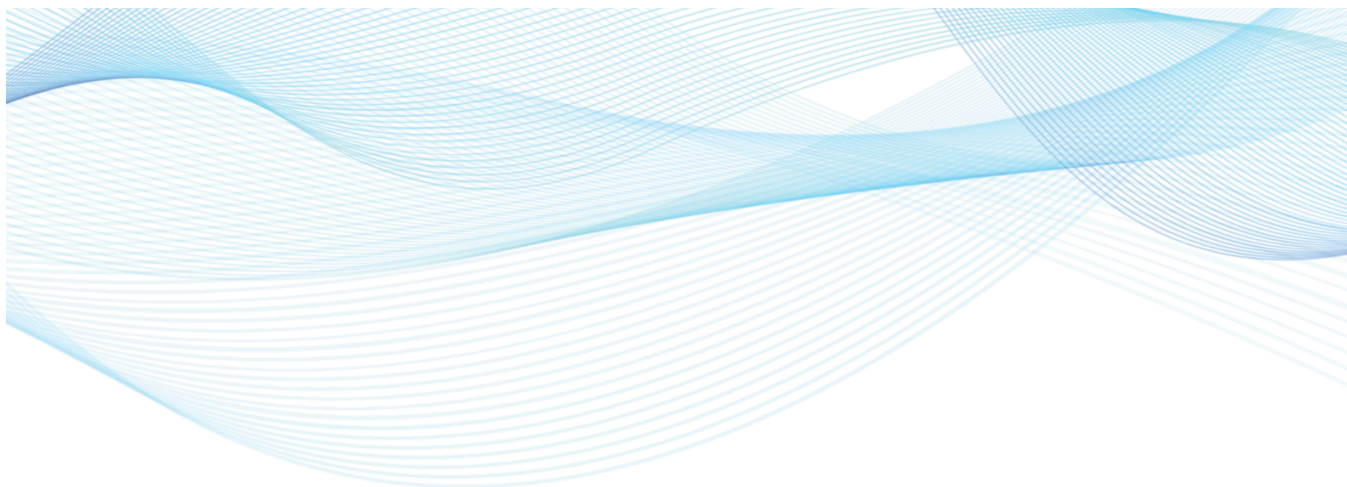




Decentralized, Farmer-First Biochar: The Lowest-Cost Path to Eliminating Stubble Burning

Prepared by the Princeton University Economic Development
Organization (PUEDO) for Nirvana Carbon Solutions

Table of Contents

Executive Summary.....	2
Introduction.....	3
Carbon Credit Markets.....	5
Voluntary Carbon Markets.....	6
Biochar C-Sinks.....	8
Climate Impact of Biochar Usage.....	12
Air Quality.....	13
Baseline Calculation.....	15
Percent Reduction.....	15
Biochar Output Impact.....	15
Soil Quality.....	15
Biochar Preparation and Production Process.....	17
Project Context and Objectives.....	17
Production Process.....	18
Social Architecture and Governance.....	19
Benefits of Biochar.....	21
Agricultural Advantages.....	21
Social and Economic Empowerment.....	24
Fostering Sustainable Development Goals (SDGs).....	26
Feasibility Study.....	31
Pilot #1 - Feasibility & Implementation Readiness.....	31
Pilot #2 - Quantitative Outcomes.....	38
Digital Monitoring, Reporting, and Verification (dMRV) System.....	41
Objectives of the dMRV System.....	41
App Functionality and Data Requirements.....	42
Governance Structure and Roles.....	42
Compliance and Enforcement Mechanisms.....	43
Operational Workflow of dMRV:.....	44
Integrated dMRV Workflow.....	45
System Strengths and Innovations.....	46
Conclusion.....	47
References.....	49

Executive Summary

Carbon markets are increasingly recognized as a powerful mechanism for financing climate mitigation, allowing verified greenhouse gas (GHG) reductions or removals to generate economic value. Biochar, a carbon-rich material produced by pyrolyzing agricultural residues, offers a high-integrity, socially inclusive solution. By converting crop residues that would otherwise be burned or left to decompose into stable carbon, biochar sequesters carbon for over a century while improving soil fertility, water retention, and microbial activity.

In India, stubble burning is a widespread practice that rapidly clears fields but releases massive greenhouse gases and particulate matter, contributing to 30–35% of winter smog and severe health impacts. Biochar provides an effective alternative by reducing methane emissions, lowering local air pollutants, and serving as a permanent carbon sink. It also enhances crop yields and nutrient retention, creating a direct link between climate mitigation and agricultural productivity.

Nirvana Carbon Solutions' flagship Carbon 1 project in Eastern India replaces open-field burning with artisanal flame-curtain pyrolysis, tracked through a robust digital MRV (dMRV) system. Each step from kiln registration to biomass application is monitored and verified using app-based tools, AI-assisted audits, and community specialists, ensuring transparent, batch-level carbon accounting. Early results indicate substantial reductions in particulate matter, methane, nitrogen oxides, and carbon monoxide, alongside measurable carbon sequestration.

I. Introduction

Over the last decade, carbon markets have emerged as a way to channel capital into climate mitigation, providing a way to sell carbon removals and avoidance to willing buyers. One rapidly growing pathway for mitigation financing involves biochar, which is produced by pyrolyzing agricultural residues like crop stubble rather than burning them in the open. This approach not only curbs air pollution but also enables long-term carbon sequestration while improving soil fertility. Additionally, among the anthropogenic sources of carbon emissions, methane stands out as a gas that has an outsized negative impact on climate change, with 25 times more warming potential than carbon dioxide. This report lays the groundwork for forthcoming guidelines on how project developers can leverage biochar to generate high-integrity, scalable carbon credits while enhancing agronomic resilience and community benefits. This report will contain an overview of how carbon markets, biochar, and MRV (Monitoring, Reporting, and Verification) methodologies can align to create a sustainable solution for agricultural waste management.

Nirvana Carbon Solutions' Carbon 1 project illustrates how biochar credits function in practice. Under baseline conditions, farmers in Eastern India burn crop residues in open fields, generating CO₂, particulate matter, and methane with no long-term carbon storage. The project replaces this with flame-curtain pyrolysis carried out by certified Artisan Biochar Producers, generating a persistent carbon sink while improving soil health and reducing air pollution. The baseline for carbon removal accounting is therefore zero, since no durable C-sink exists without the intervention. Supported by digital MRV tools from PlantVillage and strict tracking requirements, the project is expected to sequester over 11 million tCO₂e in its first five years, demonstrating how carbon credits can finance community-centered, high-integrity removal at scale.

As global standards evolve, especially with the release of Verra's VM0051 methodology recognizing avoided crop residue burning and other improved agricultural practices, biochar-based carbon credits are becoming a central pillar of high-integrity carbon removal. They offer a scientifically grounded, socially equitable, and verifiable pathway for channeling climate finance into communities that have historically received little investment despite facing severe climate vulnerability. In an era where carbon markets increasingly demand transparency and long-term impact, biochar credits represent one of the most credible and scalable solutions available for agricultural mitigation and rural climate resilience.

II. Carbon Credit Markets

As a foundational component of global climate mitigation efforts, carbon markets facilitate the exchange of verified greenhouse gas emissions reductions. These mechanisms are grounded in Article 6 of the 2015 Paris Agreement, which outlines two key pathways for international cooperation. Article 6.2 enables countries to engage in direct bilateral transfers of mitigation outcomes, provided that safeguards are in place to prevent double counting (Paris Agreement, 2015). Separately, Article 6.4 introduces a centralized framework for carbon crediting overseen by the United Nations. This mechanism is intended to replace the Clean Development Mechanism of the Kyoto Protocol, prioritizing transparency, credibility, and equitable benefit-sharing—particularly by directing a portion of revenues toward adaptation initiatives in vulnerable nations (Paris Agreement, 2015). Subsequent negotiations at COP26 and COP29 produced a comprehensive rulebook to support implementation, providing guidance not only for state-to-state exchanges but also for the design of national markets (Hucke, 2025). Although Article 6 was designed for intergovernmental use, its operational principles are increasingly shaping standards within the voluntary carbon market.

Voluntary Carbon Markets

Figure 1: Voluntary Carbon Market Stakeholders. Adapted from VCMPrimer (Dyck et al., 2024).

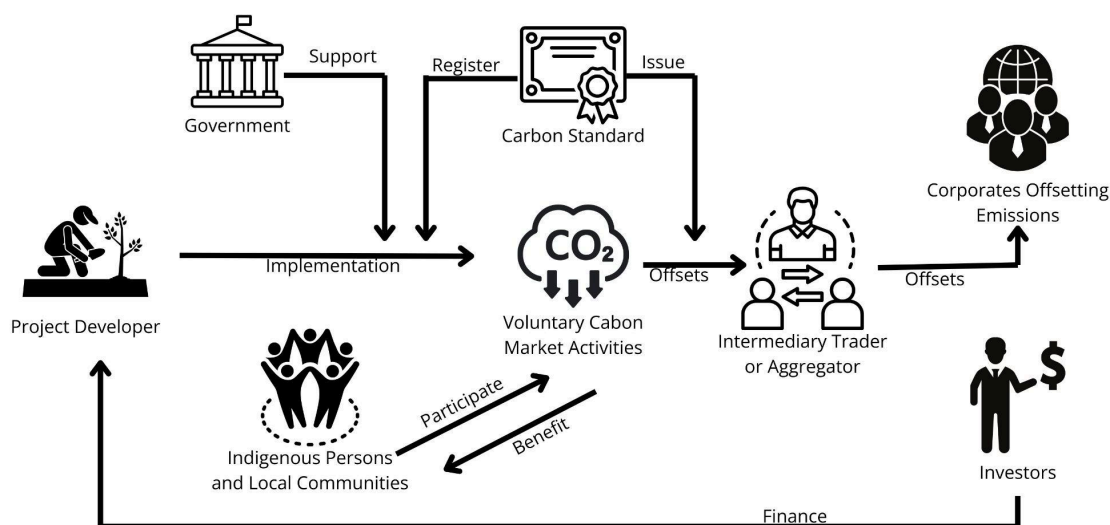


Figure 1 outlines the structure of the voluntary carbon market, highlighting the interconnected roles of governments, carbon standards, project developers, Indigenous Peoples and Local Communities (IPLCs), traders, investors, and corporate buyers. Voluntary carbon market participants including corporations, marketplaces, and brokers provide the primary funding source for the project's carbon sequestration work. Governments provide regulatory support, while carbon standard bodies such as Verra register projects and issue verified carbon credits. Project developers are responsible for implementing offset projects on the ground, often in collaboration with IPLCs, who both participate in and benefit from these initiatives. Once credits are issued, they enter voluntary carbon market activities, where intermediary traders or aggregators facilitate transactions between developers and corporate entities seeking to offset their emissions. Investors supply the necessary capital to finance projects, anticipating returns from the sale of credits. This section focuses on the role of project developers and examines how they can stay ahead of the curve in terms of emissions MRV and data transparency, particularly

as carbon standards evolve to demand higher levels of environmental and methodological integrity.

