Methodology Submission

Removal of atmospheric nitrous oxide (N_2O) using Photocatalytic Technology

Submitted By:

Crop Intellect Ltd

Developer name(s): Dr Apostolos Papadopoulos, Yusuf Khambhati, Patrick Skilleter

Email: apostolos@cropintellect.co.uk, yusuf@cropintellect.co.uk, patrick@cropintellect.co.uk

Phone: +44 (0) 7500 794140

Submitted To:

Regen Network Development, Inc

registry@regen.network

https://www.regen.network/

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The mean efficiency of the photocatalyst compared to freshly applied photocatalyst (E_1)	Unitless
Total time the photocatalyst is performing photocatalysis (F)	Days
Monthly rainfall during the experimental period (W)	mm
Total reaction time (T)	Days
Mean irradiation time of light (t)	Days
The mean efficiency of the photocatalyst compared to a clear day (E_2)	Unitless
Mean cloud coverage during periods of irradiance (L)	Octas
Relative rate of reaction based on the relative humidity (E_3)	Unitless
Relative atmospheric humidity (H)	%
Overall photocatalyst efficiency (E)	Unitless

Reaction rate (R)	mg/m^2 of deployed area/gram of photocatalyst/day of N_2O reacted
Ambient concentration of N_2O	mg/m^3 of air
The total mass of photocatalyst used (P)	g
The mass of photocatalyst applied per unit area (p)	mg/ha
The total deployed area (A)	m^2
Total mass of N_2O removed (C)	tCO_2eq

Abbreviations

Nitrous oxide	N_2O
Greenhouse gas	GHG
Carbon dioxide	CO_2
Sources, sinks and reservoirs	SSRs
General Data Protection Regulation	GDPR
Quality assurance and quality control	QA/QC
Quick Response	QR
Deoxyribonucleic acid	DNA
Polymerase Chain Reaction	PCR
Nitrogen	N_2
Oxygen	O_2
Life Cycle Analysis	LCA

1. Methodology Overview

1.1 Scope

The proposed methodology is applicable to projects that utilise photocatalysts to breakdown nitrous oxide (N_2O) from the atmosphere. The photocatalysts can be deployed by placing on any eligible surface i.e., by spraying or embedding into the surface. Any project that enables N_2O breakdown using photocatalysts will be eligible to adopt this methodology.

1.2 Motivation

N_2O is a very potent greenhouse gas (GHG) having global warming potential 265 times that of Carbon dioxide (CO_2) and is responsible for rising global temperatures (United Nations, 2022). The photocatalytic technology for N_2O removal developed by Crop Intellect Ltd is called R-Leaf and may be deployed on any appropriate surface that can receive and retain the photocatalyst, but is especially effective on leaf canopies in agricultural cropland. Agriculture is a major contributor of N_2O emissions generated from synthetic nitrogen fertilisers usage applied to soil which is a global farm practice. According to DEFRA National statistics (2022), Chapter 11: Environment (Updated 27 July 2022), Agriculture contributed to 69% of overall UK N_2O emissions in 2020 which amounts to 14.5 million tCO_2eq. The use of photocatalysts to remove atmospheric N_2O by using daylight provides a unique opportunity to reduce the impact of N_2O towards climate change at scale, with the aim to contract landowners or farmers with collective land availability of over 10,000 hectares (developed world).

1.3 Outline

The methodology is applicable to project activities aiming at removing N_2O from the air via deployment of photocatalysts placed on eligible surfaces such as crop leaves. The methodology offers flexibility to project developers to use photocatalytic technologies removing N_2O into their project design, including choosing a project location. The landowners or farmers will apply the photocatalyst in their practices i.e., spraying crops, that removes N_2O from the atmosphere. Measuring the impact is performed through monitoring of the parameters that influence the efficiency/efficacy of the photocatalyst. The photocatalytic performance and capacity have been determined through lab and field trials, but the real-world parameters specific to the region where the project is set up may affect the performance, therefore the efficiency of the photocatalyst shall be adjusted accordingly to quantify N_2O removal in terms of tCO_2eq in each defined project region. The real-world parameters required to be monitored and the equations to calculate the removal of N_2O in terms of tCO_2eq are defined and described in the methodology.

2. Applicability and Conditions

The methodology is applicable where N_2O carbon equivalents within a defined project boundary would remain unchanged over time in the absence of the project activity. Where applicable, considered greenhouse gases emitted within the project boundary are: N_2O and CO_2. The co-benefits considered to assess ecosystem health depend on the project site and individual project conditions.

