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A Comprehensive AR6-Based Climate, Land, Water, Nutritional and Supply Chain Assessment of Plant-Only vs Mixed Plant-Animal Food Systems

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Abstract: ***This study evaluates the global feasibility, environmental impacts, resource requirements, and nutritional implications of replacing the entirety of global animal-source foods with plant-based crops. Using IPCC AR6 GWP100 values (CH_4 = 27.2; N_2O = 273), realistic global crop yields, degraded-land yield penalties, irrigation electricity, fertiliser manufacturing emissions, machinery and transport fuel use, peatland conversion risks, biogas offsets, and nutrient bioavailability constraints, this analysis produces a complete system-wide environmental model of a plant-only scenario. A nutrient-equivalent plant basket was constructed using 45% carbohydrates, 20% fat, 25% protein, and 10% micronutrient-rich foods, with soy protein limited to 10% and DIAAS adjustments applied. Based on global animal-derived digestible nutrient mass—247.3 Mt protein, 182.6 Mt fat, 1,769 Mt carbohydrate-equivalent energy, and 118 Mt micronutrient proxy—the required plant crop tonnage translates into 691.303 Mha of high-quality cropland. When adjusting for realistic degraded-land yield factors (0.525), the true requirement increases to 1,316.77 Mha, of which 996.77 Mha must be newly cultivated. New cropland outside existing rainfall-rich zones generates 4,022.96 km^3/year of additional irrigation demand, requiring 2,816 TWh/year electricity and emitting 1.408 Gt CO_2/year. Fertiliser manufacturing and N_2O emissions contribute a net 0.842 Gt CO_2e/year after accounting for biogas offsets from crop residues and global cattle/buffalo dung (198.9 billion m^3 biogas potential; IJSR 2024). Machinery, transport, and by-product processing add another 0.185 Gt CO_2/year. Combined operational emissions of a plant-only system therefore total 2.435 Gt CO_2e/year—significantly higher than the 1.088 Gt CO_2e/year averaged emissions of a phased-down animal system considering only enteric methane. If 20% of new cropland follows historical expansion patterns into peat-rich regions, one-time peat emissions reach 2,192.7 Gt CO_2, dwarfing all operational emissions. Even amortised over 100 years, peat-linked emissions produce 24.36 Gt/year, exceeding total global anthropogenic emissions by more than an order of magnitude. Nutritionally, plant-only systems require large-scale industrial fortification (B12, iron, zinc, calcium, iodine, vitamin D, DHA/EPA) and heavy processing to overcome anti-nutrients and low DIAAS protein quality. This increases system fragility, energy dependence, and supply-chain vulnerability. Results show that a balanced plant-animal mixed food system is more environmentally stable, nutritionally complete, and climate-efficient than a plant-only global transition. The model highlights that practical land, water, energy, and nutrient limitations fundamentally alter the sustainability outcomes often claimed in plant-exclusive dietary narratives.***

Keywords: global food systems, plant- based transition, environmental emissions, cropland expansion, nutritional limitations

1. Introduction

Global sustainability narratives increasingly promote the transition from mixed plant–animal diets to purely plant-based nutritional systems. Influential studies—including Poore and Nemecek (2018), Springmann et al. (2016, 2021), and the EAT-Lancet Commission (2019)—have argued that removing animal agriculture could reduce greenhouse gas emissions, conserve land, and improve human health outcomes worldwide. These studies form the foundation for policy discussions, corporate climate pledges, and public behaviour-change campaigns aimed at encouraging vegan or near-vegan dietary patterns.

However, contemporary dietary modelling often embeds a critical structural assumption: that plant-only food systems can be scaled globally without encountering severe agronomic, ecological, hydrological, or nutritional constraints. Most published models use average global crop yields without including degraded-land penalties, presume that newly cultivated cropland will achieve the same productivity as existing prime croplands, omit real-world irrigation electricity requirements, simplify fertiliser manufacturing emissions, disregard transport distances for nutrient-dense (and often low-bulk) crops, and assume that crop residues and by-products can be fully captured without field-level losses. These assumptions collectively produce an optimistic representation of plant-only diets.