Carbon credits function as tradeable units that represent one metric ton of carbon dioxide or its greenhouse gas equivalent, and they are only issued when a project demonstrates verified emissions reductions or removals. As described in Carbon Credit and Carbon Offset Fundamentals, their integrity relies on principles such as additionality, permanence, measurability, and transparent third-party verification, all of which ensure that credited climate benefits are real and not double counted. Credits move through a standardized lifecycle, including project design, validation, monitored implementation, verification, issuance, and retirement, allowing buyers to claim a quantifiable environmental impact. This structure has made carbon credits a central mechanism for channeling climate finance into sectors where mitigation would otherwise be economically infeasible.

Within agricultural systems, credits typically come from two pathways: avoidance of emissions or removal of atmospheric carbon. Avoidance credits have recently faced credibility challenges due to difficulties in establishing accurate baselines and verifying outcomes across millions of hectares. These limitations have heightened interest in removal-based credits, particularly those generated through biochar. Because biochar is physical, measurable, and lab-verifiable, biochar credits offer a more concrete and durable form of carbon removal compared to many land-use or methane avoidance projects.

III. Biochar C-Sinks

The Global Artisan C-Sink Standard outlines how low-tech pyrolysis systems used by trained artisans can convert crop residues into biochar, a material rich in Persistent Aromatic Carbon capable of storing carbon for centuries to millennia. All fossil CO₂ emissions are offset by long-term carbon sinks before the registration of a biochar C-sink is validated in the Global C-Sink Registry. CO₂ is only offset with geological C-sinks, such as the persistent aromatic carbon (PAC) fraction of soil-applied biochar, that are registered in the Global C-Sink Registry. The emission offsets are realized with the registered permanent biochar C-sink whose production had caused the emission.

Historically, Carbon Standards International has proposed in the Global Artisan Guidelines to consider a ratio of 30 kg CH₄ per ton of Biochar for accounting the methane emissions occurring during the biochar production. This value comes from Cornelissen et al. (2016); an average 30 kg CH₄ emissions occurring during the production of 1 ton of biochar in a Kon-Tiki kiln has indeed been calculated, however the condition of the pyrolysis where not completely representative of the operations conducted under a certified C-Sink manager as the feedstock was high in moisture content compared to what we require from our partners.

Recently new studies were published highlighting lower emission factors. For instance, 3.6kg CH₄ per ton of biochar is reported (Cornelissen et al., 2023), while the study explains that the lower value “is probably caused by the lower moisture content of the currently used dry twigs (14.7%) than of those used in the previous study in Nepal (25%)”. This study also highlights the link between moisture content and CH₄ emission factor.

As per the latest scientific studies, the mean methane emission for Kon-tiki/Soil pit is known to be 3.6 kg CH₄/t DM biochar produced.

The Absolute Global Warming Potential of the methane emissions are calculated based on:

$$AGWP_{CH4}(100) = \sum_{y=0}^{100} (IRF(CO_2, a(y)) * [CO_2e \text{ of } CH_4 \text{ emissions per load}])$$

To calculate the Absolute Global Warming Potential (AGWP) over 100 years we are using Jeltsch-Thömmes & Joos (2019) to calculate the decay of the CO₂. Greenhouse gases decay in the atmosphere. The quantities of CO₂ still present in the atmosphere each year are added up over the 100 years, resulting in the absolute global warming potential (AGWP) over 100 years.

The decay is described by the equation:

$$[IRF(CO_{2,a}(t))] = a_0 + \sum_{i=1}^5 a_i * \exp \exp \left(\frac{-t}{\tau_i} \right) \text{ for } t \geq 0$$

With the values

i	ai	ti
0	0.008	
1	0.044	68521
2	0.112	5312
3	0.224	362
4	0.31	47
5	0.297	6

The resulting methane emissions of the produced biochar are calculated as below, with the GWP100 (CH₄) value of 25 CO₂e.

$$[CO_2e \text{ of } CH_4 \text{ emissions per load}] = [Total \text{ methane emissions}] * [GWP100_{CH4}]$$

Absolute Global Cooling Potential of SPC fraction:

The Absolute Global Cooling Potential (AGCP) of the SPC for the first 20 years is calculated as followed:

$$[AGCP(20)] = \sum_{t=0}^{20} (C_{remain}(t, SPC) * IRF(CO_{2,a}(t) * M_{biochar} * C_{content}))$$

With:

$C_{remain}(t, SPC)$ as the adjusted equation 2 of Global Artisan C-Sink Standard for the SPC fraction of the biochar (25%)

$$[C_{remain}(t, SPC)] = \frac{M_{BC} * C_{Content}}{1000} * (750 + 45 * e^{-0.5232*t} + 205 * e^{-0.009966*t}) - 0.75$$

Biochar carbon sinks are registered with the geo-localized area where the biochar or its derived products have been applied. This encompasses scenarios where biochar serves as a soil amendment or finds application in various contexts, such as construction for residential, infrastructural, or road-related purposes. In certain specific instances where marginal quantities of biochar are applied or utilized in products, the registration of so-called diffuse carbon sinks (i.e., non-geo-localized) is permitted.

The following information are registered for biochar carbon sink:

1. Feedstock of biochar production
2. Technology of production
3. Date or period of production

4. C-content and H/C ratio of biochar (measured or taken from the Ithaka database)
5. Matrix into which the biochar was mixed (compost, manure, feed, cement etc.)
6. Location of the C-sink (vector file of field location; for fields < than 1000 m² one GPS point per field is sufficient, for C-Sink Networks and C-Sink Villages only the vector file of the network and village, respectively, is needed)
7. Amount of biochar applied in tons (dry matter tons)
8. Date of application
9. Owner of the C-sink site (name, address, birth date – not necessary for C-Sink Network and C-Sink Village)
10. C-sink project design document
11. Validation report of the validation body
12. Verification report of the verification body
13. Monitoring plan of the operation
14. Confirmation of the compensation of the emission portfolio of the biochar

IV. Climate Impact of Biochar Usage

Stubble burning, the open-field burning of agricultural residues post-harvest, is a widespread practice in the Indo-Gangetic Plain, the world's second most fertile region and a key contributor to India's agricultural status. In a calendar year, there are two growing seasons and farmers need to quickly harvest and clear fields before planting the next crop (Singh et al., 2023). A mere one-week delay in sowing the next crop can result in a yield loss of 60 kg/ha (Kaur et al., 2023). Thus, farmers burn the crop residue on their fields because this method is essentially free and rapidly clears fields for farmers reliant on short planting windows. However, the environmental and health costs are staggering. According to a study by the Indian Agricultural Research Institute, in 2008-9 stubble burning released 149.24 Mt of CO₂, over 9 Mt of CO, 0.25 Mt of SOX, and 1.28 Mt of particulates (Modi, 2022). This practice contributes to 30-35% of the region's severe winter smog (Govardhan et al., 2023). The resulting pollution reduces life expectancy by 149,000 disability adjusted life-years annually and incurs approximately \$1.53 billion in healthcare costs over five years (Suleri et al., 2024). Ultimately, farmers lack affordable alternatives to stubble burning, perpetuating the practice despite its devastating impact on air quality, climate change, and public health.

In addition to greenhouse gasses, open burning emits particulate matter and black carbon, which have severe implications for air quality. These emissions are linked to acute respiratory and cardiovascular conditions, disproportionately affecting vulnerable populations in farming regions. During peak burning seasons, the air quality index (AQI) in northern India often exceeds hazardous levels, causing widespread health crises. The environmental impacts also extend to soil degradation and loss of soil organic matter. Open burning leads to the volatilization of critical nutrients, such as nitrogen and phosphorus, reducing soil fertility and necessitating

increased use of synthetic fertilizers. The cumulative loss of carbon and nitrogen from burning is estimated at 26.1 Tg and 0.35 Tg annually, significantly impacting regional biogeochemical cycles (Sahai et. al, 2011).

Artisanal biochar is a scalable, high-integrity climate mitigation solution for addressing crop-stubble burning in South and Southeast Asia. Biochar presents a scientifically robust and socially inclusive pathway for carbon offset generation. When produced via low-cost flame-curtain pyrolysis, biochar sequesters carbon for over a century and offers co-benefits for soil fertility, water retention, and air quality.

Air Quality

Agricultural burning contributes up to 40% of India's winter smog, leading to severe health issues, particularly for women and children. Fortunately, the use of biochar helps to mitigate these emissions through multiple channels. By reducing particulate emissions associated with stubble burning, biochar production improves air quality and public health outcomes. Biochar has also been shown to reduce the activity of methanogenic bacteria and increase the activity of methanotrophic bacteria, ultimately reducing methane emissions from anaerobic decomposition by up to 40%. Additionally, when biomass is converted to biochar, it acts as a long-term carbon sink, accompanying the previously mentioned benefits. Thus, these projects offer a multifaceted mitigation benefit, both functioning as a carbon sink and preventing greenhouse gas emissions associated with burning and natural biomass decay.

Nirvana Carbon Solutions' flagship biochar project, Carbon 1 in East India, eliminates crop burning and turns agricultural waste into a high-integrity carbon sink while supporting rural livelihoods and improving soil health. Carbon 1's climate impact is rooted in both direct carbon

removal and air pollution mitigation. The project achieved an estimated 200 tCO₂e in sequestration during its early stages, contributing toward our 2025 target of 10,000 tCO₂e. In parallel, by displacing open-field burning, Carbon 1 achieves drastic reductions in particulate matter (PM_{2.5}/10: 75%), methane (87%), nitrogen oxides (99%), and carbon monoxide (85%), pollutants that collectively account for 35% of India's winter smog and reduce life expectancy by 6.4 years.