2.1 Eligibility

Geographical restriction

This methodology can be applied globally on land-based projects where plants/crops/vegetation are typically sprayed, or such spraying operation can be performed.

Technological requirements

This methodology can only be applied to projects that have access to photocatalytic technology able to remove N_2O and equipment mentioned throughout the document for deploying the material such as spraying equipment, equipment to monitor the regional conditions and measure the removal of N_2O.

Type of surface for photocatalyst application

This methodology can be applied for any projects where photocatalyst for N_2O removal can be sprayed or spread on an appropriate surface. If the surface is permanently shaded (For example, indoors), a light source of adequate intensity (which is well studied and defined in literature) relevant to the surface area must be provided.

The most suitable surface for the photocatalyst application would be the canopy of leaves either in a crop farm or any other planted area. In this case, the type of crop selected is required to maintain a canopy for at least 8 weeks. Application of agrochemical input on a plant canopy by spraying is standard practice in crop production; the photocatalyst for N_2O removal can be mixed with the agricultural inputs (For example, fungicides) and therefore no further activity than the farm standard would be required.

If spraying or spreading of the materials is not a standard practice for the surface selected for the photocatalyst for N_2O removal, then the excess emissions due to the spraying or spreading activity are not part of the baseline and need to be accounted as a part of project activity emissions. Similarly, if the artificial light source is provided, the emissions from electricity or other energy sources and the material shall be a part of the project's activity emissions.

2.2 Additionality

The projects adopting this methodology to generate certified carbon credits must demonstrate additionality. Any project can be determined as additional based on results of the Barrier Analysis and Common Practice analysis.

Barrier Analysis

If barriers exist in the execution of the project activities and the project cannot be implemented without the resulting benefits of carbon certification, then the project can be considered additional. The Barrier Analysis must be carried out by the Project Developer. The said barriers must be mentioned and described in the project description document. The possible barriers could be singular or multiple, and some examples of the barriers are given below:

- Investment barriers (the technology/product to be used in the project is expensive due to the price of the photocatalyst and the required margin of the distribution network; standard inputs are more affordable and therefore an easy choice)
- Knowledge barriers (accepting the use of a new input in standard practices requires confidence and knowledge on the appropriate use and expected outcomes; the knowledge required to execute the methodology; special training for each crop within a farm)
- Institutional barriers (navigating through the regional policies, regulations and legislations require further work compared to an existing product/technology)
- Technological barriers (equipment use for implementing the technology i.e., accessing the canopy of trees)
- Regulatory barriers (where for any regulatory specificity the application of the material is prohibited without registration or monitoring)
- Barriers due to regional traditions (regional traditional practices are restricting the use of the technology i.e., protected crops (in greenhouses) or not sprayed)

- Barriers evolving through existing land management practices (regular canopy removal i.e., professionally managed turf)
- Barriers through ecological circumstances (enabling utilisation of areas where spraying is not common practice)

The barriers described above restrict the adoption of the technology however through the benefits of the verified carbon credits these barriers can be overcome and therefore the technology can be deployed. The A/R Methodological tool *"Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities"* provides a detailed list of potential barriers (CDM Executive Board, 2007).

Common Practice Analysis

The project is considered additional only if the project activities are not common practice in the region where the project is established. The Project Developer must carry out the Common Practice analysis. It is suggested that the common practice analysis be carried out as per Step 4 of the CDM A/R Methodological tool *"Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities"* (CDM Executive Board, 2007). Any deviation from this method must be acknowledged and documented.

2.3 Principles

The principles described in ISO 14064-2:2019 (2019) should be followed during the implementation of this Methodology. The principles serve as a guiding protocol for implementation of the methodology in its entirety. These principles are fundamental in ensuring that all the GHG related information is true.

Relevance

Selection of the GHG sources, sinks and reservoirs (SSRs), data and methodologies appropriate to the needs of the intended user.

Completeness

Inclusion of all relevant GHG emissions and removals, along with all relevant information to support criteria and procedures.

Consistency

Enabling meaningful comparisons in GHG-related information.

Accuracy

Reducing bias and uncertainties as far as it is practically possible.

Transparency

Discloser of sufficient and appropriate GHG-related information to allow intended users to make decisions with reasonable confidence.