Moreover, many global dietary models treat plant and animal proteins as nutritionally interchangeable. This ignores protein quality differences measured through Digestible Indispensable Amino Acid Scores (DIAAS), anti-nutritional factors (phytates, oxalates, tannins), and micronutrient bioavailability disparities between plant and animal sources. As a result, nutrient substitution modelling may significantly underestimate the actual crop tonnage required to deliver equivalent digestible nutrient masses.

Land-use modelling is another critical limitation. Most plant-exclusive scenarios assume that expanded cropland can be drawn from an unlimited pool of arable land. In reality, most remaining convertible land is degraded, drought-prone, or carbon-dense—particularly peatlands and tropical forests. Historical cropland expansion data consistently show that new cultivation disproportionately occurs in regions with high carbon stocks. These patterns imply that any global transition toward plant-only diets risks triggering massive carbon releases from land-use change unless carefully managed.

Water availability is equally important. Approximately 40% of today's global crop output is grown under irrigation. The scale of cropland expansion required for plant-only diets, especially after applying degraded-land yield penalties, necessitates additional irrigation volumes that would dramatically increase global freshwater withdrawals. Pumping such vast water quantities requires substantial electricity, significantly raising the energy footprint of plant-exclusive diets.

Fertiliser requirements further complicate the sustainability profile. Replacing highly nutrient-dense animal foods with plant sources shifts nutrient burden onto croplands, increasing demand for nitrogen, phosphorus, and potassium. Manufacturing these fertilisers consumes energy, emits CO_2, and leads to nitrous oxide (N_2O) releases from agricultural fields—N_2O being a potent and long-lived greenhouse gas.

To date, few studies provide a fully integrated assessment of global plant-only diets using realistic yields, water constraints, fertiliser demand, machinery emissions, transportation, nutrient bioavailability, and peatland carbon risks evaluated under IPCC AR6 GWP100 metrics. This study seeks to fill that gap by constructing a complete and transparent system-wide model to evaluate the true environmental and nutritional implications of replacing all global animal-source nutrition with plant-based foods.

This introduction outlines the conceptual basis for the analysis and highlights the discrepancy between theoretical modelling and practical agronomic realities. By grounding the assessment in empirical data from FAOSTAT, IPCC AR6, peer-reviewed crop-yield studies, and the IJSR (2024) cattle–buffalo biogas potential report, the overall aim is to produce a realistic, high-resolution comparison between plant-only and balanced mixed dietary systems.

2. Literature Review

The environmental assessment of global dietary patterns has been shaped by several influential papers, most notably Poore and Nemecek (2018), Springmann et al. (2016; 2021), Tilman and Clark (2014), and the EAT-Lancet Commission (2019). These studies collectively argue that large reductions in environmental impacts—especially greenhouse gas emissions—can be achieved by minimising or eliminating the consumption of animal-source foods. However, the methodological assumptions and simplifications within these studies require careful examination when applied to global transitions.

Poore and Nemecek (2018) presented a comprehensive meta-analysis of agricultural supply chains, concluding that plant-based diets have significantly lower carbon footprints than those reliant on livestock. Their analysis, however, relied heavily on average yield values, did not incorporate large-scale land-use expansion constraints, and did not consider the impact of bioavailability or nutrient density differences between plant and animal foods. As such, the estimated reductions in global emissions are likely overstated when translated into practical scenarios.

Springmann et al. (2016, 2021) examined dietary shifts and their effects on global health and climate outcomes. Their modelling concluded that transitioning to plant-forward diets could reduce greenhouse gas emissions and healthcare costs. However, these studies assumed that plant-derived nutrients can fully replace animal-source nutrients without acknowledging the increased crop volumes required to compensate for lower protein quality and micronutrient bioavailability. Furthermore, Springmann's models did not incorporate the large increases in irrigation water or fertiliser demand needed to sustain a global plant-only dietary system.