Metric	Cumulative Value	Operational Context
Usage runs fully verified	351	Runs with complete end-to-end documentation from kiln registration to soil application.
Biochar bags applied to soil	10,522 bags	Confirmed bags that passed verification and were geotagged as soil-applied.
Dry biomass diverted from open burning	~985 tons	Estimated from feedstock-to-biochar ratios; assuming 5 kg biomass per ton of biochar.
Total biochar mass	~197 tons	Assuming ~1–1.2 kg per bag depending on feedstock density and moisture content.
Estimated CO ₂ e permanently removed	~209 tons CO ₂ e	Based on IPCC factors of 2.4 – 2.6 tCO ₂ e per ton of biochar applied to soil.

Baseline Calculation

Since 5 tons of stubble would be used to produce 1 ton of biochar, our baseline is ~47kg CH₄

$$5.7 \frac{\text{kg CH}_4}{\text{ton stubble}} \times 5 \frac{\text{ton feedstock (DM)}}{\text{ton biochar (DM)}} = 28.5 \frac{\text{kg CH}_4}{\text{ton biochar (DM) that would have been produced}}$$

Percent Reduction

Using kon-tiki pyrolysis, there is a 92.4% reduction in methane emissions.

$$\frac{28.5 \text{ kg CH}_4 - 3.6 \text{ kg CH}_4}{28.5 \text{ kg}} = 87.4\%$$

Biochar Output Impact

- Bags of Biochar Produced: 19,441 20-liter bags were generated in Q2, compared to 3,960 in Q1, a 391% increase.
- Volume of Biochar: Q2 produced approximately 194,410 liters (vs. 39,600 liters in Q1).
- Soil-Applied Biochar: 114,000 liters applied and verified through our dMRV system, nearly 3X more than Q1.
- CO₂e Sequestered (Spring 2025): Estimated 47–56 tCO₂e, based on IPCC-aligned conversion metrics.

Soil Quality

When applied to soil, biochar enhances fertility by improving nutrient retention, water-holding capacity, and microbial activity, leading to increased crop yield (Schmidt &

Taylor, 2014). Improved soil fertility leads to increased crop yields and more nutritious crops. Biochar enhances soil structure, reduces erosion, and supports long-term land regeneration, which help restore degraded ecosystems, build resilience to environmental stress, and protect biodiversity.

Farmers who integrate biochar into their soils are expected to see a 20% increase in crop yield due to improved soil quality, higher water retention, and enhanced nutrient availability. Biochar application has been shown to increase the water holding capacity of paddy soils. Biochar's microstructures create a stimulating environment for beneficial bacteria to grow. The incorporation of biochar into paddy soils can alter the structure of rhizosphere microbial communities, promoting beneficial microorganisms. Research indicates that biochar application increases bacterial richness and positively influences soil enzyme activities, contributing to improved soil health.

In addition to enhancing productivity, biochar counteracts soil degradation, a major issue in continuously cultivated fields. Repeated crop cycles and open-field burning increase soil acidity, leading to nutrient imbalances and toxic conditions that reduce yields. By integrating biochar into the soil, we neutralize acidity, prevent aluminum and iron toxicity, and improve calcium and magnesium availability, ensuring a more stable and productive growing environment. Moreover, we offer farmers a choice of additional compost fertilizers, including vermicompost, organic fertilizers, and chelated calcium, further enriching the soil and strengthening plant health.

V. Biochar Preparation and Production Process

Across eastern India's agricultural belt, crop-residue burning is both a necessity and a crisis. Each harvest, farmers ignite fields of leftover rice straw and maize stalks to prepare quickly for the next planting season. While this practice clears fields within days, it also blankets cities like Kolkata in smog, releases potent greenhouse gases, and accelerates soil degradation. Nirvana Carbon Solutions (NCS) was founded to replace that destructive cycle with a circular one: transforming waste into a stable carbon sink that improves soil health and sustains rural livelihoods. Its flagship Carbon 1 Project, registered under the Global Artisan C-Sink Standard v2.1A, trains smallholder farmers to produce biochar, a carbon-rich material created by controlled pyrolysis of crop residues. Through this process, plant carbon that would have returned to the atmosphere as CO₂ or methane is instead locked into a stable form that can persist for up to a thousand years. The initiative integrates scientific rigor, digital monitoring, and equitable revenue sharing to build what NCS calls a community-owned carbon economy.

Project Context and Objectives

The project began in Paschim Medinipur, West Bengal, where open field burning incidents number in the thousands annually. Here and across neighboring states (Odisha, Assam, Bihar, and Jharkhand), smallholder farmers cultivate on plots averaging 0.2–1 hectare and live on \$2–5 per day. The Carbon 1 Project aims to:

1. Eliminate open field burning by redirecting agricultural residues into biochar kilns.
2. Increase carbon sequestration through the creation of long-lived C-sinks, verified by the Artisan C-Sink methodology.

3. Improve soil productivity by applying biochar to fields, enhancing pH balance, water retention, and nutrient storage.
4. Provide income diversification through wage payments, carbon-credit revenue sharing, and training.

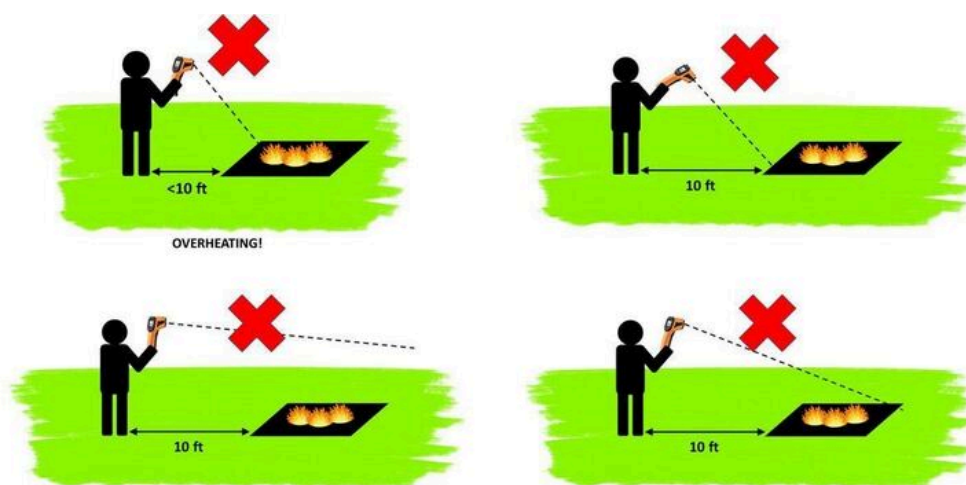
Production Process

The technical foundation of the project is described in the Biochar Preparation Process manual, which serves as a day-to-day guide for artisans and field managers. Feedstock is collected daily at sunrise, dried to under 24% moisture, and placed near designated kiln sites at least one meter away from pits for safety. Pits are pyramid-shaped and dug two meters wide and one meter deep, ensuring proximity to water sources for quenching. Controlled flame-curtain pyrolysis converts straw into biochar, maintaining temperatures around 700–800°C. Each production step is documented via the PlantVillage App through geo-tagged photos, timestamps, and data entries. Once cooled, biochar is reapplied to the farmer's field for soil enrichment.

Figure 2: Example of well-constructed soil pit kiln with raised edges for safety



Figure 3: Interactive PlantVillage app for registering work



Each ton of biochar produced under Nirvana's system corresponds to roughly 2.29 tons of CO₂e permanently removed. Methane emissions are minimal due to stringent moisture control and efficient kiln design. All emissions and offsets are recorded in the Global C-Sink Registry, which tracks feedstock type, production date, carbon content, and application GPS coordinates.

Social Architecture and Governance

The Carbon 1 Project is as much a social-enterprise model as a climate intervention. Nirvana Carbon Solution's organizational structure ensures transparency and fair compensation at every level.

Role	Responsibilities
Artisan Biochar Producer	Trained local worker who manages the kiln; earns per verified batch and receives safety gear.

C-Sink Farmer	Landowner who hosts the kiln and applies biochar to fields.
dMRV Specialist	Digitally literate youth who oversee 10–15 kilns, upload data, and mediate grievances.
District Manager	Supervises field compliance and conducts inspections.
Community Partner	Local NGO or self-help group that co-owns revenue agreements and manages payroll.

NCS’s revenue-sharing policy guarantees that at least 70 percent of carbon-credit income returns to the communities through direct payments, co-benefit projects, or wages. Daily-wage laborers are paid per West Bengal’s official minimum-wage schedule, while interns and full-time staff receive fair compensation aligned with local law.

The Carbon 1 Project supports multiple UN Sustainable Development Goals: poverty reduction, zero hunger, gender equality, and climate action. By embedding production within small farms and ensuring minimal fossil-fuel transport, the model achieves near-zero leakage and transforms pollution sources into productive assets. Its circular design advances responsible consumption and production (SDG 12) while delivering measurable climate action (SDG 13).

VI. Benefits of Biochar

Agricultural Advantages

Biochar is a carbon-rich material produced by pyrolyzing biomass under oxygen-limited conditions. In regions where crop residues are typically burned in the open, it reframes stubble from a waste problem into a managed soil amendment. First, at the field level, applying biochar improves nutrient retention, water-holding capacity, and microbial activity, thereby increasing soil fertility and crop yields (Schmidt & Taylor, 2014).

Second, these agronomic gains are accompanied by significant climate and air-quality benefits. Because biochar stores carbon in a stable form for over a century, it acts as a long-term carbon sink (Schmidt & Taylor, 2014). Producing biochar from dry feedstock also avoids most of the methane emissions that are typically associated with low-tech pyrolysis (Cornelissen et al., 2023). By displacing open stubble burning, biochar further reduces particulate pollution and associated health burdens.

Finally, the technology is explicitly designed to be low-cost and accessible for smallholder farmers, and is recognized as a valid low-tech pathway for generating carbon credits (Cornelissen et al., 2023). This creates a direct financial incentive that links environmental sustainability with improved rural livelihoods.