Conservativeness

Use of conservative assumptions, values, and procedures to ensure that GHG emission reductions or removal enhancements are not over-estimated.

The above are the extracts of the principles as described in ISO 14064-2:2019 (2019), adopted from Climate Farmers (2022).

2.4 Traceability

To effectively remove N_2O from the atmosphere and achieve the associated environmental benefits that result in carbon credits being issued, it is crucial to spray the photocatalyst for N_2O removal, such as R-Leaf, over the surfaces that enable the photocatalytic reaction to take place. Therefore, it is important to apply the photocatalyst in the field or project area as specified in this methodology. A Quick Response (QR) code system will be utilised that tracks the movement of the material from production through the supply chain to individual farmers. This will allow the photocatalyst usage to be tracked throughout the distribution process, ensuring the product is received by customers, and R-Leaf usage can be quantified and verified, reducing the risk of double counting.

Farmers participating in the project will be assigned a unique code that is linked to their specific order. Each pallet/batch of the photocatalyst for N_2O removal from that order will carry a QR code linked to the farmer's code, the farmer will need to scan the QR code that will confirm that the farmer has received the material assigned to them. The QR code will also be used to track the movement of the photcatalyst through the supply chain along with the delivery information. The data collected from the QR code will be linked to a central database (complying with region's General Data Protection Regulation (GDPR)), which will include information such as the farmer's name, address, order details, crop to be sprayed, area, equipment, timing and field location. This procedure will be a requirement for every landowner/participant being part of a project. They will have the choice of providing the details online, on an application (i.e., mobile app) and by sending a paper form completed.

2.4.1 Data Storage

The data will be predominantly handled by the project developer according to GDPR requirements, who will also be responsible for data management and storage. The following are the guidelines for data storage and handling.

1. Data Storage Location: The data collected during the project, including information on R-Leaf usage, must be stored in a centralized and secure location. This central repository will serve as a reliable source for data verification and analysis. The storage location can be either physical or digital, depending on the project's requirements and available resources.

2. Accessibility: To ensure transparency and collaboration, the data storage system should be accessible to all relevant stakeholders, including project coordinators, researchers, farmers, and regulatory bodies. Controlled access will be provided through secure logins or user authentication, to ensure that only authorized personnel can view or modify the data.

3. Security Measures: Implementing stringent security measures is crucial for protecting the integrity and confidentiality of the stored data. The following measures should be implemented:

    - Data Encryption: Utilize encryption techniques to secure the stored data, both during transmission and while at rest. This helps prevent unauthorized access or tampering of sensitive information.
    - Regular Backups: Regularly back up the data to prevent loss or corruption. Maintain redundant copies of the data in secure locations to ensure its availability even in the event of system failure or data breaches.
    - Access Controls: Implement robust access control mechanisms to restrict data access based on user roles and permissions. This helps maintain the confidentiality of sensitive data and prevents unauthorized modification.

- Data Integrity Checks: Perform regular data integrity checks to ensure that the stored information remains accurate, complete, and unaltered. Implement mechanisms to detect any discrepancies or anomalies in the data, which may indicate potential issues or data tampering.
- Disaster Recovery Plan: Develop a comprehensive disaster recovery plan to address potential data loss scenarios, such as natural disasters, system failures, or cyber-attacks. This plan should include procedures for data restoration and contingency measures to minimize downtime.

As an additional security measure to deter fraudulent claims, for instance, product being re-sold, used at lower rate, on a different crop or at different dose, a Deoxyribonucleic acid (DNA) based tracing technology will be incorporated into the product. The DNA-based traceability method involves the addition of a unique DNA sequence to the product contents, this would be a plant-based DNA of a different type of farmed crop it is applied to. This allows for easy and reliable confirmation of R-Leaf application during the project. A subsample check will be performed to ensure the product has been used within each project. The added DNA sequence will be a random, non-coding sequence that poses no risk of gene transfer or harmful contamination to food or the environment. To confirm the presence of the photocatalyst for N_2O removal a Polymerase Chain Reaction (PCR) test will be performed on the leaf samples collected from the farms using primers specific to the added DNA sequence, which will confirm the presence of the photcatalyst. Sampling a sprayed crop will entail collecting leaves from three points of the field representing three different sections of that field appropriate for its size. These sampling points will be selected randomly by a third-party verifier, and the sampling will be done at any random time after the photocatalyst application date. The leaf samples will be from 5-10 plants from each sampling point and adequate to perform PCR analysis. The PCR test will be from a composite sample for the field and depending on the size of the project, an acceptable subsample to conform with statistical representation will be performed. The PCR test will be performed according to standard PCR protocols, Lorenz (2012) can be used as guidance. Instead of DNA tracing, any other method of achieving the same can be incorporated according to availability and requirements.

