Novocarbo

Project Design Document Novocarbo

Carbon Removal Park Rhine (Dörth)

Novocarbo

Table of Contents

Project Description

Title of Project Activity

Carbon Removal Site Rhine: Removing 700tn CO2 annually since 2019.

Purpose of the Project

We developed our heritage carbon removal site in Dörth, Germany alongside our pyrolysis technology developer PYREG to annually capture around 800 tons of CO2, produce 330 tons of biochar, and generate around 3400MWh of green energy.
This was our first site and therefore the first commercial pilot which led us to develop and operate the current CDR site thyssenkrupp rothe erde and the CDR Park GVM.

List of Project Participants

1. Input material supplier: local biomass suppliers – sourcing radius of max.100 km (ternes Land und Forsttechnik GmbH)
2. Investment institutions: Hevella Capital (Hevella Beteiligungen GmbH) and GLS Bank
3. Energy (heat) offtake agreement: PYREG's plant and Marquardt's concrete plant, next to PYREG. The heat offtake agreement is contracted between PYREG and Marquardt
4. Realization partners:
    a. PYREG
    b. Ingenieursgesellschaft Dr. Siekmann + Partner (Engineering Office)
5. Technology provider - PYREG

Project background

Besides operating already two carbon removal sites since 2018 and 2022, Novocarbo is currently launching the first large-scale carbon removal project in Germany.[1]
As of today, biochar carbon removal (BCR) is the only already operating and stable CDR solution, ready to reach commercial scale now. In the pursuit of reaching NetZero globally, we

[1] Aside from our heritage facility (operating since 2018) and our industrial integration facility (operating since October 2022), our new carbon removal park in North-East Germany is set to start production in August 2023.

have successfully established a diverse portfolio of business activities by (1) actively removing atmospheric CO2 (2) creating regenerative, climate-neutral surplus energy, supplied to industrial partners and state grids and (3) sequestering the CO2 into various biochar-based products, putting this valuable carbon to novel use in soil- and material applications.

Starting the construction of our first carbon removal plant with three P500 systems and a capacity of around 800 t/a carbon credits since 2018, this plant has helped lay the foundation for the efficient operation of carbon removal projects internationally, allowing us to research and experiment with different input materials and pretreatments, post-production, as well as energy utilization.

Project boundaries

- Project phase 2018 – 2024
- The quality of biomass input
- The quality of biochar output
- Amount of carbon removal generation (t/C02)
- Amount of carbon removal certificates
- Renewable, thermal energy generation output
- Energy input
- Filter emissions

Management

Novocarbo is led by a management team that anchors diverse backgrounds and skill sets, yet complementary and indispensable for the success of the project. While Novocarbo's history dates back not more than five years, a great stake of the team combines an academic and professional experience level of up to 20 years. The expertise fields are stretching from engineering, chemistry, agriculture, and environmental natural resources to CSR, finance, management, and sustainability consulting.

At the management level, Novocarbo's CEO has an engineering background and takes the main responsibility for all production sites and supervises all strategic steps of the company's departments. With his own agricultural background, he has extensive knowledge of the carbon and environmental benefits of Novocarbo's biochar and sets the priority of always ensuring new developments and activities in this field.

The CFO/COO is overseeing all financial and internal operations and comes with an intrinsic passion for people and their well-being. Therefore, he is monitoring all social, environmental, and health-related practices of the company.

Our CCO has a business consulting, strategic communication, and agriculture background. She holds responsibility for the business unit carbon credit and has representative roles in carbon removal committees to enable knowledge transfer regarding environmental, scientific, and political-related developments.

Thus, the management can secure all planned carbon, environmental and social benefits. Further company's internal project responsibility lies with the following groups of employees:

- **Our sites and production managers** are carrying responsibility for the scouting-, construction-, and operation of our facilities as well as the production of Novocarbo's biochar. This unit incorporates engineers and business managers.
- **The sales managers of Novocarbo Biochar** for land applications have sales, gardening & agricultural backgrounds.
- **The industrial material sales- and business development managers** are exploring and developing biochar application potentials across all other industries and handle partnerships for biochar application in industrial products. They have engineering, chemistry and managerial backgrounds.
- **The carbon removal managers** hold responsibility for registrations of the facilities, life-cycle assessments, credit generation, transmission, and partnership building. They have sustainability consulting, marketing, agricultural, and business backgrounds.

- Additional external involvement lies within our project ecosystem of:
  - The biomass suppliers whom we are sourcing and selecting after high-quality standards (only certified and audited PFEC businesses)
  - Our PYREG technology provider who has global market leadership for pyrolysis machines provides us with 24/7 service and quarterly maintenance provision.
  - The certification parties for our biochar:
    - EBC as the highest biochar standard is our long-term partner. EBC lays focuses on the production of sustainable biochar to support regenerative agriculture. We've been one of the early companies certified by them and have been supporting the further development of their standard through a regular exchange.
    - CSI as the owner of the EBC standard is responsible for the operative business of EBC.
    - Bioinspecta as a third-party auditor commissioned by CSI is testing our energy concepts and biochar quality and security annually.
    - QS, like the international standard GMP+, as a food safety standard, is auditing our biochar process yearly for feed applications.

- Certification of CDRs
  - Puro works as a listing and registry for our credits.
  - For every new facility, we conduct a product and facility LCA.
  - A third-party verification (e.g., bioinspecta) is yearly conducted to ensure the safety and quality of the facility and product.

- Downstream storage partners
  - Exclusive partnerships in the agricultural and soil industry.
  - Own refinement/ soil production in Switzerland.
  - Project partners in the building industry (concrete substitution trials) and established partnerships with textile and carpet businesses for direct biochar application.

Technical Description of Project

The location for the pyrolysis technology is on-site at the headquarter of PYREG in Dörth, Germany.

Technical Description of PYREG PX500

The PYREG® plant (Figure 1 - P1.500) consists of the integrated feed tank, two metering screws, two rotary valves, the two double-screw reactors with double jackets, a process gas filter, a combustion chamber with a boiler, two flue gas blowers, a combustion air blower, a flue gas recirculation blower, and the stack.

The feed hopper distributes the input material, which must have at least 10,000 kJ/kg OS (original substance), to the reactors using screw conveyors. Dosing screws ensure uniform and controlled feeding of the PYREG® reactors, which are also arranged side by side and horizontally. In the process, the input falls through a vertical shaft, each of which is secured against uncontrolled air and gas ingress and egress by a rotary valve. A pressure sensor is installed at this point for monitoring.
Each PYREG® reactor consists of two screw conveyors working in parallel.
The screws interlock and continuously convey the input material through the reactor.

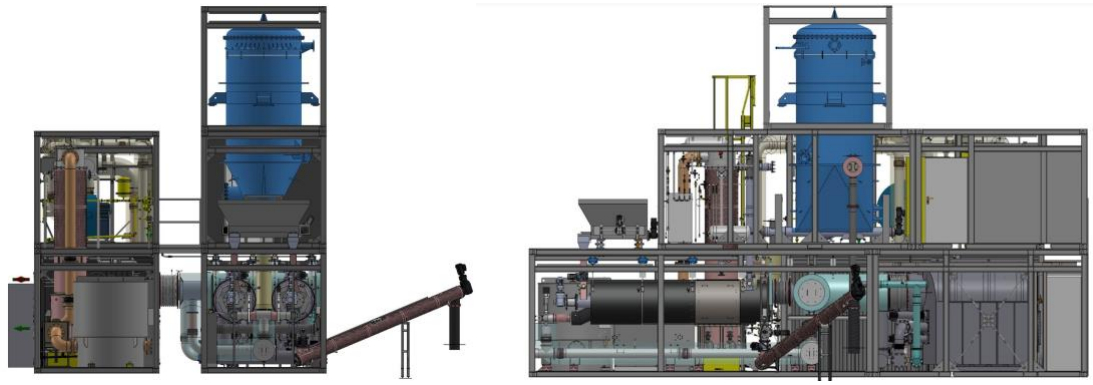


Figure 1: PYREG®-Plant (Type PX500)

Technical Performance Information

The three PYREG PX500 models in place, with 500kW fuel capacity each, come as decentralized carbonization technology which is beneficial as they can easily be integrated into various, existing infrastructures and multi-material cycles. The PYREG machines provide a unique, auto-thermal process in which up to 3.375 MWh of renewable thermal energy (as hot water, steam, or thermal oil) can be generated.
The biomass is not incinerated but rather gently degassed and then carbonized at temperatures between 500 and 750 °C in the absence of any oxygen. Further, the process gas filter is eliminating more than 99% of fine dust in the exhaust gas.

PYREG systems set international standards for quality and technology and are recognized by the US Environmental Protection Agency (EPA). The benefits for both systems are identical (PX 500 & PX 1500). They only vary in performance and specifications.

biomass | sewage sludge

PX 500 | PX 1500 | PX 6000

Fuel capacity	500 kW
Annual throughput	1.100 t OS
Annual production	300 t OS
Carbon removal potential	700 t CO_2 /a
Maximum heat output	200 kW_{th}
Personnel expenditure	4 h/d
Electricity consumption	up to 12 kW_{el}
Size	12 x 6 x 5 m (l, w, h)

Maximum values based on 8,000 operating hours. Based on mixed woodchips (80% DS), 17,5 MJ/kg DS, 6% ash. Values are approximate / can vary by project.

Figure 2: PYREG®-Plant (Type PX500)

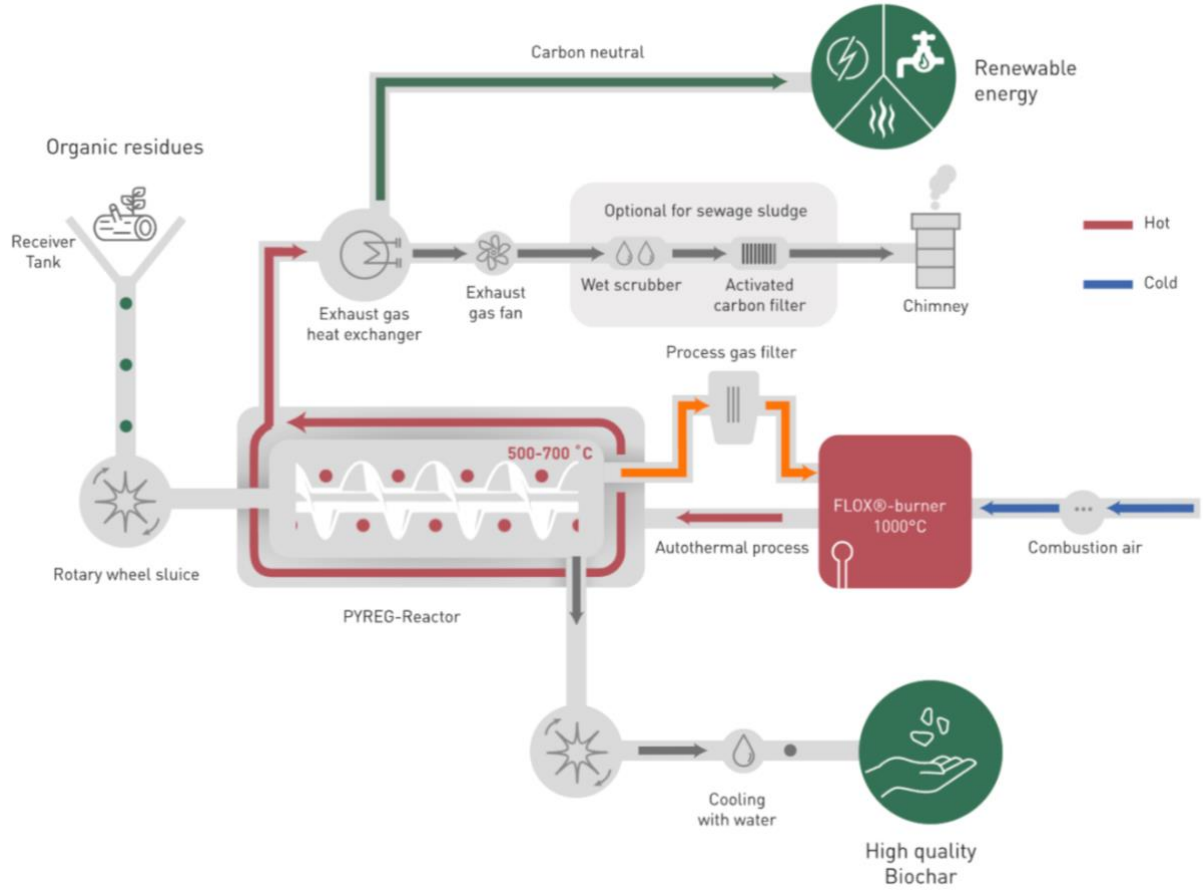


Figure 3: PYREG®-Plant Carbonisation process

Technical Workflow

The carbonisation process works as follows:

First, the input material is carbonized by the reactor temperature of 500°C to 750°C (= carbonated (biochar or mineral)). Second, the resulting process gas is freed from dust and carbon particles via a process gas filter system and transferred to a combustion chamber.

By using the process gas filter, short cleaning intervals (< 1 month) can be dispensed with. The process gas filter is monitored (differential pressure) and automatically cleaned by means of inert air (N2). Combustion takes place in a combustion chamber using a FLOX® burner at a temperature level of approx. 1,050°C.

The hot exhaust gases from the combustion chamber are directed onto the outer shell of the reactors and indirectly heat the reactors. The flue gas train can be controlled by flue gas dampers and supplies the reactors with the process heat required for carbonisation as needed.

Depending on the customer's requirements, surplus heat is used to produce warm or hot water, to heat thermal oil or to generate steam. The energy balance of the process varies depending on the design parameters. At Novocarbo, syngas escapes from the biomass and is thermally converted into a FLOX burner. The resulting heat is conducted over a double jacket to pyrolyze the new biomass. Therefore, we are not in need of any external energy sources.

The combustion is monitored with a redundant lambda measurement so that slightly over-stoichiometric combustion conditions are constantly present. The hot carbonate is discharged into a collecting screw. The collecting screw transfers the carbonate to a rotary valve, which serves as an airlock. The carbonate can then be sent for loading with the help of an ascending screw conveyor. To condition the carbonate, a temperature-controlled water injection system is located at the inlet of the diagonal discharge screw. The carbonate can then be stored safely.

