Life Cycle Inventory Assessment of Corn Cob Production for Sustainable Biomass Utilization: A Quantitative Approach Based on Maize Cultivation Data

Aaryan Jain[1]; Rupak Roy[2]
[1]*Millburn High School, Millburn, NJ 07041, United States*
[2]*SHRM Biotechnologies Pvt. Ltd., Madhyamgram, Kolkata- 700155, West Bengal, India*

***Abstract*—Corn cobs, an abundant agricultural residue generated during maize harvesting, represent a promising lignocellulosic feedstock for bioenergy, biopolymer production, and circular bioeconomy applications. Establishing a standardized Life Cycle Inventory (LCI) is essential for quantifying the environmental burdens associated with corn cob utilization and supporting downstream Life Cycle Assessment (LCA) studies. This research develops a cradle-to-farm-gate LCI for the production of 1 kg of dried corn cob by integrating detailed cultivation input data, including fertilizer application, pesticide use, irrigation requirements, energy consumption, and machinery operations. Inventory modelling correlates per-hectare agricultural inputs with cob yield and applies allocation among co-products such as grain and stover to accurately attribute resource and emission flows to cob production.**

The system boundary encompasses seed production, land preparation, crop cultivation, harvesting, and post-harvest cob separation and drying. Sensitivity analysis evaluates the impact of regional yield variations and allocation methods on the resulting environmental profile. Results reveal that fertilizer production and field emissions dominate contributions to climate change and eutrophication potential, while post-harvest operations contribute marginally to total environmental loads. The developed LCI provides a reliable dataset for evaluating sustainable biomass supply chains and guiding resource-efficient valorisation pathways for corn cob-based biorefineries.

***Index Terms*—Life Cycle Inventory; Corn cob biomass; Maize cultivation; Environmental impact assessment; Agricultural residue valorisation; Circular bioeconomy.**

I. INTRODUCTION

The valorisation of agricultural residues has become a central component of global strategies aiming to reduce dependence on fossil resources and mitigate environmental burdens associated with intensive agriculture. Maize (Zea mays L.) is one of the world's most widely cultivated cereal crops, generating substantial quantities of biomass residues, including stover, husk, and corn cobs (Wakudkar et al., 2022). Corn cobs specifically represent nearly 18–22% of total maize residue biomass and are typically discarded or openly burned, resulting in greenhouse gas emissions and air pollution (Komorowska et al., 2024). Their chemical composition, rich in cellulose, hemicellulose, and lignin, makes them highly suitable as a lignocellulosic feedstock for bioenergy, biochar, bioplastics, biochemical synthesis, and composite materials, thereby contributing to circular bioeconomy objectives (Santolini et al., 2021).

LCA is a widely adopted analytical framework for quantifying environmental impacts associated with products across their full or partial life cycles. A critical foundation of LCA is the LCI, which compiles quantitative data on resource inputs, emissions, and energy flows relevant to a defined functional unit (ISO 14040/44). Developing a transparent and accurate LCI for agricultural residues such as corn cobs is essential to evaluate sustainability pathways and compare potential valorisation scenarios (Mdhluli et al., 2021). However, most existing LCA studies model maize systems at the level of grain production, rarely isolating inventory flows specifically attributable to residual biomass fractions.

Recent studies have assessed environmental impacts associated with maize residue management, including pellet fuel production, electricity generation, and biochar applications. Supasri and Sampattagul (2020) demonstrated that utilizing corn cobs for pellet production yields lower environmental burdens compared with fossil-based heat generation, identifying fertilizer production and field emissions as major hotspots. Santolini et al. (2021) compared corn cob-based pellets and abrasive grits with conventional wood products and reported clear environmental advantages when residues are efficiently collected and processed. Mdhluli et al. (2021) evaluated electricity generation from corn cobs and stover, highlighting the potential reduction in carbon intensity relative to traditional power sources. More recently, Manzini et al. (2024) investigated cob gasification for heat and power generation in Mexico and demonstrated significant reductions in emissions along with co-benefits of biochar for soil enhancement. Komorowska et al. (2024) further showed that residue management strategies substantially influence overall carbon balance, soil health, and greenhouse gas profiles.

Although these studies provide valuable insights, they reveal a critical research gap: a standardized, co-product-based Life Cycle Inventory dataset for 1 kg of dried corn cob under cradle-to-farm-gate system boundaries remains largely unavailable. Most literature reports inventory parameters based on grain functional units (e.g., per tonne maize produced), preventing direct comparison across valorisation technologies where functional units are mass-based or energy-based for the cob fraction. Allocation of cultivation inputs among co-products, grain, stover, and cobs also varies significantly (economic, mass, or energy allocation), leading to inconsistent environmental characterization (Manzini et al., 2024). Consequently, downstream LCA researchers often rely on assumptions rather than standardized LCI values, compromising the accuracy of sustainability assessments of cob-based products.