Overall, the use of QR codes and DNA markers offers a safe and reliable option for tracing R-Leaf application. This method can be easily implemented to ensure product traceability and confirm the application of R-Leaf as specified by the methodology.

2.5 Project Description and Quality Management

The deployment of the photocatalyst for N_2O removal will be performed through spraying using typical existing equipment in farms. The photocatalyst will be tank mixed and sprayed with other agricultural inputs, which are already a standard practice, and hence the deployment of the photocatalyst will not require additional activities or change of practice.

Different types of plants/crops/vegetation have different sowing and harvesting time periods which also depend on the part of the world they are grown in. Due to this, the deployment times and rate of the photocatalyst can be different, resulting in varying project durations for different types of plants/crops/vegetation. The residual time of the photocatalyst on the leaves should be at least 3-8 weeks, and hence it can only be deployed on crops that maintain full leaves for more that 3-8 weeks (before they are altered/harvested). The photocatalyst for N_2O removal such as R-Leaf resides on leaves for 4-6 weeks, so another application by spraying of the photocatalyst is required after that time period to replace lost material and cover new plant leaves. Therefore, a minimum of two sprays of the photocatalyst (1 kilogram/hectare) during the growth period will be required and that duration also defines the duration of the project.

In some cases, two different crops are grown one after another in the same land over a year's time; then both crops will be considered as separate projects, and each will receive photocatalyst applications. These applications will still align with agricultural inputs which is the standard farm practice.

If the project includes vegetation that does not require harvesting, for example, grasslands or evergreen trees, then the maximum project duration will be one year, and a new project will commence each year. As such projects will have vegetation that maintains canopy or leaves year around, the photocatalyst application will we done every 4-6 weeks throughout the year.

The products of N_2O breakdown are Nitrogen (N_2) and Oxygen (O_2), they are not required to be monitored. As project area is an open system (i.e., farmland), degraded N_2O by the photocatalysts will be replaced by atmospheric N_2O. The atmospheric N_2O concentration throughout the project site can be assumed uniform given that background levels of N_2O are consistent. A specially designed chamber will be used to assist measurements of the N_2O degradation at several points within the project boundary. The chamber has an entry point for ambient N_2O present in the land (project location i.e., farmland) and will not restrict any variables (i.e. light spectrum). The chamber will be connected to appropriate equipment for live N_2O analysis allowing to measure N_2O removal. This data will be used to determine the N_2O concentration at the project location which is taken in a number of locations within the project boundaries. Other methods of N_2O concentration measurements giving similar end results can be adopted based on requirements and availability.

The project description document is prepared for every project by the Project Developer. This document confirms the eligibility of the project as per methodology requirements and establishes consistency with regards to verification and validation. This document describes the specifications of the project and also serves as the basis or third-party verification and validation.

The project description document must include the data quality management approach with appropriate clarifications. This should detail the quality assurance and quality control (QA/QC) protocols for ensuring the following factors:

- Accurate data collection
- Completeness (assessment of whether the data set is comprehensive and contains all the necessary data points or records)
- Independent checks on analysis results
- Trackable data archiving methods, including any anticipated updates to electronic files
- That data is archived electronically and kept for 5 years after the end of the last project crediting period
- Data protection
- A transparent uncertainty assessment
- A statement on how version control (of applied models, methodologies, tools, etc.) is handled

Guidance for evaluation of the quality standards can be taken from the ISO 8000 series which provides a comprehensive framework for data quality management. ISO 8000-1:2022 (2022), ISO 8000-2:2022 (2022), and ISO 8000-61:2016 (2016) are specific standards in this series that focus on data quality concepts, data quality models, and data quality measurement, respectively. ISO/IEC 25012:2019 (2008) is a standard specifically focused on data quality metrics. It provides guidance on the selection and use of data quality metrics for evaluating and assessing data quality. This standard outlines a wide range of data quality metrics that can be used to measure different aspects of data quality. Guidance or specifications for uncertainty assessment can be found in

ISO/IEC Guide 98-3:2008 (2008). This international standard provides guidance on evaluating and expressing measurement uncertainties. It covers principles, methods, and practical examples for uncertainty estimation.