The PYREG carbonisation plant is a plant for the thermal treatment of various input materials to convert them into biochar or minerals. For the organic ingredients to be converted into process gas and elemental carbon, the input material must be heated to temperatures of approximately 500 °C up to 750°C in the reactors. To achieve these temperatures, the reactor outer shell is heated with process heat and a controlled air flow is tolerated, which is reduced by using small opening cross-sections to such an extent that a certain stoichiometric ratio can be achieved for carbonisation. The air supply is only used to optimize the product quality through partial combustion of the organic matter and volatile hydrocarbon compounds. However, the adjustment is made in such a way that combustible gas is produced as a by-product in addition to the carbonate. This process gas is burnt - as shown - with the help of a flameless burner according to the FLOX® process.

The intensive mixing of the gas with the combustion air results in uniform and complete combustion with low CO and NOx contents. At a combustion temperature of approx. 1,050°C, only little NO, NO2 and N2O are produced despite possible high nitrogen contents in the biomass, so secondary measures for denitrification can be dispensed with.

The graphic outline in Figure 4 broadly underlines the workflow of Novocarbo's operations and highlight the created emissions during the process.

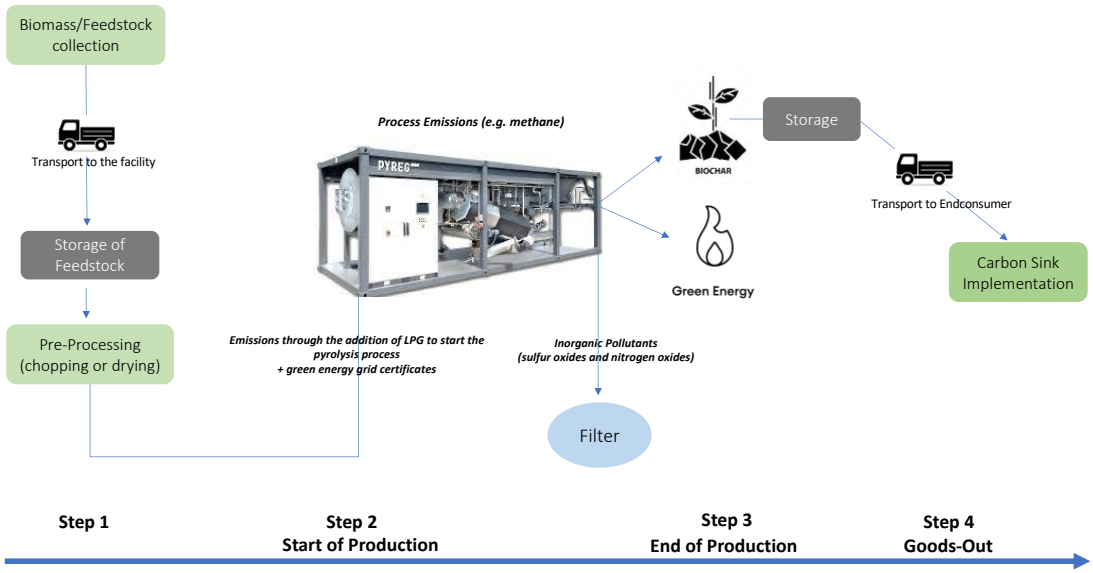


Figure 4: Novocarbo's Process Flow

Problems and Barriers being addressed by the Project

By facilitating this project, we are actively addressing problems on several layers:

1. **Green Energy Supply:** Today, we are confronted with an immature state of large-scale green energy supply. Especially for regenerative heat. Next to scarce solutions available, it may be out of lack of investment focus or infrastructure-/ location deployment capacities. The recent Russian intervention in Ukraine shows, that Europe and especially Germany need to recreate their energy infrastructure to enable a robust, continuous, and green energy flow through countries. We are counteracting energy insecurity effectively through our Green-Energy-As-A-Service principle: Surplus, regenerative energy is created within our pyrolysis process and can be transformed into heat, steam and electricity and be fed into local- and state grids and to industrial partners.

2. **Carbon Dioxide Removal (Climate Change Mitigation Practices)**:
   Today, the volume of annual greenhouse gases emitted into the atmosphere lies between 35 to 50 billion tons. This is significantly too much and needs to be drastically reduced to a minimum. While worldwide net-zero pledges and reduction measures are in place, the IPCC says that to comply with a lot of countries' 2050 climate goals we need up to 16 gigatons of CO2 removal by CDR. Novocarbo is supporting this need by delivering carbon removal and long-term carbon storage to remove one megaton of CO2 by 2030 and a gigaton by 2040.

3. **Regenerative Agriculture**
   Biochar can play an important role in the transformation to regenerative agriculture. *Regenerative* in this context means that a biodiverse fertile soil and resistance of plants is rebuilt, leading to restoring ecosystems.

Biochar has a healing function and induces a systematic change in our agricultural system by counteracting the causes of e.g., biodiversity loss and degradation of our soils, instead of the symptoms (meaning It is enhancing agricultural production by reducing diseases and increasing functionality).

This can be exemplified through biochar's ability to improve soil fertility; support soil organic carbon buildup; its water holding capacity; nutrient leakage prevention, safeguard water resources and support animal health. Please see a detailed version in the section ***Assessing Environmental Impact***.

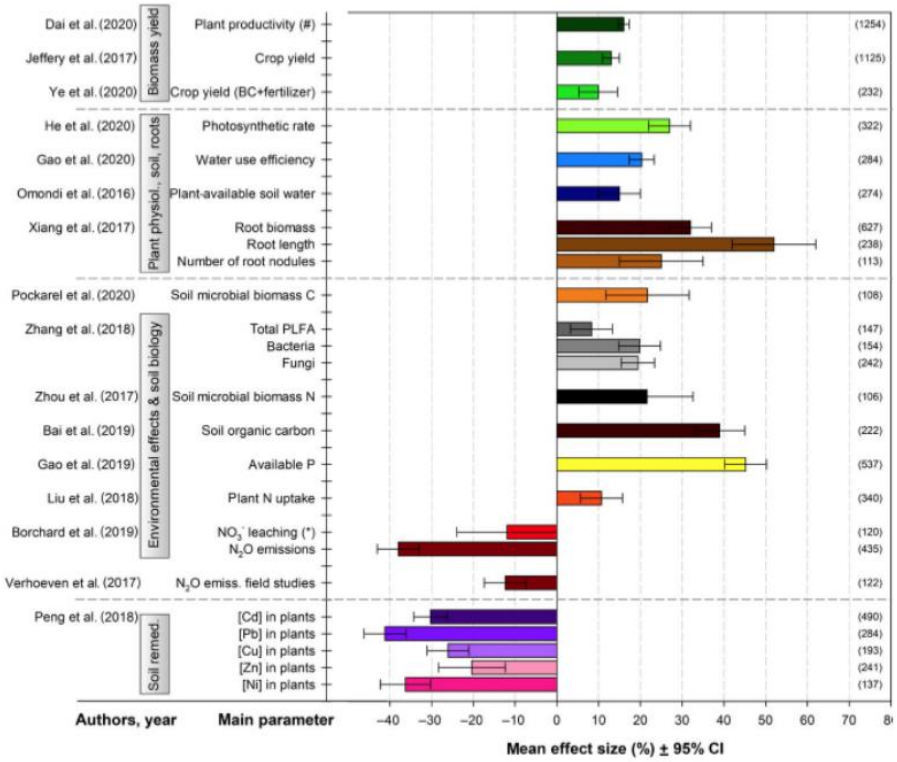


FIGURE 5 Selected parameters with the highest agronomic relevance that were investigated in the 26 reviewed meta-analyses. The mean overall effect size (% change) and 95% confidence intervals are given as reported in the original studies. The numbers in parentheses indicate the number of pairwise comparisons used for that specific parameter. Article Schmidt, H.P., Kammann, C.,Hagemann, N.,Leifeld, J.,bucheli, T.D., Sánchez Monedero, M. A., & Cayuela, M.L. (2021). Biochar in agriculture- A systematic review of 26 global meta- analyses. GCB Bioenergy, 13, 1708-1730. https://doi.org/10.1111/gebb.12889

4. Innovative Tools for Hard-to-Abate Sectors

Hard-to-abate sectors contribute to approximately 30% of global emissions. We are aiming to support these sectors in their transition phase to NetZero emissions. Especially, companies from the building and manufacturing sector (steel, cement, aluminums, industrial chemicals) will benefit from our expertise in operating pyrolysis systems to provide regenerative heat onsite at their production facilities. Also, we would offer an opportunity for *insetting*, which means the inclusion of biochar in their processes as a substitute for fossil carbon. We will also support the removal of residual emissions through our carbon removal credits.

5. **Circular Economy**

   Biochar works as a substitute for fossil carbon. We mostly use biochar to substitute virgin fossil carbon in materials like plastics and concrete. We understand our role as a junction to connect different biomass streams with the need for regenerative heat and raw materials for products. As biochar is made from waste residues, our product is closing product use cycles and therefore supports the transition to a circular economy. Also, residue usage from the food industry is used to produce biochar: It is mixed with manure to create a substrate on which to grow the raw materials needed by that same food company. Finally, the heat we generate is also circular: In Dörth we provide our surplus heat as energy for the nearby cement factory.

Our General Carbon Removal Park Project Planning

The general process, after the creation and idea phase of a carbon removal park, for the establishment and operation of a new carbon removal park would be the following:

Creation Phase

When looking into the establishment of a new carbon removal park we are making sure that we always have a heat offtake possibility in place at the respective facility (industrially integrated or through municipal utility services). Further, we ensure that the biomass supply and respective transportation will be kept at a short distance from our facility.

Planning and Execution Phase

1. Purchase and measurement of the land
2. Carrying out a public tender for the technology used
3. Preparation of various expert reports for the Federal Immission Control Act for installations (BImSchG in Germany) application
4. Application: Building and BImSchG application
5. Start of earthworks (early start of construction)
6. Hall construction and infrastructure
7. Delivery and commissioning of pyrolysis machinery (e.g., PYREG) and Organic Rankine Cycle (ORC) modules
8. Issue of BImSchG permit
9. Transition to regular operation of the facility

Our expected process timeline from the establishment to the operation of a new carbon removal park is 16 months.[2]

Novocarbo Rhine Project Development stage

The start of the construction phase of our carbon removal site *Rhine* started in Q1/2017 and was completed within the same year. The site is fully operative and produces biochar and heat since its full commercialization in 2018.

[2] While we usually expect a process timeline of around 16 months for the establishment and operation of a new carbon removal park, we know from experience that this process requires the inclusion of buffers (due to external dependencies, supply chain delays and political occurrences) stretching the timeline to an extra three to four months.

BASELINES METHODOLOGY AND ASSESSMENT OF ADDITIONALITY

Clarification Note on Additions to Methodology

We want to point out that the methodology section, except for the Baseline Scenario, Note on the Use Case of Figure 8 and the Comment on Methodology was exclusively developed by Puro.earth. We added the respective section for specific clarification and deeper understanding.

This methodology quantifies the net CO2 Removal achieved over the time horizon of 100 years by the production of biochar when used in applications placed in the environment.

CO2 removal results from the conversion of biomass to biochar with long-term chemical and biological stability, i.e., high resistance to the degradation process when placed in the environment. Carbon captured in biomass by photosynthesis is stabilized in biochar and returns to the atmosphere delayed by orders of magnitude compared to parent biomass.

This methodology is applicable to certificates issued for the CO2 removal marketplace.

Baseline Scenario

We understand a baseline as something defined by the absence of a recognized intervention. Therefore, we know that in the absence of pyrolyzing our biomass, it would most likely be either left for decomposition or for combustion. This means that all CO2 which would be trapped inside the biochar for centuries would be released back into the atmosphere within a short amount of time.

Looking into two possible scenarios

1) if biomass (g., trunk wood, waste wood, wood residues or nut shells) would be subject to combustion, tons of CO2 are released back into the atmosphere:

   Of course, we would need to determine upfront how much carbon (C) is contained in a ton of wood: The exact C content depends on the tree species, the water content, and the growing conditions, and varies between 46 and 51 per cent of the total mass. If we use a rough estimate of 50% C, this will mean that one ton of average-sized wood contains just under half a ton of carbon. During combustion, the carbon (C) of the wood combines with oxygen (O) from the atmosphere and forms carbon dioxide (CO2). Exactly one molecule of CO2 is formed from each carbon atom. The addition of two oxygen atoms makes the molecule of CO2 heavier than the carbon atom alone. If you now want to know how much heavier the molecule CO2 is in relation to the atom carbon, you must look at the so-called molar masses: This is the mass of a standardized quantity of particles, also called a mole. Carbon dioxide has a molar mass of 44 grams per mole - for carbon, it is 12 grams per mole. This gives a mass ratio of CO2 to carbon of 44/12 = 3.67. This means that roughly half a ton of carbon in a ton of wood produces about 1.83 tons of CO2 when burnt. Of course, only as much CO2 is released as was previously absorbed from the atmosphere through photosynthesis.

As a rule of thumb, 1 m³ of wood stores between 0.9 and 1 ton of CO2. Approximately, ½ of this C02 would be permanently stored in biochar. While there is no slash pile combustion in Europe, waste wood or sieve overflow from composting, are subject to waste incineration. Also, waste wood residues and sieve overflow would be used for combustion for the generation of heat and power.

2) if biomass (e.g., forest residues, deadwood, sieving, nut- and coffee shells) would be left to decompose, we could estimate the following:

   The world's deadwood currently stores 73 billion tons of carbon. New studies released in 2021 calculated that around 10.9 billion tons of this (around 15%) are released back into the atmosphere and soil each year — a little more than the world's emissions from burning fossil fuels. But this amount can change depending on insect, and fungi activity and will likely increase under climate change (acceleration of insect and fungi activity is highly likely to increase because of rising temperatures). Depending on the wood species and forest type, various studies show that the full decomposition process of, for example, wood trunks, takes between 5-8 years.
   Conclusively, the high levels of CO2 once stored, would be released back into the atmosphere within less than 10 years. Therefore, we know that our wood residues (e.g., forest residues and fine sieving) would be subject to slash pile decaying.[3]

Eligible Activity Type

An eligible activity is an activity capable of producing as output biochar with long-term stability. CO2 Removal results from organic biomass being heated with no or limited supply of oxygen, such as pyrolysis or gasification processes. The pyrolysis gases must undergo engineered emissions control to decrease methane to negligible levels.

In such processes, the biomass undergoes a carbonization reaction forming solid biochar. Biochar is a material in which the carbon atoms have bonds stronger than those found in the parent biomass and is therefore resistant to biotic and abiotic degradation processes when placed in the environment.

Biochar stability can be estimated from biochar properties, specifically the molar hydrogen to organic carbon ratio (H/C_{org}). Material with an (H/C_{org}) ratio lower than 0.2 is characterized as being hardly degradable in the environment[4].

