DIGGING

Soil Carbon Sequestration Explained

DEEP

MATERRA®

About Materra

Materra designs scalable solutions to grow and source climate-resilient, transparent and equitable cotton.

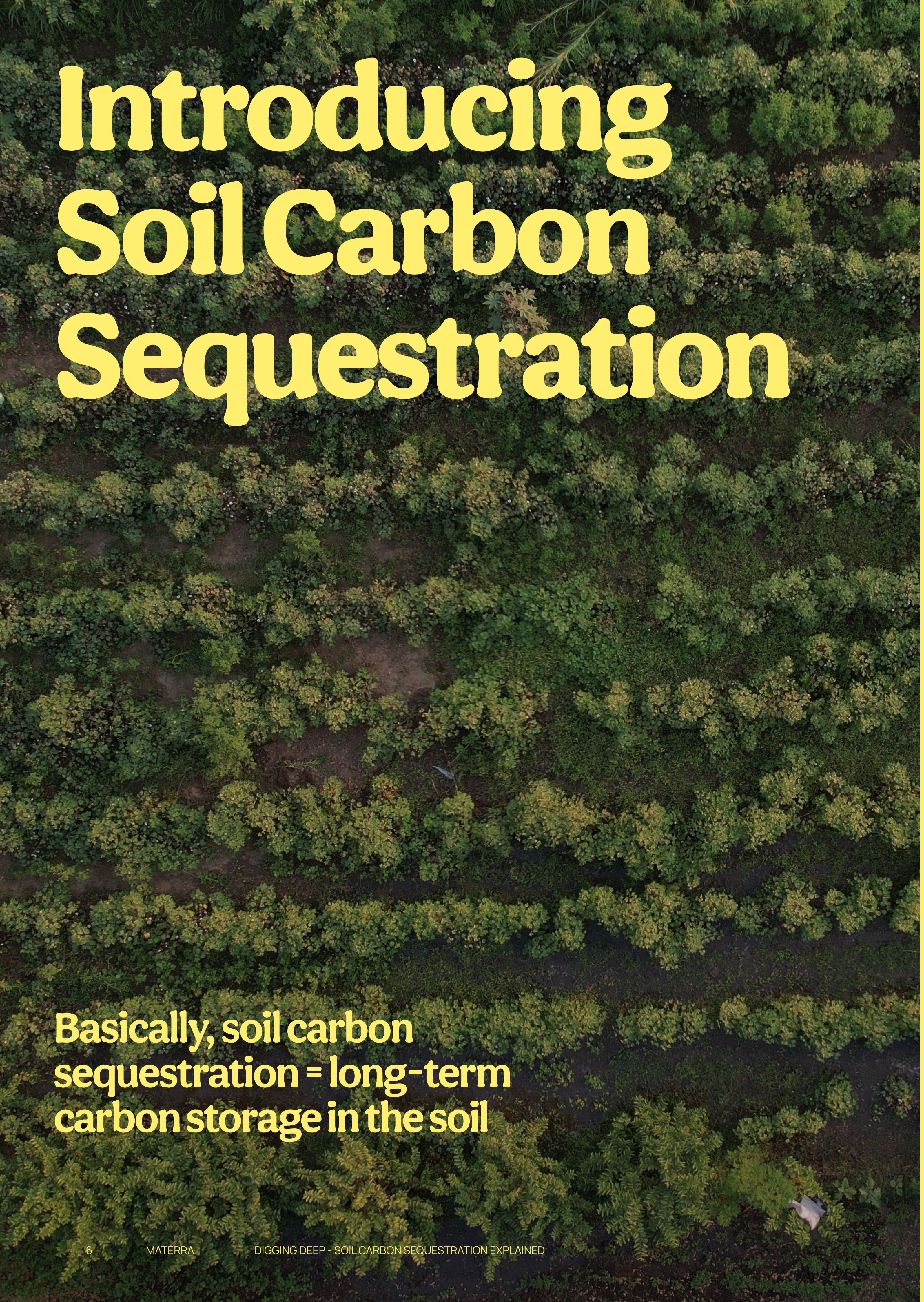
For fashion brands, farmers and the planet.

Materra builds solutions to grow and source future-proof cotton — with the data to prove it. Working with and for farmers, we design and implement custom cotton farming and sourcing programs for fashion and textile brands in India, that are climate-resilient, transparent and equitable.

Our long staple regenerative cotton and program design regenerate the soil, ecosystem and farming communities with a contextual, outcomes-based approach. Our digital technology Co:Farm complements our programs and raw fibre so brands and their customers know exactly what went into making their cotton. Co:Farm combines personalised agronomy and implementation support for farmers, while generating critical Tier-4 impact data for brands, fresh from the field.

With over 55 experienced members in the UK, India and in-field, Materra has a trans-disciplinary team — farmers and scientists, implementation experts who've managed mega cotton programs for decades, and designers crafting purposeful tools and tech. Our Cotton-As-A-Service is setting the template for supply chain transparency, making direct sourcing the new normal.

Learn more about our industry-leading regenerative cotton program at www.materra.tech



Introducing Soil Carbon Sequestration

Basically, soil carbon sequestration = long-term carbon storage in the soil

Practices

- Reducing chemical inputs
- Strategic tillage
- Cover crops
- Botanicals and microbials
- Integrated pest management
- Green manuring
- Integrated livestock
- Diversified crops