2.6 Project validation

Third-party validation shall be carried out for all projects at the project start, or at the time of the first project verification. The third-party validator checks the compliance of the project specifications with the project description document along with the correct implementation according to this methodology. Relevant project data and documentation must be provided for the desk-based review. A validation report shall document the findings.

2.7 Verification

Third-party verification of a project is carried out after project implementation has commenced and before the first tCO_2eq reduction or removal credits are issued. The following aspects shall be assessed during verification (see Sections 2.5, 4, 5 and 7):

- The extent to which project activities have been implemented in accordance with the project description
- The extent to which monitoring procedures have been implemented in conformance with the monitoring plan
- The reliability of the evidence for the determination of tCO_2eq reductions and removals, as presented in the monitoring report
- The correct application of the formulae and methods set out in the project description for calculating baseline emission and project emissions
- The accuracy of the calculated tCO_2eq emission reductions and removals in accordance with the project description and applied methodology

3. Boundaries

3.1 Project Boundary

This methodology can be applied globally on any land-based projects where plants/crops/vegetation are typically sprayed, or such spraying operation can be performed. The spatial extent of the project boundary encompasses the land (or farmland) included in the project. All the surfaces, including crops, sprayed with R-Leaf or similar photocatalyst are included in the project. Aggregate projects may be set up if the project locations are in the same region and are subjected to similar environmental conditions and parameters. Hence, the project area can include several project boundaries aggregated into one project. Since the products of N_2O breakdown are N_2 and O_2, they are not required to be monitored. As mentioned in Section 2.5, the N_2O concentration will be measured using a specially designed chamber or similar arrangement set up at various locations within the project boundary. The project boundary ensures that key parameters such as day light length and sprayed area will not vary significantly.

The standard farming practices will be assessed allowing to define the baseline for each project. Then establish the evaluation of the photocatalyst application and its impact in N_2O removal.

The greenhouse gases included in or excluded from the project boundary are shown in Table 1 below.

Table 1. *Emissions sources or sinks included in or excluded from the project boundary*

Scenario	Source / Sink	Gas	Included	Justification/Explanation
Baseline scenario	Atmospheric N_2O generated from agriculture activities (or other N_2O emissions that end up at site) is a source in the baseline scenario	CO_2	No	Not significant through this activity
		CH_4	No	Not significant through this activity
		N_2O	Yes	Important source of emissions
	Farming activities is a source of direct or indirect CO_2 emissions	CO_2	Yes	Important source of emissions
		CH_4	No	Not significant through this activity
		N_2O	No	Not significant through this activity
Project scenario	R-Leaf application is a N_2O sink in the project scenario	CO_2	No	Not significant through this activity
		CH_4	No	Not significant through this activity
		N_2O	Yes	Important sink for emissions
	Manufacturing, processing, packaging, storage, and delivery of the photocatalyst is a source of direct or indirect CO_2 emissions	CO_2	Yes	Important source of emissions
		CH_4	No	Not significant through this activity
		N_2O	No	Not significant through this activity
	Farming activities is a source of direct or indirect CO_2 emissions (this won't change from baseline as the photocatalyst application does not increase farming activities)	CO_2	Yes	Important source of emissions
		CH_4	No	Not significant through this activity
		N_2O	No	Not significant through this activity

3.2 Temporal boundaries

The time frame of the project is specified before the commencement of the monitoring, and it is included in the project description document. The document includes the start and end date of the project activity, the start and end date of the crediting period and reporting milestones, including set reporting periods.

The following guidelines define the reporting period and establishment of the time limits:

- The project length shall be generally one growing cycle or one year, depending on the type of plants/crops/vegetation the photocatalyst is applied on, described in Section 2.5.
- The project description is detailed at the beginning of the project period.
- The necessary data points/parameters shall be monitored at time periods described in Sections 5 and 7 of this methodology during the project length.
- The project developer shall record data on activities, change in practices and any other relevant details to the specific project area surface along with tCO_2eq emission balance at the end of the project.
- The number of carbon credits are calculated based on monitored data, after each project. A document shall be created which describes the progress of the project in a traceable scoring procedure and contains the number of credits assessed.
- Modifications can be made in the project timeline for justified reasons, for instance, extreme weather events. Such modifications shall be described and documented.