The eligibility of the biochar production activity is determined in the **Production Facility Audit.**

---

[3] https://theconversation.com/decaying-forest-wood-releases-a-whopping-10-9-billion-tonnes-of-carbon-each-year-this-will-increase-under-climate-change-164406#:~:text=Decaying%20forest%20wood%20releases%20a,tonnes%20of%20carbon%20each%20year.
https://www.nature.com/articles/s41586-021-03740-8
https://www.science.org/doi/10.1126/science.1201609
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6849867/

[4] Schimmelpfennig, S. and Glaser, B. (2012), One Step Forward toward Characterization: Some Important Material Properties to Distinguish Biochars. J. Environ. Qual., 41: 1001-1013. https://doi.org/10.2134/jeq2011.0146

Requirements for Activities to be Eligible under the Methodology

1.1.1. Use of biochar in applications placed in the environment (e.g., greenhouse substrates, surface water barrier, animal feed additive, wastewater treatment, insulation material, landfill/mine absorber, soil additive). Biochar sequesters carbon over centennial timescales, when not used as fuel or reductant. Therefore, its energy and reductant use are excluded, and all other uses are eligible.

1.1.2. Biochar needs to be produced from sustainable biomass: sustainably sourced biomass, or waste biomass such as agricultural waste, biodegradable waste, urban wood waste or food waste. A list of biomass types can be found in IPCC Appendix 4 Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments (Table 4AP.1)[5] and the positive list of biomass feedstock of the European Biochar Certificate[6].

- In the case of agricultural waste sustainable collection means that 30% of residues are left in the field to avoid decreasing soil health and crop levels[7].
- Timber that has been damaged by a natural disaster (e.g., fire, pests, flood) and cannot be economically recovered or used as originally intended.
- Use of invasive species, meaning plants that are not native to the region of activity and are causing environmental harm, are eligible biomass for biochar activity when the following requirements are met: i) the species to be cleared are recognized by an appropriate state or national authorities and ii) the carbonization of the cleared waste is not mandated or legally required by relevant authorities and iii) the CO2 removal Supplier has procedures in place to differentiate the invasive species from other local species and to avoid unintended clearing of existing native vegetation within the project area

1.1.3. The producer must demonstrate net negativity with results from a life cycle assessment (LCA) or carbon footprint of the biomass production and supply, the biochar production process, and the biochar use, including disaggregated information on the emissions arising at different stages. Life cycle assessment (LCA) shall present carbon footprint cradle-to-grave according to ISO standard or WRI GHG protocol.

1.1.4. The direct use of fossil fuels for heating the pyrolysis reactor is prohibited, unless only used for ignition/pre-heating or in a mobile unit and the emissions are fully included in the LCA. The use of waste heat from other industrial processes, such as bio-digesters or cement production is permitted.

1.1.5. In the biochar production process, the pyrolysis gases must be combusted or recovered through an engineered process that either negates or makes negligible any methane emissions to the atmosphere. Bio- oil and pyrolysis gases can be stored for later use as renewable energy or materials.

---

[5] Appendix 4 Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments. https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch02_Ap4_Biochar.pdf . https://doi.org/10.1021/acs.est.

[6] Positive list of biomass feedstock https://www.european-biochar.org/en/ct/2-EBC-guidelines-documents-for-the- certification

[7] Battaglia, M., Thomason, W., Fike, J. H., Evanylo, G., von Cossel, M., Babur, E., Diatta, A. (2020). The broad impacts of corn stover and wheat straw removal for biofuel production on crop productivity, soil health and greenhouse gas emissions. https://doi.org/10.1111/gcbb.12774

1.1.6. The molar H/C_{org} ratio must be less than 0.7. The H/C_{org} ratio is an indicator of the degree of carbonization and therefore of the biochar stability. Values exceeding 0.7 are an indication of non-pyrolytic chars or pyrolysis deficiencies[8].

1.1.7. Measures must be taken for ensuring a safe working environment and safe handling and transport of biochar to prevent fire and dust hazards. Such safety measures are, but are not limited to, providing a Material Safety Data Sheet, laboratory test results from UN test N.4, using a steam activation process or by other means ensuring that the biochar is sufficiently covered, moist and cool during transport and handling.

1.1.8. The eligibility of the production facility is determined in the production facility audit.

Requirements for the Production Facility Audit

1.2.1 The production facility auditor checks the production facility against the requirements for activities to be eligible under the general rules of Puro standard and the specific requirement in this methodology (section 1.1.), and the proofs and evidence needed from the CO2 removal supplier (section 5).

1.2.2. The production facility auditor checks that the Production Facility can demonstrate Environmental and Social Safeguards through one or several of the following:

- Environmental Impact Assessment (EIA)
- Environmental permit
- Other documentation on the environmental and social impacts
- When applicable, informed consent from local communities

1.2.3. The Production Facility Auditor checks that the Production Facility is able to demonstrate additionality, meaning that the project must convincingly demonstrate that the CO2 removals are a result of carbon finance. Suppliers must also show that the project is not required by existing laws, regulations, or other binding obligations.

1.2.4. The Production Facility Auditor checks that the Production Facility is capable of metering and quantifying the biochar output in a reliable manner, for the Quantification of CO2 Removal (section 4). This check also prepares the CO2 Removal Supplier for producing the periodic Output Report.

- The quantity of the biochar produced and sold is quantified and documented in a reliable manner (sections 4.2., 5.3., 5.4 and 5.5.)
- Relevant meters are in place, and they are calibrated.
- The emissions from the cultivating, harvesting, and transporting of the biomass are estimated and calculated in a reliable manner (section 4.3.)
- The energy use of the Production Facility can be quantified and the emissions from the process calculated (section 4.4.);

[8] Schimmelpfennig, S. and Glaser, B. (2012), One Step Forward toward Characterization: Some Important Material Properties to Distinguish Biochars. J. Environ. Qual., 41: 1001-1013. https://doi.org/10.2134/jeq2011.0146

- The auditor goes through the Quantification of CO2 Removal requirements with the CO2 Removal Supplier, so that the Supplier is able to calculate the CO2 Removal independently in its Output Report.

1.2.5. Collection of standing data of the Production Facility. The Production Facility Auditor collects and checks the standing data of the Production Facility and the CO2 Removal Supplier. The data to be collected by the Auditor includes:

- CO2 Removal Supplier registering the Production Facility;
- A certified trade registry extract or similar official document stating that the organization validly exists and was founded under the laws of the mother country.
- Location of the Production Facility;
- The volume of Output during the full calendar year prior to registration;
- Removal Method(s) for which the plant is eligible to receive CORCs;
- The date on which the Production Facility becomes eligible to receive CORCs;
- Whether the Production Facility has benefited from public support.
- Documentation on Environmental and Social Safeguards imposed.

Point of Creation of the CO2 Removal Certificate (CORC)

Point of Creation

2.1.1. The point of creation of the certificate is the production process of biochar (pyrolysis of biomass to biochar). However, the end use of the biochar product needs to be proven to be other than energy use.

2.1.2. The producer of the biochar is the CO2 Removal Supplier.

Assessment of Life Cycle Greenhouse Gas Emissions and Baseline

3.1. The CO2 Removal Supplier shall provide a life cycle assessment (LCA) for biochar activity including disaggregated information on the emissions arising at different stages. The system boundary is set cradle-to-grave and shall include emissions from the production and supply of the biomass, from biomass conversion to biochar, and from biochar distribution and use.

3.2. Life cycle assessment (LCA) shall follow ISO standard, WRI GHG protocol or similar method.

3.3. The default baseline emission scenario for the project activity feedstock is zero, which is a conservative assumption since it is not taking into account methane emissions derived from the decay of manure or combustion of waste biomass. However, the supplier could submit non-zero baseline emission claims if a sufficient scientific demonstration is provided and accepted by Puro.Earth.[9]

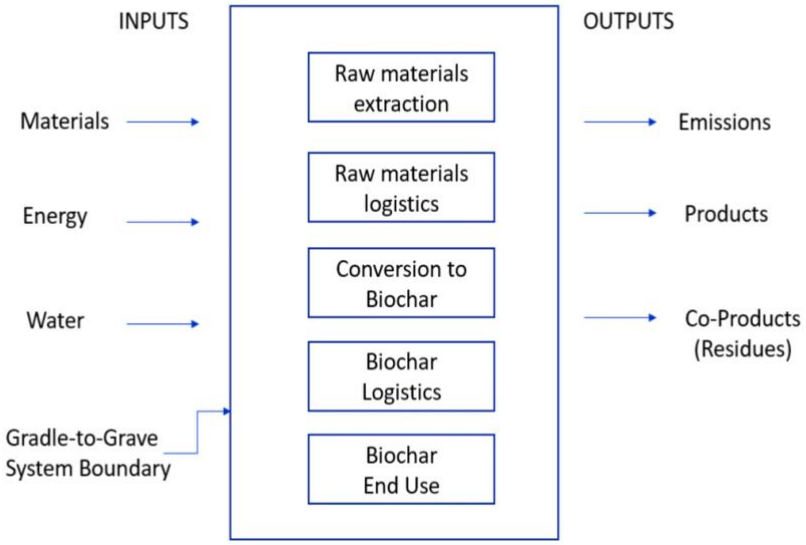
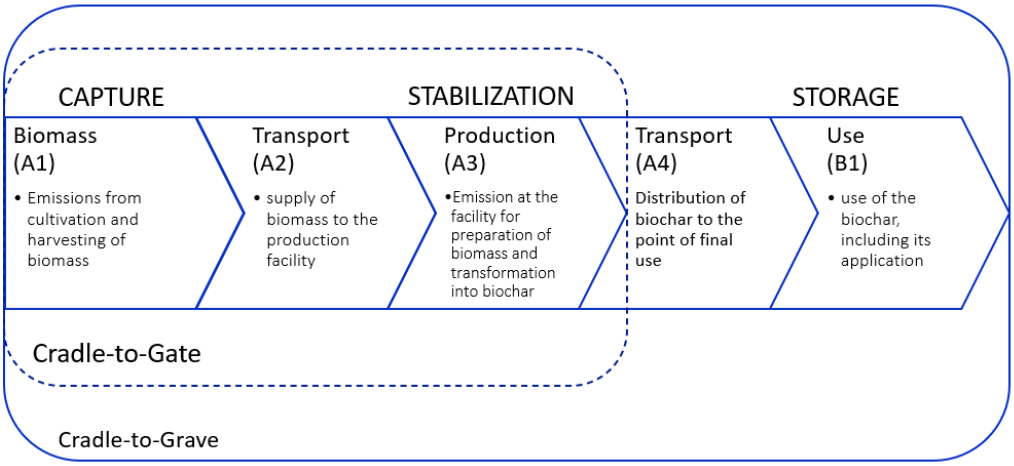


Figure 7. Overall System Boundary for life cycle assessment of a biochar activity. The details about the calculation of greenhouse gas emissions for each stage are described in Chapter 4

$E_{biomass}$= (A1) raw material extraction + (A2) raw material logistics
$E_{production}$= (A3) thermochemical conversion
E_{use}= (A4) biochar logistics + (B1) biochar end uses

A)



[9] [9] Bergman, Richard D.; Gu, Hongmei; Page-Dumroese, Deborah S.; Anderson, Nathaniel M. 2017. Life cycle analysis of biochar, https://www.fs.usda.gov/treesearch/pubs/54276

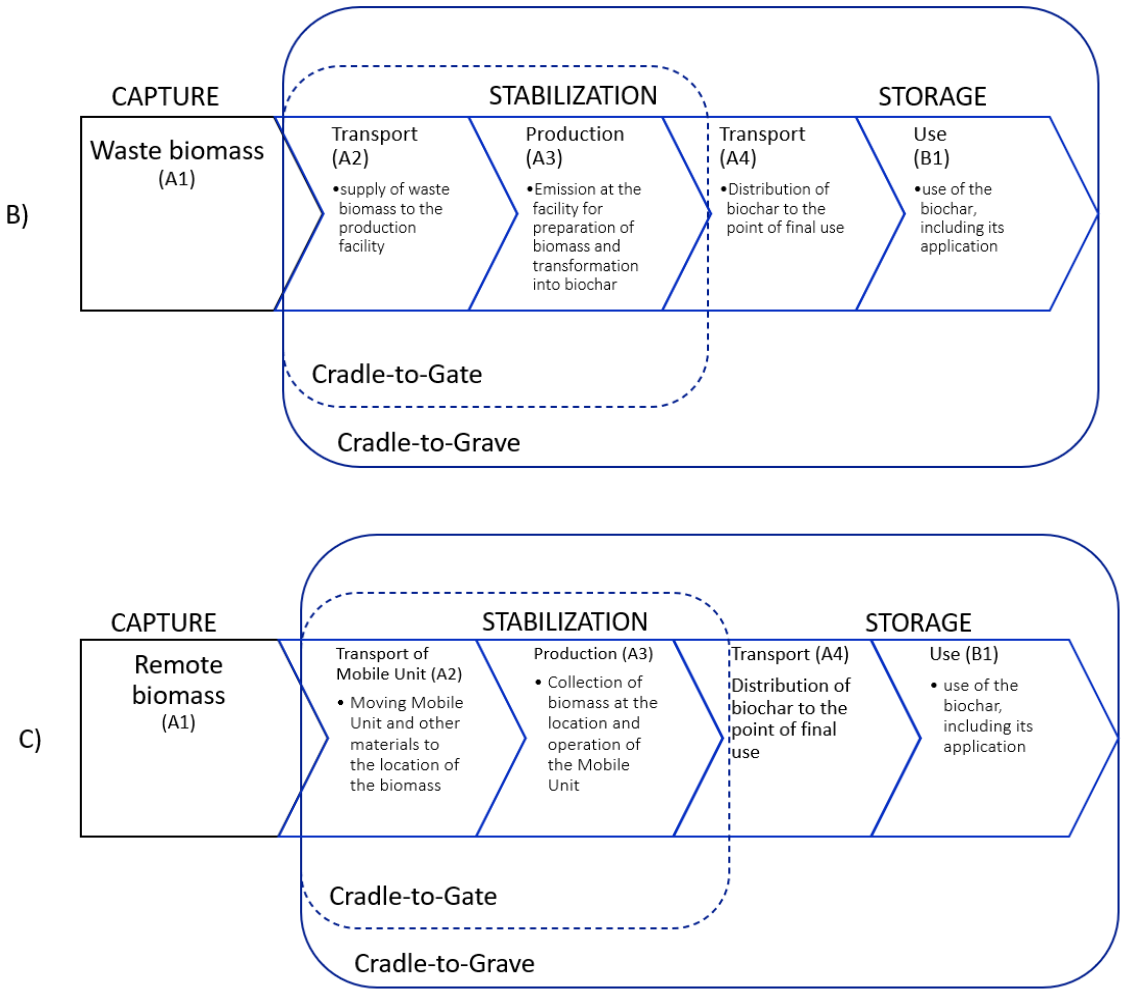


Figure 8. Overall System Boundary for life cycle assessment of a biochar activity (continued). The details about the calculation of greenhouse gas emissions for each stage are described in Chapter 4.