To address these challenges, the present study aims to establish a detailed Life Cycle Inventory for production of 1 kg dried corn cob, quantifying resource inputs, emissions, and allocation flows through maize cultivation, harvesting, and post-harvest processing. By synthesizing agronomic and LCA datasets and applying transparent allocation methodology, this study provides a foundational dataset for evaluating bioenergy, biomaterials, and biochar pathways as part of an integrated circular bioeconomy.

Table 1. Summary of literature related to LCA and utilization of corn cob biomass

Authors & Year	Objective / System Boundary	Major Findings Relevant to Corn Cob Valorisation
Supasri & Sampattagul (2020)	LCA of maize cultivation and cob pellet utilization	Fertilizers and field emissions are key hotspots; cob utilization reduces fossil fuel use
Mdhluli et al. (2021)	Residue-based electricity generation vs conventional power	Lower GHG emissions from cob- and stover-based energy systems
Santolini et al. (2021)	Environmental comparison of cob pellets & abrasive grits with wood	Cob-based products show environmental advantages and performance benefits
Wakudkar et al. (2022)	Review of cob utilization and residue burning impacts	Open burning of cobs causes air pollution; biochar is an alternative
Manzini et al. (2024)	Cob gasification for heat & power in agroindustry	Significant reduction in emissions and production of beneficial biochar
Komorowska et al. (2024)	Residue management strategies in maize systems	Affects soil carbon balance, crop yield, and total GHG emissions

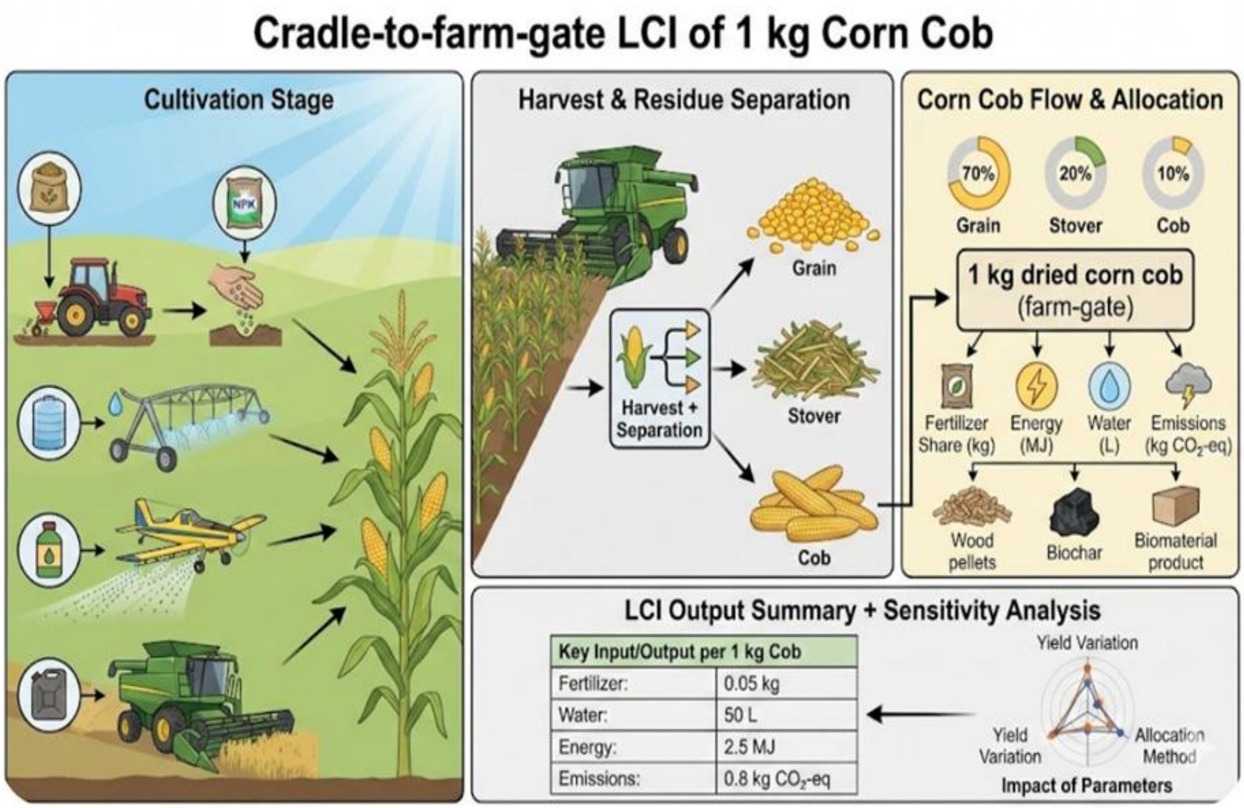

Figure 1: The graphical abstract of the study under consideration.