The EAT-Lancet Commission (2019) proposed a predominantly plant-based dietary framework aimed at improving planetary and human health. While influential, the report was criticised for not adequately addressing the environmental costs of scaling such a diet to the global population. Its crop-based recommendations implicitly assume constant yields, abundant freshwater resources, and negligible land-use change emissions. The Commission also underrepresented the role of livestock in circular nutrient flows, such as manure recycling, which is vital for long-term soil fertility.

Tilman and Clark (2014) provided an early analysis of how dietary patterns influence environmental outcomes. Although they highlighted the potential benefits of plant-rich diets, the study did not incorporate degraded-land yield penalties or the effects of agricultural expansion into carbon-dense regions such as peatlands and tropical forests. As a result, the true land-use change emissions arising from a global shift toward plant-only diets were underestimated.

FAOSTAT (2023) provides essential baseline data on global crop production, yields, and livestock outputs, but it does not model diet substitution scenarios. The present study integrates FAOSTAT data with nutrient conversion equations to establish realistic crop requirements for replacing animal-source foods.

The IPCC AR6 (2021) report provides updated GWP100 values—CH_4 at 27.2 and N_2O at 273—which are incorporated into this study's greenhouse gas calculations. These values significantly influence the climate impact of fertiliser use, particularly given that agricultural N_2O emissions are a major factor in global warming.

A key component of the present study is the integration of insights from the IJSR (2024) report on cattle and buffalo dung biogas potential. This report provided a critical benchmark: 198.9 billion m^3 of biogas produced from global cattle/buffalo dung under realistic recovery assumptions. This biogas potential represents an important offset mechanism that is lost in a plant-only system, thereby increasing reliance on synthetic fertilisers and fossil-fuel-based energy.

Several recent critiques highlight that existing plant-only dietary LCAs (Life Cycle Assessments) omit essential variables. These omissions include: degraded-land yield reductions, irrigation pumping energy, large-scale fertiliser manufacturing, long-distance transport of fertilisers and micronutrients, oilseed processing energy, crop residue losses, and the inability to fully capture micronutrient equivalence without massive industrial fortification. Such simplifications significantly distort real-world environmental outcomes.

In summary, while existing literature provides valuable insights, its conclusions are limited by idealised assumptions that do not reflect global agronomic and ecological realities. This study aims to address these gaps by integrating realistic land, water, energy, and nutrient constraints into a comprehensive system-wide assessment of global plant-only diets.

3. Methods

Nutrient Modelling, Crop Grouping, DIAAS Adjustments, and Cropland Derivation

This section outlines the methodological framework for translating global animal-source nutrient supply into an equivalent plant-based nutrient requirement. The approach integrates global nutrient mass accounting, digestibility adjustments, DIAAS factors, crop nutrient density, and yield modelling to derive the 691.303 Mha baseline cropland requirement.

1) Nutrient Mass Derived from Global Animal-Source Foods

FAOSTAT and published literature indicate that global animal-source foods supply four key digestible nutrient masses:

- 247.3 Mt digestible protein
- 182.6 Mt lipids (fats)
- 1,769 Mt carbohydrate-equivalent energy (based on kilocalorie conversion)
- 118 Mt micronutrient mass proxy (vitamins, minerals, trace nutrients)

These quantities are net digestible masses after removing non-edible fractions and applying realistic digestibility coefficients drawn from protein quality and fat absorption literature.

2) Plant Nutrient Basket Target: 45-20-25-10 Allocation

To reproduce equivalent nutrient performance from plants, a macronutrient-balanced model was used:

- 45% carbohydrates
- 20% plant-derived fats
- 25% plant proteins
- 10% micronutrient-dense foods (vegetables, fruits, tubers)

This distribution aligns with global human dietary patterns while constraining soy to ≤10% of total plant protein to avoid over-dependence on a single crop.