Maximise Soil Health

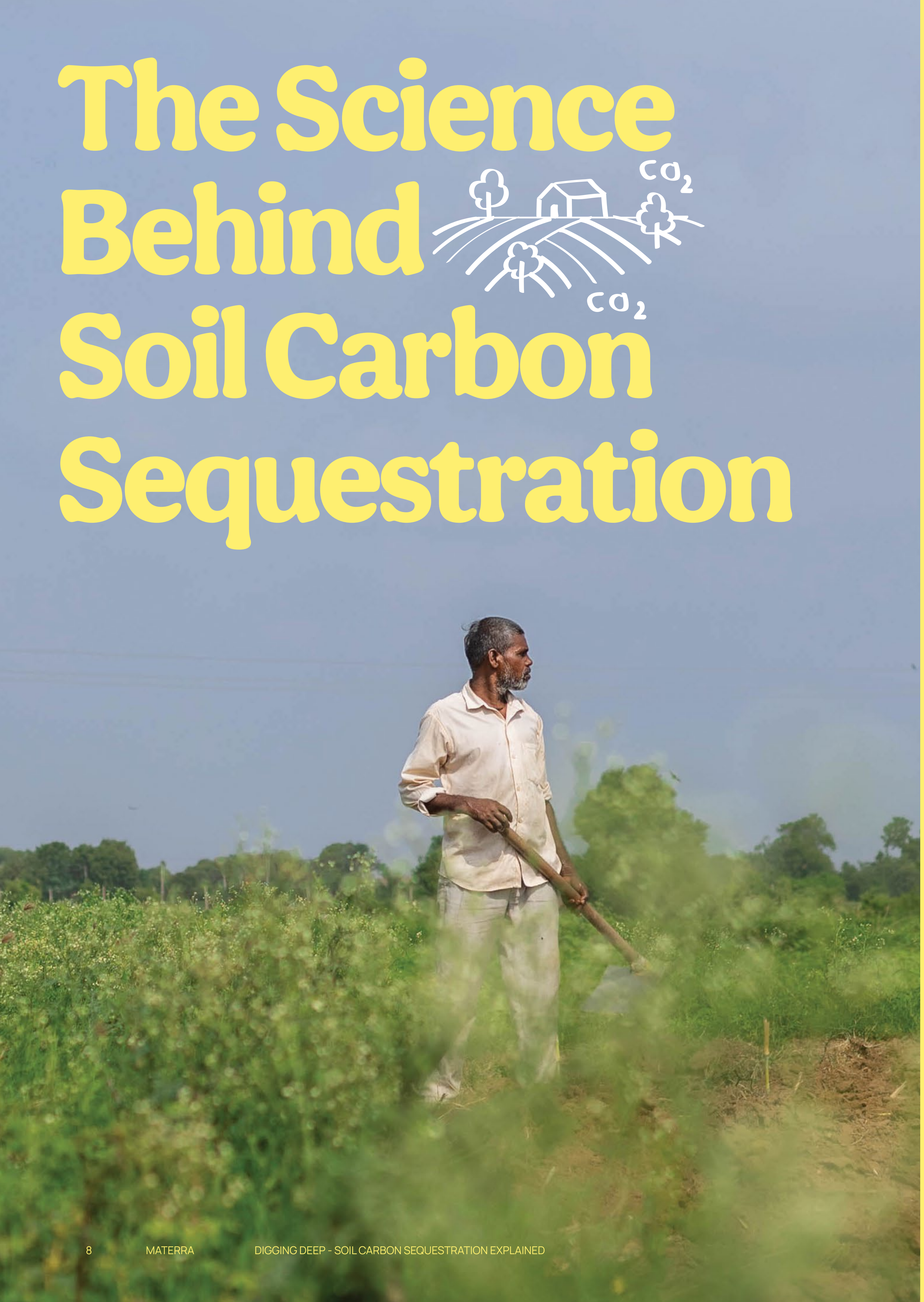
Benefits

- **Sequester carbon**
- Build climate resilience
- Decrease chemical input dependency
- Stabilise yield
- Restore biodiversity

Carbon sequestration is the transferring of atmospheric CO_2 into long-lived pools and storing it securely so it is not immediately reemitted into the atmosphere[1]. The evidence is clear that regenerative agriculture has the potential to reduce emissions and increase carbon removal from the atmosphere. The potential is, however, highly dependent upon regional effects as well as the duration of practices applied[2].

In the field, soil carbon sequestration is one of the benefits of soil health enhancement. And the improvement of soil health is the outcome of a comprehensive range of conservation and regeneration practices, all of which are intricately interconnected. One aspect of soil health is increasing soil organic matter (SOM), of which soil organic carbon (SOC) is a part. This in turn benefits carbon sequestration.

The Science Behind Soil Carbon Sequestration



Soil carbon sequestration is a complex process that demands soil health restoration, sustained commitment and diligent monitoring. The challenge lies in the diversity of approaches, particularly in quantifying, monitoring and addressing issues like permanence.

OFFSETTING VS INSETTING

Carbon credits are a market-based mechanism aimed at reducing greenhouse gas (GHG) emissions. They represent a quantified reduction or removal of GHG emissions that can be bought and sold in carbon markets.

Previously, offsets constituted the predominant form of carbon credits, enabling companies to invest in environmental projects worldwide, such as land restoration or tree planting, to 'offset' and 'balance' their own carbon emissions. However, relying on offsets as an easy, one-size-fits-all solution has led to a reduced ambition to curtail emissions within a brand's operations, and a mere transfer of responsibility. Offsets can seem like permission for business as usual, as all that a company has to do is buy credits to supposedly reduce carbon elsewhere and herein lies the problem.

Quality and Credibility

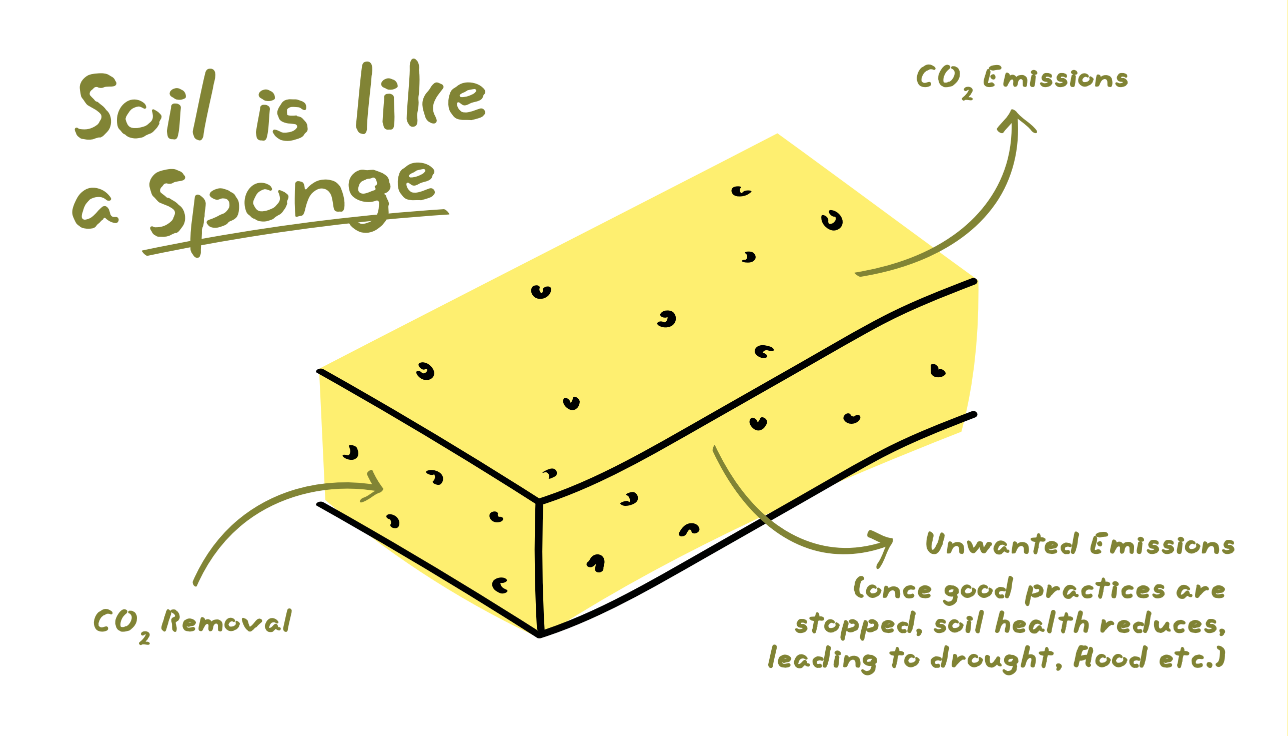
Offset projects are often beyond the direct control, line of sight or influence of the companies purchasing the offsets, raising concerns regarding the reliability of claimed emissions reductions, as well as permanence, reversibility, and additionality. Who ensures these projects do what they say and actually reduce or remove carbon over a long-term period? Who measures them?