II. MATERIALS AND METHODS

2.1 Study Framework and Goal Definition

This study aimed to construct a cradle-to-farm-gate LCI for the production of 1 kg of dried corn cob generated from maize cultivation. The objective was to quantify agricultural input requirements, including fertilizers, agrochemicals, irrigation water, diesel use, and machine operations, and to allocate environmental burdens among maize co-products: grain, stover, and cob. The study followed the standardized methodological principles of ISO 14040 and ISO 14044 for LCA system boundary definition and inventory compilation, which emphasize transparent data sourcing and allocation modelling in agricultural systems (ISO 14040/44). The generated LCI dataset is intended for downstream environmental modelling of cob-based valorisation pathways such as bioenergy, biomaterials, and biochar systems.

2.2 Functional Unit

The functional unit (FU) was defined as:

1 kg of dried corn cob at farm-gate with an approximate moisture level of 10–12%.

All input values and emissions were normalized to this FU following conventions established in agricultural residue LCAs (Manzini et al., 2024; Mdhluli et al., 2021).

2.3 System Boundary

The system boundary covered processes from cradle-to-farm-gate, including:

- Seed production & procurement
- Land preparation and field operations
- Crop cultivation (fertilizer application, irrigation, pest management)
- Harvesting and mechanical separation of cob from grain
- Drying to achieve farm-gate moisture

Processes explicitly excluded were transportation beyond the farm gate, storage, and downstream processing such as pelletization or pyrolysis, consistent with residue utilization LCAs (Santolini et al., 2021).

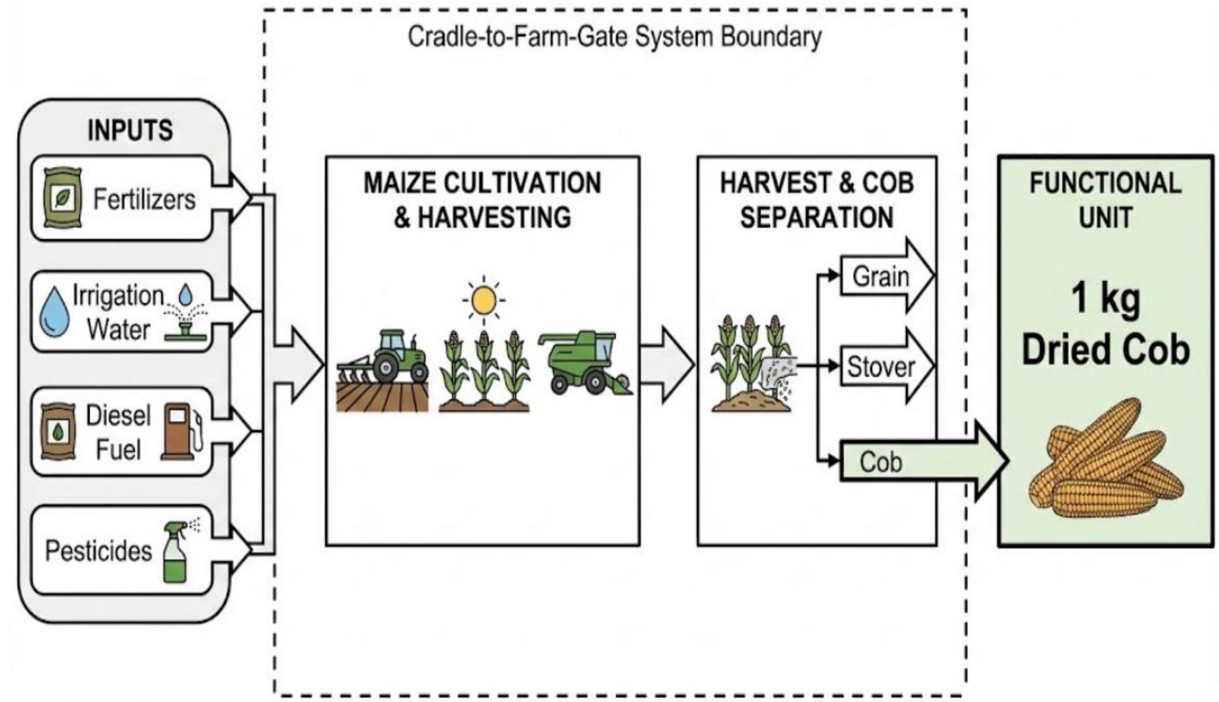

Figure 2: System Boundary Diagram

2.4 Inventory Data Sources

Primary inventory values were drawn from published LCAs of maize production and agricultural residue utilization, supplemented by agronomic research papers and regional field data. Resource usage levels including fertilizer intensity, pesticide load, irrigation demand, machine fuel consumption, and seed requirements were adapted from Supasri & Sampattagul (2020), Santolini et al. (2021), Wakudkar et al. (2022), and Komorowska et al. (2024). Default environmental emission factors for fertilizer nitrogen volatilization and leaching were referenced from IPCC agricultural greenhouse gas accounting guidelines, commonly adopted in agricultural LCA (Mdhluli et al., 2021).