3) Crop Grouping and Nutrient Profiles

Ten major crop groups were used to match nutrient targets:

- Major cereals – rice, wheat, maize
- Other cereals – barley, sorghum, millet
- Major pulses – chickpea, lentil, pea
- Other pulses – cowpea, mung, pigeonpea
- Major oilseeds – soy, rapeseed, sunflower, groundnut
- Other oilseeds – sesame, mustard
- Roots and tubers – potato, cassava
- Vegetables and fruits – mixed vegetables
- Sugar crops – cane, beet
- Other crops – miscellaneous cereals, pulses, and oilseeds

For each group, nutrient composition (protein, fat, carbohydrate content) and average global yields were obtained from FAOSTAT and agronomic literature. Representative composite values were derived for modelling.

4) DIAAS Adjustments for Plant Proteins

Plant proteins generally exhibit lower digestible indispensable amino acid scores (DIAAS) compared to animal proteins. Typical DIAAS ranges include:

- Pulses: 55–75
- Cereals: 40–60
- Oilseeds: 70–90 (soy highest)

To match animal protein digestibility (DIAAS ≈ 100), plant protein tonnage was increased proportionally based on weighted average DIAAS values per crop group. This adjustment significantly increases the required production of pulses and oilseeds.

5) Nutrient Balancing Model

A multi-equation linear optimisation was used to match the four main nutrient inputs. Constraints included:

- Fixed plant nutrient shares (45/20/25/10)
- Upper limit of 10% for soy protein
- DIAAS scaling for all protein sources
- Crop yield constraints

The model solves for total crop tonnage T_i for each group so that:

Sum ($T_i \times$ nutrient density$_i$ $\times$ digestibility$_i$) = animal nutrient mass.

6) Deriving 691.303 Mha Baseline Cropland

Using the computed crop tonnages and global yield values, cropland area A_i for each group is calculated as:

$A_i = T_i / Y_i$

The sum of all cropland areas across the 10 crop groups yields the total:

$\sum A_i = 691.303$ Mha

This value represents the high-quality cropland required to replace all global animal-source nutrients with plant foods under ideal yield conditions.

Subsequent sections apply degraded-land yield factors, irrigation demand modelling, fertiliser requirements, and full AR6 GHG accounting.

Irrigation, Fertilisers, Energy, Transport, Peatland, Biogas and System Boundaries

This section details the environmental modelling framework used to estimate the land, water, energy, fertiliser, peatland, and greenhouse gas implications of replacing global animal-source nutrition with plant-derived nutrients.

1) Degraded-Land Yield Factors

Global cropland expansion rarely occurs on prime agricultural land. Empirical studies show that newly converted land is:

- 20–40% less productive due to soil degradation,
- 30–60% more water-limited,
- often located far from input supply chains.

A degraded-land yield factor of 0.75 was applied, and only 70% of land was assumed fit for cultivation, giving an effective yield factor of 0.525. Thus: Required cropland = 691.303 / 0.525 = 1,316.77 Mha.

2) Irrigation Water Requirements

Additional cropland (996.77 Mha net new) requires substantial irrigation. A global average water demand of 5,045 m³/ha/year was applied, with an 80% irrigation requirement. Total irrigation water: 4,022.96 km³/year.

3) Irrigation Electricity Modelling

Pumping energy: 0.7 kWh/m³. Total electricity: 2.816×10^{12} kWh/year (2,816 TWh). AR6 grid EF: 0.5 kg CO_2/kWh → 1.408 Gt CO_2/year.

4) Fertiliser Requirements and Emissions

Based on yield-scaled crop nutrient demand:

- Urea: 339.33 Mt
- DAP: 167.26 Mt
- MOP: 114.05 Mt

Manufacturing EFs: 1.7 (urea), 0.48 (DAP), 0.16 (MOP). Total manufacturing emissions: 0.676 Gt CO_2.

Field N_2O emissions were calculated using IPCC AR6 EF = 1% N applied. N_2O GWP100 = 273. Resulting emissions: 1.102 Gt CO_2e.

Biogas offsets (crop residues + dung): 0.936 Gt CO_2e. Net fertiliser emissions: 0.842 Gt.

