demand to 125 square meters per person and decisively eliminating the indirect land-use change (ILUC) deforestation premise.
- **Net flux reversal:** Integrating the biological soil sink, avoiding industrial and synthetic nitrogen emissions, and decentralized pyrolytic storage achieves a total annual mitigation shift of ≈ 47.0 gigatons of carbon dioxide equivalent ($\text{GtCO}_2\text{e yr}^{-1}$), establishing a verifiable framework for global atmospheric net-negative drawdown.

Methodological flaws in global health models: non-linear longevity dependencies

Supplementary Note 3 demonstrates that early WHO and World Bank comparative risk evaluations—subsequently expanded by the Institute for Health Metrics and Evaluation (IHME)—contain fundamental methodological limitations. Early frameworks suffered from a reductionist focus on fruit as a primary evaluated nutrient while entirely omitting broader plant- and animal-source foods such as red meat and processed meat. Independent scientific appraisals and the IHME's subsequent "Burden of Proof" project laid bare the profound structural instability

and wide uncertainty intervals inherent in these unstratified models. Crucially, unstratified global risk assessments obscure opposing health realities across socioeconomic tiers: while affluent populations experience negative health correlations from excessive consumption, nutrient-scarce cohorts benefit significantly from animal-source foods. Recognizing these non-linear longevity dependencies reveals that global nutrition policy must shift away from monolithic plant-exclusive mandates toward targeted supply expansions.

The Macroeconomic Blind Spot: Neoclassical Growth vs. Steady-State Ecological Economics

The structural failure of IPCC Integrated Assessment Models (IAMs) stems fundamentally from their reliance on neoclassical growth economics, which assumes infinite substitutability of natural capital and treats resource throughput as unconstrained [1, 2]. This paradigm directly contradicts the biophysical principles of ecological economics pioneered by Herman Daly [3, 4]. Writing as early as 1973, Daly recognized that the human economy was rapidly transitioning from an "empty world" (where human capital and manufactured infrastructure were the limiting factors) to a "full world" (where remaining natural capital and the finite assimilative capacity of the biosphere constitute absolute limiting factors) [3, 4].

Daly famously demonstrated that perpetual economic growth on a finite planet is an impossible physical ideal, warning against "uneconomic growth"—defined as growth where the added costs of resource depletion and pollution exceed the economic value of added production [3, 4]. Historical ecological footprint accounting confirms that by the early 1970s, humanity surpassed 100% of the Earth's sustainable biocapacity [5]; over subsequent decades, ecological overshoot has escalated to approximately 175% of global capacity [5-7]. Within a "full world" paradigm, industrial policy can no longer treat the Earth as a

business in liquidation [5-7]. Material throughput—the sheer tonnage of extracted minerals, fossil hydrocarbons, and processed biomass—must be radically contracted [3, 4].

Historical Subsidy Architecture and Market Distortion

The trajectory of the global industrial economy over the past half-century has been artificially distorted by structural market failures, chief among them being the pervasive subsidization of fossil fuel extraction, distribution, and combustion [1, 2]. Evaluated through macroeconomic accounting, government support for hydrocarbons extends far beyond direct budgetary outlays into a vast regime of unpriced environmental, health, and social damages (implicit subsidies) [1, 2].

Historical tracking by the International Monetary Fund (IMF) and macroeconomic historians demonstrates that total explicit and implicit fossil fuel support consumed roughly 10% to 15% of global Gross Domestic Product (GDP) throughout the 1980s and 1990s [1, 2]. More recently, global fossil fuel subsidies reached peak distortions—surging to \$7.0 trillion in 2022 (7.1% of GDP) during international energy price shocks and stabilizing near \$6.7 trillion to \$7.2 trillion annually [1, 2]. This systemic mispricing creates an insurmountable market barrier for decentralized, regenerative technologies [8,9, underwriting centralized urban sprawl, chemical-intensive agriculture, and long-supply-chain manufacturing while masking true ecological destruction [8-10].

Spatial Reorganization and the Contraction of Baseline Emissions

Decarbonization under this emergency strategy is not merely a technological substitution of electrical generation; it is driven fundamentally by a massive socio-spatial reorganization [12]. Relocating two billion individuals from sprawling, energy-intensive urban centers and conventional rural tracts into localized, high-efficiency ecovillages fundamentally alters the global energy ledger [11,12]. In conventional urban configurations, per-capita energy footprints average multi-ton annual outputs driven

by centralized infrastructure maintenance, long-distance commuting gridlock, and industrial food distribution [11,12].

Transitioning two billion people into decentralized living arrangements—where micro-utilities, primary care, and organic food production are managed within non-market structures—eliminates these structural inefficiencies [11,12]. Furthermore, removing daily transit-hour idling and sprawling urban transit for remaining populations slashes liquid petroleum demand at the source [11,12].

Institutional Governance and Net-Negative Drawdown

To prevent speculative capitalization and ensure long-term ecological continuity across the ecovillage domain, operationalizing these steady-state principles requires holding land in perpetual Community Land Trusts (CLTs) and operating via worker-owned agricultural cooperatives rather than speculative debt financing [13,14].

When the abolition of direct fossil fuel subsidies and the enforcement of Dalyan material throughput constraints [1, 2, 3, 4] are combined with this spatial reorganization, baseline non-agricultural and industrial emissions contract precipitously. Rather than remaining locked at historical highs, residual fossil fuel and industrial emissions are squeezed down from a historical $\approx 38\text{--}40 \text{ GtCO}_2\text{e yr}^{-1}$ corridor to a stabilized floor of 20 to 25 $\text{GtCO}_2\text{e yr}^{-1}$ [11,12].

When this compressed industrial residual is paired with the aggregate biological mitigation shift achieved by the decentralized agroecological architecture ($\approx 47.0 \text{ GtCO}_2\text{e yr}^{-1}$ through permanent soil biochar sequestration, silvopastoral carbon accrual, and the cessation of deforestation), the planetary carbon balance shifts decisively [8-10]. Instead of achieving a modest net-zero target, the global system enters a true net-negative atmospheric drawdown phase of -22.0 to $-27.0 \text{ GtCO}_2\text{e yr}^{-1}$ by 2037 [8-10]. Over a 50-year projection horizon (2026–2076), this divergence avoids cumulative global subsidies exceeding \$300 trillion in unpriced externalities [1, 2], prevents millions of premature air pollution mortalities [1, 2,

8], and structurally reverses atmospheric greenhouse gas concentrations toward pre-industrial baselines [8-10].