In practice, this means working with residues such as rice straw and cotton stalks, which currently pose a significant environmental and public health challenge across India. In the Indo-Gangetic Plain—one of the world’s most fertile and intensively farmed regions—farmers must clear their fields quickly between cropping cycles. With limited labor and machinery, the cheapest and fastest option is open-field stubble burning. This practice, while convenient, is highly destructive: it is estimated to contribute up to 35% of the winter smog over northern India,

pushing air quality to hazardous levels in cities like Kolkata and Delhi (Govardhan et al., 2023). The associated health burden is severe, with stubble burning linked to a loss of 149,000 disability-adjusted life years and an estimated \$1.53 billion in healthcare costs over just five years (Suleri et al., 2024).

Beyond agricultural residues, the project also targets waste streams from dumping grounds and small village industries—such as sugarcane bagasse, sal leaves, bitter gourd leftovers, rice husk, coffee husk, and nutshells. These materials are similarly unmanaged and are typically either burned in the open or left to decompose, both of which release greenhouse gases without delivering any agronomic benefit.

To ensure environmental integrity, only biomass that meets the Global Artisan C-Sink Standard’s sustainability criteria is used. As of the most recent PDD draft, the project’s active and planned feedstocks include rice straw, maize stalk, maize cob, and sal leaf. These materials are classified as carbon-neutral residue biomass, making them suitable for conversion into stable carbon in the form of biochar.

The project’s feedstock consists entirely of waste biomass sourced from farmers participating in the Artisan C-Sink program and their nearby neighbors. Before biochar production, these farmers must clear their fields for the next planting season. Under conventional practice, residues would be burned in the open; under this project, the same material is instead collected—by hand, baler, or cultivator—and diverted into biochar kilns. Because only above-ground residues are removed, leaving root systems in place, this harvest does not lead to soil degradation or erosion.

All biomass used is uncontaminated and drawn from existing agricultural or natural systems, so it does not trigger land-use change or habitat loss. When additional waste streams are incorporated, they are likewise restricted to the Artisan C-Sink farmers' land or other fields and commons within roughly a 30 km radius.

In this project, all feedstock for biochar production is drawn from waste biomass that would otherwise be treated as agricultural waste. Under the baseline scenario, most of this material is either left on the field and burned in the open—causing severe air pollution—or left to decompose, releasing methane. Because the project simply diverts this waste into biochar production instead, the risk of leakage is very low. This can be seen on several fronts:

1. Limited Alternative Uses

- a. In the local context, these residues have very few competing uses. They are not a primary cooking fuel or energy source. Farmers only set aside a small share of rice straw for cattle feed, and the project explicitly sources from this same pool of feed-grade straw rather than displacing it.

2. No Need for Replacement Fuels or Inputs

- a. Since biomass is not being diverted from another essential use, channeling it into biochar production does not force households to switch to alternative fuels or inputs that might generate additional emissions.

3. Net Environmental Gains

- a. The main conventional “use” of this biomass is open-field burning, which generates substantial greenhouse gas emissions and particulate pollution. Converting it into biochar instead both avoids those emissions and locks carbon into a stable form while improving soil health.

4. Community Buy-In and Practice Change

- a. Through ongoing engagement and education, local communities are informed about the benefits of biochar relative to burning or unmanaged decay. This awareness fosters acceptance of the new practice and reduces the likelihood that farmers will revert to emission-intensive disposal methods, further minimizing leakage risks.

Social and Economic Empowerment

While the technical and environmental case for biochar is strong, its success ultimately depends on how it fits into the lived realities of farming communities. To understand these dynamics, informal conversations and observations were carried out in rice-growing villages across the Gangetic Plain. These discussions, kept deliberately general and anonymized, were meant to surface attitudes toward agricultural change rather than document specific households. A clear contrast emerged between stakeholders in Uttar Pradesh and West Bengal—two regions with deep but distinct agrarian histories. In villages around Kanpur, Uttar Pradesh, where social and political structures are often described as conservative and inward-looking, farmers acknowledged that stubble burning causes serious health problems but still expressed a strong reluctance to alter established practices. By contrast, conversations in West Bengal revealed a greater openness to experimentation and change.

Across roughly a dozen conversations in West Bengal, several recurring themes appeared. The dominant concern was short-term household survival: most farmers emphasized the difficulty of supporting their nuclear families. They highlighted the importance of direct cash transfers and other assistance programs in stabilizing their livelihoods. Within this context, there was notable interest in project models that provide immediate, even modest, cash

payments—particularly when framed as incremental monthly supplements rather than abstract annual income gains. Farmers frequently referenced government schemes aimed at modernizing agriculture or providing welfare benefits, and they were aware of NGO and research activities in the area. However, these initiatives were generally seen as peripheral: people could identify a training session or a neighbor involved in a pilot, but did not perceive such efforts as transforming village life in a broad or sustained way.

Despite this focus on immediate economic pressures, farmers showed a clear and nuanced understanding of environmental stressors. Many spoke candidly about declining soil fertility and anticipated a future in which their land would no longer produce a viable income. At that point, they might abandon rice cultivation altogether. Air pollution was described in embodied terms—burning in the throat during the winter months—yet it was also framed as an almost normalized feature of the local climate rather than an avoidable outcome of specific practices. This combination of short-term economic precarity, familiarity with targeted assistance, and recognition of environmental harm shapes how interventions like biochar must be communicated: not as a purely technical fix, but as a concrete, near-term contribution to household security that also addresses problems farmers already perceive in their fields and in the air they breathe.

The project is intentionally structured so that climate mitigation and rural employment reinforce one another rather than compete. By relying on low-cost, accessible technologies such as the Kon-Tiki flame-curtain kiln (Schmidt & Taylor, 2014), biochar can be produced directly by smallholder farmers rather than outsourced to large industrial actors. This decentralised model creates labour demand precisely when it is most needed: each ton of biochar produced is

estimated to generate roughly 13 labour days, concentrated in the post-harvest period when underemployment is typically high.

Crucially, these positions are not limited to landowners or adult men. Women and youth are engaged as kiln operators, field assistants, and digital MRV (dMRV) specialists, opening up new paid roles in communities where disguised unemployment—especially among women—is widespread. More than 80% of project revenues are channelled back into participating villages through wages and in-kind support, rather than being extracted as external profit.

Early field reports suggest that the agronomic benefits of this model are evident and meaningful to farmers. These narratives matter: they signal not only higher productivity and incomes, but also a growing sense of pride and ownership over the project, which is essential for long-term uptake and continued local employment.

Fostering Sustainable Development Goals (SDGs)

Taken together, the project is designed not just as a carbon or soil intervention, but as a rural development model that addresses multiple SDGs. At the household level, it targets smallholder farmers who depend almost entirely on agriculture for income, supporting SDG 1 (No Poverty) and SDG 2 (Zero Hunger) by improving soil productivity, raising crop yields, and creating an additional, more stable income stream through biochar production. The new roles for kiln operation, field assistance, and monitoring further advance SDG 8 (Decent Work and Economic Growth) and SDG 10 (Reduced Inequalities) by generating local employment and channeling value back into marginalized rural communities.

Health and environmental quality sit at the centre of the project's co-benefits. By replacing open-field burning with controlled biochar production, the project directly reduces air pollution and associated respiratory illness, contributing to SDG 3 (Good Health and

Well-Being). Reducing reliance on chemical fertilizers and improving soil structure also supports SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities) by reducing nutrient runoff, protecting local water bodies, and promoting safer, cleaner rural environments.

Gender and social inclusion are treated as design features rather than afterthoughts. By deliberately engaging women—as producers, operators, and dMRV staff—the project expands access to paid work and decision-making power in rural households, furthering SDG 5 (Gender Equality). The selection of participants from lower socio-economic strata and climate-vulnerable groups reinforces SDG 10 (Reduced Inequalities) by ensuring that those most exposed to climate and market shocks are among the primary beneficiaries.

On the production side, the project embodies a circular-economy approach that aligns with SDG 12 (Responsible Consumption and Production). Agricultural residues and other waste biomass—currently burned or left to rot—are transformed into a productive input that improves future harvests, reducing waste and enhancing resource efficiency. At the same time, converting biomass into stable biochar while avoiding open burning and unmanaged decay makes the project a particularly effective tool for SDG 13 (Climate Action): it delivers both emission reductions and long-term soil carbon sequestration.

Finally, by improving soil health, reducing erosion, and restoring degraded land, the project advances SDG 15 (Life on Land). Enhanced soil structure and resilience help protect local ecosystems and biodiversity, tying the climate and livelihood benefits of biochar back to the long-term integrity of the landscapes on which these communities depend.

Below is a table summarizing biochar’s alignment with SDG objectives:

SDG Goal Number and Title	Applicability
1. No Poverty	The project targets smallholder farmers who are solely or primarily dependent on agriculture. By improving soil productivity and crop yields and providing an additional income stream from biochar production, it raises farm incomes and creates employment (e.g., field officers, kiln workers), thereby contributing to poverty reduction.
2. Zero Hunger	Biochar application improves soil fertility and structure, which increases crop yields and stabilizes production. As farmers produce more and better-quality food, the project helps address local and broader food insecurity.
3. Good Health and Wellbeing	The project replaces open-field burning of residues—a major source of air pollution and respiratory illness—with controlled biochar production. This reduces exposure to harmful smoke and particulate matter, while healthier soils can support more nutritious crops, improving overall community health.
5. Gender Equality	Women in rural India frequently experience disguised or underemployment. By deliberately engaging women as biochar producers, kiln operators, and field officers, the project creates paid work opportunities, increases women’s financial independence, and strengthens their role in household and community decision-making.
6. Clean Water and Sanitation	By improving soil fertility and water-holding capacity, biochar reduces reliance on chemical fertilizers and irrigation. This helps prevent

	nutrient and chemical runoff into local water bodies, supports groundwater quality, and contributes to better sanitation and water security in rural communities.
8. Decent Work and Economic Growth	The project shifts farmers from hazardous open burning toward safer, value-adding biochar production. This creates new jobs, improves working conditions, and increases disposable income, which in turn stimulates local economic activity and supports inclusive, long-term rural growth.
10. Reduced Inequalities	Farmers are selected from lower socio-economic groups and from those most exposed to climate risks, ensuring that benefits flow to the most vulnerable. The project explicitly avoids discrimination based on caste, religion, or gender, and instead fosters more inclusive access to income and opportunity.
11. Sustainable Cities and Communities	By providing a sustainable alternative to burning agricultural waste, the project reduces smoke-related health risks and environmental damage in rural areas. At the same time, biochar-supported land management helps maintain healthier surrounding ecosystems, contributing to more resilient and sustainable rural communities.
12. Responsible Consumption and Production	The project operationalizes a circular economy model: crop residues and other biomass that were previously burned or left to rot are converted into biochar, a productive input that enhances future yields. This reduces waste, improves resource efficiency, and lowers the environmental footprint of agricultural production.