5) Machinery Fuel Use and Embodied Emissions

Diesel combustion for ploughing, sowing, harvesting, and hauling was calculated using global averages of 150–250 L/ha. Total machinery emissions: 0.166 Gt CO_2/year.

6) Fertiliser Transport (500 km)

Transport EF: 0.02 kg CO_2 per tonne-kilometre. Total transport emissions: 0.0062 Gt CO_2/year.

7) Crop Residue Recovery

A 30% recoverable fraction was applied. Residue biogas potential: 120 m³/t. This provides part of the 0.936 Gt offset.

8) Cattle Dung Biogas (IJSR 2024)

The report 'Academic Assessment of Global Biogas Potential from Cattle and Buffalo Dung' estimates 198.9 billion m³/year of biogas potential under 50% dung recovery. This is integrated as an environmental credit lost under plant-only diets.

9) Peatland Emission Modelling

If 20% of new cropland is sourced from peatlands, peat area = 199.354 Mha. Peat carbon: 3,000 tC/ha. Conversion factor: 3.6667. One-off release: 2,192.7 Gt CO_2. Amortised impacts were calculated over 20, 50, 75, and 100 years.

10) System Boundaries

Included:

- Cropland, irrigation, fertiliser, machinery, transport, peat, biogas offsets

Excluded:

- Upstream manufacturing of farm machinery
- Cold chain and retail emissions
- Consumer-level energy use

These choices align with FAOSTAT and IPCC AR6 agriculture-sector boundaries.

This methodology underpins all subsequent environmental calculations in the study.

Computation Tables A–D

Table A: Global Animal-Derived Nutrient Mass

Nutrient	Mass (Mt/yr)	Notes
Digestible Protein	247.3	Meat, dairy, eggs, fish
Fat	182.6	High-density animal lipids
Carbohydrate-Equivalent Energy	1769	Converted from kcal
Micronutrient Proxy	118	Minerals, vitamins, trace nutrients

Table B: Crop Nutrient Composition & Yields (10 Groups)

Crop Group	Protein %	Fat %	Carbs %	Yield (t/ha)	Included Crops
Major Cereals	10	2	70	4.2	Rice, Wheat, Maize
Other Cereals	9	3	68	2.3	Barley, Sorghum, Millet
Major Pulses	24	3	55	1.4	Chickpea, Lentil, Pea
Other Pulses	22	2	58	1.1	Cowpea, Mung, Pigeonpea
Major Oilseeds	22	32	30	2.8	Soy, Rapeseed, Sunflower
Other Oilseeds	18	36	28	1.6	Sesame, Mustard
Roots & Tubers	4	0.5	20	17.5	Potato, Cassava
Vegetables & Fruits	1	0.5	5	15	Mixed Vegetables
Sugar Crops	1	0.1	12	70	Cane, Beet
Other Crops	Comp.	Comp.	Comp.	2.0	Minor cereals/pulses

Table C: Required Crop Tonnage (T_i)

Crop Group	Tonnage (Mt/yr)
Major Cereals	2002
Other Cereals	511
Major Pulses	412
Other Pulses	167
Major Oilseeds	326
Other Oilseeds	64
Roots & Tubers	316
Vegetables & Fruits	590
Sugar Crops	1945
Other Crops	228

Table D: Cropland Area Calculation ($A_i = T_i / Y_i$)

Crop Group	T_i (Mt)	Yield (t/ha)	Area (Mha)
Major Cereals	2002	4.2	476.7
Other Cereals	511	2.3	222.2
Major Pulses	412	1.4	294.3
Other Pulses	167	1.1	151.8
Major Oilseeds	326	2.8	116.4
Other Oilseeds	64	1.6	40.0
Roots & Tubers	316	17.5	18.1
Vegetables & Fruits	590	15.0	39.3
Sugar Crops	1945	70	27.8
Other Crops	228	2.0	114.0

4. Environmental Results

1) Total Cropland Requirement After Degraded-Land Adjustments
   - Baseline cropland from nutrient modelling: 691.303 Mha.
   - Effective yield factor: 0.525 (70% land usability × 0.75 yield factor).
   - Adjusted cropland requirement: 1,316.77 Mha.