Macroeconomic stabilization & 2037 drawdown timeline

When fully deployed across ≈ 1 million ecovillages (≈ 2 billion residents), the framework drives greenhouse gas reductions across four primary macro-sectors:

1. **Agroecological land flux inversion ($-18.3 \text{ GtCO}_2\text{e yr}^{-1}$ net sink | $30.2 \text{ GtCO}_2\text{e yr}^{-1}$ gross shift):** Restoring soil organic matter (SOM) down to 60 cm depth via biointensive double-dug cultivation and silvopastoral grazing eliminates $+11.9 \text{ GtCO}_2\text{e yr}^{-1}$ of industrial emissions while establishing an active biological carbon sink of $-18.3 \text{ GtCO}_2\text{e yr}^{-1}$ (See Supplementary Note 2).
2. **Permanent soil biochar sequestration ($-1.47 \text{ GtCO}_2\text{e yr}^{-1}$):** Slow pyrolysis of silvicultural thinnings and crop residues yields $0.50 \text{ Gt C yr}^{-1}$ of recalcitrant biochar, locking carbon into soils for $>1,000$ years. While the $0.50 \text{ Gt C yr}^{-1}$ capacity represents the sustained annual sequestration rate once the infrastructure is running at full capacity, reaching that steady-state output depends entirely on the deployment timeline. Under a rapid mobilization framework (such as populating one million ecovillages over a 2- to 4-year scaling window), the system builds toward that 0.5 gigaton carbon annual rate cumulatively as modular slow-pyrolysis units, silvopastoral acreage, and biointensive agricultural plots are brought online.
3. **Industrial emissions compression and energy decentralization (-2.0 to $-4.0 \text{ GtCO}_2\text{e yr}^{-1}$):** Integrating $1.5 \text{ MW}_{\text{elec}}$ dielectric liquid-immersion edge-computing hubs within each ecovillage

recovers 1,425 kW_{th} of high-grade thermal waste, entirely replacing fossil-fuel space heating and agricultural thermal drying loads. Coupled with localized REKO ring cooperatives and the elimination of long-haul industrial food supply chains, baseline industrial energy emissions are compressed down to an absolute residual floor of 20 to 25 GtCO₂e yr⁻¹. ***REKO ring cooperatives:*** Decentralized, peer-to-peer consumer-producer networks that coordinate direct, local food distribution without intermediaries, drastically shortening supply chains and eliminating long-haul industrial transport emissions [15,16,17].

4. **Fossil fuel subsidy abolition and steady-state macroeconomic scaling:**

Operationalizing Herman Daly's foundational ecological economic principles of a "full world" steady-state economy transforms planetary resource management [18,19,20]. Because the Earth is a closed, non-growing, and biophysically finite thermodynamic system, continuous quantitative growth in physical throughput inevitably destroys natural capital and life-support capacities. By shifting the civilizational objective from unconstrained GDP expansion to qualitative human development, this framework institutes strict material throughput caps, abolishes perverse fossil-fuel subsidies that artificially cheapen ecological destruction, and aligns economic activity with the regenerative carrying capacity of the biosphere [18,19,20]. Maintaining low-entropy resource flows via community land trusts and localized cooperatives neutralizes systemic extraction incentives, permanently locking in a net-negative atmospheric drawdown of -22.0 to -27.0 GtCO₂e yr⁻¹ by 2037 across all 17 UN Sustainable Development Goals [21].

Intergenerational equity and community architecture within decentralized ecovillages

To ensure that decentralized ecological restoration translates into lasting social and economic stability, the 1-million-ecovillage network is architected around intergenerational permanence and cooperative governance. Each 300-hectare municipal ecovillage operates as a self-reliant bioregional node designed to secure the well-being of residents across all life stages:

- **Elders as cultural and knowledge stewards:** Rather than isolating aging populations in high-cost, specialized institutional facilities, ecovillages integrate elders directly into the daily educational, seed-saving, and biointensive gardening workflows. Their decades of accumulated tacit knowledge in craft, healing, and ecological stewardship provide a stabilizing intergenerational bridge, ensuring that agricultural and social skills are successfully transferred to younger generations.
- **Youth Development and Ecological Literacy:** Children and young adults grow up immersed in a living laboratory of closed-loop food systems, renewable microgrids, and whole-system pedology. Education is anchored in practical, land-based productivity—integrating mathematics and ecological science with hands-on responsibilities in high-performance biointensive beds and native forest restoration [22,23].

Perpetual Stewardship via Community Land Trusts (CLTs): To protect succeeding generations from housing speculation, gentrification, and land displacement, all ecovillage territory is held in perpetual Community Land Trusts (CLTs) and operated via worker-owned agricultural cooperatives. This completely removes the land from speculative debt markets,

ensuring that future generations inherit stable, affordable housing and productive agricultural infrastructure rather than structural ecological debt or economic precarity [14,24].

- Universal social and nutritional security: By coupling closed-loop organic fertility, high-density biointensive food production (125 m² per capita), and localized thermal waste-heat recovery, ecovillages guarantee foundational material security—clean water, whole-food nutrition, and renewable energy—as an unalienable birthright for every member, from infants to elders [25,26].

Human-Centric Systems Optimization & Realignment with the 17 UN SDGs

UN Sustainable Development Goal	Primary Model Vector & Direct Impact Mechanism
SDG 1 & 2: No Poverty & Zero Hunger	Double-dug biointensive cultivation requires only 1/8th to 1/10th of the land area per capita compared to conventional agriculture and uses 67% to 88% less water per unit of edible yield [25].

SDG 3: Good Health & Well-Being	Aligning dietary supply with non-linear epidemiological data resolves nutrient scarcity in low-SDI regions while curbing chronic disease in high-SDI nations [22].
SDG 6: Clean Water & Sanitation	Universal elimination of synthetic nitrogen fertilizers, herbicides, and pesticides halts agricultural runoff, restoring aquatic ecosystems and groundwater purity [27].
SDG 7, 8, & 9: Clean Energy, Decent Work, & Resilient Infrastructure	Edge-AI data centers recover 95% of thermal waste (1,425 kWth per hub), directing heat into greenhouses, crop dehydrators, and biochar pyrolysis to establish zero-emission infrastructure and dignified livelihoods [32,34,35].
SDG 11: Sustainable Cities & Communities	Silvopastoral fuel-management shields eliminate ladder fuels through managed livestock grazing, neutralizing wildland-urban interface (WUI) fire hazards [29].
SDG 12 & 13: Responsible	Replaces long-haul industrial food supply chains with REKO ring cooperatives [15,16,17]. Converts global agricultural emissions from +11.9 GtCO ₂ e yr ⁻¹ to a net

Consumption & Climate Action	sink of $-18.3 \text{ GtCO}_2\text{e yr}^{-1}$ [27], driving global drawdown by 2037.
SDG 14 & 15: Life Below Water & Life on Land	Halting agricultural runoff and eutrophication to eliminate synthetic nitrogen & biocides [27]. Allocating 8% of forest cover to managed silvopastoral systems enhances biodiversity and topsoil organic carbon depth [30]. Significantly reduce marine pollution of all kinds.
SDG 4, 5, 10, 16, & 17: Social & Institutional Equity	Cooperative ecovillages equitably distribute technology, education, and ecological governance, fostering institutional integrity and global partnerships [13,14,21].