Note on the Use Case of Figure 8

Figure 8 example **c)** is not applicable to our company system boundaries. Only system boundary examples **a)** and **b)** are.

Calculation methodology for the quantification of CO_2 Removal

The purpose of this section is to present how to calculate the amount of carbon dioxide removal certificates (CORCs) resulting from the biochar production activity over a given reporting period, i.e., for a given amount of biochar produced. First, the overall equation and its parameters are presented. Then, details about the calculation of each term are summarized.

4.1 Overall equation for net carbon sequestration over 100 years

$$\underbrace{CORCs}_{\text{Amount of net } CO_2\text{-eq removed over 100-year period by the biochar production activity}} = \underbrace{E_{stored}}_{\text{Amount of } CO_2 \text{ sequestered over a 100-year time horizon by the amount of biochar produced over the reporting period.}} - \underbrace{E_{biomass}}_{\text{Life cycle greenhouse gas emissions arising from the production and supply of biomass to the production facility, including direct land use changes.}} - \underbrace{E_{production}}_{\text{Life cycle greenhouse gas emissions arising from the transformation of the biomass into biochar, at the producing facility.}} - \underbrace{E_{use}}_{\text{Life cycle greenhouse gas emissions arising from the use of the biochar, including its distribution up to the point of final use.}}$$

Description	Amount of net CO_2-eq removed over 100-year period by the biochar production activity	Amount of CO_2 sequestered over a 100-year time horizon by the amount of biochar produced over the reporting period.	Life cycle greenhouse gas emissions arising from the production and supply of biomass to the production facility, including direct land use changes.	Life cycle greenhouse gas emissions arising from the transformation of the biomass into biochar, at the producing facility.	Life cycle greenhouse gas emissions arising from the use of the biochar, including its distribution up to the point of final use.
Unit	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq

Figure 9. The overall *equation to calculate the amount of CORCs supplied by the biochar production activity over a given reporting period. The tons unit refers here to metric tons (i.e. 1000 kg). All terms are counted as positive.*

The overall equation is made of four terms (*Figure 3*). The first term (E_{stored}) describes the amount of carbon dioxide sequestered over a 100-year time horizon by the amount of biochar produced. Its calculation is explained in section 0, and is based on new results published in the peer-reviewed scientific literature[10]. The second term ($E_{biomass}$) describes the life cycle greenhouse gas emissions arising from the production and supply of biomass to the production facility, including direct land use changes. The third term ($E_{production}$) describes the life cycle greenhouse gas emissions arising from the transformation of the biomass into biochar, at the producing facility. Finally, the fourth term (E_{use}) describes the life cycle greenhouse gas emissions that occur along the distribution of the biochar up to its point of final use. Guidelines for calculation of $E_{biomass}$, $E_{production}$, and E_{use} are given in sections 4.3, 4.4, and 4.5, respectively.

Remark on sign conventions: In the equation above (*Figure 3*), the amount of CORCs and the four terms are positive numbers. The amount of CORCs supplied is equal to the amount of carbon dioxide sequestered by the biochar *minus* life-cycle emissions from the pyrolysis process, the biomass provision, and the biochar use.

4.2 Biochar carbon storage (E_{stored})

The term E_{stored} is calculated based on the methodology by Woolf and colleagues (2021)[10] that provides an estimate of biochar carbon sequestration at any given time horizon TH, for biochar used in soils at any soil temperature T. For the purpose of this methodology, the time horizon TH is set to 100 years. If needed, results S can be calculated at any other time horizon using the supplementary information provided by Woolf and colleagues (2021)[11]. Regarding soil temperature T , there are large differences in 100-year biochar carbon sequestration between climates.

[10] Woolf D, Lehmann J, Ogle S, et al (2021) Greenhouse Gas Inventory Model for Biochar Additions to Soil. Environ Sci Technol. https://doi.org/10.1021/acs.est.1c02425
[11] Ibid.

Therefore, the methodology must be applied for a mean annual soil temperature T representative of the climate where the biochar is distributed and used. The global mean annual cropland temperature is about 14.9°C, but can vary between 5°C and 25°C between world regions.

Biochar used first in non-soil applications may have slower degradation rates. However, to date, no peer- reviewed methodology exists for estimating long-term carbon sink in such products. Therefore, the existing methodology for decomposition in soils is used even for non-soil applications, and it can be seen as a conservative estimate.

The methodology presented by Woolf and colleagues (2021) suggests three ways of calculating biochar carbon sequestration, based on the available information. Here, for the purpose of the Puro Standard methodology, only the first option is used, as is it recommended as the most accurate option.

The term E_{stored} is therefore given by the equation:

$$E_{stored} = Q_{biochar} \times C_{org} \times F_p^{TH,T_s} \times \frac{44}{12}$$

In this equation, three parameters are involved as well as a conversion factor:

- $Qbiochar$ is the amount of biochar produced over the reporting period. It is expressed in dry metric

  tonnes of biochar. Care must be taken to exclude any moisture, as including water would lead to an overestimation of the carbon actually sequestered.

- C_{org} is the *organic* carbon content of the biochar produced. It is expressed in dry weight of organic carbon over dry weight of biochar. C_{org} is determined by laboratory analyses of the biochar produced, with a representative sampling methodology. Care must be taken in case of very diverse biomass is used to produce biochar, so that the laboratory analyses are made for each type or batch separately.

$F^{TH,Ts}$ is the permanence factor of biochar organic carbon over a given time horizon TH in a given soil p at temperature T . It is also known as biochar carbon stability, and it is expressed as a percentage(%). At a given TH and T , the permanence factor $F^{TH,Ts}$ is only a function of the *molar* $H/Cs\ p\ org$ the biochar and follows the linear relationship below:

$$F_p^{TH,T_s} = c + m \times H/C_{org}$$

The *molar* H/C_{org} ratio of a biochar sample is derived from the laboratory analysis as given or calculated from laboratory analyses dividing the hydrogen *mass* content by the *organic* carbon *mass* content of the biochar, and multiplying this with the ratio of carbon molar mass over hydrogen molar mass. In other words:

$$H/C_{org}\,(molar) = \frac{m_H(\%)}{m_C\,(\%)} \times \frac{M_C\,(g\,mol^{-1})}{M_H(g\,mol^{-1})} = \frac{m_H(\%)}{m_C\,(\%)} \times \frac{12}{1.0}$$

The regression coefficients c and m are a function of the time horizon TH and the soil temperature Ts Table 1 below provides the values of these two coefficients for a time horizon TH of 100 years, and for a range of soil temperatures T . To select the appropriate coefficients c and m to use, the biochar producer should consider the regions where the biochar is likely to be used[12]. If a main region for biochar use cannot be defined, the global mean soil temperature of 14.9°C can be used as a default value. Remark on $F\,TH,Ts$ values above 100%: at lower soil temperatures and with biochar having a low pH/C , it is possible that the linear regression provides $F\,TH,Ts$ above 100%. In that case, the value should be set equal to 100%.

Soil temperature T_S	c	m
5°C	1.13	-0.46
10°C	1.10	-0.59
15°C	1.04	-0.64
20°C	1.01	-0.65
25°C	0.98	-0.66
14.9°C	*1.04*	*-0.64*

Figure 10 Regression coefficients for estimating biochar stability for a time horizon TH of 100 years at various soil temperatures T_s. Values for the closest soil temperature should be used.

- Finally, the factor $\frac{44}{12}$ is the ratio between the molar mass of carbon dioxide and the molar mass of carbon. This factor converts an amount of carbon to its corresponding amount of carbon dioxide.

[12] Annual mean soil temperature in a specific area or country could be obtained from national statistical offices, or alternatively could be derived from the global soil temperature regime map. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/worldsoils/?cid=nrcs142p2_054019

Calculation examples

Five biochars were produced by different suppliers (A-E). After accounting for the moisture in the biochar, the biochar production amount is 1000 dry metric tonnes. Lab analyses were performed to determine the organic carbon content and the hydrogen content of the biochar, expressed in dry mass.

At 10°C, the E_{stored} values are:

Biochar	$Q_{biochar}$	C_{org}	H	H/C_{org}	F_p^{TH,T_s}	E_{stored}
#	dry tonnes	%	%	mol/mol	%	tonnes CO_2
A	1000	93.8%	1.3%	0.16	100%	3439
B	1000	93.2%	1.1%	0.15	100%	3417
C	1000	83.9%	1.68%	0.24	95.8%	2948
D	1000	47.9%	1.1%	0.27	94.1%	1652
E	1000	87.7%	1.41%	0.19	98.8%	3177

At 14.9°C, the E_{stored} values are:

Biochar	$Q_{biochar}$	C_{org}	H	H/C_{org}	F_p^{TH,T_s}	E_{stored}
#	dry tonnes	%	%	mol/mol	%	tonnes CO_2
A	1000	93.8%	1.3%	0.16	93.8%	3225
B	1000	93.2%	1.1%	0.15	94.4%	3226
C	1000	83.9%	1.68%	0.24	88.6%	2727
D	1000	47.9%	1.1%	0.27	86.7%	1523
E	1000	87.7%	1.41%	0.19	91.8%	2953

At 25°C, the E_{stored} values are:

Biochar	$Q_{biochar}$	C_{org}	H	H/C_{org}	F_p^{TH,T_s}	E_{stored}
#	dry tonnes	%	%	mol/mol	%	tonnes CO_2
A	1000	93.8%	1.3%	0.16	87.4%	3007
B	1000	93.2%	1.1%	0.15	88.1%	3011
C	1000	83.9%	1.68%	0.24	82.2%	2528
D	1000	47.9%	1.1%	0.27	80.2%	1408
E	1000	87.7%	1.41%	0.19	85.5%	2748

With this information, the E_{stored} term is calculated at three different soil temperature[13].

Comment on the Soil Temperature applicable for Novocarbo

Our main biochar customers are located in the Nordics and DACH region. Therefore, the overall soil temperature applicable lies within the 10°C range.

4.3 Biomass production and supply ($E_{biomass}$)

The term $E_{biomass}$ should be derived from a life cycle assessment of biomass production and supply to the biochar production site. Typically, the life cycle assessment of biomass production and supply includes three terms:

[13] Annual mean soil temperature in a specific area or country could be obtained from national statistical offices, or alternatively could be derived from global maps of soil temperature e.g. Lembrechts et al. 2021 (https://doi.org/10.1111/gcb.16060)

Biomass production: this term shall include greenhouse gas emissions arising from all activities involved in the biomass cultivation and harvesting process, like the use of machinery and fuel, the production of fertilisers, emissions from soils following fertiliser use, machinery manufacturing and disposal.

- Direct land use changes: this term represents emissions arising at the site of cultivation of the biomass that is related to a change in land cover or land management. This can represent the emissions of carbon dioxide and other greenhouse gases from reforestation but also the loss of carbon in aboveground and belowground stocks when harvesting forest residues or agricultural residues. In many cases, direct land use changes are given a null value (0 emissions from changes in biogenic carbon stocks), but this must be justified adequately with an explicit reference situation.

- Biomass transport: this term shall include emissions arising from the transport of biomass from the harvest site to the biochar production site, ideally including fuel emissions, but also vehicle and road infrastructure emissions.

  Mobile unit transport: when a mobile carbonized or similar movable unit is used, this term shall include emissions arising from moving the unit to the biomass location.

4.4 Biochar production ($E_{production}$)

The term $E_{production}$ should be derived from a life cycle assessment of the biochar production process. This term should include all greenhouse gas emissions from the activities involved in the conversion of biomass to biochar.

List of activities that may be relevant to include in the life cycle assessment:

- Biomass handling on site (transport or conveying of the biomass within the facility)
- Drying, chipping, comminution, and/or sieving of the biomass
- Operation of the pyrolysis reactor and post-pyrolysis equipment (e.g., combustion chamber for pyrolysis gases and oil, flue gas treatment systems) or operation of the gasifier reactor and post-processing equipment
- Biochar quenching and other post-processing operations (e.g., packaging, activation)
- Biochar handling on site (transport or conveying of the biochar within the facility)
- Mobile unit fuel consumption associated with the operation of the mobile carboniser, near-location collection and handling of the biomass, but also the transport of the fuel to the location where the mobile unit is operated.

For each of the activities above, all life cycle stages (manufacturing, use and disposal) should be included. For instance, the operation of the pyrolysis reactor should include manufacturing and installation of the reactor, material, and energy inputs for operating the reactor, direct air emissions from the stack of the reactor, and maintenance and disposal of the reactor. Likewise, biomass drying, and chipping should for instance include manufacturing and disposal of the drying and chipping equipment, direct energy use from the operation of the equipment (e.g. electricity or external heat), and eventually other consumables involved in the operation and maintenance of the equipment.

Remark on the handling of co-products from the pyrolysis process:

- Depending on the configuration of the pyrolysis reactor, several other products may be generated, such as heat, electricity, or bio-oil. In most cases, a fraction of the heat generated from the combustion of the pyrolysis gases is used for sustaining the pyrolysis reaction and drying the biomass. This is an energy flow internal to the pyrolysis process and has no effect on the life cycle assessment (i.e. it does not need to be included).
- However, any excess heat, excess electricity or excess bio-oil that is not used within the pyrolysis process leads to a multi-functionality issue in life cycle assessment. In classical life cycle assessment, this can be dealt with in several ways depending on the goal and scope of the LCA, mainly: allocation or substitution.
- Here, for the purpose of the methodology, the following approach should be used:

o If the pyrolysis co-products represent high-value products or a large share of the initial biomass energy content, then an energy allocation between the biochar and the co-products must be applied. The life cycle assessment must specify how the allocation factors were calculated, and which energy unit was used (lower heating value, higher heating value, or another method).

o If the pyrolysis co-products are not deemed an important product, then all the burdens are allocated to the biochar production (allocation factor of 100%), and any excess co-product is considered as burden-free (allocation factor of 0%).

4.5 Biochar use (E_{use})

The term E_{use} should be derived from a life cycle assessment of the expected biochar use to the extent that it is known by the biochar producer. This term should include at least all greenhouse gas emissions from the transportation and handling of biochar until it is used in a mineral matrix (soil or concrete) from which it cannot be separated.