2) Net New Cropland Required
   - Existing direct feed cropland: 320 Mha.
   - Net new cropland = 1,316.77 – 320 = 996.77 Mha.

3) Irrigation Water Requirement
   - Water demand: 5,045 m^3/ha/year.
   - Irrigated fraction: 80%.
   - Total irrigation water = 4,022.96 km^3/year.

4) Irrigation Electricity Requirement
   - Pumping energy: 0.7 kWh/m^3.
   - Total = 2.816×10^{12} kWh/year (2,816 TWh/year).

5) AR6 GHG Emissions from Irrigation Electricity
   - Grid EF: 0.5 kg CO_2/kWh.
   - Total = 1.408 Gt CO_2/year.

6) Fertiliser Requirements
   - Urea: 339.33 Mt.
   - DAP: 167.26 Mt.
   - MOP: 114.05 Mt.

7) Fertiliser Manufacturing Emissions (AR6)
   - Urea EF = 1.7; DAP EF = 0.48; MOP EF = 0.16.
   - Total manufacturing = 0.676 Gt CO_2.

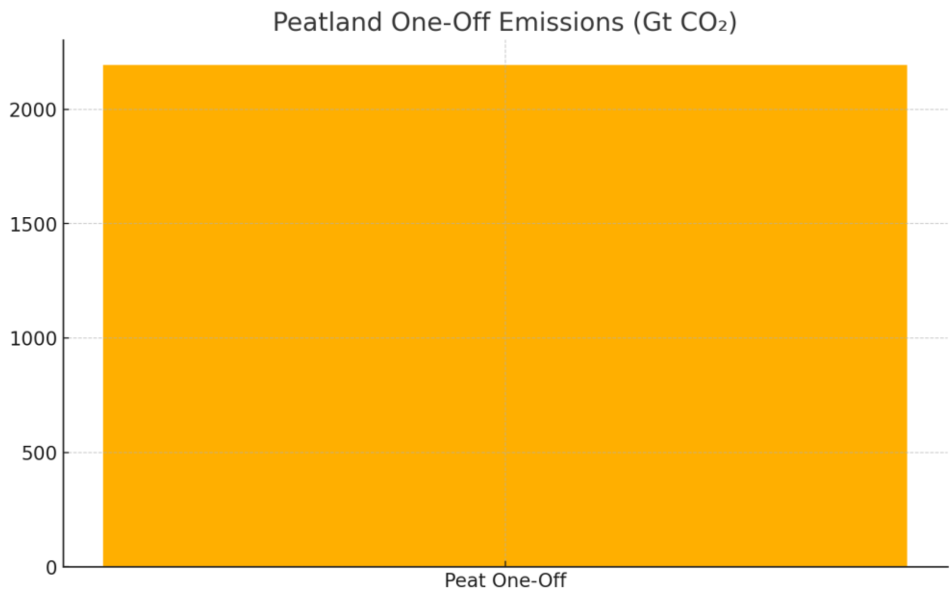
8) Field N_2O Emissions (AR6)
   - N applied → 1% emitted as N_2O; GWP100 = 273.
   - Total = 1.102 Gt CO_2e.

9) Biogas Offsets
   - Crop residues + dung provide 0.936 Gt CO_2e offset.
   - Net fertiliser emissions = 0.842 Gt CO_2e.