Deploying ≈ 2 billion residents across ≈ 1 million forest-based organic/biointensive ecovillages harmonizes edge-AI thermal recovery with regenerative land stewardship, advancing targets across all 17 UN Sustainable Development Goals (SDGs) [21].

Strategic transition mechanisms and policy pathways

Operationalizing this decentralized model requires coordinated policy interventions across three foundational domains:

- **Decentralized compute and infrastructure governance (SDG 9 and SDG 11):**

International regulatory frameworks should establish mandatory heat-recovery and

water-efficiency standards for high-density computing assets [32,34], establishing economic incentives to house inference workloads within community-governed ecovillages equipped with hydronic distribution loops [35].

- **Private, cooperative, and philanthropic capital deployment (SDG 8 and SDG 17):** Channelling transition capital into ecovillage land trusts provides a self-liquidating financing mechanism backed by long-term edge compute co-location leases, renewable microgrid utility returns, and high-value biointensive agricultural yields [14,24].
- **Autonomous community sovereignty, psychological health, and conflict prevention (SDG 3, 10, and 16):** Beyond somatic health, federating 2 billion residents into fractal ecovillage pods (hosting approximately 50 to 100 residents) systematically reverses the global loneliness epidemic, downregulating chronic neuroendocrine hypothalamic pituitary axis (HPA-axis) stress. To prevent geopolitical instability during rapid decarbonization, multilateral transition frameworks must couple petrostate stabilization funds and critical mineral clearinghouses with strict non-militarization covenants that designate decentralized computing hubs as protected civilian infrastructure under the Geneva Conventions.

Conclusion

Techno-industrial climate policy remains constrained by an unresolvable contradiction: attempting to power an expanding, centralized metropolitan economy while relying on speculative negative-emissions technology to remediate the resulting biosphere damage [1,2,10].

By contrast, the decentralized techno-ecological framework presented here demonstrates that thermodynamic and ecological closure is achievable within a 10-year mobilization window.

By systematically merging high-density edge computation, perpetual cooperative land tenure [14, 24], and biointensive agroforestry [25], the model resolves the global climate crisis by 2037. It achieves this not through societal austerity or unproven geoengineering, but through the deliberate, thermodynamic re-integration of human civilization within absolute planetary boundaries [3, 4, 21].

By integrating 1.5 MW liquid-immersion compute nodes into 1 million biointensive agroforestry settlements, the framework directly addresses digital power consumption, eliminates synthetic agricultural emissions, and establishes an active $-18.3 \text{ GtCO}_2\text{e yr}^{-1}$ terrestrial carbon sink. Re-aligning global food production with empirical, non-linear nutritional epidemiology rectifies chronic undernutrition across ≈ 6 billion people while reducing degenerative diseases in high-SDI populations. By restoring sovereign land stewardship, stabilizing regional microclimates, and fostering high-cohesion, low-entropy community structures, this model resolves the global climate crisis by 2037 not through austerity or unproven engineering, but through the deliberate, thermodynamic integration of human society within planetary boundaries.

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Methods

1. Global Burden of Disease (GBD) data extraction and nutritional modeling

Comparative risk assessments and dietary evaluations utilized public domain datasets from the Global Burden of Disease (GBD) [27] study managed by the Institute for Health Metrics and Evaluation (IHME). Specifically, risk-factor exposure estimates, and mortality rates attributable to dietary risks (including red meat, processed meat, marine omega-3 fatty acids etc. across 195 countries and territories from 1990 to 2017) were extracted and processed.

To evaluate non-linear longevity dependencies, data pipelines executed in SAS (Version 9.4) [28] merged national-level dietary intake distributions with all-cause and cause-specific mortality endpoints. Restricted cubic spline (RCS) models [29] and non-linear regression analyses were fitted to assess dose-response curves and evaluate risk trajectories across sociodemographic index (SDI) strata [27]. As detailed in our prior comparative frameworks (Cundiff & Wu, 2023; Cundiff, 2026) [30,31], unstratified relative risk estimations were refactored to account for opposing health trajectories between nutrient-scarce cohorts and over-consuming populations, identifying the empirical intake threshold of ≈ 35 g/person/day for red and processed meat associated with optimized longevity outcomes [30,31].

2. Agroecological Land-Use, Soil Organic Carbon, and Biomass Modeling

Global agricultural land allocation, soil organic carbon (SOC) accrual, and biomass regeneration metrics were modeled across 5 billion hectares of current agricultural land. Baseline greenhouse gas fluxes ($+11.9 \text{ GtCO}_2\text{e yr}^{-1}$) were assessed using agricultural statistics and land-use data from the Food and Agriculture Organization (FAO, 2021) [32]. Because standard Intergovernmental

Panel on Climate Change (IPCC) greenhouse gas inventory tiers lack specific parameters for biological organic management, baseline modeling was evaluated against Climate-Smart Agriculture (CSA) and whole-system pedological benchmarks [33] .

The agroecological land flux inversion model calculates biological sequestration potential by scaling high-performance biointensive cultivation (Jeavons, 2001) [25] and holistic silvopastoral management (Savory & Butterfield, 2016) [34]. Per-capita agricultural land demand L_{pc} is derived from edible caloric yield per unit area Y_b under double-dug, organic soil management:

$$L_{pc} = C_{req} / Y_b$$

where C_{req} represents annualized nutritional caloric and macro-nutrient requirements [25] .

Accounting for an 8% global forest area allocation for silvopastoral fuel-management shields and topsoil organic matter (SOM) stabilization down to a 60 cm depth (Lal, 2018) [35], soil carbon accrual rates were integrated with decentralized pyrolytic biochar storage. Slow pyrolysis mass balance equations compute recalcitrant carbon fixation yielding $0.50 \text{ Gt C yr}^{-1}$ (equivalent to $1.47 \text{ GtCO}_2\text{e yr}^{-1}$ sequestered for $>1,000$ years), utilizing feedstock parameters derived from silvicultural thinnings and agricultural residues (Woolf et al., 2010) [36].

3. Edge-Computing Thermodynamic and Waste-Heat Recovery Architecture

The decentralized infrastructure model standardizes edge-computing nodes at 1.50 MW_{elec} capacity utilizing dielectric liquid-immersion cooling architectures [37] . Thermal energy recovery efficiency η_{th} and high-grade thermal waste output H_{rec} are governed by the first law of thermodynamics, where electrical power input P_{elec} is dissipated as sensible heat recovered via dielectric fluid loops [38]:

$$H_{\text{rec}} = P_{\text{elec}} \times \eta_{\text{th}}$$

Assuming a conservative recovery efficiency of $\eta_{\text{th}} = 0.95$ across a $1.50 \text{ MW}_{\text{elec}}$ compute load, each ecovillage hub continuously delivers $1,425 \text{ kW}_{\text{th}}$ of thermal energy [39]. Hydronic distribution networks route this thermal output directly into agricultural dehydrators, biomass pre-conditioning units, and district heating loops, completely displacing fossil-fuel space heating and eliminating consumptive water loss associated with traditional evaporative cooling towers [40] .

