Environmental Footprint of Reactive Nitrogen in Indian Agricultural Sector: An Extended Input-Output Analysis

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Motivation:

Agriculture essential for human sustenance

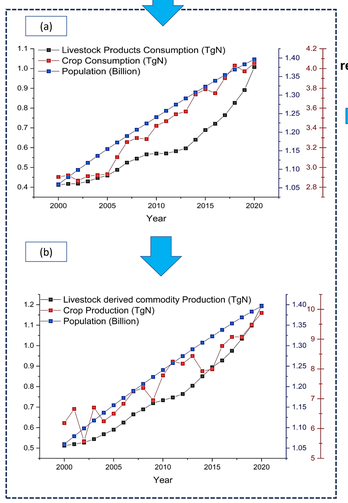


Figure 1: (a) Figure shows the rise in consumption of crop and livestock products (TgN) along with the population rise **(b)** depicts the rise in production (TgN) of the same

Environmental damages resulting from **reactive nitrogen (Nr)**[1]

- Nr includes products of nitrogen fixation, including **biologically, photochemically and radioactively active nitrogenous compounds.**
- **Nr is emitted** in **various forms** (e.g., NH_x, N_2O, NO_x) from a diverse **range of sources** (agriculture, industry, transport) and **impacts all environmental media from local to global scales**[2].

- In response , **UNEA pledged to reduce the Nr waste globally by 2030.**
- Despite the comprehensive discussion of Agriculture, Forestry, and other Land use (AFOLU) for climate change[3],the **complex interplay of food demand, land and resource management for food security and its multi-scale impacts, particularly on-air pollution needs to be characterized.**

Responding to this challenge, requires quantifying Nr source and pollutant contributions, tracking multi-sectoral flows and resulting multi-media impacts.

Objective: To develop **a comprehensive input-output accounting of Nr flows** with focus on **cropland and livestock sector** in India.

Methodology:

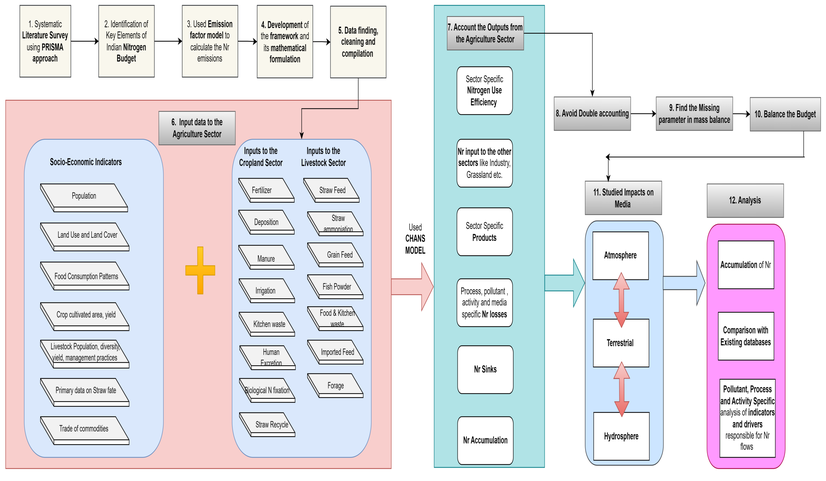


Figure 2: Environmentally Extended Input–Output Accounting (EEIOA) from the Indian agriculture sector

- Developed **Environmentally Extended Input-Output Accounting (EEIOA) model** to link the sources of N inputs, **track multi-sectoral and multi-media flows to final environmental impacts** (Figure 2).
- It quantifies **key Nr components like NO_x, N_2O, NH_3, and non-reactive N_2-N** released nationally. National-scale data is obtained from literature surveys, agricultural organizations, and national and international data repositories to complete the N-cycle in Indian cropland.
- The output Nr emissions are compared with the existing database like **GFED and EDGAR.**
- The quantification of Nr in different media, across different sectors has been used **to address the food, feed and fuel insecurity issues due to the increasing population.**

Findings:

Figure 4: Outcomes of the EEIO Accounting of Nr flows in Indian cropland sector (2020)