Invisibility of implementers

Traditional farming communities often lack any meaningful representation in the decision-making processes, ending up finding themselves marginalised or exploited. Capitalistic dynamics may disrupt local agricultural practices, and lead to conflicts over land rights and displacement, exacerbating these communities' social inequities and environmental degradation. As reported by the Guardian[3], the absence of oversight from leaders in offsetting projects like Verra exacerbates these challenges — local residents are left unaware, unsupported and even abused.

This is where insetting comes in. According to the International Platform for Insetting[4], insetting projects are interventions along a company's value chain designed to generate greenhouse gas emissions reductions and carbon storage while creating positive impacts for communities, landscapes and ecosystems.

Insetting strategy is a significant departure from external offsetting projects, as generating positive impact is placed at the very heart of business operations, rather than as an afterthought. !



HOW CARBON IS SEQUESTRATED

Carbon can be sequestered in the soil through various practices, particularly in farming systems, such as conservation agriculture, balanced fertilisation, cover cropping, agroforestry and restorative land use and management. Think of the soil as a sponge. Like a good quality sturdy sponge that absorbs water, healthy soil can absorb CO_2, preventing it from leaking into the atmosphere. Stop taking care of it, however, and the soil may not be able to be of much help in mopping up any CO_2 emissions.

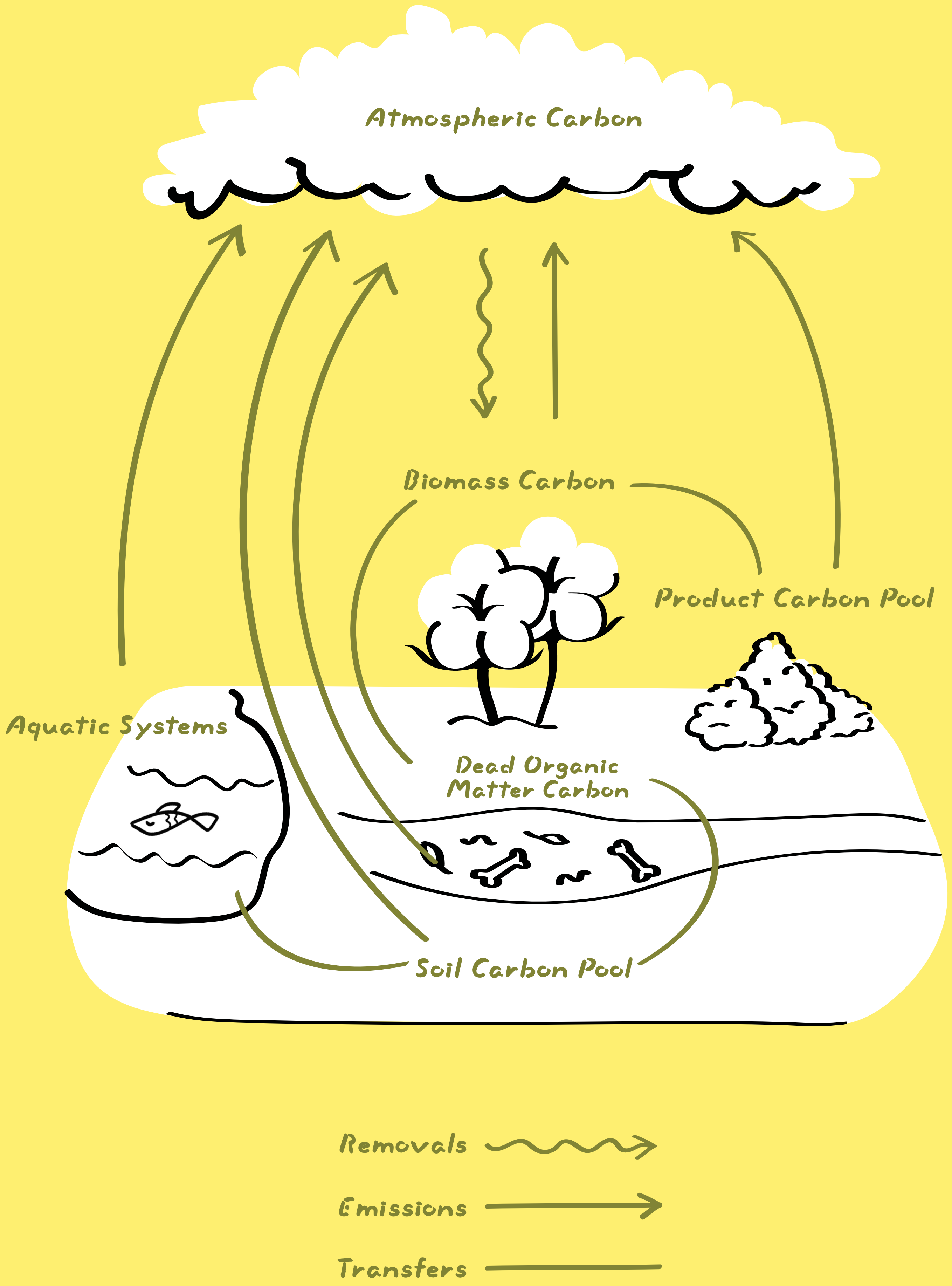
A 'carbon pool' is a component of the climate system with the capacity to store, accumulate, or release carbon[5]. The soil carbon pool is the largest carbon pool in terrestrial ecosystems and it hinges on a delicate balance between the addition of dead plant material (such as leaf and root litter), and losses through the decomposition and mineralisation of organic matter, known as heterotrophic respiration[6]. Carbon enters the soil as root exudates or through the decomposition of root and aboveground plant residues. This process, driven by microbial activity, releases nutrients essential for plant growth, thereby closing the loop in the carbon and nutrient cycles within the soil.

