Methodology Concept Note Submission

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Concept Note Details:

1. Title of Proposed Methodology:

(Tentative title, can be updated)

Removal of atmospheric nitrous oxide (N_2O) using Photocatalytic Technology

2. Summary:

(Brief summary of the methodology concept, including any background information, ecological outcomes, and indicators measured)

The proposed methodology is applicable for project activities aiming at removing N_2O from the air via deployment of technologically advanced photocatalysts on crop leaves. The photocatalytic technology to breakdown N_2O under UV light is well established and published [1]. Crop Intellect Ltd has conceived a disruptive innovation called R-Leaf®, where photocatalysts are altered through a specialised process called double doping to enable them to work under normal visible light (found outdoors rather than UV light). The material is not absorbed by the plant, therefore, whilst on the surface of plants and exposed to daylight, they continuously remove N_2O from the atmosphere. Through this innovation, we aim to achieve large-scale impact on greenhouse gas removal and contribute towards sustainable development.

The nitrification and most importantly the denitrification processes carried out by soil microorganisms are responsible for N_2O generation and release into the atmosphere [2]. The Nitrogen (N) required for these processes comes from the soil applied nitrogen fertilizer inputs as a part of standard farming activities globally [2]. Photocatalysts are proven to breakdown and remove atmospheric N_2O effectively [1]. The R-Leaf photocatalysts are selective for N_2O gas and have been formulated in a simple to use formula that is tank-mixed with other inputs sprayed on plant leaves or any other surface area. This facilitates ease of R-Leaf® deployment directly on crop farming land, and due to the vast area covered by arable or other crops, it is an effective and economical way to remove N_2O at a significant and meaningful scale. Although the R-Leaf® technology is specific and IP protected which allows a widespread adoption, the methodology can also be used by projects based on other photocatalytic technologies for N_2O removal. The by-products of the photocatalytic reaction removing N_2O are inert including N_2 and O_2. The amount of photocatalysts used per hectare is 1000g prepared into a formulation of 2 litres. This is applied at appropriate timings in broadacre crops (UK, T1 and T2 growth stages for cereals, tank-mixed with other standard scheduled inputs). These timings

coincide with a good crop coverage to host R-Leaf® and the release of N_2O through the nitrogen applications. Hence, there is no additional cost or environmental impact due to photocatalyst application for N_2O removal. The period of functionality for R-Leaf is approximately 5 months. The amount of N_2O removed by R-Leaf technology has been calculated and measured by laboratory experiments quantitatively and also validated in the field studies.

The target crops are broadacre (cereals) aiming to maximise the impact of photocatalysts in N_2O removal. Although we have optimised processing the material to work under normal light in a cost-effective manner, farmers will still conceive the solution as an extra cost. The reduction of synthetic nitrogen application and replacement with R-Leaf is unlikely to be adopted by most farmers due to the perception of losing yield. However, the environmental benefit of the photocatalytic technology is **not** the reduction of synthetic Nitrogen usage, but the **direct removal** of N_2O from the atmosphere, which comparatively has a much higher impact. Therefore, the adoption of such photocatalytic technology is unlikely to be at meaningful scale unless there is a clear Return on Investment (ROI) to the farmer. We aim to enable the use of photocatalytic technology for N_2O removal in farming with help of Regen Network, which will comprise an incentive to adopt R-Leaf® and other similar technologies to reverse climate change.

This is meant to be a globally applicable methodology with high scalability, but initial projects using this methodology will likely be in UK, Europe and the USA. The reason behind this is our understanding of the farming processes in these areas and the availability of broadacre agriculture. It is envisaged that the success in those markets will fuel expansion into other continents at a more economical efficiency.

The photocatalyst can be sprayed on any surface to remove atmospheric N_2O from any emission pathways. However, according to DEFRA National statistics, 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_2 eq [3]. Hence, this methodology focuses on agricultural activities because it is a prominent source of N_2O emissions. Additionally, the spraying of the photocatalyst would not require any change in standard farming practices as it would be mixed in the spraying tank with other chemical or mineral inputs, thereby, avoiding any additional cost or environmental impact that the spraying equipment might have i.e., for non-agricultural usage. Moreover, the broadacre crops (cereals) are grown widely across the world and are vital in terms of global food security [4]. Nevertheless, there is a wide range of potential applications of the technology such road verges, forests, train tracks, green walls and other green infrastructures and even other surfaces.