13. Climate Action	Converting biomass into biochar sequesters carbon in a stable form for decades to centuries while also avoiding the greenhouse gas emissions associated with open burning and unmanaged decomposition. This dual impact—long-term carbon storage plus avoided emissions—makes the project a direct climate mitigation measure.
15. Life on Land	Biochar improves soil structure, water retention, and nutrient cycling, which reduces erosion and land degradation. These changes help restore and maintain terrestrial ecosystems, build resilience to climate and environmental stress, and support biodiversity in agricultural landscapes.
17. Partnerships for the Goals	The project depends on collaboration among smallholder farmers, local implementers, and carbon credit buyers or investors. These partnerships mobilize finance, technical support, and local knowledge, demonstrating how cross-sector cooperation can advance environmental sustainability and rural socio-economic development simultaneously.

VII. Feasibility Study

Pilot #1 - Feasibility & Implementation Readiness

Problem Context:

The Problem: Agricultural-Waste Burning in the Indo-Gangetic Plain

- Smallholder farmers routinely burn rice-straw residue to clear fields, releasing 35+ Mt CO₂e each year.
- Straw fires drive 35–40 % of winter smog across North India, cutting regional life expectancy by an estimated 149,000 life-years annually and adding US \$1.5 billion in healthcare costs (5-yr horizon).

Our Solution: Biochar for Circular, Community-Driven Carbon Removal

- Farmers convert straw to biochar, a stable soil amendment that sequesters carbon > 1,000 years and boosts yields $\approx$ 20 % YoY.
- High-integrity biochar credits (verified by Carbon Standards International) finance the model, while eliminating open burning.

Field Mapping & Pit Optimization

Nirvana deploys a GIS-based optimization system that combines Sentinel-2 NDVI imagery, water source mapping, and travel path minimization to generate efficient biochar pit locations. This ensures that each pit is accessible, productive, and linked to a reliable water source, all while reducing daily field costs and minimizing travel and planning time that would be done manually.

1. NDVI & Route-Based Planning

- a. NDVI data from Sentinel-2 is used to identify edge zones located on the edges of fields and forests for pits.

- b. An optimization algorithm overlays this with mapped water bodies (ponds, canals, mini-pumps) to locate pits where quenching water is accessible.
- c. Each route is optimized to keep pits within 700 m clusters and ≤ 2 km total travel distance per field manager.

2. Pre-Season Mapping and Operational Rehearsal

- a. Field mapping begins three months before each production season, combining satellite data with in-person field visits to verify accessibility, ownership, and feasibility.
- b. Nirvana refines algorithm-generated points using local knowledge from prior field visits (e.g., terrain barriers, social boundaries) to create maps in Google Earth with Field Managers and Executive Managers, rehearsing daily burn routes and logistical plans ahead of deployment.
- c. This rehearsal-based planning ensures operational readiness and efficient execution once the season begins, where each specialist monitors 10-15 kilns, for a minimum of 2 pits to a maximum of 8 pits per day.

Organisational Structure

The success of Nirvana Carbon Solutions' rural biochar program hinges not only on kilns and credit protocols but on a living human infrastructure, a distributed array of executive managers, field managers, and artisans. We implement 3 roles specifically for a flat organizational structure so the individuals working on the ground receive the majority of the carbon credit revenue. Every layer of the organization is directly connected to the field, there are no detached 'office staff,' only individuals with firsthand field experience and on-the-ground knowledge.

1. Executive Manager

Profile: Executive Managers are individuals with hybrid experience in rural development and business administration. They have the interpersonal fluency to navigate both community leadership and quality assurance expectations.

a. Core Responsibilities.

- i. Engage in agreements with landowners, communicate that agreement with farmers who actually work the land and maintain these relationships over the course of the biochar placement.
- ii. Identify and provide a locally adapted incentive structure for biochar production. Coordinate local financial transactions.
- iii. Oversee operations across field managers in villages.
- iv. Liaise between field staff and external partners, conducting weekly calls with the Nirvana central team to report KPIs and challenges.

b. Compensation & Incentives:

- i. They are incentivized to expand operations by adding new villages in their region and are also responsible for connecting and onboarding new Executive Managers.

2. Field Manager

Profile: Field Managers are digitally fluent young adults who monitor kilns, and each field manager has passed at least 12th grade and is embedded in the village.

a. Core Responsibilities:

- i. Recruit and roster artisans for kiln shifts including mapping of fields and efficient pit location.

- ii. Verify burns through the dMRV app, ensuring complete photographic and metadata documentation. Responsible for rejected burns, working directly with the dMRV team.
- iii. Responsible for supply of safety equipment, making sure that everyone follows safety procedures. Ensures that kiln design meets safety standards.
- iv. Maintain supply of clean drinking water, electrolyte mix, snacks, to support artisans during intensive labor.
- v. Coordinate straw supply logistics in order to ensure that performance metrics are met – where there is a 1.5 hour burn time and 30 bags of 80L produced.
- vi. Ensures security with conversations with the local government to assure that no external threat affects production.

b. Compensation & Incentives:

- i. ₹100 per verified biochar-pit burn. They are paid strictly “per run,” motivating them to maximize daily burns.
- ii. Additionally, they are incentivized to provide more prospective field managers.

c. Training Procedure

- i. Overall Training Protocol: We assist through online video calls in pit size verification, straw collection, and placement by identifying prevalent wind direction, and biochar production for the first 3-5 runs. This training is completed before the season starts in every village.

1. Based on dMRV data, smaller training loopholes are identified and one-on-one training sessions are scheduled for achieving 99.99% success rate in Production and Usage.
 2. dMRV experts are available and monitoring 24 hours, 7 days a week, on WhatsApp to support during active sessions.
- ii. Two-level training (≈ 5 h total):
1. Field-data entry—remote, 1:1 with Nirvana; covers burn logging and data capture.
 2. Live monitoring—second 1:1 session on verifying images and submitting runs for approval.

3. Growers

Profile: Growers include farmers from rural, low-income households, often landless laborers or subsistence farmers. Many participate seasonally, balancing this work with caregiving responsibilities, migrant labor, or the opportunity to earn income while staying close to home.

Growers are called “growers,” not “laborers,” to affirm dignity and ownership.

- a. Core Responsibilities:
- i. Collect dry agricultural residue (paddy straw, mustard stalks, coconut coir) from nearby fields
 - ii. Operate flame-curtain kilns: igniting, managing combustion, and performing the quenching process
 - iii. Transport and apply biochar to fields through trenching methods, maintain kilns and report any tool degradation.
- b. Compensation & Incentives:

- i. Daily wage of ₹400 during the off-season, when rural employment opportunities are limited.
 - ii. Provision of food: Breakfast is also provided as part of the daily support.
 - iii. Seasonal bonuses during Durga Puja and Eid to acknowledge their role and foster inclusion
- c. Training Procedure
- i. Growers must pass certification exams and receive mandatory safety training. They are required to wear face coverings, full-sleeved clothing, and proper footwear during production. Field training is completed before the season in every village.
 - ii. Growers regularly receive WhatsApp messages requesting short 90-second videos showing their current activities. These videos are cross-referenced with dMRV app records to verify real-time engagement and prevent falsification.

Community Building & Social Capital

1. Global Engagement & Relational Capital: Investors, interns, and international stakeholders regularly engage with all levels of management through calls that help maintain strong relationships and showcase the organization's field-connected leadership, an aspect often seen as a mark of credibility and prestige.
2. Gamcha Ceremony: A pre-season ritual where growers are given a traditional towel (gamcha), and families share a communal meal with field staff. This fosters dignity and strengthens bonds between villagers and the biochar team.
3. Field Songs & Visual Storytelling: Drawing from agricultural extension methods, Nirvana co-created call-and-response songs that encode biochar pit steps, helping

growers retain sequencing protocols. These outperform traditional posters in knowledge retention.

4. Direct Engagement & Mobilization Through Results: Community trust builds organically when farmers see visible improvement in their soil after biochar application. Within one season, peer-to-peer comparisons drive demand. Additionally, Executive Managers often visit influential farmers at their homes and keep contact lists to streamline enrollment.

Free tea and snacks are offered, but no formal budget is allocated to mobilization events.

Internal Control and Compliance Assurance

1. Inspection Protocols & Role Accountability

Internal inspectors, trained to flag un-pyrolyzed biomass, incomplete quenching, and improper bagging, conduct annual audits, spot checks, and follow-up visits. Producers, inspectors, and managers each operate under defined scopes of responsibility and are evaluated annually.

2. Graduated Sanctioning System

Violations are handled through a tiered structure:

- a. Minor Infractions (e.g., incomplete documentation): Trigger formal warnings and retraining.
 - b. Major Infractions (e.g., repeated moisture non-compliance): Lead to temporary suspension from production.
 - c. Severe Infractions (e.g., resale of biochar, falsifying data): Result in public expulsion during community meetings to reinforce accountability.
3. Appeals Process & Governance Oversight

Farmers may file written appeals within 14 days of sanctions. The Internal Approval Body, comprising both NCS leadership and partner NGO heads, reviews appeals, enforces database security, and ensures due process across the system.

Pilot #2 - Quantitative Outcomes

Current Project Footprint

- 31 villages across West Bengal & Odisha participated in the second pilot (Nov 2024–Mar 2025).
- Over 350 production runs from that pilot removed ≈ 200 t CO_{2e}.
- Credit spot prices have averaged US \$130 / t, with 80% of funds flowing directly to communities; co-founders have taken no salary for two years to maximise reinvestment.