It doesn't end here, though. The carbon sequestration within the soil carbon pool is inherently impermanent and reversible. Without ongoing management or in the face of unforeseen events like fire, flood, or drought, soil carbon may erode or leach into aquatic systems, or be emitted back into the atmosphere through decomposition.

Something that often isn't talked about is that multiple other GHGs are relevant to agricultural systems, e.g. Methane (CH_4) from enteric fermentation and manure management, and Nitrous Oxide (N_2O) emissions from agricultural soils.

Here's the kicker: N_2O poses a significant climate threat due to it having 296x higher global warming potential than CO_2 over a 100-year horizon. N_2O primarily originates from microbial activities in the soil through agricultural processes like nitrification and denitrification.

A fundamental approach to mitigating N_2O emissions from agricultural soils involves precisely matching the spatial and temporal needs of plants to the supply of mineral Nitrogen(N) derived from fertiliser applications, legume-fixed N, organic matter, or manures[7]. Relevant practices include managing N supply through adjustments in application rates, timing, and types of fertilisers, utilising slow-release fertilisers and nitrification inhibitors, adopting better tillage and irrigation practices, incorporating soil amendments like biochar and lime, and implementing appropriate crop rotation, for example, integrating leguminous crops.



Program Management

THE REALITY OF SOIL CARBON SEQUESTRATION

Soil carbon sequestration is a complex process affected by several factors, notably soil type and texture, land use practices, climate conditions, and vegetation cover. Going back to the initial definition by Rattan Lal[1], carbon sequestration involves the process of transferring atmospheric CO_2 into long-lived pools and securely storing it to prevent immediate re-release.

But what is considered long-lived or long-term? For carbon credits, long-term is termed as permanence and it means CO_2 must remain sequestered during the period of the credits, which are typically issued for a 100-year period.

However, as noted by researchers[8], the notion of permanence often refers more to the duration of the carbon sequestration practice rather than the stability of the soil carbon itself. Once the management practice concludes, the assumption is that any accumulated soil carbon will rapidly dissipate.

For smallholder farmers who are already marginalised, the practicalities of the permanence requirement are virtually impossible to implement. Firstly, expecting perpetual commitment from individual farmers or organisations raises serious ethical questions regarding intergenerational obligations and equitable distribution of responsibilities, particularly in regions with complex power dynamics and land tenure systems. Secondly, technological limitations and financial constraints hinder the feasibility of continuous monitoring, especially in less developed areas where advanced remote sensing may not be scalable or effective. This can be due to factors like smaller farm size and limited satellite resolution. Implementation partners also face a substantial data burden when reporting any reversals or emissions and reacting to all those evolving protocols.

UNCLEAR GUIDANCE AND EVOLVING RISKS

If we had to boil it down, we'd say the scientific understanding regarding carbon sequestration is still evolving and incomplete, and therefore guidance also cannot be and hasn't been fully finalised yet. A given practice may lead to carbon storage for a certain period only, before this carbon is leaked back into the atmosphere. For instance, this range can be as small as when farmers discontinue cover-cropping practices, or as significant as when agricultural activities cease on a project site, leading to a change in land use. Plus, soil carbon levels can vary significantly across space and change slowly over time. Direct measurement of soil carbon is resource-intensive and costly, limiting the feasibility of comprehensive sampling efforts. There's currently a lack of data on spatial and temporal patterns of soil carbon accrual across working farms and under different management practices. This scarcity impedes the development of workable estimation models essential for comprehensively understanding and managing soil carbon dynamics.

One of the biggest challenges of insetting is the current absence of a clear industry-wide definition of insetting and recognised best practices, complicating its integration with corporate reporting standards due to major issues like credit trading not always aligning with physical material flows.

Plus, as mentioned in the WBCSD's latest report on Scope 3 emissions in Agricultural & Food value chains[9], the complexity and fluidity of agricultural supply chains make it difficult to delineate the boundaries of what exactly constitutes 'within' a supply or value chain, further complicating the tracking and verification of GHG removal projects.

A recent publication in the *European Journal of Soil Science*[10] has also found that a whopping 90% of plant residues added into the soil are quickly released as CO_2 into the atmosphere, requiring farmers to apply 10 times more carbon than they expect to sequester. Another case study[11] in Araku Valley, southeastern India (a tree-planting offsetting project) found that the local villagers knew absolutely nothing of carbon credits, further prompting the question — Of what use is a carbon credits or sequestration project if the communities where projects are located are not even informed about the nature of the project, or involved as conversation partners?