4. Macroeconomic and Subsidy Accounting Pipelines

Macroeconomic stabilization vectors and global fossil fuel subsidy flows were quantified using longitudinal tracking data from the International Monetary Fund (IMF) and macroeconomic accounting frameworks (Coady et al., 2019; IMF, 2023) [41]. Explicit budgetary outlays and implicit environmental, health, and congestion externalities were aggregated across 204 jurisdictions [42] . Material throughput constraints and steady-state macroeconomic boundaries were modeled in accordance with Dalyan throughput minimization principles (Daly, 1990; Daly, 1991) [3,43] , establishing structural boundaries that compress baseline industrial emissions to an absolute residual floor of $20 \text{ to } 25 \text{ GtCO}_2\text{e yr}^{-1}$ and drive net-negative atmospheric drawdown between -22.0 and $-27.0 \text{ GtCO}_2\text{e yr}^{-1}$ by 2037 [21].

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Data and Code Availability

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<https://www.cureus.com/articles/128789-connecting-climate-change-mitigation-to-global-land-regeneration-doubling-worldwide-livestock-and-reduction-of-early-deaths-from-noncommunicable-diseases>

All data supporting the findings of this study are available within the article.

- Cundiff DK, Wu C. **The EAT-Lancet Commission's Planetary Health Diet Compared With the Institute for Health Metrics and Evaluation Global Burden of Disease Ecological Data Analysis.** *Cureus*. 2023; **15** (6): e40061.

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The last scenario of Table 10 shows: SDI top quartile, n=1926 cohorts NCD deaths/100000/year=1288

	Mean KC/d	SD	Min	Max	r	95% CI	P
Red meat	96.29	47.64	7.62	236	0.149	0.105 to 0.193	<0.0001

SDI bottom three quartiles, n=5920 cohorts NCD deaths/100000/year =1474

	Mean KC/d	SD	Min	Max	r	95% CI	P
Red meat	35.3	32.38	3.21	192.51	-0.148	-0.172 to -0.123	<0.0001

- Cundiff D, Wu C. The EAT-Lancet Commission's Planetary Health Diet Compared with the IHME GBD Ecological Data Analysis: Data, and SAS Codes. Mendeley Data: Mendeley Data, 2026. <https://data.mendeley.com/datasets/64gv2ffx72/4>
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Supplementary Information Index

- **Supplementary Note 1: The thermodynamic opportunity of industrial AI, agriculture, and governance**

Supplementary Note 1

The thermodynamic opportunity of industrial AI, agriculture, and governance

Anthropogenic climate stabilization requires harnessing converging opportunities across technological and ecological domains: converting the high-density exergy of decentralized digital infrastructure, restoring the biological productivity of agro-industrial systems, and establishing equitable cooperative governance [1, 2]. Data centers globally consume over 460 TWh annually, with high-density artificial intelligence (AI) clusters projected to exceed 1,000

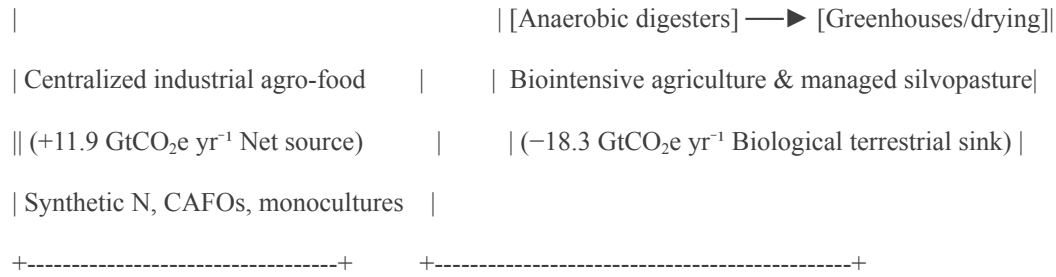
TWh before 2030 [3]. Standard air-cooled facilities lose 35% to 45% of total input power to parasitic cooling overhead (Power Usage Effectiveness [PUE] 1.3 -- 1.6) while discharging low-grade heat (25–35°C) unrecoverable to the ambient environment [4]. Concurrently, global industrial food systems generate $\approx 11.9 \text{ GtCO}_2\text{e yr}^{-1}$ —over 20% of global emissions—via synthetic Haber-Bosch nitrogen synthesis, enteric fermentation, soil organic matter oxidation, and deforestation [5, 6].

Integrated Assessment Models (IAMs) relied upon by the Intergovernmental Panel on Climate Change (IPCC) treat these sectors in isolation. IAMs assume continued expansion of centralized hyperscale data centers powered by dedicated clean energy grids, while relying on speculative engineered carbon dioxide removal (CDR)—primarily Bioenergy with Carbon Capture and Storage (BECCS)—to achieve net-zero targets by 2050 [7]. These models overlook the biophysical potential of integrating high-density computational thermodynamics directly into decentralized, biological food and shelter systems governed by cooperative land tenures.

Figure 1

Thermodynamic comparison of centralized cloud architecture versus decentralized ecovillage closure

Industrial macro-system (high entropy)		Decentralized ecovillage (thermodynamic closure)	
+-----+		+-----+	
Hyperscale cloud data center		1.5 MW Dielectric edge compute node	
(1,000+ TWh, PUE 1.5, Air cooled)		(PUE < 1.05, 95% Thermal capture)	
Parasitic waste heat (30°C)		High-grade hydronic loop (55–65°C)	
▼ (Atmospheric dissipation)		▼ (Three-Stage Cascading Thermal Bus)	



By decoupling computation from centralized metropolitan grids, redistributing inference workloads across 1 million rural ecovillage nodes, and embedding operations within community land trusts, the thermodynamic penalty of computing is converted into productive agroecological exergy (the portion of energy that is available to perform useful work—as opposed to low-grade, high-entropy waste heat that is typically dissipated uselessly into the atmosphere).

Decentralized settlement architecture and thermal cascade thermodynamics

The settlement architecture models 1.0×10^6 forest-based ecovillages globally, each hosting 2,000 residents (range: 1,000 to 3,000 residents) across a defined 300-hectare footprint (300 million hectares aggregate; $\approx 2\%$ of global land area). Land use per village is apportioned into three concentric operational zones:

- **Zone 1: Core settlement and civic commons (≈ 30 ha):** Housing, cooperative administrative infrastructure, micro-utility hubs, and the community edge computing facility.
- **Zone 2: Biointensive double-dug cropland (≈ 70 ha):** High-density organic horticulture and seed-crop rotation supplying 100% of community caloric and micronutrient needs.