Cumulative Production Output

Metric	Cumulative Value	Operational Context
Usage runs fully verified	351	Runs with complete end-to-end documentation from kiln registration to soil application.
Biochar bags applied to soil	10,522 bags	Confirmed bags that passed verification and were geotagged as soil-applied.
Dry biomass diverted from open burning	~985 tons	Estimated from feedstock-to-biochar ratios; assuming 5 kg biomass per ton of biochar.

Total biochar mass	~197 tons	Assuming ~1–1.2 kg per bag depending on feedstock density and moisture content.
Estimated CO ₂ e permanently removed	~209 tons CO ₂ e	Based on IPCC factors of 2.4 - 2.6 tCO ₂ e per ton of biochar applied to soil.

Strategic Recommendations

1. 10% Women's Wage Incentive

- a. This is a supplementary payment: an additional 10% is paid on top of the grower's regular earnings, deposited only into their wife's bank account. The goal is to promote women's financial inclusion and support/incentivize digital banking adoption and government ID KYC.

2. Shift to Digital Electronic Payments & Financial Literacy

- a. Transition all field payments to digital banking, ensuring wages and bonuses are only disbursed via verified bank accounts. Use digital payments to track eligibility for carbon credits, ensuring transparency and accountability across all production teams.
- b. Distribute pictorial "how-to" guides and Bengali WhatsApp voice notes to support low-literacy users in accessing and managing their bank accounts.

3. Digitizing Contracts & Training Access

- a. Nirvana is developing a low-bandwidth platform to provide field teams with access to all essential materials, including safety protocols, FPIC consent forms, and training videos, even in areas with limited connectivity.

- b. The platform features Bengali voiceovers (both formal and colloquial), lightweight animations, and QR-linked pit maps, ensuring usability for low-literacy users and enhancing understanding of field procedures.

By moving away from reliance on external platforms like PlantVillage, Nirvana gains full control over contract delivery, training engagement, and compliance tracking at scale.

VIII. Digital Monitoring, Reporting, and Verification (dMRV) System

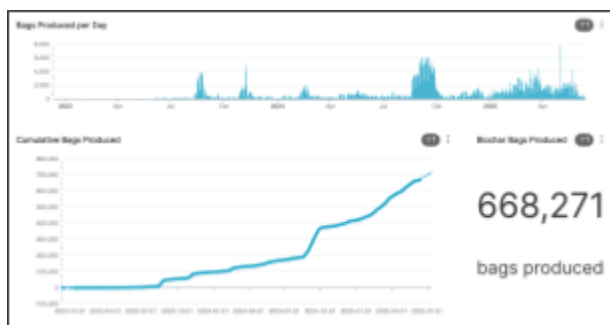
This section outlines the structure, functionality, and operational procedures of the digital Monitoring, Reporting, and Verification (dMRV) system implemented by Nirvana Carbon Solutions (NCS) to ensure the scientific and operational integrity of its artisanal biochar project. Developed in close collaboration with the PlantVillage initiative at Penn State University, this system serves as both a technological backbone and a compliance framework for documenting and verifying the production and application of biochar by rural communities across Eastern India. Drawing from memos, internal control systems, and the Global Artisan C-Sink Standard, the report details how the dMRV infrastructure supports accountability, transparency, and long-term carbon sequestration.

Objectives of the dMRV System

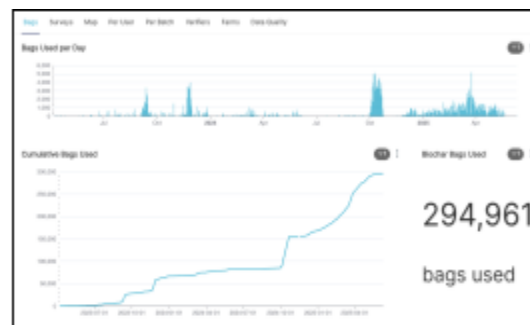
The dMRV system aims to deliver accurate tracking by creating a detailed, verifiable record of every biochar production step, from kiln registration and biomass drying to the pyrolysis process, bagging, and field application, enabling precise, batch-level quantification of carbon sequestration. It integrates community participation with scientific rigor by embedding monitoring duties in a local workforce of dMRV specialists while upholding high standards through third-party AI systems and university partnerships. Finally, it assures compliance with artisanal biochar protocols by layering app-based monitoring with surprise inspections, structured data audits, and a robust internal control system.

App Functionality and Data Requirements

The dMRV system runs on the PlantVillage app, where field managers and artisans register each kiln with two geotagged, time-stamped photos documenting dimensions and context. A Penn State ML backend verifies image/metadata consistency, flags anomalies (e.g., geotags or moisture), and demands corrections or rejects entries. All data is stored encrypted with daily backups, 10-year audit logs, and tiered access requiring admin authentication and periodic permission renewals.



Production-side analytics of the cumulative generation of biochar bags via the PlantVillage app.



Daily and cumulative usage of biochar application bags through monitoring in dMRV PlantVillage app

Governance Structure and Roles

The dMRV system is supported by a multi-tiered governance structure, with responsibilities distributed across organizational, regional, and local levels:

- Artisan C-Sink Manager: Ensures end-to-end compliance with the Global Artisan C-Sink Standard, approving training, auditing reports, coordinating with certifiers, and driving continuous improvement.
- dMRV Specialists (Field Managers): Digitally literate locals monitor 10–15 kilns, collect app data, verify procedures, upload visual/numeric proof, support grievances, and complete 12th grade plus ongoing tech/ethics training.
- Internal Inspectors: Run scheduled and surprise audits of specialists, check data consistency and safety/technical compliance, and issue photo-verified reports with corrective actions.
- District Managers: Coordinate across villages, liaise with authorities, track compliance trends, surface systemic issues, and deliver quarterly regional reviews.

Compliance and Enforcement Mechanisms

Before gaining access to the dMRV app, all artisans and specialists undergo a structured training program. This includes modules on the technical steps of biochar production, the correct usage of measuring instruments, and ethical data handling practices.

Inspection Regime:

- Internal inspectors conduct inspections at least bi-annually for each kiln site, with an additional 30% subjected to random spot checks.
- These inspections involve revisiting app-submitted data, physically inspecting moisture levels, checking for unrecorded bags, and interviewing workers about process adherence.

- Artisans are periodically asked to send short 90-second WhatsApp videos documenting their ongoing activities. These video submissions are cross-checked with dMRV app records to confirm participation.
- An annual verification audit occurs whenever artisan production doubles or when farmer involvement is increased by 100 farmers.

Operational Workflow of dMRV:

Step 1: Kiln Registration Prior to first use, every kiln is registered with unique identifiers and detailed photos. Photos include a depth shot, surface measurement with reference tool, and overall frame showing context. Take a photo every day, before pyrolyzing the biochar, of the Artisans who will be working on the pits; The Artisans should take the photo while holding up their Artisan ID and Government ID.

Step 2: Stubble Drying and Collection After drying, the moisture content must be measured and fall within 0–25%. Photos of the pile and hygrometer readings are uploaded to prove compliance. The stubble source must be within a 5Ha area connected to the farmer-participant's land.

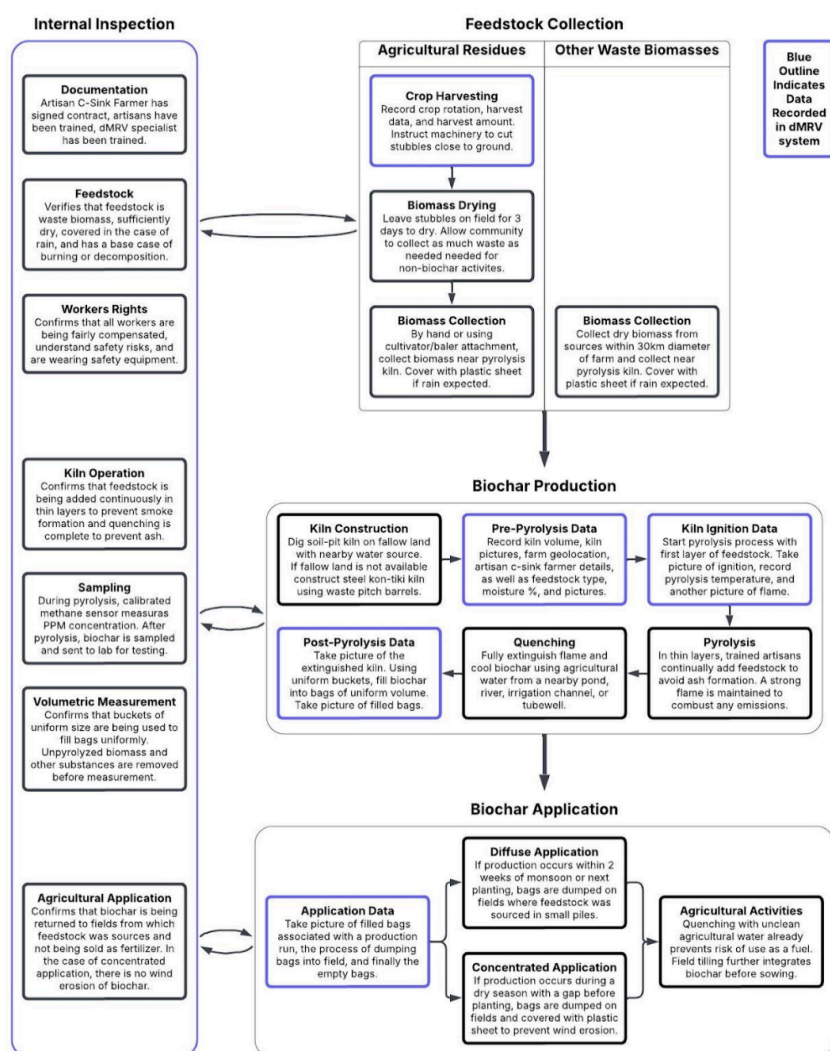
Step 3: Pyrolysis Logging Temperature data is logged at multiple intervals during the burn, which lasts 1-1.5 hours. Multiple photos are required, including the sequence of pre-burn, active burn, thermometer screen, and quenching. During the pyrolysis process, take another photo of the artisans working on the biochar pits; This is to ensure that the Artisans are staying and working on creating biochar.

Step 4: Measurement and Bagging Each bag of biochar must be measured using standardized 20L buckets. Each filled bag must be visibly full, with the bucket placed in front and the kiln in

the background to confirm field context. After bagging, please take one last photo of the Artisans with the cooled, bagged biochar.