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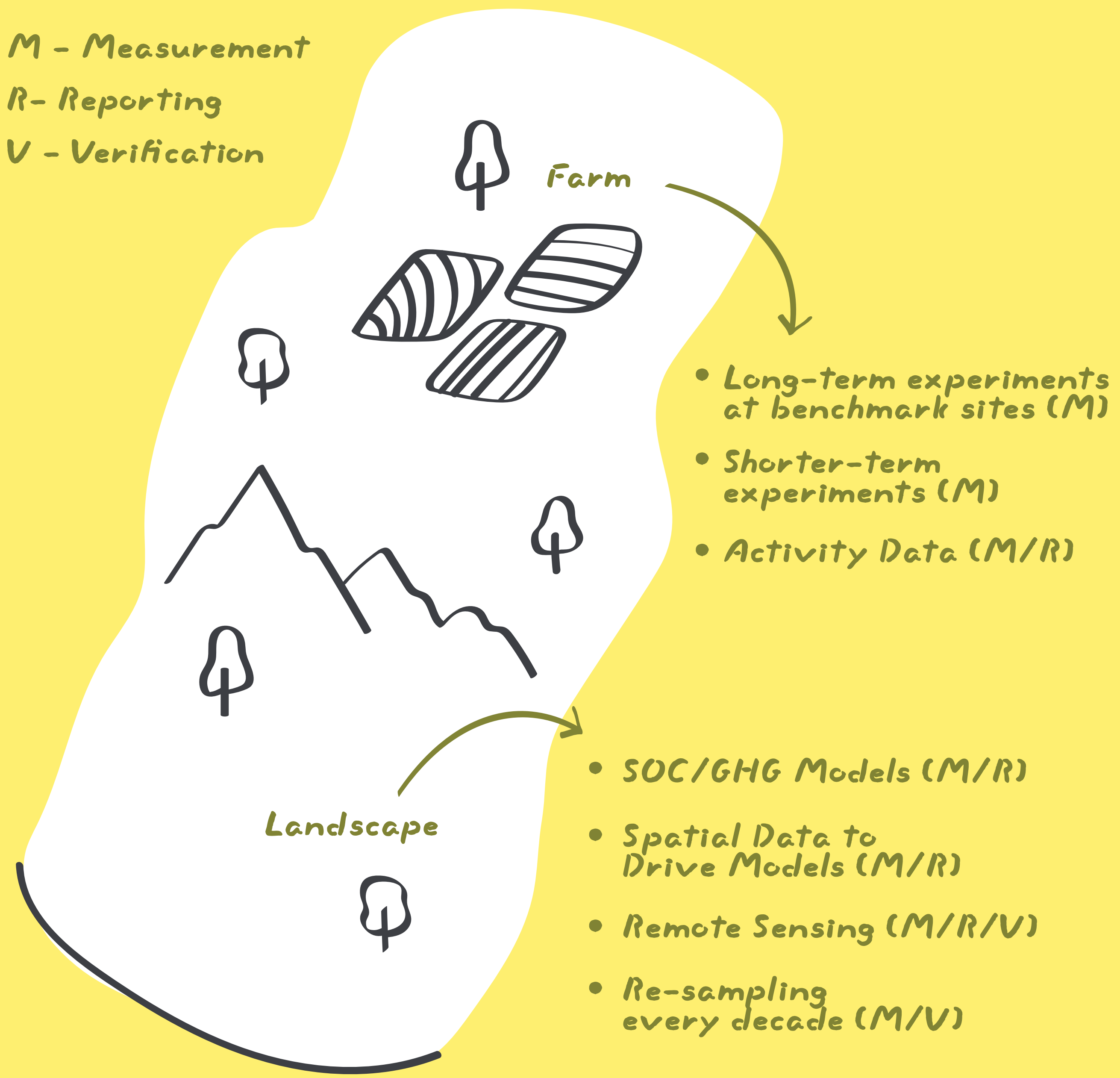


SOIL CARBON MRV: ACADEMIC PERSPECTIVE

The MRV (Measurement, Reporting, and Verification) process is crucial for soil carbon sequestration — it ensures the accuracy, transparency, and integrity of reported carbon reductions. The recommended holistic approach[12] to soil carbon MRV encompasses farm and landscape measurements coupled with benchmark testing and continuous monitoring. This comprehensive strategy is supposed to integrate direct measurements, sophisticated SOC modelling, and remote sensing technologies to deliver precise and ongoing assessments of soil carbon dynamics. However, it poses significant challenges due to the inherent variability of SOC across different landscapes and over time, the slow and uneven process of carbon accumulation in soils, and the high costs and technical complexities involved in soil sampling and analysis. To add to this are the difficulties in standardising MRV protocols across diverse agricultural practices and environmental conditions.

SOIL CARBON MRV: PROTOCOL PERSPECTIVE

While scientists advocate for a nuanced approach that integrates sampling, modelling, and remote sensing, the reality of operationalising these methods into protocols speaks directly to what carbon markets demand.

Protocols often adopt either model-based estimations or hybrid methods that combine episodic soil sampling (e.g., every five years) with process-based modelling to account for the complex, context-dependent nature of soil carbon sequestration. Given the variability of SOC across different environments, prescribing a uniform number of sampling strata and intervals within a protocol may not always be practical or even informative.

This diversity in approach – especially in how scientists, protocols and practitioners quantify soil carbon sequestration and address important issues like the permanence and additionality of sequestered carbon – poses a big challenge. It risks generating credits and claims that lack equivalence or comparability, further complicating the trustworthiness of impact assessment.

	FAO - GSCOC[13]	GHG Protocol LS&R[14]	Verra VM0042 2.0[15]
Measurement Frequency	Every 2 years for model inputs Every 4 years for measured SOC stock	At least every 5 years	At least every 5 years
SOC Quantification Methodologies	Measure and Model	Not specified, but references SHI SHS Protocol and FAO GSOC - MRV Protcol	Measure and Model
Data Requirement	SOC Content %, bulk density of the fine earth fraction and equivalent soil mass	SOC content%, bulk density and equivalent soil mass	SOC content %, bulk density and equivalent soil mass
Sampling Strategy	Stratified random sampling Geotagged locations Minimum of 3 strata and 5-10 sampling locations each	Not specified	Stratified random sampling Geotagged locations
Sampling Depth	Mininum 30cm derived from 0-10cm and 10-30 cm layers, ideally up to 1m	Not specified	Minimum 30cm and if possible to >50cm with 2 seperate sample

Plus, the benefits of engaging in carbon markets for smallholder farmers remain uncertain. FAO's Global Soil Organic Carbon Map[16] shows that India's projected sequestration potential under sustainable soil management scenarios ranges from 0.05 - 0.15 tCO_2e/ha/year. Even with an ambitious promise of €135/tCO_2e carbon pricing, the funds allocated to individual Indian farmers may only amount to €5-€35 per year, which is less than 2.5% of the average agricultural household income. The potential benefits could be more significant for larger, more fertile farms with better soil health (e.g. some of those in Australia and the US).