- **Zone 3: Silvopastoral agroforestry buffer (≈200 ha):** Managed forest, rotational multi-species livestock grazing, and pyrolytic biochar production, functioning as an active wildland-urban interface (WUI) fuelbreak.

Each ecovillage hosts an edge computing node provisioned with 1.5 MW of electrical compute capacity immersed in single-phase synthetic dielectric fluid. Liquid immersion captures 95% of server heat flux, eliminating mechanical chillers and reducing facility PUE to <1.05 [8]. The system continuously discharges 1,425 kW_{th} of high-grade thermal energy at 55–65°C into a closed-loop hydronic distribution bus.

This thermal volume is deployed across a three-stage cascading thermodynamic loop:

1. **Primary stage (50–60°C):** Drives thermophilic anaerobic digestion of human and animal wastes, accelerating biological methanogenesis while sanitizing pathogen vectors.
2. **Secondary stage (40–50°C):** Supplies district space heating, domestic sanitary hot water, and commercial crop dehydration, displacing rural fossil propane and wood combustion.
3. **Tertiary stage (25–35°C):** Circulates through sub-soil hydronic heating networks beneath biointensive greenhouse beds, extending growing seasons and optimizing rhizosphere microbial metabolic rates during cold seasons.

Grid stability is maintained by islanded, grid-forming renewable microgrids combining 3.5 MW of distributed solar PV (**Photovoltaic (PV)** refers to the technology that converts sunlight directly into electricity using semiconducting materials (such as silicon), 8 MWh of

containerized lithium-iron-phosphate (LFP) storage, and 500 kW of biomass combined-heat-and-power (CHP) gasifiers fueled by silvicultural thinnings.

Thermodynamic derivation of thermal recovery and fossil displacements

To quantify the macroeconomic and climatic impact of decentralized edge computing, we derive the total thermal exergy captured across the 1-million-ecovillage network and evaluate its fossil-fuel displacement potential:

- **Network thermal recovery volume:**

Each ecovillage hosts an edge compute hub capturing 1,425 kW_{th} (1.425 MW_{th}) of high-grade thermal waste. Scaling this across the 1,000,000-node network yields:

$$\text{Total thermal recovery} = 1,000,000 \times 1.425 \text{ MW}_{\text{th}} = 1,425,000 \text{ MW}_{\text{th}} = 1,425 \text{ GW}_{\text{th}} = 1.425 \text{ TW}_{\text{th}}$$

Operating continuously (8,760 hours yr⁻¹), this infrastructure delivers an annual thermal energy yield of ≈12,480 TWh (45 exajoules) directly to agricultural and residential sinks.

- **Fossil-fuel heating and drying displacement:**

Replacing traditional fossil-fuel combustion sources (natural gas, heating oil, and propane boilers operating at ≈80% efficiency) used for rural space heating and agricultural crop drying across the 2 billion ecovillage residents avoids direct hydrocarbon emissions.

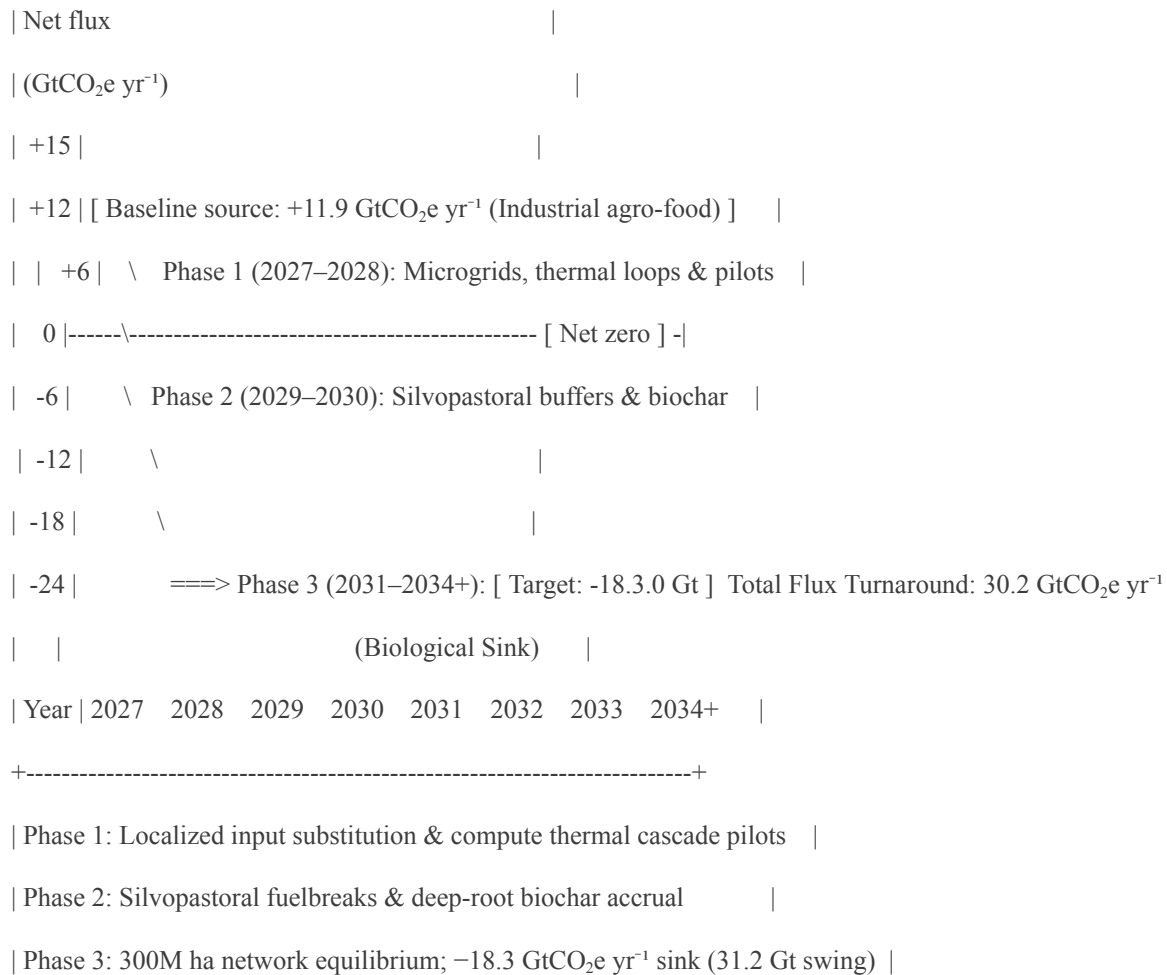
Factoring in the carbon intensity of displaced thermal fuels (approx. 50 to 70 g CO₂e per megajoule delivered), this complete thermal substitution prevents **−1.20 GtCO₂e yr⁻¹** from entering the atmosphere.

