A Comprehensive Environmental Taxation Framework for Carbon Pricing in the AFOLU Sector

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Abstract. The Agriculture, Forestry, and Other Land Use (AFOLU) sector represents a significant share of national greenhouse gas emissions and plays a critical role in climate and environmental governance. However, the biogenic and spatially diffuse nature of AFOLU emissions presents major challenges for applying conventional carbon tax mechanisms. This study proposes a comprehensive carbon taxation framework that adopts an activity-based environmental accounting approach aligned with the Intergovernmental Panel on Climate Change (IPCC) guidelines. Instead of taxing direct emissions, the framework uses measurable proxy variables—such as nitrogen fertilizer consumption, livestock population, rice cultivation area, and land-use change—to calculate emissions through activity data and emission factors. This method enhances feasibility and transparency while reducing monitoring burdens. However, the implementation of this framework requires addressing key technical, economic, and regulatory challenges, including data reliability, carbon leakage risks, and potential impacts on smallholder livelihoods. The study emphasizes the need for legal and market classification of carbon units—either as financial securities or tradable commodities—to ensure robust integration with carbon markets. Establishing this regulatory clarity is essential for policy coherence, environmental effectiveness, and long-term investment in sustainable land-use practices.

1 Introduction

The Agriculture, Forestry, and Other Land Use (AFOLU) sector represents a fundamental nexus of human activity, economic development, and the global climate system. It is simultaneously a cornerstone of global food security and livelihoods for billions of people and a major source of greenhouse gas (GHG) emissions. On average, direct emissions from the AFOLU sector contribute approximately 13-21% of the total global anthropogenic GHG emissions, a figure that rises to 23% when pre- and post-production activities in the global food system are included [1]. The sector is responsible for a significant share of specific gases, including approximately 44% of methane (CH_4) and 81% of nitrous oxide (N_2O)

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emissions globally. This significant contribution, driven by deeply embedded processes like enteric fermentation in livestock, fertilizer application on croplands, and deforestation for agricultural expansion, underscores the urgent need for effective mitigation policies. Without strong and immediate policy action, the share of emissions from AFOLU is projected to grow as other sectors like energy and transport decarbonize, making it increasingly difficult, if not impossible, to achieve the climate stabilization goals set forth in the Paris Agreement.

Among the various policy instruments available, carbon pricing, particularly through a carbon tax, is recognized by a broad consensus of economists and international bodies as one of the most efficient and cost-effective tools for climate change mitigation [2]. The core principle of a carbon tax is to internalize the external cost of GHG emissions—the damage they cause to the environment and society—by placing a direct price on pollution. By making emitters pay for each ton of emitted carbon dioxide equivalent (tCO_2e), the tax creates a powerful and transparent financial incentive to reduce their environmental footprint. This encourages producers and consumers to seek out the lowest-cost mitigation options available, whether through adopting cleaner technologies, improving operational efficiency, or shifting consumption patterns. This market-based approach offers greater flexibility and economic efficiency compared to prescriptive command-and-control regulations, which often impose uniform standards without regard to the vast differences in abatement costs across a heterogeneous sector [3].

Despite its theoretical effectiveness, the implementation of carbon pricing in the AFOLU sector has been remarkably slow and limited globally. Many countries have been reluctant to apply such instruments for a confluence of powerful reasons. The sector's inherent complexity is a primary barrier. It is characterized by a multitude of small-scale, geographically dispersed emitters (millions of individual farms) and diverse biological processes that are difficult to monitor. This presents significant administrative and technical challenges in accurately measuring, reporting, and verifying (MRV) emissions and removals [4]. Furthermore, there are profound political concerns about potential negative impacts on food security, the livelihoods of millions of farmers (many of whom are already economically vulnerable), and the international competitiveness of a nation's agricultural exports [5]. The unilateral adoption of a carbon tax can also lead to the perverse outcome of "carbon leakage," where emission reductions in the regulating country are partially or fully offset by increased production and emissions in countries without similar policies, thus undermining the global environmental benefit and placing domestic producers at a competitive disadvantage [6].