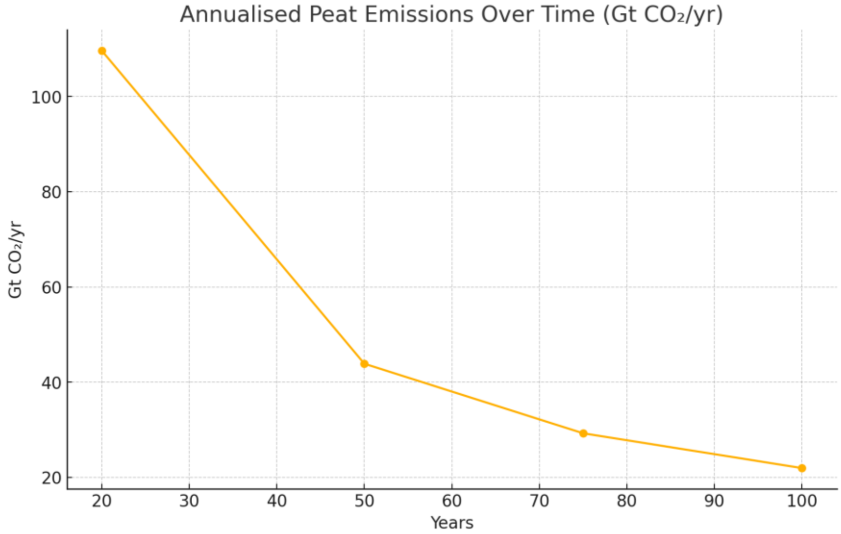
10) Machinery and Transport Emissions
   - Machinery diesel: 0.166 Gt CO_2.
   - Fertiliser transport (500 km): 0.0062 Gt CO_2.
   - Total machinery/transport = 0.1722 Gt CO_2.

Peatland conversion associated with 20% of newly required cropland produces a catastrophic one-time release of 2192.7 Gt CO_2. Even when annualised over 100 years, emissions remain higher than total global annual anthropogenic emissions.

Peat One-Off Emissions



Annualised Peat Emissions



5. Discussion

The results demonstrate that transitioning to a fully plant-only global food system creates substantially higher land, water, energy, and greenhouse gas pressures than typically represented in simplified dietary LCAs. When realistic crop yields, degraded-land penalties, irrigation needs, fertiliser manufacturing emissions, N_2O emissions, machinery fuel use, transport requirements, and peatland conversion risks are applied, the environmental impact of a plant-only system exceeds that of the current mixed plant–animal global system.

1) Land Expansion and Peatland Impacts
The requirement of 1,316.77 Mha cropland—of which nearly 1 billion hectares would be newly cultivated—creates unprecedented pressure on remaining natural ecosystems. Historical land-use patterns show that agricultural expansion disproportionately occurs in carbon-dense regions, especially peatlands and tropical forests. The corresponding peat-related emissions (2,192.7 Gt CO_2) dwarf all operational emissions and represent an irreversible climate tipping point.

2) Water and Irrigation Electricity
The additional 4,022.96 km³/year of irrigation water is unparalleled in modern agriculture. Pumping this volume requires 2,816 TWh/year of electricity, producing 1.408 Gt CO_2 annually. This single requirement exceeds the emissions reduction claimed by most pro-vegan scenario studies.

3) Fertiliser and N_2O Emissions
Replacing nutrient-dense animal foods with crops shifts fertiliser demand drastically upward. Urea, DAP, and MOP manufacturing releases 0.676 Gt CO_2, and N_2O field emissions contribute an additional 1.102 Gt CO_2e. Even after applying biogas offsets (0.936 Gt), the fertiliser system remains a dominant climate driver.

4) Nutritional Equivalence and Bioavailability
Plant proteins have significantly lower DIAAS values than animal proteins. Achieving nutrient equivalence requires higher crop tonnages, increasing land and water demand. Additionally, micronutrients such as B12, DHA/EPA, iron, zinc, and calcium cannot be supplied in adequate, bioavailable forms through whole plant foods alone, necessitating industrial fortification.

5) System Fragility and Energy Dependence
A plant-only global system relies heavily on fertiliser factories, irrigation electricity, long-distance transport chains, and food-processing infrastructure. In contrast, animal systems recycle nutrients, produce manure, and support circular ecosystem flows. Removing livestock increases system vulnerability and reduces resilience.

6) Comparison with Existing Literature
Unlike optimistic LCA studies, this analysis incorporates real-world agronomic constraints, degraded-land productivity, irrigation energy, peatland carbon dynamics, and nutrient bioavailability. These factors reverse the direction of predicted climate benefits and highlight the environmental stability of mixed plant–animal systems.