	India	China	USA
Market Share in 2020-21	25.8%	24.2%	13.1%
Average Farm Size (ha)	1.4	4.5	180.5
Soil Carbon Sequestration Potential (tCO_2e/ha/year)	0.05 - 0.15	0.05 - 0.30	0.05 - 0.50
Carbon Credit Benefit per Farmer per year (price at €135/tCO_2e)	€5 - 35	€25 - 200	€1,400 - 12,000
Annual Income per Rural Household	€1,400	€2,600	€47,000
% of Farmer Annual Income	0.3 - 2.5%	1 - 8%	3 - 26%

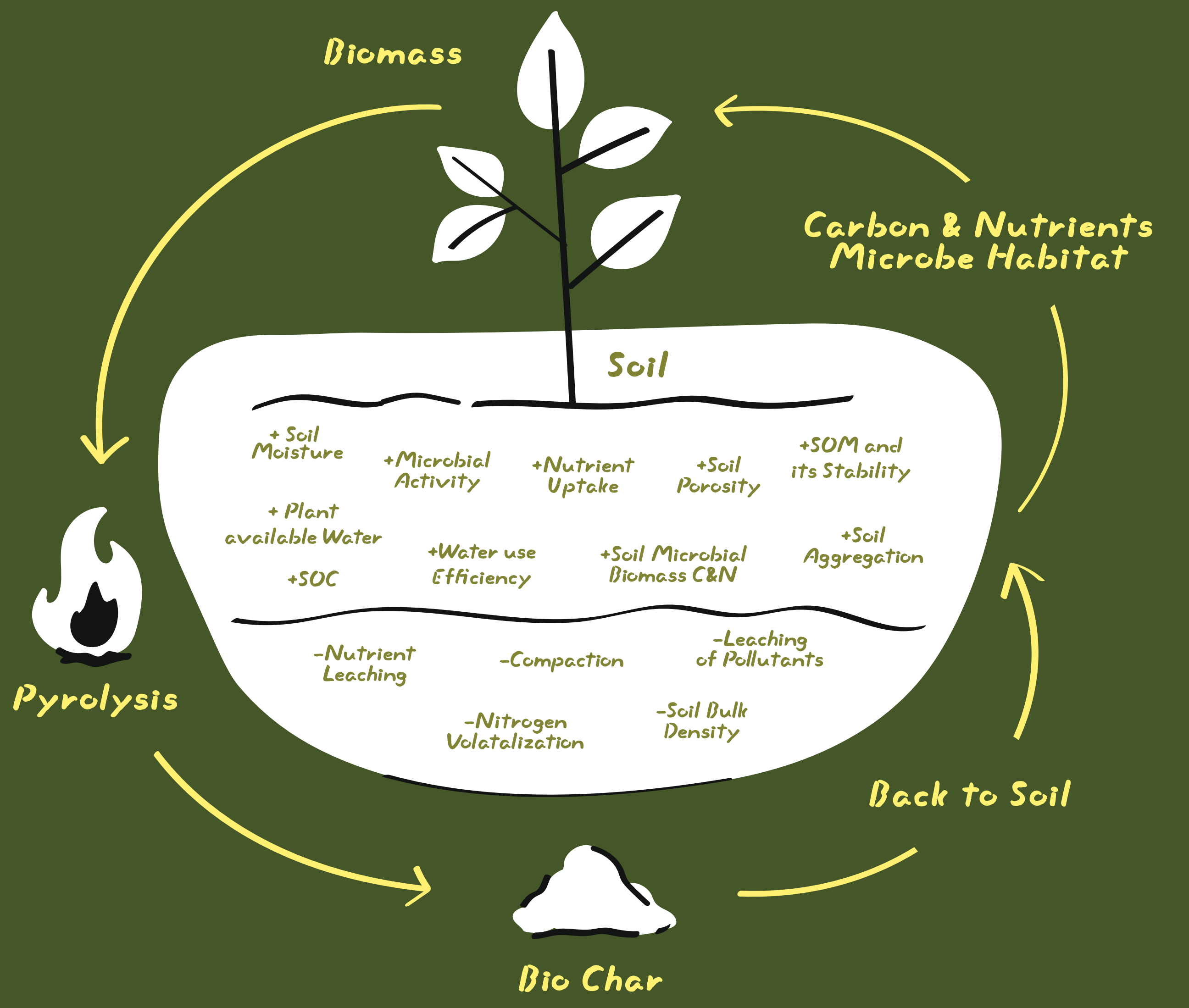
Data source references: 17-23

A Spotlight on BioChar

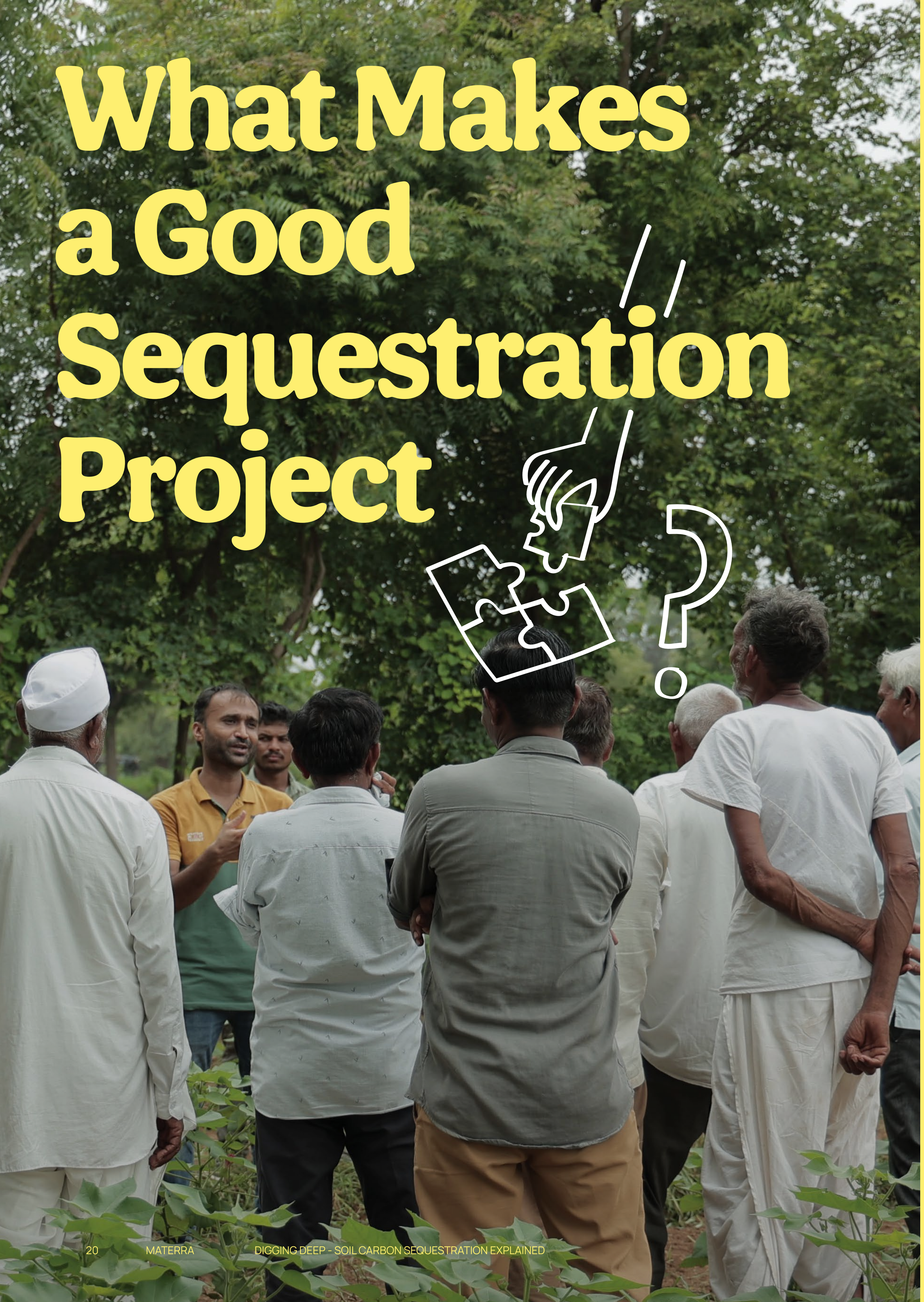
Biochar is a compelling potential solution for smallholder farmers, offering a dual promise of robust carbon sequestration and soil amendment. A 2021 *Nature Geoscience paper*[24] found that biochar systems have greater emission reductions compared to other approaches such as cropland management and wetland restoration. By converting biomass into a stable form of carbon, biochar addresses the critical issue of long-term carbon storage, while also improving soil health, moisture retention, and nutrient availability.