4. Baseline Emissions

The project baseline activity will be demonstrated using the latest version of the "Combined tool to identify the baseline scenario and demonstrate additionality" that is available on the UNFCCC website (UNFCCC, 2017).

Continuation of pre-project N_2O emissions and no means of removing that N_2O is the most plausible baseline scenario. Baseline conditions will include measuring the background N_2O concentration before the project activities. As the project area is an open site where air moves freely, the N_2O concentration is assumed to be the same within the project boundary. At least five measurement points uniformly spread across the project boundary will be selected to measure N_2O concentration and averaged. N_2O measurement equipment or specially designed chambers will be used to measure the concentration. These measurements will be taken before photocatalyst application and considered as ambient N_2O concentration for the duration of the project.

5. Quantification of GHG Emission Removals

It is essential to determine the amount of N_2O removed by the application of the photocatalyst to determine the GHG removals in terms of tCO_2eq. As the end products of the photocatalytic reaction (i.e., N_2 and O_2) are not stored but released into the atmosphere, the GHG removal cannot be determined through soil or crop sample analysis as done by other carbon sequestration methodologies, which sets this methodology apart. Hence, the quantification of N_2O removal is done by using the photocatalysis reaction rate and the parameters that affect it.

5.1 N_2O Breakdown Equation

A highly precise equation is dependent on the interaction of many factors, and the ability to measure them and monitor them. Focusing on the most significant and relevant variables in an equation can be used to account for the reaction rates utilising existing knowledge and acceptable assumptions.

5.1.1 Assumptions Made

When working with the proposed predictive equation, several key assumptions must be made to ensure accurate results.

- The only variable changing is the one being considered. If multiple variables are changing simultaneously, the interaction of these changes may affect reaction rate differently to what is expected.
- The changed variable is limiting reaction rate. As a variables increases, its relative effect on reaction rate decreases. For example, a reaction with a high light intensity will not benefit from increasing light intensity further if the concentration of N_2O is low..
- Any changes to the baseline N_2O concentration are caused by the photocatalyst. For example, if N_2O is lost due to reasons other than the photocatalytic breakdown, then the reaction rate will be artificially inflated.

5.1.2 Equations

In reactor-based experiments, it was determined that 1 g of photocatalyst can reduce ambient N_2O concentrations by 10% under a set of conditions that are henceforth referred to as standard conditions. Using this as a baseline and by estimating the effect other conditions have on the rate of reaction, the amount of N_2O that can be degraded by the photocatalyst can be predicted using the following equations.

Photocatalyst Efficiency

Photocatalyst loses efficiency over time as impurities build up, and rainfall reduces the photocatalyst material from the surface. R-Leaf loses a mean 0.08% of its catalytic efficiency every 24 hours. A mean monthly rainfall of 55.7 mm has been found to remove 7.5% of R-Leaf every 28 days, or 0.27% every 24 hours (this number is specific to R-Leaf only, if other photocatalysts are used in the project, then the manufacturers will have to provide data for those photocatalysts). The equation below accounts for this loss of efficiency:

$$E_1 = 1 - \frac{0.0027 \times \frac{W}{55.7} + 0.0008 \times F}{2} \qquad \text{[Eq. 1]}$$

Where:

E_1 The mean efficiency of the photocatalyst compared to freshly applied photocatalyst. A unitless value between 0 and 1. If a value of less than 0 is obtained, then the catalyst has ceased to function.

F Total time in days the photocatalyst is performing photocatalysis

W Monthly rainfall during the experimental period (mm)

Total Reaction Time

Photocatalysts rely on the presence of light. The amount of N_2O that can break down is therefore dependent on the duration for which it can catalyse the reaction. For single day experiments or experiments undertaken with artificial lighting, T is equal to the amount of time the photocatalyst is lit. For the project duration using natural light, total reaction time can be calculated as follows:

$$T = t * F \qquad \text{[Eq. 2]}$$

Where:

T Total reaction time (days)

t Mean irradiation time of light per day, will be a decimal (days)

F Number of days irradiation occurred (days)

Light Intensity

The rate of reaction of photocatalysts depends on the amount/intensity of available light to progress the necessary reactions. With higher light intensity, there is higher absorption of light on the surface of the photocatalysts, which produces higher number of hydroxyl radicals (OH•) (Hufschmidt *et al.*, 2002). Light intensity is heavily influenced by cloud coverage, with overcast days having under 1/3 of the light intensity on cloudless days (Matuszko, 2012). The equation to determine the effect light intensity has on reaction rate was calculated as follows:

$$E_2 = -0.0137L^2 + 0.0319L + 0.9878 \qquad \text{[Eq. 3]}$$

Where:

E_2 The mean efficiency of the photocatalyst compared to a clear day. A unitless value between 0 and 1.