Step 5: Application to Soil The final step logs the GPS coordinates of the field, and photos of the biochar application are taken. Additional photos include the empty bags, soil integration, and receipt of payment to the farmer. Submit the photo proofs on PlantVillage to be properly paid.

Integrated dMRV Workflow



The diagram above visualizes the full end-to-end dMRV-aligned operational workflow, from feedstock collection and kiln construction through pyrolysis and final soil application. All blue-outlined boxes indicate datapoints recorded in the PlantVillage system, confirming where digital monitoring intersects with field-level activities and internal inspections.

System Strengths and Innovations

The system delivers investor-grade credit integrity by linking each tonne of biochar to a tamper-resistant data trail that includes geotagged images, AI-driven anomaly checks, and independent cloud audit logs, enabling credits to be issued confidently and traded without discount. Data moves directly from field phones to Penn State's PlantVillage servers, where an external algorithm validates or rejects each batch; because Nirvana cannot modify these records, buyers and registries avoid conflict-of-interest risk. At the same time, a locally hired cadre of dMRV specialists converts monitoring costs into rural income, lifting seasonal wages and keeping verification costs below industry norms, a model designed to replicate quickly across new regions without sacrificing effectiveness.

IX. Conclusion

The practice of open-field stubble burning in India presents a significant challenge to both climate and public health. Farmers, pressed for time between rapid cropping cycles, often burn crop residues as a low-cost and immediate solution for clearing their fields. While convenient, this approach generates substantial greenhouse gas emissions, releases particulate matter and black carbon into the atmosphere, and diminishes soil fertility through nutrient loss. The resulting air pollution contributes to widespread respiratory and cardiovascular illnesses, while also exacerbating regional smog during winter months, ultimately impacting life expectancy and public healthcare costs. Beyond its human health implications, this practice accelerates soil degradation, necessitating higher fertilizer use and disrupting regional biogeochemical cycles.

Against this backdrop, biochar emerges as a practical and scientifically validated intervention. Produced through the pyrolysis of agricultural residues under controlled, oxygen-limited conditions, biochar transforms otherwise waste material into a long-term carbon storage solution. In addition to sequestering carbon for over a century, its use improves soil fertility, water retention, and microbial activity, thereby enhancing agricultural productivity. By diverting crop residues from open-field burning to biochar production, greenhouse gas emissions are substantially reduced, and air quality is improved. Furthermore, biochar mitigates methane emissions from decomposing biomass, offering additional climate benefits beyond carbon storage.

The implementation of artisanal biochar projects, such as Nirvana Carbon Solutions' Carbon 1 initiative, demonstrates that these environmental gains can be coupled with tangible social and economic benefits. By employing low-cost flame-curtain kilns, smallholder farmers

can produce biochar themselves, generating new sources of income while reducing emissions. This decentralized model also creates local labor opportunities, engaging women and youth in production and monitoring roles, and fostering a sense of ownership and empowerment within participating communities. Crucially, all biomass used for biochar production is sourced sustainably from residues that would otherwise be burned or left to decay, minimizing risks of unintended consequences such as land-use change or displacement of essential resources.

The integration of a digital monitoring, reporting, and verification (dMRV) system ensures that biochar production adheres to rigorous standards. By combining geotagged and time-stamped documentation with AI-assisted verification and local oversight, the system allows precise quantification of carbon sequestration while maintaining transparency and traceability. This approach reinforces accountability and provides confidence to carbon markets, linking measurable environmental outcomes with financial incentives for participating farmers.

In conclusion, the adoption of biochar represents a multi-dimensional solution that addresses environmental, climatic, and social challenges simultaneously. By converting agricultural residues into stable carbon, improving soil productivity, and generating new livelihood opportunities, biochar offers a pathway toward sustainable rural development. Programs led by organizations like Nirvana Carbon Solutions illustrate that carefully designed interventions can provide measurable climate mitigation, reduce health risks, and strengthen local economies, all while engaging communities in sustainable agricultural practices. As such, biochar represents not only a climate and air-quality solution but also a model for integrating environmental stewardship with socioeconomic development in regions facing urgent agricultural and public health pressures.

References

- Balagus, N., Jacob, D. J., Lorente, A., Maasakkers, J. D., Parker, R. J., Boesch, H., Chen, Z., Kelp, M. M., Nesser, H., & Varon, D. J. (2023). A blended TROPOMI+GOSAT satellite data product for atmospheric methane using machine learning to correct retrieval biases. *Atmospheric Measurement Techniques*, 16(16), 3787–3807. <https://doi.org/10.5194/amt-16-3787-2023>
- Battye, W., Aneja, V. P., & Schlesinger, W. H. (2017). Is nitrogen the next carbon?. *Earth's future*, 5(9), 894-904.
- Boomitra. (n.d.). <https://boomitra.com/>
- Cayuela, M.L., Sánchezmonedero, M.A., Roig, A., Hanley, K., Enders, A., Lehmann, J., 2013. Biochar and denitrification in soils: when, how much and why does biochar reduce N₂O emissions? *Sci. Rep.* 3, 1732.
- Cayuela, M.L., Zwieten, L.V., Singh, B.P., Jeffery, S., Roig, A., Sánchez-Monedero, M.A., 2014. Biochar's role in mitigating soil nitrous oxide emissions: a review and metaanalysis. *Agric. Ecosyst. Environ.* 191, 5–16.
- Civillini, M. (2025, March 4). *Revealed: Shell's massive stake in dubious rice carbon offsets*. Climate Change News. <https://www.climatechangenews.com/2023/03/28/revealed-how-shell-cashed-in-on-dubious-carbon-offsets-from-chinese-rice-paddies/>
- Cornelissen, G., Sørmo, E., de la Rosa, R. K., & Ladd, B. (2023). Flame Curtain Kilns produce biochar from dry biomass with minimal methane emissions. *Science of The Total Environment*, 903, 166547. <https://doi.org/10.1016/j.scitotenv.2023.166547>
- Donofrio, S., Patrick, M., Steve, Z., & William, M. (2021, January 12). *State of the voluntary carbon markets 2020*. Forest Trends. <https://www.forest-trends.org/publications/state-of-the-voluntary-carbon-markets-2020-2/>
- Dyck, M., Trouwloon, D., & Streck, C. (2024, February 8). *Chapter 8: How is the voluntary carbon market structured?*. [vcmprimer.org. https://vcmprimer.org/chapter-8-how-is-the-voluntary-carbon-market-structured/](https://vcmprimer.org/chapter-8-how-is-the-voluntary-carbon-market-structured/)
- Estrada, L. A., Varon, D. J., Sulprizio, M., Nesser, H., Chen, Z., Balagus, N., Hancock, S. E., He, M., East, J. D., Mooring, T. A., Oort Alonso, A., Maasakkers, J. D., Aben, I., Baray, S., Bowman, K. W., Worden, J. R., Cardoso-Saldaña, F. J., Reidy, E., & Jacob, D. J. (2024). *Integrated Methane Inversion (IMI) 2.0: An Improved Research and Stakeholder Tool for Monitoring Total Methane Emissions with High Resolution Worldwide Using Tropomi Satellite Observations*. <https://doi.org/10.5194/egusphere-2024-2700>
- Gómez-Gallego T. (2022). N-damo, an opportunity to reduce methane emissions?. *Environmental microbiology reports*, 14(5), 697–699. <https://doi.org/10.1111/1758-2229.13114>
- Govardhan, G., Ambulkar, R., Kulkarni, S., Vishnoi, A., Yadav, P., Choudhury, B. A., Khare, M., & Ghude, S. D. (2023). Stubble-burning activities in north-western India in 2021: Contribution to air pollution in Delhi. *Heliyon*, 9(6). <https://doi.org/10.1016/j.heliyon.2023.e16939>
- Han, X.G., Sun, X., Wang, C., Wu, M.X., Dong, D., Zhong, T., Thies, J.E., Wu, W.X., 2016. Mitigating methane emission from paddy soil with rice-straw biochar amendment under projected climate change. *Sci. Rep.* 6, 24731.
- Hu, Q., Li, J., Xie, H., Huang, Y., Canadell, J. G., Yuan, W., Wang, J., Zhang, W., Yu, L., Li, S.,

- Lu, X., Li, T., & Qin, Z. (2024). Global methane emissions from rice paddies: CH4MOD model development and application. *iScience*, 27(11), 111237. <https://doi.org/10.1016/j.isci.2024.111237>
- Hucke, C. C. (2025, February 6). *Why the COP29 Article 6 decision strengthens high-integrity carbon markets*. Center for Climate and Energy Solutions. <https://www.c2es.org/2025/02/why-the-cop29-article-6-decision-strengthens-high-integrity-carbon-markets>
- Hughes, D., McCloskey, A., Cheptoo, B., Areba, F., Gobanya, J., & Bhupathi, L. (2025). The Biochar App Data. Penn State University; Plant Village.
- IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647.
- Jeffery, S., Verheijen, F.G., Kammann, C., Abalos, D., 2016. Biochar effects on methane emissions from soils: a meta-analysis. *Soil Biol. Biochem.* 101, 251–258.
- Jez, A. A., Alexander, B. D., & Shaikh, A. R. (2023). Carbon credit and carbon offset fundamentals. Mintz.
- Kaur, M., Singh, D., Anand, A., & Singh, T. (2023). Do attributes of happy Seeder Technology influence its adoption speed? an investigation using duration analysis in Northern India. *International Journal of Agricultural Sustainability*, 21(1). <https://doi.org/10.1080/14735903.2023.2198324>
- Knoblauch, C., Maarifat, A.A., Pfeiffer, E.M., Haeefe, S.M., 2011. Degradability of black carbon and its impact on trace gas fluxes and carbon turnover in paddy soils. *Soil Biol. Biochem.* 43, 1768–1778.
- Kozicka, K., Gozdowski, D., & Wójcik-Gront, E. (2021). Spatial-Temporal Changes of Methane Content in the Atmosphere for Selected Countries and Regions with High Methane Emission from Rice Cultivation. *Atmosphere*, 12(11), 1382. <https://doi.org/10.3390/atmos12111382>
- Lee, J.-M., Jeong, H.-C., Gwon, H.-S., Lee, H.-S., Park, H.-R., Kim, G.-S., Park, D.-G., & Lee, S.-I. (2023). Effects of Biochar on Methane Emissions and Crop Yields in East Asian Paddy Fields: A Regional Scale Meta-Analysis. *Sustainability*, 15(12), 9200. <https://doi.org/10.3390/su15129200>
- Li, K., Bai, K., Jiao, P., Chen, H., He, H., Shao, L., Sun, Y., Zheng, Z., Li, R., & Chang, N.-B. (2024). Developing unbiased estimation of atmospheric methane via machine learning and multiobjective programming based on Tropomi and GOSAT Data. *Remote Sensing of Environment*, 304, 114039. <https://doi.org/10.1016/j.rse.2024.114039>
- Loaiza, S., Verhot, L., Valencia, D., Guzmán, P., Amezcuita, N., Garcés, G., Puentes, O., Trujillo, C., Chirinda, N., & Pittelkow, C. M. (2024). Evaluating greenhouse gas mitigation through alternate wetting and drying irrigation in Colombian rice production. *Agriculture, Ecosystems & Environment*, 360, 108787. <https://doi.org/10.1016/j.agee.2023.108787>
- Lorente, A.; Borsdorff, T.; Butz, A.; Hasekamp, O.; Schneider, A.; Wu, L.; Hase, F.; Kivi, R.; Wunch, D.; Pollard, D.F.; et al. Methane retrieved from TROPOMI: Improvement of the data product and validation of the first 2 years of measurements. *Atmos. Meas. Tech.* **2021**, 14, 665–684.
- Lovell, R. J. (2019a). Identifying alternative wetting and drying (AWD) adoption in the