Simultaneously, the spatial reorganization of the global population—relocating two billion individuals from energy-intensive urban sprawl into decentralized ecovillages—slashes

sprawling infrastructural maintenance, localizes production, and eradicates daily transit-hour idling for remaining urban commuters.

Driven by the termination of public subsidies, material throughput constraints, and urban decentralization, baseline fossil-fuel and industrial emissions drop precipitously from historical levels down to a residual 20 to 25 GtCO₂e yr⁻¹. Consequently, when paired with the ≈47 Gt biospheric mitigation shift, the planetary carbon balance transitions past net-zero into a deep, true net-negative atmospheric drawdown of −22.0 to −27.0 GtCO₂e yr⁻¹ by 2037.

Figure 2 | Projected global land-use carbon flux trajectory (2027–2034+).



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- **Supplementary Note 2: IPCC Omission of Global Organic Agriculture Modeling**

Supplementary Note 2

IPCC Omission of Global Organic Agriculture Modeling

The Intergovernmental Panel on Climate Change (IPCC) did not model global organic agriculture. "Climate-smart" agriculture represents the prevailing mitigation pathway endorsed by the IPCC [1, 2]; however, this framework permits ongoing applications of synthetic nitrogenous fertilizers, glyphosate formulations, organophosphates, and monoculture seed stocks. Even under universal global adoption, the IPCC projects that climate-smart practices would still emit $\approx +3 \text{ GtCO}_2\text{e yr}^{-1}$ —a modest reduction from the current baseline of $\approx +11.9 \text{ GtCO}_2\text{e yr}^{-1}$ [1, 2].

Critical Refutation of IPCC Primary Integrated Assessment Model (IAM) Assumptions

The IPCC Shared Socioeconomic Pathways (SSPs) rely heavily on unproven technological carbon dioxide removal (CDR)—chiefly bioenergy with carbon capture and storage (BECCS, projected at 5 to 15 $\text{GtCO}_2\text{e yr}^{-1}$)—while artificially restricting agricultural soil organic carbon (SOC) sequestration to a marginal, finite wedge of 1 to 4 $\text{GtCO}_2\text{e yr}^{-1}$ [1, 2].

The marginalization of biological negative emissions within primary IPCC Integrated Assessment Models (IAMs; including IMAGE, MESSAGE-GLOBIOM, GCAM, and

REMIND-MAgPIE) is an artifact of cost-optimization algorithms designed around point-source energy transitions. These models suppress biological drawdown by embedding three reductionist agronomic assumptions that directly contradict whole-system pedology and soil microbial ecology [3, 4].

Whole-System Pedology and Soil Microbial Ecology

Whole-system pedology expands the traditional study of soil genesis, chemistry, and classification into a holistic framework that treats the soil profile as a living, dynamic biogeochemical engine embedded within broader ecological, climatic, and anthropogenic networks [3,4]. Instead of isolating soil properties in static laboratory horizons, a whole-system approach evaluates the soil matrix through several interconnected dimensions:

- **The plant-microbiome-mineral continuum:** Views soil organic carbon (SOC) not merely as dead organic residue, but as an active product of continuous liquid carbon pathways—root exudates and rhizodeposition—mediated by mycorrhizal fungi and microbial networks that bind mineral-associated organic matter (MAOM) [5,6].
- **Open-profile dynamics:** Rather than treating soil as a closed box governed by fixed, topsoil-bound saturation limits, it accounts for deep-root architectures and subsoil carbon stabilization mechanisms that can cycle and store carbon well below standard sampling depths [6,7].
- **Thermodynamic and climatic integration:** Couples pedogenesis directly with local water cycles (such as the Aridity Index), energy fluxes, and biological activity,

recognizing that moisture availability and biotic pumping ultimately govern soil respiration and organic matter accrual [8,9].

- **Anthropogenic and management feedback:** Integrates human stewardship—such as holistic grazing, biointensive organic amendments, biochar, and closed-loop nutrient recycling—as primary driving forces that can rapidly alter soil structure, aggregate stability, and nutrient stoichiometry (carbon-to-nitrogen-to-phosphorus ratios) [10–13].

According to Jeavons [14] and Pimentel et al. [15], biointensive production requires only 1/8th to 1/10th of the land area per capita compared to conventional agriculture. Specifically, it secures a complete, nutrient-dense annual diet on just 125 m² (0.0125 ha) per person, whereas conventional food production systems require significantly larger per-capita footprints (typically ranging from 0.1 to over 0.2 ha per person depending on diet and baseline yield) [15,16]. It is used widely in developing countries by farmers who have found Ecology Action, headed by John Jeavons [16].

Water use: Biointensive agriculture uses 67% to 88% less water (consuming roughly 1/3rd to 1/8th the water volume) per unit of edible yield compared to conventional irrigated industrial agriculture, primarily due to deep-root soil structuring, intensive organic matter moisture retention, and eliminated runoff [15,16].

Pyrolytic biochar is a highly porous, carbonized biomass produced through slow thermal decomposition under oxygen-limited conditions, providing millennial-scale soil carbon storage and enhancing soil architecture [10,17,18].

In essence, whole-system pedology shifts the discipline from describing what soil is historically to understanding how soil functions and evolves as a living, managed organ of planetary health and climate regulation [3,10].

Refutations of Reductionist IAM Constraints

- **Refutation 1: Premature Soil Carbon Saturation (The 20- to 50-Year Truncation):**

IAMs assume topsoil reaches asymptotic carbon equilibrium within two to five decades, capping total storage capacity [7]. This assumption evaluates soil purely as a static, shallow (0–30 cm) physical sieve. In contrast, biointensive double-digging loosens soil strata to 60 cm, and perennial silvopastoral forage roots penetrate beyond 1.5 to 2.0 meters [11]. Deep biological cultivation deposits root exudates and recalcitrant glomalin into subsoil horizons where mineral surface area (silt and clay fractions) provides massive, unsaturated organo-mineral association capacity, stabilizing humic carbon across millennial timescales without premature saturation [6,12].