Biochar comes with its own set of challenges, like any other solution. The stability of biochar varies depending on feedstock and production conditions. The biochar production through pyrolysis, can result in significant carbon loss if the gases are not captured and managed correctly. Its impacts are soil *x* crop *x* biochar *x* environment *x* management dependent. Plus, the MRV of carbon benefits is still unclear, requiring trials and experiments.

At Materra, we are conducting field trials with biochar in 2024-26 to test its effects on soil properties as well as on cotton fibre quality. The trials involve meticulously designing field experiments that integrate its application with control plots. We are implementing robust monitoring protocols to assess soil health, plant growth, and SOC enrichment over multiple seasons. Stay tuned for further updates!



What Makes a Good Sequestration Project



As highlighted earlier, soil carbon sequestration is a complex process that requires a context-specific approach for any tangible success. All the current models are certainly not flawless, but they are continually evolving and improving. To wade through this complexity effectively, it is crucial to understand your position and engage with local stakeholders. It's always better to start somewhere and even pave the way for other brands, rather than do nothing in uncertainty. The climate crisis demands action — so act we must.

Here are some steps that we believe can contribute to a good soil carbon sequestration project.

First, take **a deep dive into understanding the web of impacts and dependencies the fashion industry has on soil ecosystems**. This involves aligning with established environmental initiatives, such as the Science-Based Targets initiative (SBTi) Forests, Agriculture, and Land (FLAG) Guidance, the Taskforce on Nature-related Financial Disclosures (TNFD), and the Greenhouse Gas Protocol's Land Sector and Removals Guidance (LSRG).

Then comes the **identification and engagement with key stakeholders - from suppliers to local farming communities**. This is more than just project design; it's about collaborating with local farmers and organisations directly on the ground to co-create socially equitable solutions.

It's here that the project's objectives are crystallised, informed by **a baseline assessment of current practices and aimed towards ambitious yet attainable targets** over a projected 25-year lifespan, underpinned by dynamic purchasing agreements to ensure flexibility and responsiveness to changing conditions. This ensures long-term soil health improvement, stabilising soil organic carbon levels and ensuring the economic viability of farmers' sustainable practices.

Implementation involves **a series of rigorous and scientifically robust MRV actions**. Direct measurement of SOC, alongside advanced modelling of sequestration potential and validation through field teams and/or remote sensing, forms the backbone of this phase. This ensures the project's interventions are accurately quantified and verifiable, aligning with globally accepted protocols like those from Value Change Initiative, VM0042 and the Gold Standard. Meticulous documentation and reporting are critical for transparency and accountability, and provide a solid foundation for credible claims and storytelling.

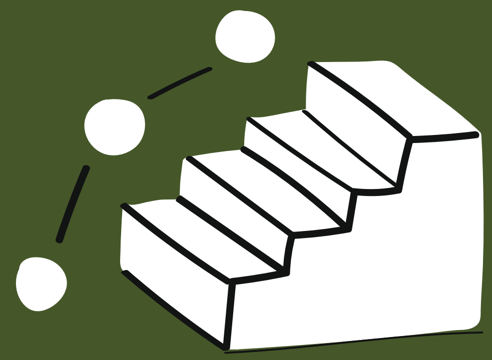
Beyond immediate environmental benefits, aim for **scalability and long-term engagement across the fashion value chain**. This not only involves direct interventions in soil carbon sequestration but also encompasses a broader strategy using data and technology throughout the value chain.

Agricultural vitality is irrevocably tied to the health and fertility of the soil, far beyond the simplistic metric of carbon sequestration alone.

Steps to a Good Sequestration Project

Understanding the Context

Aligning with Scope 3 GHG Goals,
SBTi's FLAG Guidance, TNFD,
GHG Protocol LSRG, etc.



Setting Clear Objectives

- Baseline assesment and target setting.
- 25 year project length with 5-year dynamic purchasing agreements.

Long-term Commitment + Scaling

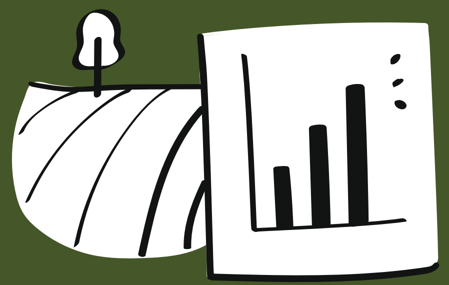
Using data and technology to drive scale and efficiency across the value chain.

Locating the Interface with Soil Carbon

- Dependency analysis and impact screening.
- Project design with suppliers and local community, i.e Materra and Farmers.

Implementation and MRV

- Direct SOC measurement.
- Modelling sequestration potential.
- Validating through remote sensing.
- Re-sampling and accepted protocols(eg. Verra Soil, Gold Standard).
- Documenting and reporting.



Taking the Next Steps

There's no escaping it – soil carbon sequestration is difficult to get right. It's easily reversible, hard to measure, and could lead to greenwashing, but if managed correctly can do real good for both communities and the planet.