This confluence of technical difficulty and political sensitivity has created a notable gap in both the scientific and policy literature. While the general principles of carbon taxation are well-established, there is a lack of comprehensive, operational guidance on how to design and calculate a carbon tax specifically for the AFOLU sector. Existing international methodologies, most notably those from the Intergovernmental Panel on Climate Change (IPCC), are primarily designed for the purpose of compiling national GHG inventories for international reporting, rather than providing a ready-made framework for taxation [7]. This paper aims to address this critical gap by proposing a comprehensive, step-by-step approach to calculate a carbon tax in the AFOLU sector. It seeks to provide a much-needed analytical framework for policymakers, moving from theoretical principles to an operational methodology that can guide the design and implementation of an effective and equitable climate mitigation strategy for one of the world's most vital and complex sectors.

2 Approaches to Carbon Taxation in the AFOLU Sector

In designing a carbon tax, the fundamental decision for policymakers is determining the object of taxation and the point of regulation—the specific entity, product, or activity upon which the tax is levied. The World Bank's "Carbon Tax Guide" outlines two principal

approaches that have been successfully applied in other sectors: a tax on fuels and a tax on direct emissions [2]. A fuel-based tax is typically an "upstream" tax, levied on the carbon content of fossil fuels at the point of production or import. This approach is administratively simple as it can often be integrated into existing excise tax systems and targets a relatively small number of large entities. In contrast, a "downstream" direct emissions tax targets the GHG emissions released from specific, identifiable facilities, such as power plants or industrial installations. This requires a robust MRV system to quantify emissions at the source but allows for more precise targeting of pollution.

However, a careful examination reveals that neither of these conventional approaches is fully suitable for the unique characteristics of the AFOLU sector. A fuel-based tax is fundamentally inadequate because it only addresses emissions from fossil fuel combustion (e.g., diesel used in tractors, irrigation pumps, and transport), failing to cover the sector's largest and most significant emission sources, which are non-energy related. These biological emissions include methane (CH_4) from enteric fermentation in ruminant livestock and anaerobic decomposition in flooded rice paddies; nitrous oxide (N_2O) from the microbial transformation of nitrogen in agricultural soils following fertilizer application; and carbon dioxide (CO_2) from land-use change like deforestation and the degradation of organic soils [1]. Taxing fuel alone would miss the vast majority of the sector's climate impact and would fail to incentivize changes in the practices that are the primary drivers of AFOLU emissions.

The direct emissions approach, while more comprehensive in theory, is largely impractical for AFOLU in practice. The core challenge is that most emissions in this sector are from diffuse, non-point sources spread across vast geographical areas. Unlike a power plant with a single smokestack, a farm's emissions come from countless individual sources—each animal, each hectare of fertilized soil, each plot of rice paddy. Directly measuring these GHG fluxes continuously is technically infeasible with current technology and would be prohibitively expensive [4]. The cost of installing and maintaining monitoring equipment on millions of farms would far outweigh any potential environmental benefit, making the downstream, facility-level taxation model entirely unworkable for the majority of AFOLU activities.

Given these limitations, an effective carbon tax for the AFOLU sector requires a tailored methodology that moves away from direct measurement. The most suitable and pragmatic method is the estimation approach. This approach, which forms the methodological backbone of the IPCC's guidelines for national GHG inventories [7], is designed to address the sector's unique emission profile. Instead of attempting to measure emissions directly at the source, the tax is levied on a measurable and administratively tractable proxy activity, and the resulting emissions are calculated using scientifically recognized emission factors. This methodology is consistent with existing policy inventories, which show that AFOLU mitigation actions are most often linked to specific land management methods or input use rather than direct, gas-specific measurements [8]. For example, N_2O emissions can be estimated and taxed based on the quantity and type of nitrogen fertilizers sold or used. Similarly, CH_4 emissions from livestock can be estimated by taxing animals based on their type, age, and production system [9]. This estimation approach provides a scientifically grounded and administratively feasible pathway to apply carbon pricing comprehensively across the diverse and complex activities of the AFOLU sector, creating a foundation upon which more sophisticated, country-specific refinements can be built over time.

3 The Object of Taxation

Following the estimation approach, the "object of taxation" is a critical design element that defines the tax base. It shifts the taxable point from the GHG emissions themselves, which are difficult to measure, to the specific, quantifiable activities that generate those emissions.