3. Project Activity:

(Activity, land management intervention, or earth stewardship practices this methodology supports. Examples may include nature-based solutions such as over cropping, rotational grazing, reforestation, but it can also include social or community-focused programs which regenerate ecosystems.)

The proposed methodology will be applicable to projects that utilise photocatalysts (enabled to catalyse under normal light) sprayed on broadacre agricultural crops with the purpose of removing nitrous oxide from the atmosphere.

Project Design Phase (before project physically starts).

The area to be used for a project (boundary) is crop farming land, predominantly growing cereals (winter wheat, winter barley) along with other broadacre crops i.e., oil seed rape, potato, sugar beet and grassland as found typically in a crop rotation. It will further include soya, cotton, maize, and other crops depending on the project's location i.e., in the US and Europe. 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.

In this example, we are looking at a typical cereal farm in the UK/EU. The methodology will be applicable globally as the cultivation of cereals is similar. The baseline for the project activity is not based on any changes to the current farming practices (as it is difficult to force farmers to reduce the use of synthetic nitrogen) but to the removal of N_2O by using special photocatalyst sprayed on the crop surface. The manufacturing, processing, packaging, storage, and delivery of R-Leaf have been calculated as the baseline. The Climate Impact Forecast (CIF) tool* supported by the European Innovation Council has validated a removal of 5.4 tCO_2 equivalent/year per hectare by using 2 litres of R-Leaf on a cereal crop, yielding an average 7tn/ha per season (functional unit = 1 ton of wheat). The link to CIF validation process** can be found in the Footnotes. The calculation has taken into account the baseline, which is provided in CO_2 equivalent.

As part of the evaluation and validation to measure the impact, the crop yield, field characteristics and history, weather data and the emissions in the locality will also be taken into account.

* https://impact-forecast.com/
** https://impact-forecast.com/cif-validations

Project Implementation Phase.

A typical project will include spraying of the photocatalyst for N_2O removal on the broadacre crops grown by the farmers within the project. In this example, a farmer of cereals (i.e. 500ha winter wheat) would add the recommended amount of photocatalyst (i.e., 1lt of R-Leaf product containing 500g of the photocatalyst) into the spraying tank at growth stage T1 and repeat at T2. The photocatalyst would reside on the surface of the plant foliage and on a daily basis, it will absorb day light and enable photocatalysis to breakdown N_2O. The farmer would add the photocatalyst for N_2O removal to the spraying tank without any requirement of extra activity to existing practices. The N_2O levels at the project site (subsample) will be monitored and compared against the baseline conditions before project implementation and after to quantify the amount of N_2O removed in form of tCO_2 eq/year.

The validation of the CIF tool resulted in valid, positive, and significant for validity of forecast, impact compared to the baseline, and magnitude of impact, respectively. The validation supported the calculations and references for the mitigation of climate change with impact reduction potential of 5.4 tCO_2 eq/year. This was based on the use of the photocatalytic technology sprayed on a winter wheat crop at 2 litres per hectare over the season (see Figure 1).

Figure 1. *The impact reduction potential of 5.4 tCO_2 eq/year per hectare by application of 2 litres of R-Leaf established by Climate Impact Forecast tool*

Farmer and distributor participations, along with stakeholder engagement, would also be promoted through activities that include *inter alia* consultation events, farm visits, conferences, exhibitions in agriculture, publications, media, breakfast meetings and seminars/webinars. A grievance platform will be set up for the stakeholders as a part of project activities, where they will be able to access the progress reports, convey their concerns and make suggestions and queries.

4. Monitoring Approach:

(How do you intend to monitor the project activity, including any data or tools which might be used)

The impact of the photocatalyst for N_2O removal to achieve the stated impact can be directly linked to its application in the farms. This is because once sprayed, the photocatalyst will continue to work under sunlight without requiring any other inputs or maintenance. Therefore, it is essential to ensure that it is actually applied on to the crops. It is proposed that each photocatalyst container would carry a unique QR code that has to be scanned in order to claim the carbon credits generated by project activities. This will track the photocatalyst usage and provide specific details for its use within the project.