- Vietnamese Mekong River Delta: A change detection approach. *ISPRS International Journal of Geo-Information*, 8(7), 312. <https://doi.org/10.3390/ijgi8070312>
- Michel, S. E., Lan, X., Miller, J., Tans, P., Clark, J. R., Schaefer, H., Sperlich, P., Brailsford, G., Morimoto, S., Moossen, H., & Li, J. (2024). Rapid shift in methane carbon isotopes suggests microbial emissions drove record high atmospheric methane growth in 2020–2022. *Proceedings of the National Academy of Sciences*, 121(44). <https://doi.org/10.1073/pnas.2411212121>
- Modi, S. (2022). Stubble burning menace: Problem & solution. *International Journal of Science and Research (IJSR)*, 11(9), 1037–1044. <https://doi.org/10.21275/sr22924162409>
- Nathan, B., Maasakkers, J. D., Naus, S., Gautam, R., Omara, M., Varon, D. J., Sulprizio, M. P., Estrada, L. A., Lorente, A., Borsdorff, T., Parker, R. J., & Aben, I. (2024). Assessing methane emissions from collapsing Venezuelan oil production using Tropomi. *Atmospheric Chemistry and Physics*, 24(11), 6845–6863. <https://doi.org/10.5194/acp-24-6845-2024>
- Nesser, H., Jacob, D. J., Maasakkers, J. D., Lorente, A., Chen, Z., Lu, X., Shen, L., Qu, Z., Sulprizio, M. P., Winter, M., Ma, S., Bloom, A. A., Worden, J. R., Stavins, R. N., & Randles, C. A. (2024). High-resolution US methane emissions inferred from an inversion of 2019 Tropomi Satellite Data: Contributions from individual states, urban areas, and landfills. *Atmospheric Chemistry and Physics*, 24(8), 5069–5091. <https://doi.org/10.5194/acp-24-5069-2024>
- Nguyen, B.T., Van Nguyen, N. Biochar Addition Balanced Methane Emissions and Rice Growth by Enhancing the Quality of Paddy Soil. *J Soil Sci Plant Nutr* 23, 2998–3009 (2023). <https://doi.org/10.1007/s42729-023-01249-9>
- Nikolaisen, M., Hillier, J., Smith, P., & Nayak, D. (2023). Modelling CH₄ emission from Rice Ecosystem: A comparison between existing empirical models. *Frontiers in Agronomy*, 4. <https://doi.org/10.3389/fagro.2022.1058649>
- Nirvana Carbon Solutions. (n.d.). *Nirvana Carbon Solutions - Biochar Feasibility Report*. <https://docs.google.com/document/d/1rlsHek5fRlTEFhFPMwwNMlaRwnlTYfHelSne04Y28tk/edit?usp=sharing>
- Panda, S. (2025, April 29). Case Study: Creating a Viable Financial Model for High-Integrity Community-Led Biodiversity Reforestation in Panama's Azuero Peninsula. *Princeton University Certificate Program in Finance*. https://docs.google.com/document/d/1yAhGXEBJzF53s--_cw-QcspdDzDCar3MembZKQOsXOU/edit?usp=sharing
- Paris Agreement, December 12, 2015, United Nations Treaty Series Online, registration no. I-54113, <https://unfccc.int/process/the-paris-agreement/cooperative-implementation>.
- Porsborg-Smith, A., Nielsen, J., Owolabi, B., & Clayton, C. (2025, February 6). *The voluntary carbon market is thriving*. BCG Global. <https://www.bcg.com/publications/2023/why-the-voluntary-carbon-market-is-thriving>
- Qi, L. et al. Biochar application increased methane emission, soil carbon storage and net ecosystem carbon budget in a 2-year vegetable–rice rotation. *Agriculture, Ecosystems & Environment* 292, 106831 (2020).
- Qu, Z., D.J. Jacob, L. Shen, X. Lu, Y. Zhang, T.R. Scarpelli, H. Nesser, M.P. Sulprizio, J.D. Maasakkers, A.A. Bloom, J.R. Worden, R.J. Parker, and A.L. Delgado (2021), Global distribution of methane emissions: a comparative inverse analysis of observations from

- the TROPOMI and GOSAT satellite instruments, *Atmos. Chem. Phys.*, 21, 14159–14175, doi:10.5194/acp-21-14159-2021.
- Sagrilo, E., Jeffery, S., Hoffland, E., Kuyper, T.W., 2015. Emission of CO₂ from biochar amended soils and implications for soil organic carbon. *Glob. Change Biol. Bioenergy* 7, 1294–1304.
- Saunois, M., Martinez, A., Poulter, B., Zhang, Z., Raymond, P., Regnier, P., Canadell, J. G., Jackson, R. B., Patra, P. K., Bousquet, P., Ciais, P., Dlugokencky, E. J., Lan, X., Allen, G. H., Bastviken, D., Beerling, D. J., Belikov, D. A., Blake, D. R., Castaldi, S., ... Zhuang, Q. (2024). *Global Methane Budget 2000–2020*. <https://doi.org/10.5194/essd-2024-115>
- Sahai, S., Sharma, C., Singh, S. K., & Gupta, P. K. (2010). Assessment of trace gases, carbon and nitrogen emissions from field burning of agricultural residues in India. *Nutrient Cycling in Agroecosystems*, 89(2), 143–157. <https://doi.org/10.1007/s10705-010-9384-2>
- Schmidt, H. P., & Taylor, P. (2014). Kon-Tiki flame cap pyrolysis for the democratization of biochar production. *The Biochar Journal*, 14–24. Retrieved from <https://www.biochar-journal.org/en/ct/39>
- Singh, A., Vishnoi, A. S., Banday, A. H., Bora, P., & Pandey, P. (2023). Influence of stubble burning on air quality of Northern India: A case study of indo-gangetic plains of India. *Environmental Monitoring and Assessment*, 195(4). <https://doi.org/10.1007/s10661-023-11027-w>
- Singla, A., Dubey, S.K., Singh, A., Inubushi, K., 2014. Effect of biogas digested slurry-based biochar on methane flux and methanogenic archaeal diversity in paddy soil. *Agric. Ecosyst. Environ.* 197, 278–287.
- Song, Y., Song, C., Choi, S.-E., Kim, J., Kim, M., Hwang, W., Roh, M., Lee, S., & Lee, W.-K. (2024). Estimating Methane Emissions in Rice Paddies at the Parcel Level Using Drone-Based Time Series Vegetation Indices. *Drones*, 8(9), 459. <https://doi.org/10.3390/drones8090459>
- Stanway, D. (2024, August 29). *Carbon Registry Verra rejects China rice projects*. Reuters. <https://www.reuters.com/world/asia-pacific/carbon-registry-verra-rejects-china-rice-projects-2024-08-29/>
- Suleri, A., Bhushan, C., Khillare, T., Naithani, A., Zahid, J., & Khan, M. (2024). The Air We Share Towards Reduced Transboundary Air Pollution Across India and Pakistan. https://csdronline.com/wp-content/uploads/2024/04/AirWeShare_CSDR_IPCC_Online-1.pdf
- Suthar, G., Singh, S., Kaul, N. & Khandelwal, S. Analyzing methane emissions in five Indian cities using TROPOMI data from sentinel-5 precursor satellite. *Urban Climate* **58**, 102174 (2024).
- The International GEOS-Chem User Community. (2024). geoschem/GCClassic: GCClassic 14.4.1 (14.4.1). Zenodo. <https://doi.org/10.5281/zenodo.12584192>
- United Nations Framework Convention on Climate Change (UNFCCC). (n.d.). *The Paris Agreement*. Retrieved from <https://unfccc.int/process-and-meetings/the-paris-agreement>
- Wang, C., Liu, J.Y., Shen, J.L., Chen, D., Li, Y., Jiang, B.S., Wu, J.S., 2018. Effects of biochar amendment on net greenhouse gas emissions and soil fertility in a double rice cropping system: a 4-year field experiment. *Agric. Ecosyst. Environ.* 262, 83–96.
- Wang, J., Meng, X., & Li, F. (2015). A computationally efficient scheme for the inversion of large scale potential field data: Application to synthetic and Real Data. *Computers & Geosciences*, 85, 102–111. <https://doi.org/10.1016/j.cageo.2015.09.005>

Zhao, C., Qiu, R., Zhang, T., Luo, Y., & Agathokleous, E. (2024). Effects of Alternate Wetting and Drying Irrigation on Methane and Nitrous Oxide Emissions From Rice Fields: A Meta-Analysis. *Global change biology*, 30(12), e17581.
<https://doi.org/10.1111/gcb.17581>