5. Proofs needed from the CO_2 Removal Supplier 5.1 Principle

5.1.1. The biochar output from a production facility is determined as eligible for issuance of CO2 removal certificates once the facility has undergone a process of third-party verification by an auditor against the specific methodology for biochar. This verification is done in a **Production Facility Audit**. The verification ensures that the corresponding CO2 removal has taken place, that relevant Environmental and Social Safeguards are in place and that the CO2 removal is considered permanent as defined in the methodology.

5.1.2 For the activity to be eligible for producing biochar for which CO2 removal certificates can be issued, the following proofs (5.2- 5.4) need to be presented by the CO2 Removal Supplier (in this case, the producer of biochar).

5.2 Biomass production and supply

5.2.1 Proof of the sustainability of the raw material used. Proof to be presented:

In the case of forest biomass raw material:

- Forest Stewardship Council (FSC) Forest Management Certification; or
- Sustainable Forestry Initiative (SFI) Forest Management Certification; or

- Programme for the Endorsement of Forest Certification (PEFC) Sustainable Forest Management Standard; or
- Other reputable sustainable forest certification programs with high scientific standards and market recognition, regardless of whether they are public or private in nature. Puro. Earth reserves the right to make the determination of eligibility for the certification program. In the case of other waste biomass raw material:
- Raw material needs to be sourced sustainably; however, certificates are not needed, as it is waste material.

5.2.2 Life cycle assessment data for biomass production and supply must be provided and documented. In particular, climate change impact must be presented in a disaggregated way exhibiting the contribution of the different life cycle stages described in section 0.0

5.3 Biochar production

5.3.1. The biochar producer must provide data trail and documentation on the amount of biochar produced. This includes i) continuous production documentation for the whole period (record keeping), taking into account any significant changes or stops in production, and ii) data and methodology applied to calculate the dry mass of biochar produced.

5.3.2. The mobile unit or carbonizer operator must, at a minimum, provide the following data on the amount of biochar produced: i) continuous load cell measurement of the biochar production for the whole period ii) water input measurement. The dry mass of the amount of produced biochar is calculated using the measured weight of biochar from load cells deducted with the weight of the water that was input. Additional measurement equipment for greater accuracy can be proposed by the operator.

5.3.2. Life cycle assessment data for the biochar production process must be provided and documented. In particular, climate change impact must be presented in a disaggregated way exhibiting the contribution of the different life cycle stages described in section 0.

5.3.3 The following biochar properties must be determined via laboratory analyses, as they are required for the quantification of the biochar carbon sequestration: total organic carbon content, total hydrogen content, and calculated H/C_{org} ratio.

5.4 Biochar use

5.4.1. Life cycle assessment data for the biochar use must be provided and documented. In particular, climate change impact must be presented in a disaggregated way exhibiting the contribution of the different life cycle stages described in section 4.

5.4.2. Proof that the end-use of the product does not cause CO2 to return to the atmosphere (it is not used as fuel or reductant). The proof can be an offtake agreement, documentation of the sale or shipment of the product, or indicating the intended use of the product. Care should be taken to exclude the amount of biochar that is likely to end up in waste incineration and not in a mineral matrix (soil or construction use) from which it cannot be separated.

5.4.3. Justification on the soil temperature was selected for the biochar carbon sequestration calculation.

5.5 No double-counting (specific double-counting)

5.5.1. Double counting is avoided using the Puro Registry, with a system of unique identification of each CORC that guarantees it is only used once. Each CORC in the registry contains information on Production Facility registration and crediting period dates, verification, issuance and retirement transactions as well as the title and ownership over time.

5.5.2 A statement is needed from the CO2 Removal Supplier that the underlying physical product (biochar) in which the CO2 is stored will not be sold or marketed as "climate positive" if the CO2 removal certificate associated with the underlying physical product (biochar) is removed from the underlying product and sold to another stakeholder not associated with the underlying physical product.

5.5.2. Check of the packaging of the product (how the product is branded) is needed if CO2 removal certificate associated with the underlying physical product (biochar) is removed from the underlying product.

5.5.3. No marketing and branding claims can be made by the end-user (user of biochar) that the underlying physical product (biochar) is a carbon sink when the decoupled CO2 removal certificate has been sold to and accounted by another stakeholder not re-associated with the underlying physical product. The proof can be an offtake agreement, documentation of the sale or shipment of the product, indicating the procedures for claiming the CO2 removal certificate.

Comment on the Permanence Calculation used in Puro. earth's Methodology

It is to say that the current methodology in place (Puro. earth) is not reflecting the newest scientific development regarding permanence calculation.

In the following, we would like to give you two comments from two different perspectives that clearly explain and argue why the current methodology used needs to be updated and how a >1000 years of permanence claim can be proven. The comments reflect our thinking about biochar permanence and were be published in early 2023.

Comment 1

We believe the science that biochar permanence is based on, will be deeply altered in the next 2 years with geologists taking over the research field. The following section is based on the results of a recent biochar study, published by H.Sanei in February 2023.

From a historical point of view, biochar became the first subject of research for its potential as a soil improver, respectively enhancing agricultural production. This approach reached a wide consensus, that a broad variety of residues was tested as further feedstock and new technologies and machines were designed. By now, there are several mature technologies on the market, that transform organic residues into energy and biochar. However, most of the scientific research dedication is reduced to scientists from the agricultural-, mechanical-, and environmental engineering space. Therefore, we are happy to share that, the carbon stability of organic carbon in biochar is currently the subject of intense research by the Lithospheric Organic Carbon (LOC) lab, Department of Geoscience, Aarhus University and Geological Survey of Denmark and Greenland (GEUS).

A preview of Biochar Permanence by Geologists from Aarhus University and the Geological Survey of Denmark[14]

Preliminary results are retrieved from the Organic Carbon (LOC) lab, Department of Geoscience, Aarhus University and Geological Survey of Denmark. State-of-the-art geochemistry and advanced optical microscopic methods are being used to assess the stability of carbon bonds in biochar. The preliminary results show that the stability of carbon is partly controlled by the feedstock but most importantly by the maximum pyrolysis temperature.

The histogram below shows carbonized (biochar) products of various feedstock at 500°C, 700°C, and 900°C pyrolysis temperatures. Let's investigate the degree of different carbon liabilities:

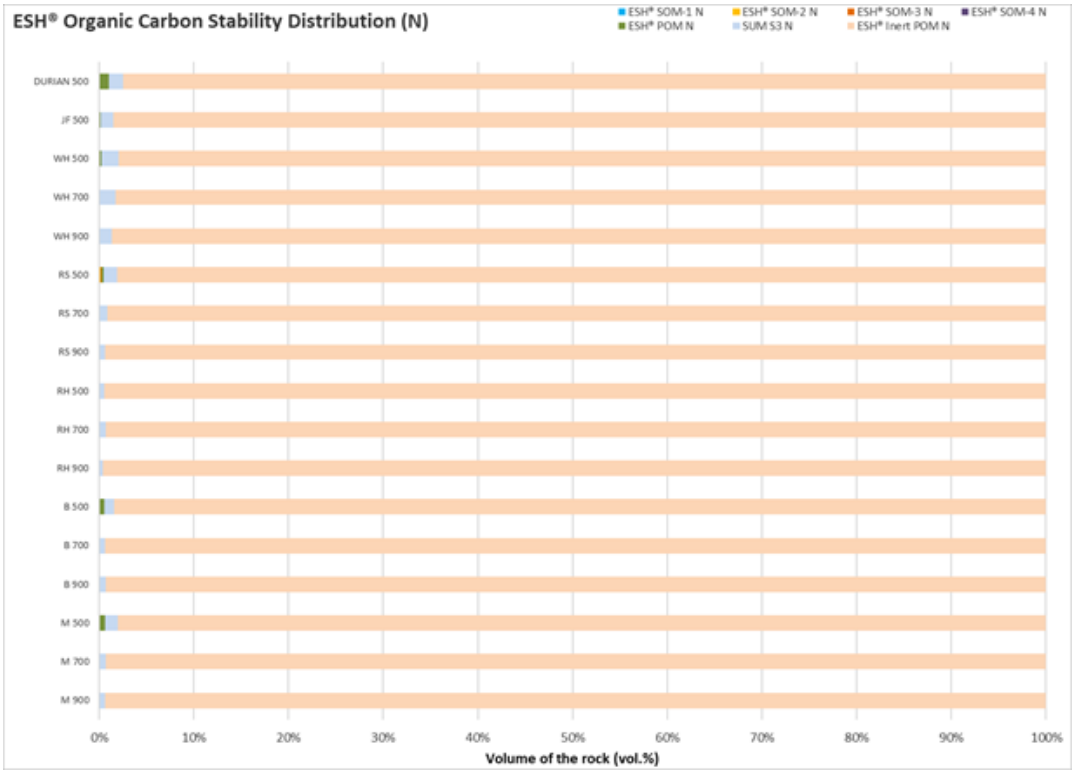


Figure 11 Results of Organic Carbon Stability Distribution

[14] Sanei, H. and Petersen, H. I.: Carbon permanence of biochar; a lesson learned from the geologically preserved charcoal in carbonaceous rocks, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-10913, https://doi.org/10.5194/egusphere-egu23-10913, 2023.

The result shows different degrees of carbon liability, ranked in the following order (i) labile soluble organic matter-SOM, (ii) labile particulate organic matter-POM, (iii) labile oxidized organic matter-S3, and finally (iv) inert organic matter. The result shows that generally, all biochar samples consist of more than 97% "inert organic matter".

The "inert organic matter" fraction is assessed and defined based on geological parameters, in **par with an extremely stable carbonaceous matter in coal and other geological rocks**, well preserved under oxic- or anoxic conditions for hundreds of millions of years (Taylor et al., 1998). Organic geochemistry and organic petrology are two scientific disciplines that are dedicated to studying the carbonaceous (carbon-rich) geological matter.

Based on these disciplines most biochar is regarded as "inertinite" maceral, the most stable organic constituent of coal. Microscopic measurements of incident light reflectance show that carbon has the same level of aromatization and molecular ordering as those in anthracite and meta-anthracite coals (Sanei, Ingermann Petersen,2023). These are the most stable forms of carbon that can be possibly found in the earth's crust**.** Examples of such a stable carbon can be seen in the 299 million years of Australian coals that were deposited under shallow, highly oxic conditions (inertinite-rich Permian coals) (Hunt & Smyth, 1989). The research by Sanei et al. shows that in most cases**,** biochar contains the most stable form of carbon that can be stored for a geological time period. It is difficult to imagine a condition in the shallow, low temperature of the upper earth crust that could lead to the degradation of such inert forms of organic carbon. The results of this study highlight the need for re-thinking carbon permanence of biochar within the context of the deep geological carbon cycle.

Comment 2

The Permanence of Soil-applied Biochar

This reflects the executive summary of the permanence chapter of the Global C-Sink Certification Guidelines by Hans-Peter Schmidt, Johannes Meyer zu Drewer, and Nikolas Hagemann, Ithaka Institute for Carbon Strategies, Zurich, 30th November 2022.

Biochar that was produced at pyrolysis temperatures above 550°C and presenting a molar H: C ratio below 0.4 is highly persistent when applied to the soil. 75% of such biochar carbon consists of stable polycyclic aromatic carbon and will persist after a soil application for more than 1000 years independent of the soil type and climate. 25% of the biochar carbon must be considered as labile or semi-labile presenting a mean residence time in soil of 50 to 100 years depending on soil type and climate. Soil-applied biochar contains thus two distinct carbon pools with different permanence and thus different carbon sink values. The climate service obtained from the stable fraction of biochar (75% of the C-content) can be considered of equal permanence as geological storage.

Biochar is a heterogenous carbonaceous material that consists of two distinct carbon pools with different degrees of persistence when applied to the soil. The stable polycyclic aromatic carbon (SPAC) pool, which consists of clusters with more than seven aromatic rings, is not susceptible to degradation. The SPAC pool has a mean residence time (MRT) in a soil largely exceeding 1000 years (Bowring et al., 2022; Howell et al., 2022), independent of common environmental factors. The labile carbon pool, which contains aliphatic, small aromatic, and heteroaromatic carbon species, is more easily degradable in soil (Rombolà et al., 2016).

Some compounds of the labile carbon pool can be degraded within the first year; others will persist for decades and even centuries depending on the chemistry of the aliphatic and small aromatic compounds and their physical placement within the porous structure of the biochar. On average, its MRT is in the order of 50 to 100 years, depending on the biochar, the soil, and the climate (Bowring et al., 2022; Hilscher & Knicker, 2011; Pisani et al., 2014).

In the environment, each of the carbonaceous compounds separated in those two respective carbon pools shows distinct degradation dynamics that can be described by an individual degradation curve. If biochar is incubated for one or two, or even eight years, as done in scientific lab studies (Kuzyakov et al., 2014; Lehmann et al., 2015) and the resulting degradation data are then mathematically extrapolated into the far future, the prediction of the degradation dynamic is erroneous because it assumes that the biochar consists only of a labile and semi-labile carbon pool (aliphatic and small clusters of aromatic and heteroaromatic rings). Over a timescale of thousands of years, SPAC will eventually also be degraded (Bowring et al., 2022), but this information is barely contained in degradation data ranging only over the first decade.
All incubation studies observed that the rate of biochar degradation slows down exponentially with time and that the experimental data can be fitted with bi- or trimodal decay functions (Lehmann et al., 2015; Wang et al., 2016; Zimmerman & Gao, 2013). However, this exponential decay only concerns the labile carbon pool, but practically not the SPAC pool, which does not significantly decompose over centuries in soil (Bowring et al., 2022; Howell et al., 2022). Projecting from the labile and semi-labile carbon pool on the behaviour of the entire biochar in the long distant future is not adequate.

The amount of persistent carbon (SPAC) in each biochar depends mainly on the pyrolysis conditions (i.e., temperature, residence time, heating rate, particle size, carrier gas, pressure) but also on the feedstock (i.e., lignin and ash content of biomass) (McDonald-Wharry, 2021). The SPAC content can be quantified by hydrogen pyrolysis (HyPy) (Ascough et al., 2009; Rombolà et al., 2016) or by Raman spectroscopy (McDonald-Wharry, 2021; McDonald-Wharry et al., 2013). HyPy analysis is reliable and proven but too complex and thus expensive to be used in routine analysis. Raman spectroscopy is a cost-efficient analytical method and is currently under methodological evaluation for e.g. the certification of carbon credits by EBC (European Biochar Certificate) and others.