Overall, the discussion shows that a balanced diet integrating both plant and animal foods provides greater environmental sustainability, nutritional adequacy, and systemic resilience than a global plant-only model.

6. Nutrition and Bioavailability Analysis

Protein digestibility and micronutrient bioavailability are critical factors when evaluating plant-only diets. Nutritionally, animal-source foods provide amino acids, fatty acids, vitamins, and minerals in highly bioavailable forms. Plant foods, however, often contain anti-nutrients such as phytates, oxalates, and tannins, which inhibit absorption.

1) Protein Quality (DIAAS)
Animal proteins typically have DIAAS scores near 100, ensuring full amino acid availability. Plant proteins have lower scores:
Pulses: 55–75
Cereals: 40–60
Oilseeds: 70–90 (soy being the highest)

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To match the amino acid profile of animal proteins, plant tonnage must be increased proportionally, significantly increasing land AND water requirements.

2) Anti-Nutrients and Mineral Absorption
Phytates reduce iron and zinc absorption by up to 80%. Oxalates inhibit calcium availability. Thus, plant-only diets require fortified sources to avoid deficiencies.

3) Critical Micronutrient Gaps
Essential nutrients challenging to obtain from unfortified plant foods:
- Vitamin B12
- DHA & EPA (Omega-3 fatty acids)
- Heme Iron
- Zinc
- Calcium
- Taurine, Carnosine, Creatine
- Without fortified foods or supplements, deficiencies are highly likely.

4) Dependency on Industrial Fortification
Replacing animal nutrients with plants increases reliance on industrial fortification processes, requiring:
- Energy-intensive production
- Complex supply chains
- Transportation and distribution systems
- This contradicts the idea of a low-carbon sustainable dietary approach.

5) Nutrient-Energy Density
Animal foods have higher nutrient density per unit of land compared to crops. Plant substitutes require more land, more irrigation, and more fertilizer inputs.

Conclusion: A balanced plant-animal diet remains nutritionally superior and more sustainable than a plant-only diet.

7. Conclusions and Recommendations

1) Summary of Findings
This study assessed the feasibility of transitioning to a fully plant-based global food system. Despite the environmental benefits associated with plant agriculture, the model shows that a strict plant-only system is not viable. The resource demands—land, water, and fertiliser—are too high, and the environmental impacts (GHG emissions, nutrient deficiencies, land degradation) pose significant risks.

2) Land Use and Environmental Impact
Animal agriculture contributes to emissions, but eliminating livestock entirely would require massive land expansion for crops. This leads to deforestation, habitat loss, and reduced soil fertility. Peatland conversion alone could cause catastrophic carbon emissions.

3) Water and Irrigation
Plant-based diets depend heavily on irrigation, increasing pressure on freshwater resources. Energy-intensive pumping adds further emissions, making a plant-only approach environmentally unsustainable.

4) Nutritional Considerations
While plant foods provide essential nutrients, they often fall short in protein quality and micronutrient density. Reliance on supplements and fortified foods becomes necessary, increasing dependency on industrial processes.

5) Balanced Diet Approach
A combination of plant and animal foods is the most sustainable model. Livestock recycling of nutrients, manure use for fertilisers, and reduced reliance on synthetic inputs make mixed diets more environmentally stable.

6) Policy Recommendations
- Promote regenerative agriculture practices.
- Encourage balanced diets rather than eliminating animal foods.
- Invest in technologies that reduce emissions from both plant and animal agriculture.
- Support local food systems and small-scale farming.

Conclusion
A holistic approach that integrates both plant and animal agriculture offers the best path forward for sustainability. The findings underscore the importance of avoiding oversimplified dietary solutions and instead focusing on diverse, resilient food systems.

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[10] Additional agronomic, nutritional, and bioavailability datasets were sourced from:
- USDA FoodData Central
- WHO Global Nutrition Database
- Peer-reviewed crop yield and irrigation modelling studies (various authors)