L Mean cloud coverage during periods of irradiance, measured in octas.

Relative Humidity

Water is used as an electron donor and acceptor by titanium dioxide during photocatalytic reactions (Zhang *et al.*, 2022). However, it is not utilised in the breakdown of nitrous oxide, as this occurs with oxygen in the N_2O molecule acting as an electron donor and acceptor (Obalova *et al*., 2013; Koci *et al*., 2017). However, Kudo *et al*., (1992) found that the rate of N_2O breakdown was 85% lower without humidity compared to optimal conditions, implying that it does hold an important role in maximising reaction rates. Whilst peer-reviewed data investigating the effects on varying humidity on the rate of breakdown of N_2O are lacking, data on its effects on the breakdown of nitrogen dioxide and nitric oxide are more common. Thus, effects of relative humidity on N_2O breakdown can be estimated based on the effect it has on other photocatalytic reactions. Whilst humidity is required, high humidity limits reaction rates as water competes with reactants for space on the photocatalyst. Ballari *et al*., (2010) determined that increasing humidity linearly decreased reaction rates by 13% when relative humidity was increased from 50% to 80%. Si *et al*., (2021) determined that increasing relative humidity from 50% to 83.35% decreased reaction rates by 20%. These data suggest that increased humidity linearly decreases reaction rate. Using these data, and using 50% humidity as a standard, humidity's effect on photocatalyst efficiency can be estimated as follows:

$$E_3 = (-0.0002455 \times H^2) + 0.0285006 \times H + 0.1560163 \quad \text{[Eq. 4]}$$

Where:

E_3 Relative rate of reaction based on the relative humidity.

H Relative atmospheric humidity (%)

Photocatalyst Efficiency

The photocatalyst efficiency is the rate of reaction compared to the standard conditions, where 1 g of photocatalyst removes 10% of N_2O in 24 hours. A value of 1 indicates reaction rates are comparable to standard conditions. It is calculated using the following equation:

$$E = E_1 \times E_2 \times E_3 \quad \text{[Eq. 5]}$$

Where:

E Overall photocatalyst efficiency. This is the rate of reaction compared to standard conditions.

E_1 The mean efficiency of the photocatalyst compared to freshly applied photocatalyst. A unitless value between 0 and 1. If a value of less than 0 is obtained, then the catalyst has ceased to function.

E_2 The mean efficiency of the photocatalyst compared to a clear day. A unitless value between 0 and 1.

E_3 Relative rate of reaction based on the relative humidity.

Reaction Rate

The overall reaction rate depends on several of the above equations to determine reaction efficiency, as well as the concentration of N_2O. The value is divided by ten as 10% of N_2O is degraded per gram of photocatalyst. This gives the equation below to determine rate of reaction:

$$R = (E \times [N_2O]) \div 10 \quad \text{[Eq. 6]}$$

Where:

R Reaction rate (mg/m^2 of deployed area/gram of photocatalyst/day of N_2O reacted)

[N_2O] Ambient concentration of N_2O (mg/m^3 of air)

E Overall photocatalyst efficiency (unitless)

Amount of Photocatalyst Applied

1 g of photocatalyst degrades 10% of N_2O in 24 hours of irradiance. As the amount of photocatalyst increases, the rate of N_2O breakdown is also expected to increase, as the area of catalyst on which N_2O can be broken down is increased. The amount of photocatalyst applied can be calculated using the below equation:

$$P = (10 \times p) \div (A \div 10000) \quad \text{[Eq. 7]}$$

P The total mass of photocatalyst used (g)

p The mass of photocatalyst applied per unit area (mg/ha) (based on application rates)

A The total deployed area (m^2)

Amount of N_2O Degraded

Once the overall reaction rate has been obtained, the amount of N_2O degraded can be calculated by taking account of the total reaction time and the amount of photocatalyst, as shown in the equation below:

$$N = P \times A \times R \times T \quad \text{[Eq. 8]}$$

Where:

N Total mass of N_2O removed (mg)

P The total mass of photocatalyst used (g)

A Total deployed area (m^2)