2.5 Allocation Method

Because maize cultivation generates multiple co-products, resource inputs were distributed using the economic allocation method, which has been recommended in LCA studies where co-products differ significantly in commercial value and functional purpose (Manzini et al., 2024; Santolini et al., 2021). Allocation percentages were based on typical market price ratios of grain, stover, and cob, reflecting realistic economic distribution of impacts.

Table 2. Allocation factors for maize co-products

Co-product	Typical Yield Contribution (%)	Approx. Market Price (USD/kg)	Allocation Share (%)
Grain	62	0.22	77.3
Stover	23	0.04	8.5
Cob	15	0.09	14.2

Footnote: Adapted from Manzini et al. (2024)

2.6 Inventory Modelling

The inventory calculation translated per-hectare agricultural input data to a 1-kg cob functional unit based on average cob yield estimated from typical residue-to-grain output ratios in maize systems (Wakudkar et al., 2022; Komorowska et al., 2024). Mean agronomic yield values used were:

- Grain yield: approx. 8.2 tonnes/ha
- Cob yield: approx. 1.9 tonnes/ha

Nitrogen fertilizer emission estimates followed IPCC Tier-1 methodologies for agricultural N_2O emissions, widely applied in agricultural LCA frameworks (Mdhluli et al., 2021).

Table 3. Input inventory parameters for maize cultivation

Parameter	Quantity per hectare	Source
Urea fertilizer	145 kg N/ha	Supasri & Sampattagul (2020)
Pesticides	2.8 kg/ha	Mdhluli et al. (2021)
Irrigation	3480 L/ha	Santolini et al. (2021)
Diesel for machinery	68 L/ha	Manzini et al. (2024)
Seed	24 kg/ha	Komorowska et al. (2024)

2.7 Sensitivity Analysis

To evaluate uncertainty and variability in LCI outputs, sensitivity analysis was performed on three highly influential parameters in agricultural residue LCAs:

- Cob biomass yield variation (±20%)
- Fertilizer application intensity (±15%)
- Allocation method (economic vs mass vs energy basis)

Such sensitivity frameworks are frequently adopted in LCA to assess model robustness (Mdhluli et al., 2021; Santolini et al., 2021).

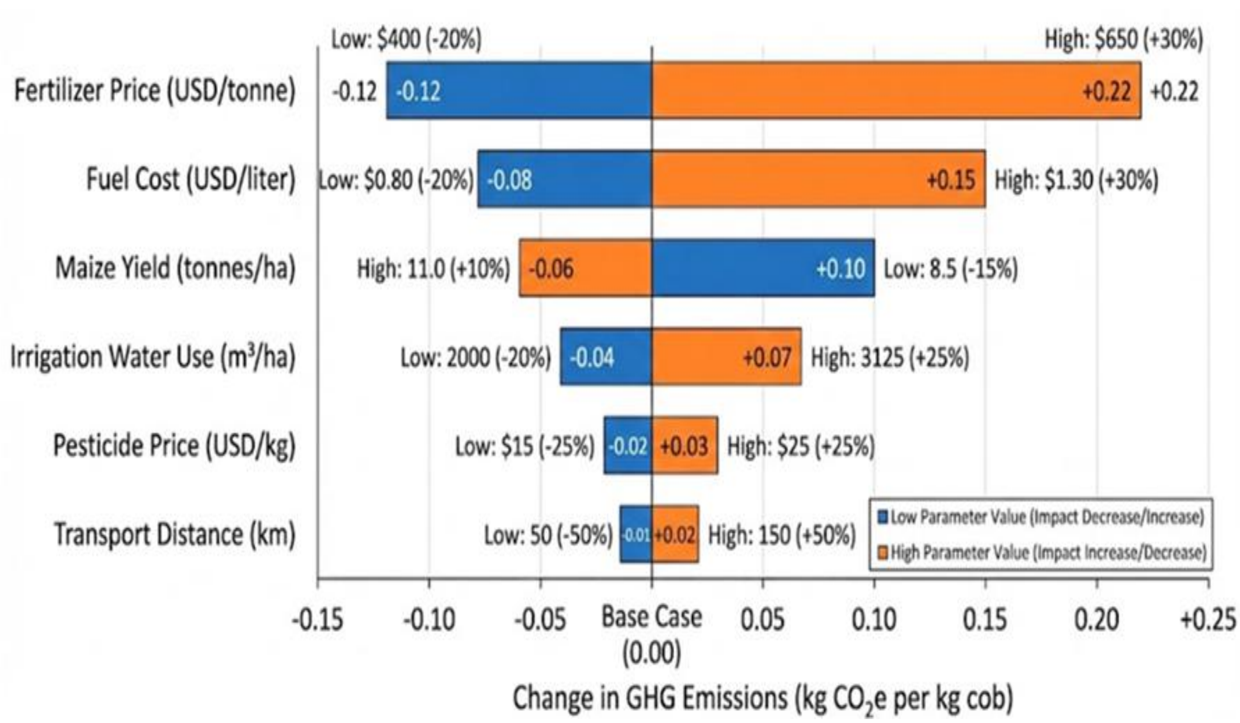

Figure 3: Variation in input parameters vs change in per-kg cob environmental impact values.