What is important to recognise is the nuanced role that these projects play in enhancing the livelihoods of smallholder farmers. Carbon credits can present themselves like a shiny new toy but agricultural vitality is irrevocably tied to the health and fertility of the soil, far beyond the simplistic metric of carbon sequestration alone.

What fashion needs is a collaborative approach that spans industries, shifting towards longer-term engagements and collaborative approaches. Short-term projects and quick fixes are not the solution. By investing in and piloting new innovations, grappling with the challenges of ensuring permanence, and navigating the complexities of MRV, we've tried to underscore the collective journey towards setting global standards that can foster regenerative agricultural practices.

Here's what you can do next!

- Agree on your brand position on carbon accounting, insetting and offsetting. This starts with understanding your brand's specific reporting context and locating your interface within soil ecosystems.
- Seek out partnerships to drive meaningful progress – Public-Private Partnerships (PPPs), reputed local NGOs and supply chain partners, or collaborations within the industry – to share risks and resources.
- Explore substantial 5-25-year project commitments with legal and buying teams. Carbon accumulates slowly in the soil and the associated benefits are not low-hanging fruits but require sustained effort from farmers and deserve long-term dedication.
- Book a technical Q&A with the Materra team. Our experienced impact team is always happy to understand your brand's needs, outline the legislative landscape and guide you through possible solutions.

Glossary[25]

A

Additionality - The concept that a project or activity leads to emission reductions or removals that would not have occurred in the absence of the incentive generated by the crediting or insetting mechanism.

B

Baseline - The emissions level corresponding to the scenario in which the project or activity is not awarded the incentive generated by the crediting or insetting mechanism.

C

Carbon credit - A certified unit issued by a carbon credit program or standard, representing one metric tonne of carbon dioxide equivalent, traded in carbon markets.

Carbon insetting - The utilisation of carbon credits or other units generated within a company's value chain to offset the company's emissions or other environmental and social impacts. While originating from carbon offsetting, the term 'insetting' now encompasses projects beyond carbon credits, such as those aimed at improving livelihoods or preserving biodiversity.

Carbon market - A marketplace where units, allowances, or credits are traded among entities. Referred to as a 'voluntary' carbon market when used for voluntary purposes or certified by voluntary programs, and as a 'compliance' market when used to comply with legal obligations.

Carbon offsetting - The use of carbon credits or other units to compensate for a country's or company's emissions covered by a compliance or voluntary target.

G

Greenhouse gas - Gases in the earth's atmosphere that trap heat, including carbon dioxide, methane, nitrous oxide, and fluorinated gases. Each gas is assigned a Global Warming Potential to compare its warming impact to that of carbon dioxide over a specified period, typically a 100-year time horizon, termed as carbon dioxide equivalent or CO_2-e.

L

Leakage - Increased emissions outside of project boundaries resulting from project activities intended to reduce or remove greenhouse gas emissions. For instance, an action causing emissions reductions in one place may also cause increases elsewhere due to land expansion or activity displacement.

M

Measurement, reporting and verification - A system or protocol for tracking specific methods and outcomes, transparently communicating information, and validating its accuracy and completeness. Often abbreviated as MRV.

P

Permanence - The requirement that issued carbon credits represent long-term reductions or removals, with measures in place to mitigate the risk of reversal. For soil carbon projects, permanence generally requires maintaining activities that lead to soil organic carbon accrual.

Protocol - A guidance document containing rules, standards, deductions, and parameters for calculating or estimating emission reductions or removals. It also guides the monitoring, verification, and reporting processes for projects involving carbon crediting or insetting.

R

Reduction - The act of diminishing emission levels of carbon dioxide or other greenhouse gases into the atmosphere compared to a predetermined baseline.

Removal - The process of actively capturing atmospheric carbon dioxide and securing it in carbon sinks, such as forests, soils, and oceans, or through engineered solutions like carbon capture and storage.

Reversal - A loss in carbon that was previously sequestered, typically due to harvesting, clearing, weather events, or management practices. Reversal risk is directly related to permanence.

S

Scope 1, 2, 3, Emissions - Classification of direct and indirect emissions from a company. Scope 1 covers direct emissions from owned sources, Scope 2 covers indirect emissions from purchased electricity, and Scope 3 includes all other indirect emissions occurring in a company's value chain.

Soil carbon sequestration - The process of transferring atmospheric CO_2 into long-lived pools and securely storing it to prevent immediate reemission. It involves the net additional storage of carbon from atmospheric carbon dioxide in soil pools, after accounting for any greenhouse gas losses.

Soil organic carbon - The carbon contained within soil organic matter, often abbreviated as SOC.

Soil organic matter - The fraction of soil consisting of decomposed plant, animal, and microbial material.

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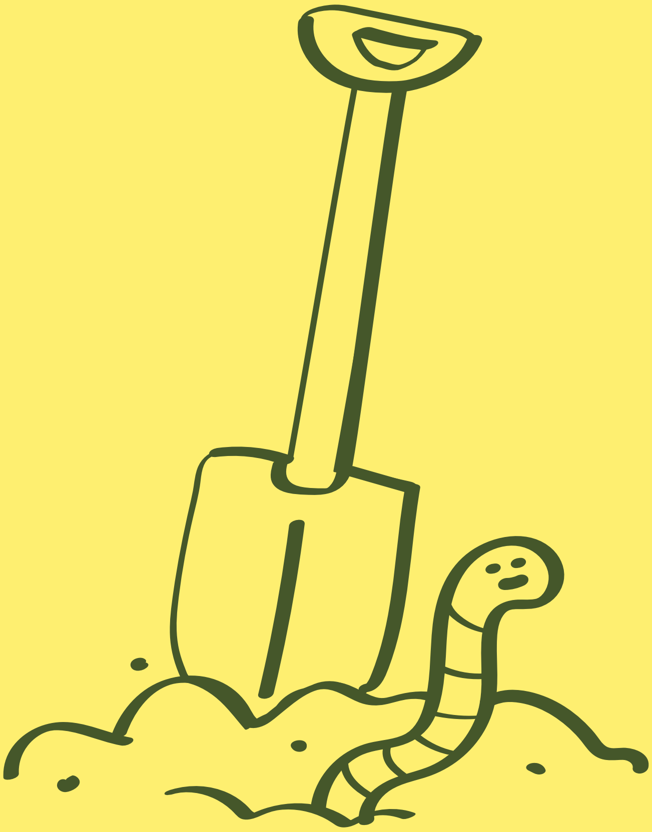
CREDITS

Written by: The Materra Team



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