Table 1 describes the Greenhouse gases that are included in the project boundary at different activity stages.

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

For baseline, the background N_2O levels will be measured before the start of project activities. And during the project, a Modelling approach will be adopted that will make use of the N_2O removal capacity of the photocatalyst, which in case of R-Leaf has been established and confirmed from numerous Lab tests and field trials, done internally as well as by independent accredited bodies. Modelling Parameters that will be taken into account will be localised data from the specific locations of the project collected from weather stations including light intensity, rainfall, seasonal variability in growth (historic data) and will be included in the adjustment of impact by the sprayed photocatalysts. Other variables considered will be the soil type and characteristics, cultivations and practices, crop responses to nitrogen, spraying equipment (nozzles and pressure) and other tank mixed agrochemical inputs, which will be considered when calculating the atmospheric N_2O removal. This calculated data can be verified by spot measurements and sub samples at strategic locations during set periods for each growing season.

The Climate Impact Forecast tool described earlier in Section 3 can be used to generate tCO_2 eq emissions from the project activity. The tCO_2 eq/year emissions from the manufacturing, processing, packaging, storage, and delivery of R-Leaf has already been incorporated in The Climate Impact Forecast tool data inputs before generating the final validation of removal as 5.4 tCO_2 eq/year per hectare, translating to impact reduction potential. These parameters will be adjusted to ensure conformity with the project. Other tools can also be integrated or used into these calculations enabling other technologies to utilise the methodology.

Software tools used by farmers and distributors advising the growers will be accessible to compile that data. From a point of view of additional negativity of the R-Leaf's product life cycle, we will use existing and validated data of all components used above the baseline and subtract them from the benefits.

5. Additional Information:

(Please provide any additional information relevant to the proposed methodology)

Since its inception, it has taken over 5 years of research and development to bring R-Leaf technology to commercialisation. Laboratory trials by external experts (Imperial College London, University of Lincoln) have shown that in simulated outdoor condition N_2O is reduced to inert elements (N_2 and O_2) with the data in a quantitatively manner to calculate the capacity of the R-Leaf material. Experiments determined the retention of 80% of the R-Leaf material on leaves for a period of 4-6 weeks after the application meaning that the material remain potent and work daily. Numerous publications have also been identified on breakdown of N_2O and the quantification of the photocatalysts capacity has been used for our validation. Apart from lab experiments, numerous field trials (in-house and independent) have been conducted by spraying R-Leaf on crops and shown no negative effects to the crops and in most cases a positive effect in yield through nitrogen use efficiency.

Agriculture is a major contributor of N_2O emissions using synthetic nitrogen fertilisers which is a global practice. 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 in agriculture. The technology has a negligible baseline as it is used at 1kg per hectare during the season and delivery onto crops is by spraying together with other inputs applied as a standard practice. The proposed methodology offers direct removal of N_2O from the atmosphere through usage in crop production including other managed land which is distinctive compared to existing ones. We strongly believe the methodology will be an important addition contributing to Regen Registry to expand further into N_2O abatement and make a significant positive impact to reducing climate change. The technological advancement in photocatalysts proposes a strong opportunity for global reach and significant impact using the agricultural sector as the main supporter. Enabling the sector to widely adopt the technology provides a strategic opportunity for Regen Network to further strengthen its impact and achieve its goals.

References:

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[2] Bouwman, A.F., 1996. Direct emission of nitrous oxide from agricultural soils. Nutrient cycling in agroecosystems, 46(1), pp.53-70.

[3] DEFRA National statistics, 2022. Chapter 11: Environment. GOV.UK. Available at: https://www.gov.uk/government/statistics/agriculture-in-the-united-kingdom-2021/chapter-11-environment#:~:text=Agriculture%20is%20the%20major%20source,dioxide%20emissions%20in%20the%20UK.

[4] Yu, Q., Xiang, M., Wu, W. and Tang, H., 2019. Changes in global cropland area and cereal production: An inter-country comparison. Agriculture, Ecosystems & Environment, 269, pp.140-147.