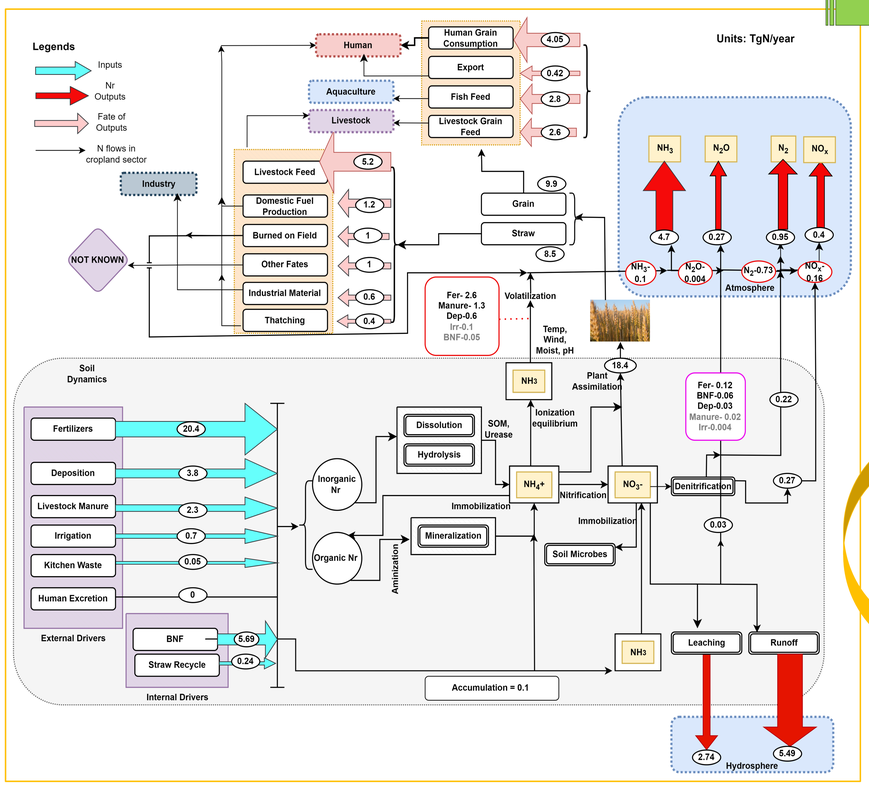
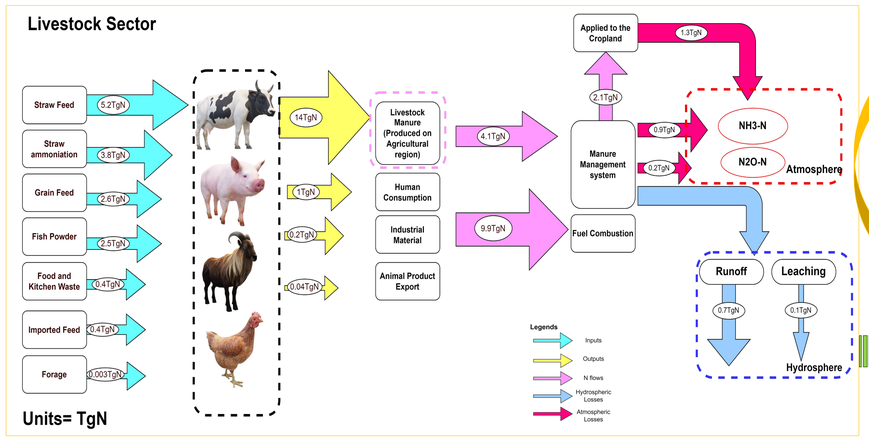


Figure 5: Outcomes of the EEIO Accounting of Nr flows in Indian livestock sector (2020)



References:

1. Sutton, M., Oenema, O., Erisman, J. et. al. (2011). Too much of a good thing. Nature 472, 159–161.

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Discussion:

- **Highest contributing Nr sources to the cropland** are fertilizer application, Biological Nitrogen Fixation (BNF), deposition and manure application (96% of total N inputs). Fertilizer application and deposition emerge as a new Nr sources, responsible for 68% of NH_3 and 56% of N_2O emissions from cropland.
- **The Nitrogen use efficiency (NUE) of the crops** varying from **47% to 55%** between 2000-2020. The overall trend of NUE and soil accumulation of N has declined over the years.
- **60% of the Nr enters hydrosphere** as NO_2- and NO_3- through leaching and runoff , **40% has enters atmosphere as NH_3** (35%), through **volatilization** and NO_x (3%) through combustion and N_2O (2%) through denitrification.
- Study **overestimates Nr emissions versus GFED**: six times higher for NO_x and NH_3, ten times higher for N_2O. **Underestimates:** 1.8 times lower NH_3, 1.4 times lower NOx vs. **EDGAR**; N_2O aligns with EDGAR.

✓ *Indicative Dietary shifts; a possible cause of rise of Nr in environment*

- Protein intake increased from **9 gN/pc/day to 10.7 gN/pc/day**, with vegetarian sources contributing 82-91% from 2000-2020. Grain consumption per capita per day decreased significantly from **75.3% to 65.1%** over the same period**, signifying dietary shifts**.

3Fs insecurity: Food, feed and fuel

- **Human nutritional security** relies heavily on **grain consumption**, accounting for 68% of human nitrogen intake.
- **Livestock grain feed** as input to livestock feed has decreased from **43% to 26%.**
- Majority of **livestock nutritional security is derived from straw**, with a 58% increase from 2000 to 2020. This helps alleviate competition for food and feed security.
- **Fate of the crop residues**
  - 22% of the crop residues is surplus (11% burned on fields and 11% having unknown fates).

Potential for using surplus crop residues

- Crop residue pellets mixed with thermal fuel for thermal power generation, **reducing environmental damage by 5-10% as suggested by government officials**.
- Rest of the crop residue has **potential for waste valorization** to address national fuel security.

- **Manure application, second only to fertilizer use**, is a major NH_3 emitter, with **bovine animals** contributing **80-83% of manure generation**.
- 30% of produced manure undergoes treatment, with **27% lost to the atmosphere during management**, and **32% released from applied manure onto cropland**.

Conclusions:

- India's significant yield gap raises a compelling concern: **while efforts to enhance food security are crucial,** they inadvertently **contribute to environmental challenges by adding excess nitrogen, impacting NUE, and leading to Nr release, intensifying the environmental dilemma**.
- The integrated inclusion of **atmospheric, hydrosphere and terrestrial addition of Nr** is not reflected in today's regulation. This is the **first attempt in India**, that study **N flows to characterize losses and impacts that have implications for Nexus of 3Fs:** Food, Feed and Fuel. This study opens a room for policy makers **to decode the 3Fs security issues with simultaneous decrease in Nr emissions.**
- Despite increasing fertilizer and manure use**, food security** remains a concern due to **decline in the NUE and existing yield gaps.** The excess Nr is both **an economic as well as an environmental loss, particularly for air and water quality.**
- Total **per capita protein intake rises** while **grain consumption declines**, indicating **dietary shifts.** Further analysis of **commodity-specific per capita consumption is needed for conclusive insight.**