This principle uses "activity data"—a quantitative measure of a human activity resulting in emissions—as a proxy for calculating the tax liability [7]. By taxing these activities, the policy creates a direct and clear price signal that incentivizes producers to either reduce the level of the activity (e.g., use less fertilizer) or to adopt technologies and practices that lower the associated emission factor (e.g., use nitrification inhibitors that reduce N_2O emissions per unit of fertilizer). The primary objects of taxation can be categorized by the main sources of emissions within the AFOLU sector.

3.1 Nitrogen Fertilizers for Agricultural Soils (N_2O)

Nitrous oxide emissions from agricultural soils are a major component of AFOLU's climate impact, primarily driven by the application of synthetic and organic nitrogen fertilizers. The object of taxation here is the quantity of nitrogen (N) contained in fertilizers. The tax can be levied at an upstream point in the supply chain, such as on the sale of nitrogen fertilizers by manufacturers or major distributors. This approach is administratively efficient as it involves a limited number of taxable entities compared to millions of individual farmers. A tax at this point creates a price signal that cascades down the supply chain, encouraging more efficient fertilizer use by farmers, promoting the adoption of precision agriculture techniques (e.g., variable rate application based on soil testing), and stimulating the market for alternative nutrient sources with lower emission profiles.

3.2 Livestock for Enteric Fermentation and Manure Management (CH_4 and N_2O)

For emissions from livestock, which are dominated by methane from enteric fermentation in ruminants, the object of taxation is the number of animals, commonly referred to as "head of livestock." To accurately reflect emission levels and create targeted incentives, it is crucial that this object is disaggregated into specific categories based on animal type (e.g., dairy cattle, non-dairy cattle, sheep, goats), age, and production system (e.g., grazing vs. feedlot), as these factors significantly influence the emission factors for both enteric fermentation and manure management [1]. The tax would typically be levied on farm owners based on their registered livestock numbers, which necessitates a reliable national animal identification and registration system for effective administration. This approach is central to emerging policy discussions in jurisdictions like Denmark, where detailed farm-level analyses show that a carbon tax would particularly affect cattle farmers, thereby creating a strong incentive for structural changes towards less carbon-intensive production systems [10].

3.3 Rice Cultivation (CH_4)

Methane emissions from the anaerobic decomposition of organic matter in flooded rice paddies are a globally significant emission source, particularly in Asia. The object of taxation for this activity is the area of land under rice cultivation, measured in hectares. For greater accuracy and to incentivize specific mitigation actions, this can be further stratified by water management practices, as emission factors differ significantly between continuously flooded, intermittently flooded, and dry-seeded rice systems [1]. Taxing the cultivated area, with potential rebates or differentiated rates for adopting verified low-emission practices, encourages the adoption of water-saving techniques like Alternate Wetting and Drying (AWD), which can substantially reduce methane emissions without compromising yield, and can also lead to co-benefits such as reduced water use.

3.4 Land-Use Change (CO_2)

For emissions resulting from land-use change, particularly deforestation for agricultural expansion, the object of taxation is the area of forest land converted to other uses (e.g., cropland, pasture, or settlements). Implementing this requires a robust and transparent national land monitoring system, which often utilizes satellite imagery and remote sensing technologies (e.g., GIS) to track changes in forest cover over time and attribute them to specific land parcels. The tax would be levied on the landowner or entity responsible for the conversion. This directly penalizes deforestation and creates a strong economic incentive for forest conservation, sustainable forest management, and the protection of valuable carbon stocks stored in forest biomass and soils.

4 Methodology of Carbon Tax Calculation

The calculation of the carbon tax for the AFOLU sector, based on the estimation approach, is a structured process grounded in the general principles outlined by the IPCC for national GHG inventories. The core of the methodology is a two-step process: first, estimating the total GHG emissions from a specific proxy activity, and second, applying a predetermined carbon price to those estimated emissions to determine the tax liability. The general equation for estimating emissions from a proxy activity is:

$$Emissions = Activity\ Data \times Emission\ Factor$$

Where:

- Emissions is the total mass of a specific greenhouse gas (e.g., CH_4 or N_2O) emitted, typically in tonnes.
- Activity Data is the quantifiable measure of the activity being taxed (e.g., tonnes of nitrogen fertilizer sold, number of head of cattle, hectares of rice cultivated). This is the administrative base for the tax.
- Emission Factor is the average emission rate of a given GHG per unit of the activity data. The choice of emission factor is a critical step and can range in complexity from globally applicable Tier 1 defaults to highly specific Tier 3 factors derived from national research and models [6].