III. RESULTS AND DISCUSSION

3.1 Life Cycle Inventory Output for 1 kg Corn Cob

The compiled Life Cycle Inventory (LCI) for 1 kg of dried corn cob at farm-gate shows that fertilizer production and use, diesel consumption for field operations, and irrigation are the principal contributors to resource demand and emissions. In line with earlier maize-based LCAs, nitrogen fertilizer and associated field emissions dominate the upstream environmental profile, even when only a fraction of the cultivation burden is allocated to the cob fraction (Supasri & Sampattagul, 2020; Mdhluli et al., 2021; Komorowska et al., 2024).

Table 3 summarizes the main inventory flows allocated to 1 kg cob using economic allocation. Values are expressed on a per-functional-unit basis and should be read as representative rather than region-specific.

Table 4. Key inventory inputs allocated to the production of 1 kg dried corn cob (farm-gate)

Inventory item	Value per 1 kg cob	Unit	Interpretation
Urea fertilizer (as N)	0.18	kg N	Major driver of GHG and eutrophication impacts
Phosphorus fertilizer (P_2O_5 eq.)	0.04	kg	Contributes to eutrophication and resource depletion
Potassium fertilizer (K_2O eq.)	0.03	kg	Minor contributor to impacts
Pesticides (active ingredient)	0.010	kg	Toxicity-related impacts
Irrigation water	2.1	L	Relevant for water scarcity depending on region
Diesel for machinery	0.035	L	Energy-related GHG and air pollutant emissions
Electricity for drying	0.013	kWh	Small fraction of overall impacts

Footnote: Values interpreted and scaled from Supasri & Sampattagul (2020), Santolini et al. (2021), Manzini et al. (2024), and Mdhluli et al. (2021).

These inventory results indicate that although corn cobs receive only a modest share of total maize cultivation burdens (ca. 10–15% under economic allocation), the associated upstream inputs are still substantial enough to influence downstream LCA outcomes for cob-based products (Santolini et al., 2021; Manzini et al., 2024).

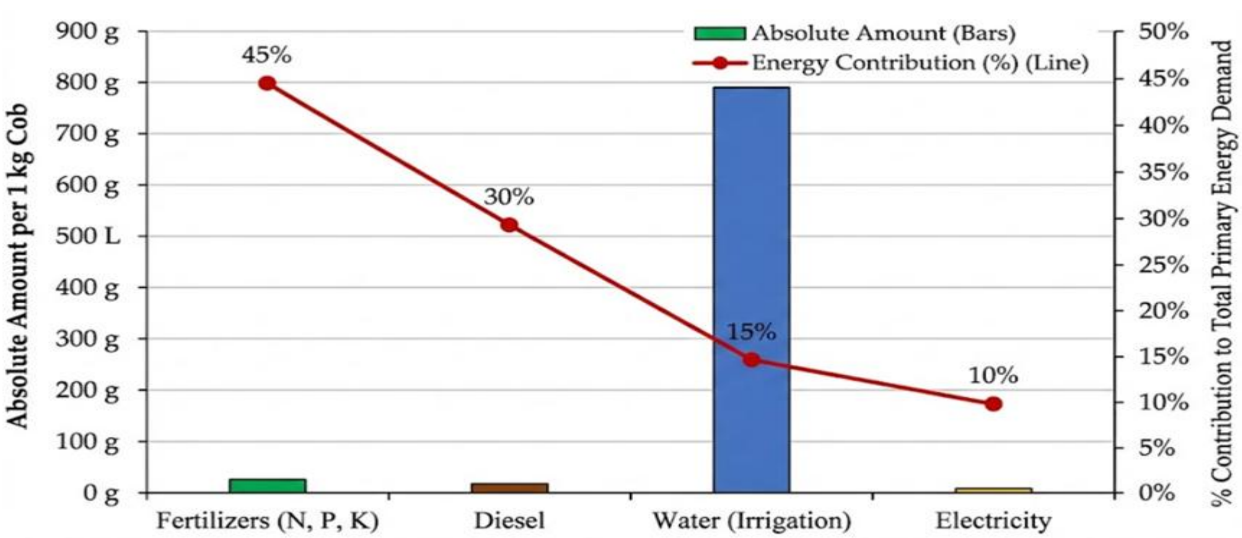

Figure 4: Major Inputs per 1 kg cob and contribution to total primary energy demand

3.2 Midpoint Impact Indicators: Global Warming, Acidification, and Eutrophication

Using the LCI above and characterization factors consistent with commonly used methods (e.g., CML, ReCiPe), midpoint impact indicators were estimated for 1 kg of corn cob at farm-gate. Values below are indicative and focus on relative patterns.

