Global Artisan C-Sink

Guidelines for Carbon Sink Certification for artisan biochar production

Developed by the Ithaka Institute for Carbon Strategies, 2022 - version 1.0 (6th October 2022)

The geographical scope of the Global Artisan C-Sink is limited to Low-Income, Lower Middle Income and Higher Middle Income countries as defined by the World Bank classification of countries"

Abstract

To limit climate change, the carbon dioxide removal (CDR) from the atmosphere and subsequent transformation and storage of the extracted carbon is indispensable. Most negative emission technologies (NET), especially those that can be implemented rapidly at relevant scales, use plant photosynthesis to perform CDR. The CDR capacity of plants is highest under tropical and subtropical climates. Therefore, tropical agriculture must play a major role in achieving the removal and sequestration of at least 800 billion tons of CO_2eq by the end of the century, which is necessary to achieve the goals defined in the Paris Treaty**.** As smallholder farmers cultivate most tropical agricultural land, the certification of carbon sinks, i.e., the accumulation and storage of carbon in soil and biomass, must be organized in a generic and decentralized manner. Such carbon sinks may include shorter-term and easy reversable C-sinks (i.e., shade trees, soil organic carbon, biomass materials) or long-term persistent sinks (i.e., biochar produced from agroforestry residues). The climate services provided through the establishment and maintenance of carbon sinks by smallholder farmers will have to be bundled into marketable products (i.e., carbon certificates or tokens), generating additional income for farmers and creating economic incentives for the new industrial sector of agricultural climate services. Stringent monitoring, reporting and verification (MRV) is needed to create trustworthy carbon sinks on smallholder farms, but also on larger estates, within farmers cooperatives, on public land, and at biomass processing industries. It must be transparently accounted for, controlled, and inscribed in a public carbon sink register.

The present *Global Artisan C-Sink* certification guidelines define how to certify biochar made in an artisanal way with Kon-Tiki type pyrolysis. The guidelines regulate the control procedures for sourcing of biochar feedstock, the training and examens for artisan biochar producers, the tracking of biochar application, and the use of smartphone-based monitoring and C-sink registration.

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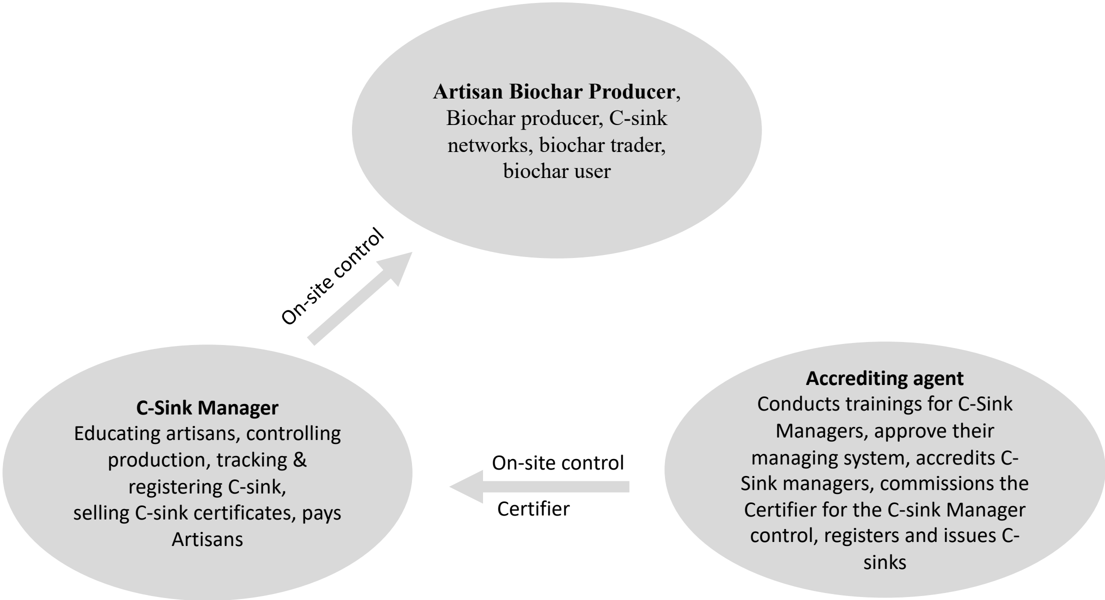
Glossary

The Global Artisan C-Sink certification system consists of a tripartite structure interlinking the following three entities: (1) biochar producer; (2) C-sink manager; (3) international accrediting agent and certifier.