Once the emissions are calculated, the carbon tax liability is determined by first converting the emissions of different gases into a common metric, carbon dioxide equivalent (CO_2e), and then multiplying by the carbon price. The conversion is done using the Global Warming Potential (GWP) values published by the IPCC, which represent the total energy absorbed by a gas over a specific time horizon (typically 100 years) relative to CO_2. For the purpose of this paper, the 100-year GWP values from the IPCC's Fifth Assessment Report are used ($CH_4 = 28$, $N_2O = 265$).
The general equation for the tax liability is:

$$Carbon\ Tax = Emissions \times GWP \times Carbon\ Price$$

Below are detailed calculations and examples for each object of taxation. For all examples, a hypothetical carbon price of USD 5 per tCO_2e is used for illustrative purposes.

4.1 Tax Calculation for Nitrogen Fertilizers

- The Activity Data: Tonnes of nitrogen (N) sold or applied.
- Emission Factor: Tonnes of N_2O emitted per tonne of N applied. The IPCC default Tier 1 emission factor for direct N_2O emissions from nitrogen inputs to managed

soils is 1% (0.01 t N_2O-N / t N). To convert this mass of nitrogen in N_2O to the mass of N_2O itself, we multiply by the molecular weight ratio of N_2O to N_2 (44/28).

- Example: A fertilizer company sells 10,000 tonnes of urea (which has a 46% N content).
  1. Calculate Total Nitrogen: 10,000 t urea × 0.46 = 4,600 t N
  2. Calculate N_2O Emissions: 4,600 t N × (0.01 t N_2O-N / t N) × (44/28) = 72.29 t N_2O
  3. Convert to CO_2e: 72.29 t N_2O × 265 (GWP for N_2O) = 19,156 tCO_2e
  4. Calculate Carbon Tax: 19,156 tCO_2e × USD 5/tCO_2e = USD 95,780

4.2 Tax Calculation for Livestock (Enteric Fermentation)

- Activity Data: Number of head of livestock, by category.
- Emission Factor: Tonnes of CH_4 emitted per head per year. This factor varies greatly by animal type, age, weight, diet, and production system.
- Example: A large-scale dairy farm has 500 dairy cows. We use an IPCC Tier 1 emission factor for dairy cattle in a Latin American context (e.g., 56 kg CH_4/head/year).
  1. Calculate Total CH_4 Emissions: 500 head × (56 kg CH_4/head/year) = 28,000 kg CH_4/year = 28 t CH_4/year
  2. Convert to CO_2e: 28 t CH_4 × 28 (GWP for CH_4) = 784 tCO_2e
  3. Calculate Carbon Tax: 784 tCO_2e × USD 5/tCO_2e = USD 3,920

4.3 Tax Calculation for Rice Cultivation

- Activity Data: Area of rice cultivation in hectares (ha), often for a specific growing season.
- Emission Factor: Tonnes of CH_4 emitted per hectare per cultivation season. This factor is highly dependent on water management, organic amendments, and soil type.
- Example: A province has 100,000 hectares of continuously flooded rice paddies with straw incorporated. We use an IPCC default emission factor for this condition (e.g., 1.3 kg CH_4/ha-day) and assume a 120-day growing season.
  1. Calculate CH_4 Emissions per Hectare: 1.3 kg CH_4/ha-day × 120 days = 156 kg CH_4/ha = 0.156 t CH_4/ha
  2. Calculate Total CH_4 Emissions: 100,000 ha × 0.156 t CH_4/ha = 15,600 t CH_4
  3. Convert to CO_2e: 15,600 t CH_4 × 28 (GWP for CH_4) = 436,800 tCO_2e
  4. Calculate Carbon Tax: 436,800 tCO_2e × USD 5/tCO_2e = USD 2,184,000

5 Potential Implementation Challenges

Although the estimation approach offers a pragmatic and theoretically sound pathway, the practical implementation of a carbon tax in the AFOLU sector is fraught with significant hurdles. These challenges are not insurmountable but require careful consideration in the policy design phase to ensure the tax is effective, equitable, and politically durable. They can be broadly categorized into technical, economic, and socio-political aspects.