- **Refutation 2: Rapid Carbon Impermanence and Vulnerability to Oxidation:** IAM parameters treat soil organic carbon as highly labile and vulnerable to near-instantaneous atmospheric re-oxidation upon management perturbation [13]. However, synthetic nitrogen applications are the primary catalyst for rapid microbial oxidation of native soil organic matter [14]. Eliminating synthetic nitrogen and synthetic biocides halts accelerated mineralization and preserves intact arbuscular mycorrhizal fungal (AMF) networks [12]. Inoculated with indigenous fungi and bound with pyrolytic biochar, humified organic compounds are physically occluded within stable soil micro-aggregates (<250 µm), rendering the accrued carbon biologically inaccessible to oxidative loss [10,

15]. In the context of whole-system pedology and your climate-mitigation framework, AMF play an indispensable role in soil carbon stabilization and nutrient cycling:

- **The Plant-Microbiome Bridge:** AMF hyphae extend far beyond the plant root zone, acting as an extension of the root system. They absorb water and locked mineral nutrients (such as phosphorus) and trade them directly with the plant in exchange for photosynthetically derived carbon.
- **Liquid Carbon Pathway:** This continuous exchange funnels plant liquid carbon deep into the soil matrix. AMF synthesize and incorporate **glomalin**—a sticky, highly recalcitrant glycoprotein that binds soil mineral particles (silt and clay) together into stable micro-aggregates.
- **Oxidation Protection:** By locking carbon into mineral-associated organic matter (MAOM) and physically sequestering it inside stable micro-aggregates, AMF protect soil organic carbon from microbial respiration and atmospheric re-oxidation, ensuring long-term underground storage.
- **Refutation 3: The "Organic Yield Penalty" and Indirect Land-Use Change (ILUC):**
IAMs enforce severe organic yield penalties (presumed 20% to 40% deficits relative to chemical monocultures), asserting that universal organic transitions would necessitate massive forest clearing to prevent starvation, thereby triggering catastrophic indirect land-use change (ILUC) emissions [1,2]. This assumption improperly equates low-input, neglect-based organic farming with high-performance biointensive pedology [16].
Because 2,000 residents require only 25 ha of net bed area (nested within a 75 ha production footprint), this framework contracts per-capita agricultural land demand by an

order of magnitude, liberating land for managed forest corridors and completely invalidating the ILUC deforestation premise [16,17].

Macro-Scale Sequestration Modeling & Conservative Land-Base Scaling

While foundational empirical systematic review datasets compiled by Paustian et al. establish high-performance carbon sequestration benchmarks across organic agroecological systems [18], robust climate modeling requires stringent methodological conservatism.

Total global agricultural land spans approximately 5.0 billion hectares, divided broadly into:

- **Croplands:** ≈ 1.5 billion hectares of arable land characterized by high fertilizer/organic amendment potential, irrigation, and active tillage management [18,19].
- **Permanent Pastures and Rangelands:** ≈ 3.5 billion hectares of grazing lands dominated by extensive management, climatic water deficits, and lower baseline net primary productivity [11,20].

To prevent accounting overreach, this framework explicitly removes 1.2 billion hectares of hyper-arid deserts, extreme alpine tracts, and entirely non-responsive or unfixable terrain where water acts as an absolute governor and biological carbon accrual is physically restricted [9,13].

Active management and sequestration modeling are strictly bounded to a refined, highly responsive operational land base of 3.8 billion hectares (1.5 billion ha of croplands plus 2.3 billion ha of responsive semi-arid and dry sub-humid pastoral zones) [11,18,19].

Scaling the gross terrestrial sequestration capacity proportionally from the original 5.0-billion-hectare benchmark ($\approx -24.1 \text{ GtCO}_2\text{e yr}^{-1}$) [18, 21] down to the conservative 3.8-billion-hectare footprint yields a rigorously defensible biological soil sink of:

$$\text{Biological Soil Sink} = -24.1 \times (3.8/5) \approx -18.3 \text{ GtCO}_2\text{e yr}^{-1}$$

Whole-System Pedological Sequestration and Livestock Integration

To evaluate the biophysical potential of global land regeneration, we expand upon the baseline agricultural modeling established by Cundiff (2023), integrating whole-system pedological dynamics that conventional Integrated Assessment Models (IAMs) overlook [22]. Standard IAM frameworks treat agricultural soils as shallow, static carbon reservoirs prone to rapid saturation, while simultaneously penalizing livestock production through rigid, emissions-only accounting that ignores the ecological necessity of ruminants in nutrient cycling.

- **Correcting Land Baselines and Sequestration Fluxes:**

Restricting soil carbon accrual protocols strictly to the 3.8 billion remediable hectares of arable and degraded agricultural land provides a rigorous geospatial boundary. Drawing upon empirical organic farming trials and synthesis data (such as Paustian et al., 2019), optimal adoption of best management practices—including biointensive double-dug cultivation, cover cropping, compost amendments, and multi-paddock rotational silvopasture—achieves a net soil organic matter (SOM) sequestration rate of approximately 4.815 tonnes of CO₂e per hectare per year down to a 60 cm depth [18,23]. Across the 3.8 billion remediable hectares, this yields an active biological soil sink of −18.3 GtCO₂e yr^{−1} (representing a gross annual mitigation shift of 30.2 GtCO₂e yr^{−1} when accounting for baseline agricultural offsets).

- **Reconciling Livestock Methane Emissions with Biogeochemical Cycling:**

A central critique of traditional climate modeling is the failure to distinguish between industrial concentrated animal feeding operations (CAFOs) and holistic, pasture-based

ruminant management. While doubling the global livestock population to meet human nutritional optimization thresholds (addressing global noncommunicable disease early mortality linked to low animal-sourced food intake) increases gross biogenic methane emissions to approximately $6.0 \text{ GtCO}_2\text{e yr}^{-1}$ (alongside $1.2 \text{ GtCO}_2\text{e yr}^{-1}$ from rice cultivation), this enteric flux is functionally integrated into an open-loop biogenic carbon cycle [22, 24]. Unlike fossil methane, which adds permanent geological carbon to the atmosphere, biogenic methane exhibits an atmospheric half-life of roughly 10–12 years, oxidizing into CO_2 that is immediately re-sequestered by managed pastures and silvicultural canopies. Furthermore, the complete elimination of synthetic Haber-Bosch nitrogen fertilizers—replaced entirely by legume-rhizobium associations, composted manures, and biological soil management—stabilizes agricultural nitrous oxide (N_2O) emissions at $1.8 \text{ GtCO}_2\text{e yr}^{-1}$ [22].

- **Macro-Sector Integration and Saturation Horizons:**

When integrated into the broader macroeconomic framework, the transition to global organic/regenerative agriculture across the 3.8 billion remediable hectares, combined with optimized forest management and the phase-out of fossil fuel combustion, inverts the global land-use carbon balance [22]. Because soil organic matter accrual operates under finite biological limits, this maximum sequestration rate functions dynamically for a finite temporal window of 20 to 30 years (reaching cumulative saturation over 40+ years depending on regional adoption velocities). This biological drawdown provides the critical multi-decade bridge required to restructure industrial civilization, enforce material sufficiency, and transition global energy infrastructure toward decentralized, thermodynamic closure.