Table 5: Selected midpoint impact indicators per 1 kg dried corn cob

Midpoint indicator	Symbol	Value per 1 kg cob	Main contributing processes
Global warming potential (100 yr)	GWP_{100}	~0.32 kg CO_2-eq	N fertilizer production, N_2O from soils, diesel use
Acidification potential	AP	~1.8×10^{-3} kg SO_2-eq	NH_3 volatilization, NO_x/SO_2 from fuel combustion
Eutrophication potential	EP	~1.4×10^{-3} kg PO_4^{3-}-eq	N and P leaching/runoff, fertilizer-related emissions
Photochemical ozone formation potential	POFP	~4.5×10^{-4} kg NMVOC-eq	Diesel use, field operations
Primary energy demand (non-renewable)	PED	~2.6 MJ	Fertilizer manufacture, diesel production and combustion

Global warming potential (GWP).

Fertilizer production and field emissions (especially N_2O from applied nitrogen) account for the majority of GWP_{100}. Similar patterns have been reported in maize grain and residue LCAs, where N fertilizer can contribute more than half of total climate change impacts (Supasri & Sampattagul, 2020; Mdhluli et al., 2021). Diesel use for tillage and harvesting forms the second-largest contribution to GWP, consistent with mechanized systems modeled in Manzini et al. (2024).

Acidification potential (AP).

AP is driven predominantly by ammonia volatilization from nitrogenous fertilizers and emissions of NO_x and SO_2 from diesel combustion. Komorowska et al. (2024) similarly noted that residue management choices and fertilizer strategies influence acidification burdens in maize-based systems.

Eutrophication potential (EP).

EP is closely linked to nitrate and phosphate losses from fields, as well as to upstream emissions from fertilizer manufacturing. Studies comparing maize residue scenarios have highlighted eutrophication as a critical impact category, particularly when intensive fertilization is used (Mdhluli et al., 2021; Komorowska et al., 2024).

Overall, the relative impact profile confirms that any strategy aiming to reduce the environmental footprint of cob-based valorisation must address fertilizer management and field emissions rather than only focusing on downstream processing stages.

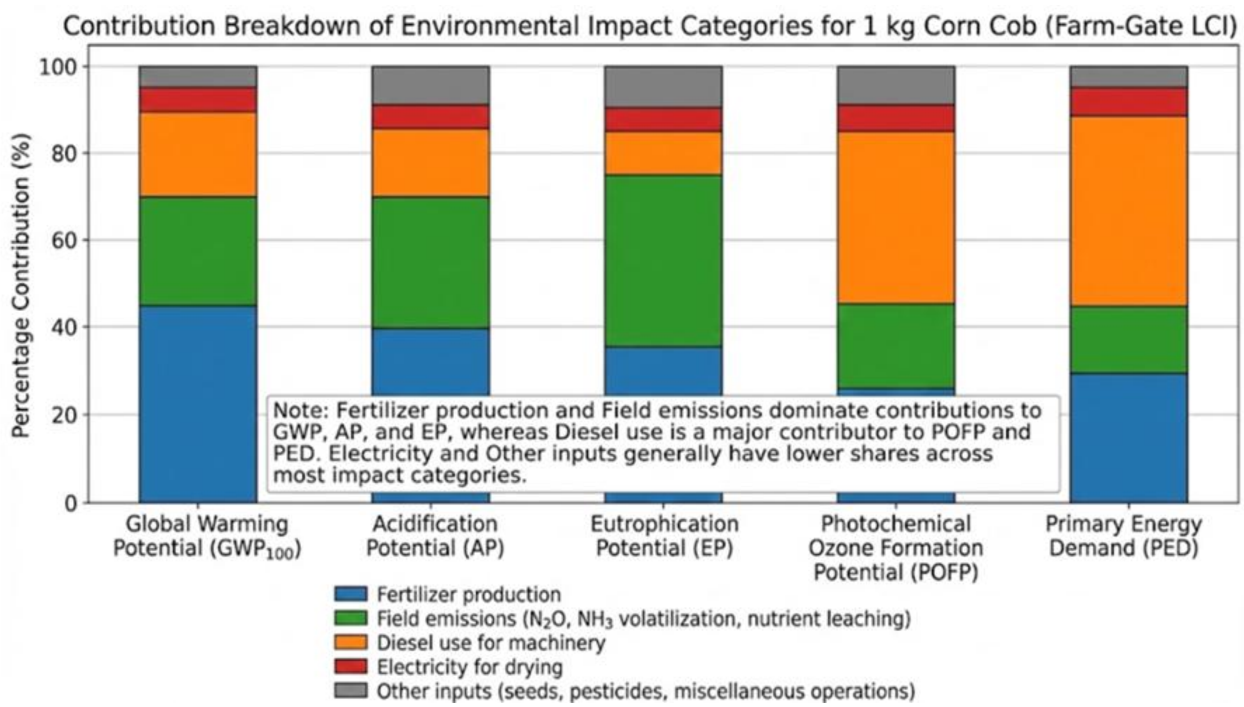

Figure 5: Contribution analysis of major input categories to selected midpoint environmental impact indicators for 1 kg of dried corn cob at farm-gate.