Other parameters of biochar, such as production conditions (e.g., temperature) and elemental composition (i.e., using molar H: C and O: C ratio), which are frequently used as proxies for the degree of aromatization (Woolf et al., 2021) and thus persistence is not yet sufficiently reliable. Pyrolysis temperature, i.e., the actual temperature inside the biomass particle during conversion, cannot be measured in most industrial pyrolizers and does not capture the effects that heating rate, residence time, particle size, and pressure have on the formation of SPAC (Santín et al., 2017). While the molar H: C ratio can be measured with sufficient precision, some fractions of biochar with low H: C can still be labile and more susceptible to degradation than the SPAC fraction of that same biochar (Howell et al., 2022) and is thus a proxy with limited significance. A possible accounting method currently under review is the following:

For as long as SPAC is not yet analyzed, average biochar data from literature are used with caution and conservative security margins to estimate the SPAC content and thus the portion of biochar carbon that is going to endure as Carbon Removal for more than 1000 years. Based on the degradation experiments published so far and considering that the calculated decay functions express only the degradation dynamic of the labile and semi-labile biochar carbon

pool, the carbon calculated as remaining after 100 years is regarded as the minimum SPAC fraction of a biochar with an H:C ratio < 0.4 and an N-content < 1%. Applying the conventionally assumed average degradation rate of 0.3% per year, the 74% of carbon remaining after 100 years (Schmidt et al., 2020) can be considered SPAC.

This roughly 75 % of the initial biochar carbon corresponds well to the experimental data presented by Howell et al. (2022), finding 75% SPAC for various engineered biochar with H: C ratios below 0.4 using the HyPy quantification method.
To the best of the current scientific knowledge, it is safe to assume that biochar with an H: C ratio below 0.4 and less than 1% of nitrogen can be best described by a 2-pool model presenting.

(1) A persistent carbon fraction of 75% with an MRT of >1000 (1400-14400 years), competitive with geological carbon storage and suitable for CO_2-emission compensation
and
(2) A labile pool with an MRT of 50-100 years offering an additional, valuable climate cooling service, yet of a different quality than SPAC.

Additionality Test

In today's voluntary carbon market, there are multiple explicit, and implicit methods used to assess Additionality across carbon removal projects. Table 1 below shows some of the major methods by which Additionality is assessed.

Common Practice	While the use of biochar for soil nutrient retention and improvement originated over 2,000 years ago, Biochar Carbon Removal (BCR) is a relatively young technological CO2 removement approach like most technological CDR methods.
Investment Analysis	Carbon finance is of elementary importance to us. It will give us the possibility to create additionality in the following areas: • Reducing our revenue risk (risk insurance and an enabling vehicle to do future planning) • Support our scaling operations globally. • Offer biochar at a marketable price. • Stimulate the increase of future biochar output. • Give us the opportunity to work further on pilot- and R&D projects. **Exemplary Cost Breakdown** (based on biochar production and project financing costs for our CDR park Baltic Sea) **for 2024:** Raw production costs per ton of biochar (€/t) [redacted] Revenue from selling heat per ton of biochar (€/t) [redacted] Production costs per ton of biochar (€/t) [redacted] Project financing costs per ton of biochar (€/t) [redacted] **Total production costs per ton of biochar (€/t)** [redacted] Current market price per ton of biochar (€/t) [redacted] **Loss of selling biochar per ton of biochar (€/t)** - [redacted] Revenue from selling Carbon Removal Certificates per ton of biochar (€/t) [redacted] **Net earnings per ton of biochar (€/t)** [redacted]

	Without the Carbon Credit sale, the price for biochar would need to go up to [redacted] per ton of biochar, which lies [redacted]% above the current market price. Moreover, production volumes of biochar in Europe are forecasted to increase significantly over the next years. It can be expected that the average price for a ton of biochar will rather go down to [redacted] or [redacted] , thereby increasing the additionality effect of Carbon Removal Certificate sales (I.e., without the Carbon Removal Certificate sales, the production of the biochar would not happen = the Removal would not happen). Therefore, it becomes clear that we will not be able to offer biochar for a reasonable price, generate sales and risk our ability of overall production if it was not for carbon finance. Overall, we will be responsible for fundamentally cutting large amounts of CO2 emissions, doubling our output by 2024 and will reach a removal level of 1Mt by 2030. Thus, climate financing will help us to get closer to reaching this milestone and work towards an economy which operates within the planetary boundaries. As a baseline (counterfactual) scenario, without carbon finance, we would not be able to offer affordable biochar. As an effect, we would not generate the necessary sales, which has the effect of zero production output. Ultimately, we could not scale our business and the necessary pyrolysis technology. Conclusively, we would not be able to remove the necessary tons of CO2 from the atmosphere. In fact, without our usage of biomass, it would be left for degradation or combustion, releasing tons of CO2 back into the atmosphere, and contributing negatively to the already high level of atmospheric CO2. This proves that without the additional support of carbon finance, the project would not be economically feasible.
Barrier Analysis	The below barrier analysis is valid for all upcoming carbon removal sites and parks (incl. location) of ours. The carbon removal site Rhine is especially not affected by funding barriers and the below, as it is in effective operation since 2018. All measures were taken to ensure none of the below would pose a barrier. Looking into **technological barriers**, from an employment perspective a barrier lack of skilled workers for our production sites could become a risk as production facilities are not located in attractive areas (e.g. outside of cities and rural regions). However, we take active scouting measures in professional networks and run advertisements in local newspapers and activate local networks for employer marketing purposes in advance. Also collaborating with our technology provider PYREG helped us to ensure a local, educated workforce to run our first pyrolysis site from the start. From an R&D and deployment perspective of PYREG's machinery, PYREG is the leading international manufacturer of pyrolysis technology. When problems occur, we can mainly rely on our provider's extensive knowledge in resolving them. Looking into **funding barriers,** a substantial, current barrier could be that our initial funding of around € 8M cannot be secured because of delay in the decision, or uncertainty about investment willingness by potential LPs. This would result in us not being able to finance the next carbon removal sites and parks. However, we have a credit line from our main shareholder of up to € 7 Mio. just for the first production park Baltic Sea and secured substantial upfront investment for our pyrolysis machinery at the Rhine facility. As shareholder & bank loans have been installed already, we determine this barrier to be low. Looking into **economic barriers** we see that due to the ongoing economic crisis (including the impact of the Ukraine- Russian war), it is likely that input material

	prizes will remain at high levels over the next 12-24 months. This could leave our project's cash-flow negative for the first years. We counteracted this for our first carbon removal sites by securing fixed feedstock input prices, maintaining high operations hours and increasing carbon credit demand (very likely to increase). Another economic risk lies in a potential inability to sell and distribute the produced biochar. This is why right from the start of the operations of our carbon removal site Rhine, we put tremendous focus on having an experienced sales team build up an international trader network and working on the expansion of it on a daily level. Looking into **political barriers**: We are aware that the legislative landscape for CDR technologies support and incentives for overarching deployment is still an ongoing discussion, yet to be specified and deployed. Specifically, for us as a company, we are facing the barrier of political consensus on more wide-ranging legislative approval and support of our soil- and material application of biochar. As we already established an extensive trader network for biochar in the Nordics and DACH region, we are still seeking incentivized support beyond soil application possibilities (e.g., political recommendation to industries of substitute benefits of biochar with cement and polymers). As we generally do keep track of any upcoming regulatory changes on all levels (regional, national, and international) and know from experience that if potentially, we would not be able to use a certain material in the future, we would be able to accommodate for this in time. However, looking into the broad scope of political initiatives, we see that there is a high interest in enabling more support for green technologies which are encouraging for us rather than blocking (please see the *regulatory surplus* section). In sum, we evaluate the above-described barriers to be of low - intermediate significance and therefore not preventing our overall project's implementation of the two carbon removal sites and our carbon removal park in Germany.
Regulatory Surplus	We identified the following regulations and frameworks which require GHG emission reduction within a specific timeframe: • **European Green Deal Initiatives**: EU Fit for 55: cutting emissions by 55% until 2030 compared to 1990 levels. • **US Inflation Reduction Act Adoption**: $369bn investment in climate technologies (clean tech, carbon removal • **Net Zero Industry Act Proposal**: This sets a goal for the EU to domestically produce at least 40% of the technology it needs to achieve its climate and energy targets by 2030. It proposes a list of eight strategic net zero technologies that would benefit from an even faster permitting process within what is defined as "net zero strategic projects": which are solar photovoltaic and solar thermal technologies, onshore wind and offshore renewables, battery/storage, heat pumps and geothermal energy, electrolysers and fuel cells, sustainable biogas/biomethane technologies, carbon capture and storage (CCS), and grid technologies. • **European Trading System (ETS) Adoption**: The EU Emissions Trading System (EU ETS) is a market-based approach for setting a price for carbon dioxide (CO2) emissions. It works on a 'cap and trade' basis whereby a 'cap' or limit is set on the total greenhouse gas (GHG) emissions allowed from specific sectors of the economy each year, with the aim of achieving emissions reductions over time. Carbon removal is

	not yet included under the EU ETS, but the Commission is set to report, by 2026, on how negative emissions could be accounted for and covered by emissions trading. • **Carbon Removal Certification Framework (CRCF) Proposal**: A voluntary regulatory framework for the certification of carbon removals (CRCF), which will be the first of its kind in width of covered CDR methods, pending adoption by co-legislators. The stated goal is to foster and accelerate the scale-up of sustainable carbon removals, which includes a wide variety of CDR methods to be applied by land managers, industries, and others to capture and store atmospheric or biogenic CO2, as well as fight greenwashing, and harmonies carbon removal market conditions. • **EU`s Corporate Sustainability Reporting Directive (CSRD) Adoption**: reporting requirements indirectly require carbon removal and reduction measures. • **EU's Fertilizing Regulation 2019/1009**: Biochar has been subject to long-term and wide-ranging studies. Due to the co-benefits which result from the application of biochar, the EU is officially recommending biochar for agricultural purposes, supporting the regenerative transformation of this industry. The updated EU rules on fertilizers (Regulation 2019/1009) apply from 16 July 2022 onwards: They have been extended to cover all types of fertilizers, including organic ones such as those derived from pyrolysis and gasification processes. All of them are beneficial for our work on carbon removal and will either support and incentivize us in creating an adequate infrastructure to deploy and scale our technology faster or incentivize companies to collaborate with CDR providers like us.

Monitoring and Verification Plan

The monitoring will be carried out in such a way that the indicators of our carbon removal parks' project performance and emissions can be readily compared with the baseline scenario.

Boundaries

- Quality of biomass input,
- Quality for biochar output
- Renewable, thermal energy generation output
- Filter emissions
- Energy input

Data collection and auditing

It is to say that the monitoring is conducted until the delivery of the biochar and transition by our customer into a permanent sink. We have contracts in place that will be signed by the customer, guaranteeing non-combustion or other usages than direct transfer into an end sink.

However, we conduct bi-yearly audits of our biochar and facility. They will be conducted by third-party auditors and biochar specialists, and contain lab analysis of production samples, and technical reporting as well as a life cycle assessment analysis.

All results (including lab tests, audit reports, sheet for safe transport and treatment of biochar and life cycle assessment) will be digitally stored and archived in the company's drive for a period of over 10 years as well as publicly accessible stored in the database of our certification bodies (e.g., CSI). Additionally, all non-confidential results will be made publicly available on request.

Crediting Period

The crediting period of our carbon removal site will end in 2024. In general, the project generated credits, biochar, and green heat. Credits will be generated throughout the whole crediting period of 6 years until 2024.

Retirement and Monitoring of Credits derived from Rhine Site

Year of carbon credit sale	Number of credits sold and retired	Registry Monitoring/ Publication
2020	16	CSI
2021	738,5	CSI
2022	641	CSI (361), Puro.earth (280)
2023 (state 10/23)	1258	CSI (419), Puro.earth (839)

Carbon Accounting and Quantification with puro.earth

This exemplified carbon credit upload document gives an exemplified insight into the carbon credit calculation and biochar production reporting period via the puro. earth registry. For more information visit our public database.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1				biomass: only forest residues												
2				lab test: dated september												
3				2022-12-07 to 2023-2-15												Total
4	Produced and shipped biochar (wet)	tonnes		63,30												63
5	Average Moisture content	%		23,2 %												
6	Produced and shipped biochar (dry)	tonnes		48,61												49
7																
8	Gross embodied CO2	tonnes CO2/unit		2,954		2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954	
9	Gross embodied CO2	tonnes CO2		144		-00	-00	-00	-00	-00	-00	-00	-00	-00	-00	144
10																
11	A1 Biomass supply	tonnes CO2/unit		0,088												
12	A2 Wood chips transport	tonnes CO2/unit		0,030		0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	5,030
13	A3 Electricity use	tonnes CO2/unit		0,126		-00	-00	-00	-00	-00	-00	-00	-00	-00	-00	0,126
14	A3 Start-up fuel (liquid petrolium gas)	tonnes CO2/unit		0,055		-00	-00	-00	-00	-00	-00	-00	-00	-00	-00	0,055
15	A3 Packaging	tonnes CO2/unit		0,019		-00	-00	-00	-00	-00	-00	-00	-00	-00	-00	0,019
16	A3 Direct emissions	tonnes CO2/unit		0,00001		0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,400
17	A3 Rest	tonnes CO2/unit		0,001												
18	A4 Biochar transport	tonnes CO2/unit		0,179												
19	B1 Packaging waste treatment	tonnes CO2/unit		0,022												
20	B1 Application of biochar	tonnes CO2/unit		0,029		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,039
21	Emissions from process	tonnes CO2/unit		0,5475		0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	6
22																
23																
24	Net embodied CO2	mtCO2e/unit		2,407		2,413	2,413	2,413	2,413	2,413	2,413	2,413	2,413	2,413	2,413	
25																
26	CORCs			117		-00	-00	-00	-00	-00	-00	-00	-00	-00	-00	117

The snippet aims to demonstrate the detailed calculation behind the sum of CORCs derived from our reported biochar production period:

On the left side, there is a granular breakdown of activities in which emission factor has been previously defined through an LCA, and which require manual editing for every CORC reporting done.

Assessing Carbon Removal Quality Parameters

Operating in an unregulated market, in which avoidance and removal projects mistakenly are often observed as equally productive, we know that it is of critical importance to define and communicate transparently where one's projects strive best, and where they have their limits. Therefore, we want to highlight the known four parameters to evaluate carbon removal projects from the eye of Novocarbo:

Additionality We know that the GHG removal must be added to the results achieved by the project. Towards the underlying additionality question of "What would have happened if the project had not been carried out. Would the same amount of CO_2 have been stored?", the answer is no: We know that in the absence of pyrolyzing our biomass, it would most likely be either left for decomposition or for combustion. This means, that all CO_2 which would be trapped inside the biochar for centuries, would be released back into the atmosphere within a short amount of time.