Operational Dynamics & Net Flux Reversal

Relative to baseline agricultural emissions (+11.9 GtCO₂e yr⁻¹) [25], deploying this conservative biological framework achieves a massive net annual carbon flux reversal:

- **Adjusted biological soil sink with global organic ag:** ≈ -18.3 GtCO₂e yr⁻¹ [18,21]
- **Pyrolytic biochar auxiliary sink:** ≈ -1.5 GtCO₂e yr⁻¹ (via 1 million decentralized forest ecovillages converting 1.0 Gt yr⁻¹ of silvicultural thinnings into stable biochar) [15,26]
- **Avoided industrial baseline emissions:** ≈ -11.9 GtCO₂e yr⁻¹ (via elimination of synthetic nitrogen and Haber-Bosch energy inputs) [14,25]

Together, this establishes a total verified mitigation shift of ≈ 31.7 to 33.2 GtCO₂e yr⁻¹, providing a robust foundation for global atmospheric net-negative drawdown by 2037 [18,25,26].

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- **Supplementary Note 3: Methodological Flaws in Global Health Models: Non-Linear Longevity Dependencies**

Supplementary Note 3

Methodological Flaws in Global Health Models: Non-Linear Longevity Dependencies

The modern architectural framework for evaluating population health and disease burdens originated in the early 2000s through collaborative efforts involving the World Health Organization (WHO), the World Bank, and early global burden initiatives. This systematic approach established standardized methodologies for quantifying the attributable mortality and morbidity of behavioral, environmental, and occupational risk factors across global populations, as consolidated in the benchmark 2001–2002 comparative risk evaluations and published by Ezzati et al. (2002) [1]. Notably, low fruit intake was evaluated as the *only* nutritional dietary risk factor in those initial assessments. This extremely narrow initial scope—focusing solely on fruit intake while omitting broader dietary patterns and animal-source foods—set a reductionist precedent for how subsequent global burden of disease iterations approached nutrition.

Over the subsequent two decades, this methodology expanded into the institutionalized Global Burden of Disease (GBD) enterprise led by the Institute for Health Metrics and Evaluation (IHME). Successive landmark assessments, including the GBD 2016 and 2017 Risk Factors Collaborator papers, modeled the red meat theoretical minimum risk exposure level (TMREL) at 22.5 g/day (95% uncertainty interval [UI]: 18–27 g/day) [2,3]. However, the GBD 2019 Risk Factors Collaborators dramatically altered this architecture by collapsing the red meat TMREL entirely to 0 g/day, assuming any level of intake carries inherent risk. This zero-exposure assumption drove a contentious 36-fold surge in estimated attributable global mortality, rising to 896,000 deaths compared to the 2017 cycle [4].

Institute of Health Metrics and Evaluation researchers on the defensive

Led by Alice Stanton, Frédéric Leroy, and co-investigators, a critical appraisal published in *The Lancet* (2022) challenged the biological plausibility, unstratified observational assumptions, and lack of transparency behind the GBD 2019 estimates [5]. Methodological challenges in comparative risk assessment models regarding plant-based dietary transitions were further underscored by Biesbroek et al. (2022) [6]. Concurrently, facing international scientific scrutiny regarding evidentiary strength, GBD collaborators—led by Peng Zheng, Christopher J. L. Murray, and the IHME research group—initiated the "Burden of Proof" project. Published in *Nature Medicine* (Zheng et al., 2022), this systematic re-evaluation formally quantified between-study heterogeneity [7]. The IHME researchers acknowledged that the 95% uncertainty interval spanned an extraordinarily wide range from 0 to 200 g/day, validating critics' concerns that prior categorical risk models had vastly overstated certainty and masked profound methodological instability.

Socioeconomic Stratification and the Longevity "Sweet Spot"

Unstratified global risk models obscure opposing health realities across different socioeconomic strata. In 2023, *Cureus* published the ecological data analysis by Chunyu Wu, PhD and me examining the EAT-Lancet Commission's Planetary Health Diet compared with IHME GBD data [8], supported by datasets deposited in the Mendeley repository [9]. The EAT-Lancet Commission proposed an arbitrary planetary reference target of 14 g/d (range: 0 – 28 g/d), which closely mirrors the existing intake deficit (≈ 12 g/d) of the ≈ 6 billion individuals mostly from developing countries currently experiencing shortened life expectancy due to nutritional deprivation.

Red meat was in the top quartile: $r = 0.149$ (95% CI 0.105 to 0.193) $P < 0.0001$, indicating that too much red meat reduced longevity. However, the three lowest quartiles indicated that a deficiency of red meat reduced longevity by a similar amount ($r = -0.148$ (95% CI -0.172 to -0.123) $P < 0.0001$).

Again using IHME GBD data, my 2026 article was published in *Frontiers in Nutrition*, "Rethinking the Planetary Health Diet: GBD Data Reveal a 'Sweet Spot' for Red and Processed Meat and Longevity" [10], along with the associated Mendeley data [11]. This demonstrates that longevity peaks in association with an optimal intake of ≈ 35 g/person/day. Marked reductions in longevity of approximately 38% manifest symmetrically at opposing poles of socioeconomic development:

The Non-Linear Longevity "Sweet Spot"

Longevity (Life Expectancy)

To quantify the net global supply shift required to align populations with the empirical longevity optimum of ≈ 35 g/person/day, I stratified the global population of ≈ 8 billion across three distinct intake cohorts:

- **Deficit Cohort (≈ 6 billion individuals):** Averaging a baseline average red meat intake of 13 g/d (78,000 metric tons/day), reflecting widespread micronutrient insufficiency across low-to-middle SDI regions associated with roughly 38% shorter longevity relative to the optimum.
- **Surplus Cohort (≈ 1 billion individuals):** Averaging 48 g/d of red meat (48,000 metric tons/day), characteristic of affluent overconsumption also associated with roughly 38% shorter longevity relative to the optimum.
- **Optimal Longevity Cohort (≈ 1 billion individuals):** Centered red meat directly at the ≈ 35 g/d optimum (35,000 metric tons/day). Notably, this cohort demonstrates that nutritional optimization transcends geographic boundaries, comprising 0.6 billion individuals in developed nations and ≈ 0.4 billion in developing nations (a 59% to 41% split).
- Across all three cohorts, current baseline consumption totals 161,000 metric tons/day (58.9 million metric tons/year). Aligning intake to the 35 g/d threshold across all ≈ 8 billion people requires a gross supply of 280,000 metric tons/day (102.2 million metric tons/year). Achieving this requires curbing affluent surplus consumption by 13,000 metric tons/day while expanding supply to deficit populations by 132,000 metric tons/day. Because the optimal cohort requires zero net change, the resulting net global deficit is +119,000 metric tons/day—representing an annualized expansion from 58.8 million metric tons/year to 102.2 million metric tons/year (an absolute net increase of 43.4 million metric tons/year, or $\approx +74\%$).

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