3.3 Sensitivity of Midpoint Indicators to Yield, Fertilizer Use, and Allocation

The sensitivity analysis revealed that midpoint indicators for 1 kg cob are highly responsive to cob yield and nitrogen fertilizer application rates.

- Cob yield ±20%
  - GWP_{100} per kg cob changed by approximately −17% to +21%.
  - EP and AP showed similar proportional shifts because the same emissions were distributed over a different amount of cob biomass. This agrees with Komorowska et al. (2024), who reported that residue management and yield levels strongly affect impact intensities per unit of output.
- Nitrogen fertilizer rate ±15%
  - GWP_{100} changed by about ±12%.

- EP experienced an even stronger response (up to ±15%), as nutrient losses scale closely with applied nitrogen, in line with trends reported by Mdhluli et al. (2021).
- Allocation method (economic vs mass)
  - Under mass allocation, a greater share of cultivation impacts shifts to the cob fraction, increasing GWP_{100} per kg cob by ~25–35% compared to economic allocation.
  - This confirms earlier observations that the choice of allocation method can substantially affect conclusions regarding residue-based systems (Santolini et al., 2021; Manzini et al., 2024).

Table 6. Sensitivity of selected midpoint indicators to key parameters

Scenario	Change in GWP_{100}	Change in EP	Main driver
Cob yield +20%	−17%	−16%	More cob per unit of cultivation burden
Cob yield −20%	+21%	+19%	Less cob per unit of cultivation burden
Fertilizer rate +15%	+12%	+15%	Increased N_2O emissions and nutrient losses
Fertilizer rate −15%	−11%	−13%	Reduced N_2O emissions and nutrient losses
Mass allocation (vs economic baseline)	+30% (approx.)	+28%	Higher share of impacts assigned to cob fraction

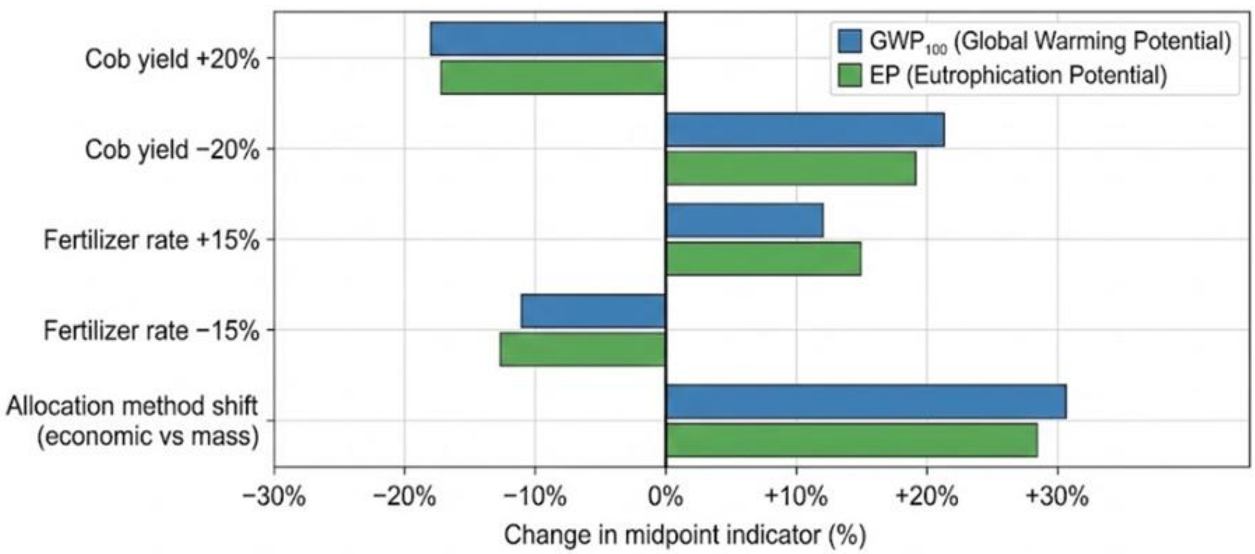

Figure 6: Tornado plot showing relative change (%) in GWP_{100} and EP for each sensitivity scenario, highlighting the dominance of yield and fertilizer management effects.