Permanence The question of durability and permanence is an ongoing scientific debate, which we are currently elaborating on with several institutes and CDR associations. Mainly, it is to say that functionally, biochar carbon remains sequestered over multiple centuries, with mean residence times (MRT) up to 1000 years, if not even more: according to the European Biochar Institute and research, done by Bowring et al. (2020), calculations confirmed PyC's MRT at 2,760 years.

However, most scientific results vary between a storage permanence of 300 to more than 1000 years. Often, a constant average degradation rate of 0.3% annually, is based on the most conservative assumption for carbon degradation of biochar based on meta-analytical data.
Puro.earth decided to determine a "guaranteed durability minimum" of 100 years, according to the following assumptions: At 101 years biochar carbon is not released all at once. For biochar that is not mixed in soil but rather in any other mineral matrix (such as concrete), there is no microbial respiration, and the durability is longer.

Finally, consideration for the risk of physical reversal defined by the IPCC state that in the certified durability term of 100 years, the contribution from natural reversal (microbial respiration in soil mix) is accounted for and only the carbon that is stored at the 100-year mark is represented in the CORC. Any other physical reversal risk is deemed not relevant. In IPCC's 6th Assessment Report (Working Group III, Summary for Policymakers), paragraph C.11.3 reads "The removal and storage of carbon dioxide through vegetation and soil management can be reversed by human or natural disturbances; it is also prone to climate change impacts. In comparison, carbon dioxide stored in geological and ocean reservoirs and as carbon in biochar is less prone to reversal. (High confidence). [15]

[15] Long-term, science-based methodological support is achieved through:
-Bowring et al. (2020 preprint). They are using a calculation based on assumptions, confirming PyC's MRT at 2,760 years.

However, we would like to refer to the executive summary "Mean Residence Times of Natural Pyrogenic Carbon" recently published by the Ithaka Institute[16]

Calculations of global inputs and depositions of naturally produced pyrogenic carbons (PyC) can test how robust and conservative the assumption of these average persistence rates over 100 years is. Forest, bush and steppe fires are incomplete combustions, which transform part of the biomass into chars, i.e. PyC. According to recent surveys of natural fires, 5-15% of the biomass carbon involved in the fire is converted to PyC (Santín et al., 2016). Natural PyCs are similar in structure and material properties to industrially produced biochar. However, it can be assumed that the stability of high HTT industrial biochar, and thus the mean residence time (MRT), is even higher than that of natural PyC (Howell et al., 2022; Santín et al., 2017) due to more controlled and homogeneous high-temperature conditions.

Mainly through forest and steppe fires, about 0.114-0.383 Pg (petagrams) of PyC have formed on earth annually (Santín et al., 2016). Globally, the total mass of PyC in soils is 71-212 Pg, in nearshore sediments 400-1200 Pg, and in further ocean sediments 80-240 Pg (Bird et al., 2015; Santín et al., 2016), resulting in a global PyC pool of 550-1,650 Pg (excluding PyC dissolved in water bodies and groundwater sediments). Based on the dimension of the global PyC pool and the annual input of PyC of 0.114 - 0.383 Pg given above, the average MRT of PyC can be calculated as:

$$\mathrm{MRT} = \frac{Global\ PyC-pool}{annual\ PyC\ input}$$

The MRT range of natural PyC could thus be calculated as (550 Pg / 0.383 Pg a-1 to 1,650 Pg / 0.114 Pg a-1 =) 1,440 to 14,500 years. This time frame is confirmed by Bowring et al. (2022) who determined a minimum MRT of 2,760 years using the same data basis but without including sedimentary PyC.
If we use the extrapolation of Reisser et al. (2016), according to which the PyC content of soil organic carbon (SOC) is 14%, and the global content of SOC is 1,500 to 3,000 Pg (Scharlemann et al., 2014) the global PyC content in soils would be about 210 - 420 Pg (Leifeld et al., 2018). From the annual PyC input of 0.114 - 0.383 Pg, the MRT for PyC in soils would be (210 Pg / 0.382 Pg a-1 to 420 Pg / 0.114 Pg a-1) 550 to 3,700 years. Since the MRT of PyC in sediments is significantly higher than in soils, the difference between the two calculations is plausible. Note, however, that most of the PyC in nearshore sediments are originally derived from PyC leached from soils (Coppola & Druffel, 2016) so that much longer MRTs than the calculated

-Budai et al. (2012) & Camps et al. (2015) Biochar Carbon Stability Test Method: An Assessment of Methods to Determine Biochar Carbon Stability. Technical report.
-Kuzyakow et. al. (2014): Biochar stability in soil: Decomposition during eight years and transformation as assessed by compound-specific 14C analysis
-(IPCC, 2019; Kuzyakov et al., 2014; Lehmann et al., 2015; Leng et al., 2019; Zimmerman and Gao, 2013). Using the bimodal decomposition functions, which are now the scientific consensus, the calculations yield mean residence times of several centuries to millennia, depending on the degree of aromatization of the PK (H/Corg ratio)

[16] by Hans-Peter Schmidt, Johannes Meyer zu Drewer, and Nikolas Hagemann Ithaka Institute for Carbon Strategies, Zurich, 30th November 2022

550 to 3,700 years would result for soil-PyC, except that the pyrogenic carbon would no longer be found in soils but as deposits in sediments (Coppola et al., 2014).[17][18][19][20][21][22][23]

Leakage. The risk of displacing activities that cause GHG emissions from the project site to another site is not present at most levels otherwise common in climate projects: Neither do we protect a certain habitat which causes clearings next to our facility nor is active in any sort of other operations, resulting in GHG emissions which can be traced back to our actions. The leakage to be considered is the one of additional biomass needed. If a pyrolysis site buys woodchips that have so far been used for energy production by a gasifier and if the gasifier plant is no longer able to source woodchips it will be taken offline. If that electricity is, then replaced by fossil-based electricity there is leakage. We take this concern seriously and react to it by only sourcing residues, that have no other direct use. We do not source biomass with a product value. Two mechanisms secure that our biomass is a residue/waste:

1. Our business plan allows only a minimum price to be paid for the input material. High-quality woodchips are the first-usage product and are excluded from our business model of the high price.

2. According to the ISO standard used in the LCA, the CDR methodology will account for emissions from input material as soon as it comes with a price that exceeds logistic and preparation costs. This mechanism prevents us to use any biomass with a product value as an input material.

Verification. Our carbon removal project can be verified through the known carbon removal credit registry and verification body Puro.earth: Puro is taking care of the accreditation of our removal park from the registration process of our facility (which includes a product LCA, 3rd party auditing and lab analysis of our biochar) until the credit issuance and contracting measures for offtake agreements.

---

[17] Santin, C., Doerr, S. H., Kane, E. S., Masiello, C. A., Ohlson, M., de la Rosa, J. M., Preston, C. M., & Dittmar,
T. (2016). Towards a global assessment of pyrogenic carbon from vegetation fires. Global Change Biology, 22(1), 76–91. https://doi.org/10.1111/gcb.12985

[18] Santin, C., Doerr, S. H., Merino, A., Bucheli, T. D., Bryant, R., Ascough, P., Gao, X., & Masiello, C. A. (2017).
Carbon sequestration potential and physicochemical properties differ between wildfire charcoals and slow pyrolysis biochars. Scientific Reports, 7(1), 11233. https://doi.org/10.1038/s41598-017-10455-2

[19] Howell, A., Helmkamp, S., & Belmont, E. (2022). Stable polycyclic aromatic carbon (SPAC) formation in wildfire chars and engineered biochars. Science of The Total Environment, 849, 157610. https://doi.org/10.1016/J.SCITOTENV.2022.157610

[20] Bird, M. I., Wynn, J. G., Saiz, G., Wurster, C. M., & McBeath, A. (2015). The Pyrogenic Carbon Cycle. Annual
Review of Earth and Planetary Sciences, 43(1), 273–298. https://doi.org/10.1146/annurev-earth-060614-105038

[21] Scharlemann, J. P., Tanner, E. V., Hiederer, R., & Kapos, V. (2014). Global soil carbon: understanding and managing the largest terrestrial carbon pool. Carbon Management, 5(1), 81–91. https://doi.org/10.4155/cmt.13.77

[22] Leifeld, J., Alewell, C., Bader, C., Kruger, J. P., Mueller, C. W., Sommer, M., Steffens, M., & Szidat, S. (2018).
Pyrogenic Carbon Contributes Substantially to Carbon Storage in Intact and Degraded Northern Peatlands. Land Degradation & Development, 29(7), 2082–2091. https://doi.org/10.1002/ldr.2812

[23] Coppola, A. I., & Druffel, E. R. M. (2016). Cycling of black carbon in the ocean. Geophysical Research Letters,
43(9), 4477–4482. https://doi.org/10.1002/2016GL068574

Assessing carbon finance additionality

We know that without carbon finance we would not be able to run our carbon removal projects and offer biochar at an affordable price.

It will give us the possibility to create additionality in the following areas:

1. Reducing our revenue risk (risk insurance and an enabling vehicle to plan).
2. Support our scaling operations globally.
3. Offer biochar at a convenient, marketable price.
4. Stimulate the increase of future biochar output.
5. Give us the opportunity to work further on pilot- and R&D projects.

Overall, we will be responsible for fundamentally cutting large amounts of CO2 emissions, double our output by 2024 and will reach a removal level of 1Mt a year by 2030. Thus, climate financing will help us to get closer to reaching this milestone and work towards an economy which operates within the planetary boundaries.

A baseline (counterfactual) scenario would simply be, that without carbon finance, we would not be able to offer affordable biochar. As an effect, we would not generate the necessary sales, which has the effect of zero production output. Ultimately, we could not scale our business and the necessary pyrolysis technology. Conclusively, we would not be able to remove the necessary tons of CO2 from the atmosphere. In fact, without our usage of biomass, it would be left for degradation or combustion, releasing tons of CO2 back into the atmosphere, and contributing negatively to the already high level of atmospheric CO2.

Also, the energy and heat produced at this facility are solely for captive consumption and do not receive financing for example through the German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz) as our production does not qualify for it.

Assessing Environmental Impact

Regarding the assessment of our carbon removal park's environmental impact, it is to say that we can assure you with high confidence that any negative impact of biochar applications and our production is firmly low. However, with the intention to provide a clear overview and give everyone the opportunity for an individual assessment, the following sections will be separately dedicated to the environmental benefits and risks that our project and biochar product comes with.

Assessing Environmental Benefits

Water stewardship. Biochar avoids negative effects on water: when added together with fertilizers in agriculture or when present in the soil it prevents the leakage of nutrients and the eutrophication of our rivers, lakes, and seas. When used in stormwater treatments in cities, as we did for example in Stockholm or in Geneva, biochar filters harmful substances that are part of our city life (e.g., caffeine, heavy metals, chemicals, and medical substances).

Water holding capacity. Biochar can retain up to 3 times its own weight in water. It acts like a sponge in the soil, holding water back from sinking into deeper parts of the soil if the soil is dry. It also helps water drainage if the soil is saturated with water due to its spongy structure and very good water adhesivity. Therefore, it has a water management function in the soil: for heavy clay soils as much as for sandy light soils. It prevents waterlogging and root rot and at the same time acts as a water reservoir in times of drought. With climate change affecting European summers being dryer than before, biochar helps reduce irrigation – this is especially the case for private gardens, urban green places as well as agriculture and food production of any kind. Our biochar has been used for its water management benefits in reforestation projects to increase the survival rate of seedlings.

Filtration capacity. Its potent filtration capacity makes biochar well-suited for direct applications in **water, stormwater, and wastewater treatment.** Biochar is used in rain beds and in green/blue infrastructure projects in cities. Specifically, our biochar has been used for these reasons in Scandinavia and Switzerland to protect rivers and lakes from runoff pollutants. It also has been used as a natural filter in rivers and lakes that are already contaminated. We have been part of successful research conducted at the University of Galway to regenerate lakes in Ireland.

While wastewater from food production is not released in the rivers in Germany, this is common practice in coffee production, where biochar has proven to protect natural water reservoirs. We developed a concept on how to use biochar to filter the wastewater that occurs when washing coffee beans – holding back nutrients, that must otherwise be added with mineral fertilizer in the next growing period and improving the environmental impact of this huge amount of wastewater being released into the rivers and potentially harming local communities.[24]

Also, biochar proves beneficial as a general **safeguard for water resources.** Less nutrient leakage results in less nitrogen and phosphor in our lakes, river, and seas.

Addressing waste reduction. A co-benefit in this category is the effective treatment of residues with no further use: e.g., sieve overflow in German disposal & composting plants. Waste materials like these can be processed through pyrolysis and enter a part of a circular, sustainable cycle.
General ecosystem protection. Support the prevention of wildfires by removing excess forest residues (e.g., removal of damaged wood and deadwood, coffee, or cocoa shells in the tropics that are causing unregulated wildfires).

Let's investigate the **application in animal feeding and bedding**. Biochar application can reduce emissions of slurry and manure in the stables and during storage, where most emissions happen. Therefore, it reduces the need for mineral fertilizer, as nutrients in the natural fertilizers of animal production are preserved. Also, it improves animal health of foot diseases and

[24] This aspect of biochar is not applying for our specific research project, as our in Europe produced biochar is very unlikely to be shipped to the tropics.

breathing, and decreases the need for antibiotics (especially in dairy farming due to udder health and hoof health).[25]

Here is an overview of **the benefits of biochar as a soil amendment**:

- helps prevent leakage of phosphor and nitrate.
- reduces emissions of nitrous oxide.
- reduces the need for irrigation, thus saving water.
- improves soil health and therefore restores a major resource.
- improves yield, therefore helping build sustainable economies.
- improves plant resilience to fungi diseases.
- enables the capacity of cation exchange: meaning it is easier for plants to uptake nutrients.
- can decrease the intake of specific toxins e.g., cadmium intake of cocoa nuts, therefore improving human health.

Especially regarding the **buildup of soil organic carbon**. Biochar has proven to speed up the upbuild rates of soil organic carbon, leading to a more fertile soil and water increase in water holding capacity.

As a **supplement in soil production**, biochar:

- substitutes peat and therefore helps preserve wetlands and prevents the enormous methane emissions that occur, when peat is harvested.
- reduces methane emissions in composting processes.
- helps cities turn more climate-resilient and livable due to filtration and water retention when substrates are used for stormwater management and blue-green infrastructure including rain gardens and rooftop greening (important note: we have just finished our own research for our substrates with the Leibniz Institute of freshwater ecology and inland fisheries in Berlin, Germany. This research proves the excellent filtration capabilities of our biochar substrates for street water runoff, thus protecting our water resources).