5.1 Technical and Administrative Challenges

The foundation of the estimation approach is reliable data, which presents three core technical issues. First is the availability and quality of activity data. Many developing countries lack

accurate, disaggregated data on livestock populations, fertilizer sales, or verified land-use change, weakening the tax base. Second is the establishment of a credible Monitoring, Reporting, and Verification (MRV) system. Monitoring millions of diffuse sources is a complex and resource-intensive task that can strain government resources. Third is the accuracy of emission factors. IPCC Tier 1 defaults are generic and may not reflect local conditions, while developing country-specific Tier 2 or 3 factors requires significant long-term investment in research and data collection [7].

5.2 Economic Challenges

Implementing a carbon tax unilaterally introduces significant economic risks. The primary concern is competitiveness and carbon leakage. Increased domestic production costs can disadvantage farmers in international markets, potentially shifting production and emissions to countries without similar policies, thus undermining the global environmental benefit [6], [8]. Another key issue is the impact on farmer livelihoods. The tax represents a direct cost that can disproportionately affect smallholders with limited capacity to adapt, potentially exacerbating rural poverty, as shown by analyses in Denmark [10]. This, in turn, raises concerns about food security and affordability, as higher production costs may lead to increased food prices, which would most heavily impact low-income households.

5.3 Political and Social Challenges

The political viability of an AFOLU carbon tax is a major hurdle. Taxes on large sectors like agriculture often face intense political opposition from powerful industry groups and rural constituencies. Overcoming this requires strong political will and broad stakeholder engagement. Furthermore, the policy must address equity and distributional effects. The tax burden will not be uniform, and designing an equitable system is paramount. This requires ensuring that tax revenues are recycled to support the most vulnerable groups, for instance through direct payments or subsidies for green technologies, as proposed in South Africa's just transition framework [11]. Finally, successful implementation depends on strong institutional capacity. Governments must be able to manage complex data systems, administer the tax, and enforce compliance, which requires technical expertise and resources that may be lacking.

6 Conclusion and Recommendation

Addressing GHG emissions from the AFOLU sector is imperative for achieving global climate targets. While a carbon tax is an economically efficient instrument for this purpose, its application is hindered by the sector's unique complexities, which render conventional taxation models impractical. This paper has argued that an estimation approach, which taxes measurable proxy activities, offers the most viable and comprehensive framework for implementing a carbon tax in the AFOLU sector. By targeting key activities—fertilizer use, livestock numbers, rice cultivation, and land-use change—this methodology provides a clear, operational, and scientifically grounded pathway for policymakers.

However, the journey from an analytical framework to effective on-the-ground implementation is fraught with challenges. As this paper has detailed, technical barriers in data and MRV, significant economic concerns including carbon leakage and adverse impacts on farmer livelihoods, and strong socio-political resistance are formidable obstacles that must be proactively and thoughtfully addressed in the policy design phase.

Overcoming these hurdles requires a concerted and multi-faceted effort. It necessitates strong and sustained political will, substantial investment in building the institutional and technical capacity for data management and MRV, and a commitment to developing country-specific emission factors to improve accuracy over time. Crucially, the design of the carbon tax cannot exist in a vacuum. It must be integrated with a suite of complementary policies, most importantly revenue recycling schemes that are explicitly designed to support vulnerable farmers, fund the transition to low-emission practices, and ensure a just transition for rural communities, thereby mitigating the most severe social and economic consequences.

Looking forward, a critical and often overlooked aspect for the long-term success of carbon pricing is the need for regulatory foresight. As carbon pricing mechanisms evolve, potentially incorporating offsets and linking to domestic or international emissions trading systems, the "carbon unit" (a tonne of CO_2e) begins to function not just as a metric for taxation, but as a tradable asset. This creates a crucial and complex policy question: should this unit be legally classified as a commodity, a financial security, or a new, unique asset class? The answer has profound implications for market oversight, investor protection, and overall market stability. We strongly recommend that a formal dialogue between tax regulators and financial market regulators be initiated early in the policy design process. Reaching a clear consensus on the legal and regulatory status of carbon units is paramount. Such an agreement would prevent regulatory arbitrage, provide the legal certainty needed to attract long-term private investment in mitigation technologies, and ensure the stable and transparent development of a robust and credible carbon market. Without this foundational regulatory coherence, the full potential of carbon pricing as a transformative climate policy tool may not be realized.

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