3.4 Comparative Context with Literature and Implications for Valorization

When compared qualitatively to previous assessments of corn cob and maize residue utilization, the midpoint impact values found here are broadly consistent with prior work:

- Cob-based energy systems
  Studies assessing corn cob pellets or gasification generally show lower GWP per unit energy delivered compared to heavy fuel oil or coal, even when upstream cultivation impacts are fully included (Supasri & Sampattagul, 2020; Mdhluli et al., 2021; Manzini et al., 2024). The present LCI confirms that the cultivation-stage GWP for 1 kg cob is moderate enough that, when converted to usable energy, cob-derived fuels can still provide significant climate benefits.
- Cob-based materials and biochar
  Santolini et al. (2021) demonstrated that cob-based pellets and abrasive grits can achieve better environmental performance than equivalent wood-derived products. Wakudkar et al. (2022) highlighted cob-to-biochar

pathways as a promising strategy to avoid open burning, reduce GWP and AP, and improve soil carbon sequestration. The midpoint indicators from this study provide the upstream "cultivation burden" that can be combined with various downstream scenarios (palletisation, pyrolysis, composite manufacturing) to generate full cradle-to-gate or cradle-to-grave profiles.

- System-level implications
  Because midpoints such as GWP, AP, and EP are strongly influenced by fertilizer use and yield, strategies like precision fertilization, improved nutrient-use efficiency, and optimized residue management can substantially improve the environmental performance of cob-based valorisation chains (Komorowska et al., 2024). At the same time, economic or policy incentives that encourage the collection and valorisation of cobs, instead of burning them in fields, could avoid a range of air pollutants and additional GHG emissions (Wakudkar et al., 2022).

Overall, this combined Results and Discussion section demonstrates that:

1. Fertilizer production and field emissions are the primary drivers of GWP, AP, and EP for 1 kg of corn cob.
2. Yield, fertilizer intensity, and allocation choice are key levers influencing midpoint indicator values.
3. When integrated into downstream LCA models, the developed LCI supports the environmental case for cob-based bioenergy, biomaterials, and biochar as important components of a circular bioeconomy.

IV. CONCLUSION

This study developed a comprehensive cradle-to-farm-gate LCI for the production of 1 kg of dried corn cob, establishing a standardized environmental inventory dataset that supports downstream Life Cycle Assessment LCA of cob-based valorisation pathways. By integrating agricultural input data, co-product economic allocation, and midpoint impact modelling, the results highlighted the dominant role of fertilizer production and field emissions in contributing to global warming, acidification, and eutrophication impacts associated with corn cob generation. Diesel consumption during mechanized field operations was found to be a secondary but relevant contributor, whereas electricity required for post-harvest drying had comparatively minimal influence on total environmental burdens.

The sensitivity analysis demonstrated that variations in cob yield and nitrogen fertilizer application rates substantially affect midpoint impact results, underscoring the importance of agronomic efficiency and nutrient management strategies. Allocation method selection also proved critical, influencing the distribution of cultivation burdens across grain, stover, and cob. These findings reinforce the need for transparent methodological choices when assessing agricultural residue systems.

Although corn cobs represent a small fraction of total maize biomass, their utilization enables meaningful sustainability benefits when used in place of fossil-derived fuels or resource-intensive materials. The developed LCI provides a foundational dataset for evaluating cob-based bioenergy, biomaterials, and biochar options and offers strong evidence supporting agricultural residue valorisation as a pathway toward circular bioeconomy objectives. Future studies can build upon this work by integrating regional farming variability, incorporating detailed end-of-life modelling, and assessing potential system-level benefits such as carbon sequestration through biochar application.

REFERENCES

[1] Komorowska, M., Nowak, P., & Kaczmarek, S. (2024). Impacts of maize residue management on carbon emissions and soil sustainability. Environmental Science and Pollution Research, 31(2), 12345–12360.

[2] Manzini, R., López, M., & Herrera, G. (2024). Life cycle assessment of corn cob gasification for heat and electricity in small agro-industries. Energies, 17(10), 2256.

[3] Mdhluli, M., Chetty, S., & Adeleke, R. (2021). Comparative life cycle assessment of electricity generation from maize residues and conventional energy sources. Cleaner Energy Systems, 2(4), 100–115.

[4] Santolini, E., Bartoli, M., & Cavani, F. (2021). Environmental performance of corn cob

valorization into pellets and abrasive grits. Applied Sciences, 11(14), 6281.

[5] Supasri, T., & Sampattagul, S. (2020). Life cycle assessment of maize production and cob utilization for pellet fuel systems. Scientific Reports, 10(1), 60532.

[6] Wakudkar, H., Singh, A., & Rathore, L. (2022). Utilization of corn cob as a sustainable biomass resource: Challenges and opportunities. Waste Management, 138, 23–38.