Climate resilience and material emission reduction in the broader scope can be addressed through the co-benefits in materials as well:

When we investigate **concrete production**, biochar can substitute parts of cement as well as sand in concrete while improving product attributes (paper by Benjamin Reinke of Novocarbo and Mensah, Shanmugam, Narayanan, Razavi et.al 2021 "Biochar-Added Cementitious Materials—A Review on Mechanical, Thermal, and Environmental Properties").
Additionally, adding biochar to common injection moulding processes will substitute polypropylene, made from fossil feedstock:
We managed to add up to 35% of biochar to a common polypropylene without altering the material and being able to run through the injection moulding process.

[25] Animal health: Used as a bedding, biochar reduces infections of foot and udder (dairy production and poultry). It also improves the air in stables (pig, dairy, beef, and poultry). Used as a feed supplement for cows, udder infections will decrease significantly, reducing the need for antibiotics.

Also, biochar proves beneficial as a **filler material.** It has very good insulation attributes and water absorption. Especially in the textile industry, we are currently working and testing opportunities with fashion companies to make use of these to substitute non-sustainable materials. We are currently working with the Fraunhofer Institute on biochar's potential to substitute raw materials needed in battery production (e.g., silver).

Social equity is addressed, through the fact that our project is not limiting or excluding any group, gender, ethnicity, nationality, or race from work opportunities with us. It is the opposite: we are understanding our project as an opportunity for no-boundary employment, and especially encourage local communities to job applications to stimulate regional economics. All in all, all materials prove how biochar helps to transition into a greener economy.

Finally, from the technological perspective, it is to say that one of our project's core co-benefits is the provision of regenerative heat, produced during the pyrolysis, thus, substituting fossil energy.

Assessing Environmental Risks

First, it is to say that biochar has been subject to long-term and wide-ranging studies. Due to the co-benefits which result from the application of biochar, the EU is officially recommending biochar for agricultural purposes, supporting the regenerative transformation of this industry. The updated EU rules on fertilizers (Regulation 2019/1009) will apply from 16 July 2022 onwards: They have been extended to cover all types of fertilizers, including organic ones such as those derived from pyrolysis and gasification processes.

However, there is a risk, that biochar might have a negative impact if it is poorly produced, biomass input is polluted, and inorganic pollutants (such as sulfur oxides and nitrogen oxides) are released through the pyrolysis process. We actively mitigate this risk by constant tests and sample checks of our biomass and generally can rely on full quality assurance through our EBC certificate, verifying all our related activities through an overarching production audit. Further, related to the inorganic pollutants, we have filter systems with integrated detectors, which are collecting the harmful molecules and help us monitor thresholds/ boundary values for present content.

Additional environmental harm lies in associated emissions resulting from the transportation of biomass to and from the facility. The use of diesel vehicles results in additional emissions of criteria pollutants that can be harmful to the environment and people. We are working on transportation solutions with our logistic partners that result in fewer emissions, such as replacing our internal vehicles with electric and hybrid plug-ins. Also, we are committed to facilitating decentralized and modular transport of biomass to reduce the general transport length to our end consumers and customers.

It is to say, that there are necessities for the right treatment of biochar as downsides could occur: One of them would derive from adding biochar in too high quantities, and without recharging it to sandy soils with a lot of dryness. This will hardly lead to any positive effects:
At first, before being inhabited by microorganisms and loaded with nutrients, the biochar could even lead to a decrease in soil life. Also, if plants are integrated into pure biochar from input materials without high nutritious value, such as wood, which is the input material we mainly use, they would most likely not survive.

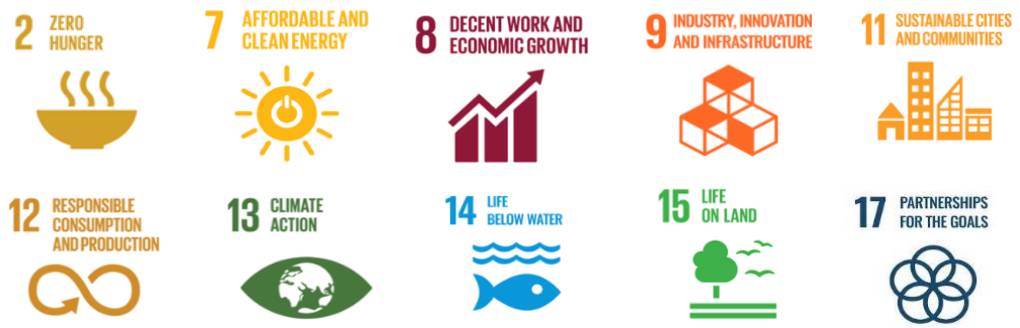
That is why the incorporation into the soil and the incorporation of animal bedding/feed into slurry or manure is so important. However, if water leaching occurs and carries the biochar itself into rivers and lakes, this is not a downside as the carbon does not decompose in the water (Schmidt, et.al Acroscope 2021). Biochar carbon removal does not present any general material risks of reversal once biochar has been mixed into a soil or mineral matrix. Reversal risk mitigation is already done on the methodology level in Puro Standard for biochar by setting requirements that exclude the risk-prone conditions.

Inappropriate use of biochar (i.e., in energy or other oxidative applications) is prevented by the Puro Standard requirements and verified annually by an independent 3rd party from the evidence that each biochar batch is used in eligible applications. Different soil temperature (cold vs. tropical climate) leads to different microbial activity in biochar. This factor is already included in the scientifically calculated storage durability with the location-specific data in the Puro Standard biochar methodology, as opposed to many other methodologies.

Change in biochar elemental composition, due to change in thermochemical process conditions is mitigated by regular laboratory testing for annual audits.
Fire risk prior to biochar being mixed into a soil or mineral matrix during transport. Such risk is mitigated by proper biochar quenching, and handling of the biochar, which is verified by an independent 3rd party during the facility audit.

Forest fires are rightly seen as a significant risk for biogenic carbon dioxide removal based on reforestation and afforestation. Forest fires are less of a substantial risk for biochar when biochar is used in forests. If used in forests, biochar is added to the soil where low oxygen levels prevent full combustion. Even if minor percentages of biochar were to be found on the surface, biochar does not ignite at the same temperatures as raw biomass, as it is a thermochemical material produced at 450-1000 degrees Celsius.

Sustainable Development Goals[26]



Stakeholder Engagement

Societal Benefits

We generate benefits for multiple parties during the execution of our carbon removal park and site project. Local communities are building a substantial element to it: they form a valuable workforce for operations on our carbon removal sites and parks. At our heritage site in Dörth, we can rely on very qualified personnel of our technology developer PYREG.

Further, we are contributing to greener industrial areas with our heat concepts: structurally poor regions and urban districts will benefit from our heat supplies mid- to long term. Our carbon removal site in Dörth is feeding the surplus heat to a next-door cement factory. At the carbon removal site thyssenkrupp rothe erde, we are feeding the surplus heat into our industrial integration partner's network from thyssenkrupp rothe erde. Furthermore, the area around our carbon removal park Baltic Sea is supposed to become a best practice example of how our biochar and green energy are nurturing the local economy and communal well-being:

---

[26] SDG 2: Improving efficiency in agriculture (less need for irrigation & fertilizer, healthy plants, hence less damage due to diseases) and respective yield increase.
SDG 7: regenerative energy as heat and electricity to municipality networks and through industrial integrations
SDG 8: We operate in a relatively new market and offer labor opportunities: Our sites are mainly located in more remote areas with few job opportunities. Therefore, we welcome local workforce
SDG 9: New materials and innovations; We help decarbonizing industries that might not be able to survive in the long run. We contribute to infrastructure through building parts of heating networks and helping the green industry park in GVM evolve.
SDG 11: storm water management, green roof support, rain bed provision, long term city-tree support.
SDG 12: we recycle waste and substitute fossil carbon or peat.
SDG 13: active engagement in carbon dioxide removal
SDG 14: see above (environmental benefits) from safeguarding water to water filtration.
SDG 15: we support the increase of biodiversity, healthy soils, secure wetlands by substituting peat and help plants to be more resilient and healthier.
SDG 17: partnering with industries, local communities, and municipal infrastructure and supporting their individual set SDGs with our energy, biochar, or CDR credit. We are part of an ecosystem of scientist working on regenerative agriculture and CDR worldwide and pushing the boundaries.

Economically, we stipulate economic growth and wealth creation by enabling local employment opportunities at our production sites and industrial growth through local biomass sourcing and biochar production.

Additionally, we will engage communities in an ongoing and transparent manner throughout our project's lifetime which starts with our biomass/feedstock supply: we are only working with certified, regional PFEC biomass businesses and are aiming to source within a radius of 80km. We are building high capacities in biochar carbon removal know-how through our participation in community gatherings, governmental relations services, and cross-sector partnerships, and are eager to go further and inform beyond our existing activities.

With all future projects, we will always include local business development agencies (Wirtschaftsförderungsverbände): Local communities will be engaged to visit our sites and create pilot-project with us. For instance, we are planning to engage with the local schools and kindergartens to create raised gardens and grow organic vegetables and fruit on biochar substrates near our pyrolysis sites. In the region of our NC Ruhr site, we plan to include local feedstock street trimming and bring it back to the community by offering biochar to the nearby communities to preserve their city trees.

Counterparty Dependency for Rhine Site

High dependency
Medium dependency
Low dependency

Counterparty	Dependency level	Notes
Biomass supplier		We are mainly sourcing our PFEC certified biomass for the Rhine site from one supplier, hence the high dependency
Energy buyer		Low dependency as the energy is primarily used for self-consumption and parts are fed into the heat network of a nearby cement company without costs
Biochar customer		The demand for our biochar increased throughout the last three years, leading to higher demand than supply opportunities. As we have a diversified customer network in place, we are not reliant on one offtake agreement. Furthermore, we create our own carbon-securing application by producing substrates with up to 70% biochar. We market those substrates to urban infrastructure projects mainly.
Carbon Credit buyer		Without the generation of carbon credits and their continuous respective sales, one of our substantial revenue streams, used for project financing, would be absent. We are generating carbon credits through the biochar produced at the Rhine site since 2019, and by now have a wide-ranging customer pool present, including forward- and pre-purchase contract opportunities. Also, the importance of decarbonization and political support is beneficial in attracting customers. Hence, we are positive to remain long-term buyer interest for carbon credits.
Employees for site operation		We do see a high dependency here as the workforce needed to operate the machinery is essential for the success of our project. While the employees can be replaced by a new workforce in case of resignation, illness etc, their presence and understanding of running the site operations is of the highest importance.

Building Permit (BimSchG)		Not necessary in our case as we have a direct integration with PYREG and operate our machines on their site.
Bank & Loan Institutions		Our full pre-financing for the first three PX500 was secured in 2018
Media & Press		We managed to already generate national media coverage for this site, our approach, and the biochar technology since 2019 (e.g., article in ZEIT, Galileo and BETD Berlin). More is always welcomed but dependency for the success of the project is relatively low.
Technology provider and & support		We are dependent on PYREG's service department for maintenance and problem support: We rely on their technical expertise in the machinery and their problem-solving approaches when running into malfunctions and errors in their accurate operation.

Stakeholder Comments

For our carbon removal park (e.g., Novocarbo Baltic Sea) we do have a partially state-led stakeholder process in place that everyone can publicly influence: The public invitation to tender is a measure partially co-organized by local authorities, to encourage anyone interested to respond to it. The carbon removal site Rhine required a state registration process that was following the above.

Since day one of the construction process, we also established an informative sign, indicating our reasoning for creating this carbon removal park and informing about our intended contribution to counteract climate change. We are aiming for an opening event, working as an "open door", in Q3/2023. Everyone will have the opportunity to visit our plant and get familiar with our company and processes.

In addition, we already worked closely with the local media (newspaper and television) and are planning further coverage upon our carbon removal park's Baltic Sea opening.

Publications

- 2023, Response on UNFCCC Removal activities under the Article 6.4 mechanism 2023, A6.4-SB005-AA-A09, version 0.40, accessible under: https://unfccc.int/sites/default/files/resource/Novocarbo.pdf
- 2022, Commentary on the Verra Biochar Methodology 2022 with Southpole and Forliance as part of the Expert round
- 2022, Contributors for Project Together's Farm-Food- Climate- Challenge 2022 manifest on Transformation for agriculture in Germany https://projecttogether.org/bundesfamilienministerium-foerdert-krisenchat-mehr-wirksame-hilfe-fuer-die-mentale-gesundheit-junger-menschen/
- 2022, Tagesspiegel Publication "CO2-Entnahme und die Krux der effektiven Ausgestaltung" https://background.tagesspiegel.de/energie-klima/co2-entnahme-und-die-krux-der-effektiven-ausgestaltung
- 2022, Project Report within the framework of the European Innovation Partnership "Agricultural Productivity and Sustainability" (EIP-AGRI) from European Agricultural Fund for Rural Development (EAFRD) and the Ministry of Rural Areas and Consumer Protection Baden-Württemberg from March 2019 to early 2022: The "Rhizo Lens" project was launched in March 2019 https://www.biooekonomie-bw.de/fachbeitrag/aktuell/novocarbo-verarbeitet-pflanzenabfaelle-zu-pflanzenkohle https://www.bio-pro.de/aktivitaeten/bereich-biooekonomie/eip-agri-projekt-rhizo-linse
- 2021, Mensah, R.A.; Shanmugam, V.; Narayanan, S.; Razavi, S.M.J.; Ulfberg, A.; Blanksvärd, T.; Sayahi, F.; Simonsson, P.; Reinke, B.; Försth, M.; et al. Biochar-Added Cementitious Materials—A Review on Mechanical, Thermal, and Environmental Properties. Sustainability 2021, 13, 9336. https://doi.org/10.3390/ su13169336
- 2020, German Institute of Food Technologies (DIL), Research Group of the Food Industry: AiF 20221 N Pflanzenkohle als Fütterungszusatz zur Reduktion der Skatol- und Indolkonzentration im Schweinefleisch",Zwischenbericht 2020

- Master theses on Novocarbo:

    - 2023, Eckhardt Maximilian, NaCO-Aufschluss von Weizenstroh zur Herstellung von bleichbaren Faserstoffen

    - 2022, K.P. Prianka: Biochar application in Agriculture and in Blue-green infrastructure for stormwater management incl. results of filtration testing with Novocarbo's biochar vs. conventional substrate and vs. pure biochar, in cooperation with Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB)

Thank you for your interest and help to support a transition to an economy which operates within the planetary boundaries,

The Novocarbo Team