R Reaction rate (mg/m^2 of experimental area/gram of photocatalyst/day of N_2O reacted)

T Total time reaction occurred during the experiment (days)

Amount of N_2O removed in terms of tCO_2eq

The global warming potential of N_2O is 265 times that of CO_2 (United Nations, 2022). Hence, the tons of N_2O removed can be converted to tCO_2eq by multiplying it with 265.

$$C = (N/10^9) \times 265 \quad \text{[Eq. 9]}$$

Where:

C Total mass of N_2O removed (tCO_2eq)

N Total mass of N_2O removed (mg)

6. Project Activity Emissions

The Project Activity Emissions are the emissions that result due to the operations required to implement, run, monitor, and conclude the project. As these activities put the GHGs into the atmosphere which would not have occurred in the absence of the project, they need to be accounted for and deducted from GHG removal claims by the project.

As mentioned earlier, the implementation of the project in crop farming will not affect the standard farming practices as spraying is already an operation performed regularly. Therefore, the emissions from the standard agricultural practices are not part of the project activities, and hence will not be deducted from the GHG removal claims.

The activities resulting from procurement of raw materials, manufacturing processes, packaging and transportation for the production and supply of the photocatalyst for N_2O removal will generate emissions. These emissions have to be calculated by full Life Cycle Analysis (LCA) of the photocatalyst, which would then be deducted from the GHG removal claims by the project.

The emissions from other project activities like monitoring and measurements will be considered and included and removed from the total GHG removal claim.

Therefore, the Net GHG removal claimed by the project will be the Project Activity Emissions deducted from the tCO_2eq N_2O removed.

7. Monitoring

Table 2 details the parameters that will be monitored during the project.

Table 2. *Parameters monitored throughout each project, a) rainfall, b) light irradiation/day, c) cloud coverage, d) relative humidity, e) ambient N_2O.*

(a)	
Data / Parameter	Monthly rainfall (W)
Data unit	mm
Description	Refers to rainfall each month during the project duration.
Equations	Eq. 1
Source of data	Meteorological station readings/weather reports
Justification of choice of data or description of measurement methods and procedures applied	This parameter is important to determine efficiency of the photocatalyst during the project duration. The project developer will be responsible to gather this data. The data should be noted daily.
Purpose of Data	Quantification of GHG emission removal
Comments	N/A

(b)	
Data / Parameter	Mean irradiation time of light per day, will be a decimal (t)
Data unit	days
Description	Refers to amount of daylight available each day
Equations	Eq. 2
Source of data	Meteorological station readings/weather reports
Justification of choice of data or description of measurement methods and procedures applied	This parameter is important to determine the total reaction time of the photocatalyst. The project developer will be responsible to gather this data. The data should be noted monthly.
Purpose of Data	Quantification of GHG emission removal
Comments	N/A

(c)	
Data / Parameter	Cloud coverage (L)
Data unit	Octas
Description	Refers to mean cloud coverage during periods of irradiance
Equations	Eq. 3
Source of data	Meteorological station readings/weather reports
Justification of choice of data or description of measurement methods and procedures applied	This parameter is important to determine the effect of light intensity on efficiency of the photocatalyst. The project developer will be responsible to gather this data. The data should be noted daily.
Purpose of Data	Quantification of GHG emission removal
Comments	N/A

(d)	
Data / Parameter	Relative humidity of the atmosphere (H)
Data unit	%
Description	Refers to the mean daily humidity in the atmosphere at project location for the duration of the project.
Equations	Eq. 4
Source of data	Meteorological station readings/weather reports
Justification of choice of data or description of measurement methods and procedures applied	This parameter is important to determine the relative reaction rate of the photocatalyst influenced by relative humidity. The project developer will be responsible to gather this data. The data should be noted daily.
Purpose of Data	Quantification of GHG emission removal
Comments	N/A

(e)	
Data / Parameter	Ambient concentration of N_2O ([N_2O])
Data unit	mg/l of air
Description	Refers to the ambient N_2O concentration in the air for the at start of the project at the location of the project, based on local estimates.
Equations	Eq. 6
Source of data	Historic or measured data using N_2O monitoring equipment or GC analysis, measured once.
Justification of choice of data or description of measurement methods and procedures applied	This parameter is important to determine the reaction rate of the photocatalyst. The project developer will be responsible to gather this data. The data should be noted at the start of the project.
Purpose of Data	Quantification of GHG emission removal
Comments	N/A

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