Artisan Biochar Producer	An *Artisan Biochar Producer* prepares and controls the biomass feedstock and produces biochar manually in a Kon-Tiki-type kiln. The *Artisan Biochar Producer* received a qualified training in the craft of biochar production and succeeded in a final examen.
Accrediting Agent	*Carbon Standards International (CSI)* is in the role of Accrediting Agent. CSI (1) conducts trainings for the C-Sink Manager, (2) accredits the C-Sink Manager, (3) accredits tools and methods used by the C-Sink Manager, (4) verifies the reporting by the C-Sink Manager and the Certifier, (5) conducts trainings for the Certifier, (6) accredits the Certifier, (7) accredits the laboratories. CSI may (8) provide software for on-site control, tracking, certification, and registry of the produced biochar and C-sinks.
Artisan Pro	*Artisan Pro* is a certification class for companies, cooperatives, or any other entity producing > 100 m3 of biochar per year using diverse biomass feedstock not necessarily produced on the same farm where the biochar will be applied.
Certifier	The *Certifier* is a by CSI accredited certification body. The Certifier (1) verifies on a regular basis the correctness and effectiveness of the C-Sink Manager's training and monitoring duties, (2) certifies the C-Sink

	Manager, (3) executes onsite and remote inspections, (4) certifies Artisan Producers, Traders, and C-sinks.
C-Sink Farmer	A *C-Sink Farmer* produces biochar from feedstock of his farm and applies the biochar as biochar-based fertilizer on his farm. He participates in a C-sink network with other farmers in his region and is certified as part of the C-sink network. The maximum annual biochar production is 100 m^3. If he produces more, the C-Sink Manager must register him as Artisan Pro.
C-Sink Network	A *C-Sink Network* unites up to 1000 C-Sink Farmers of a same region producing each less than 100 m^3 biochar per year.
C-sink Register	The *C-Sink Register* contains the physical location of each C-sink, the date and applied amount of carbon, the carbon persistence, the owner of land, and the owner of the C-sink certificate.
Artisan App	A smartphone application provided or accredited by Carbon Standards International, which enables the monitoring and collection of all data required for C-Sink certification.
Kon-Tiki	Kon-Tiki is a generic name for all types of flame curtain or flame cap pyrolysis that are used by farmers worldwide. There is no restriction to metal kilns nor to the shape of it, it just covers the principle of artisan biochar making using a flame curtain to protect the pyrolysis zone from combustion. The Kon-Tiki is not a brand name but a catchy name for a method to produce biochar on-farm that is used in uncountable languages and facilitates farmer communication on a global scale.
Region	A certification region is a defined region of a country or an entire country but cannot cover more than one country.
C-Sink Manager	The C-Sink Manager is an organization firmly anchored in the respective region that (1) organizes the trainings and examens for the Artisan Biochar Producer, (2) monitors and controls the biochar production of C-Sink Networks and Artisan Pro entities, (3) verifies the quality and quantities of produced and traded biochar (4) tracks and verifies the application of biochar; (5) prepares all data for the C-sink registry, (6) may issue and sell C-sink certificates. The C-Sink Manager is monitored and certified by the accredited Certifier. A company that acts as C-Sink Manager can become C-Sink Manager in several regions and countries but must be certified for each individual country.
Standard Developer & Holder	The Global Artisan C-Sink Standard was developed and is continuously updated by the Ithaka Institute. The Global Artisan C-Sink Standard is owned by Carbon Standard International and can only be used under a licensing agreement. CSI is the Standard Holder managing the entire licensing and accreditation process.
Trader	A biochar trader buys biochar from C-sink farmers, C-sink farmer networks, and/or Artisan Pro producers. He may process the biochar into biochar-based products and sell those or the pure biochar to farmers or industries (e.g., for construction materials). The traders must be certified under Global Artisan and are not allowed to trade biochar that is not certified under Global Artisan. C-sinks can only be certified when a full tracking to the final sink is provided.

1. Introduction

Since 2020, carbon sinks created by industrial production of biochar and its subsequent application in agriculture or durable materials can be certified according to the EBC C-sink standard to create tradeable climate service tokens (Schmidt et al., 2020). The underlying requirements, e.g., the tracking of the biomass from its source to the pyrolysis plant or of the biochar from the production site to its final application site, have been adapted to the situation in Europe. Here, biochar is mainly produced by biomass recyclers, municipalities, and industries with large heat demand. The biochar is partly processed by specialized manufacturers and/or is distributed via the agricultural wholesale trade throughout Europe. Moreover, EBC C-sink requires the EBC-certification of the pyrolysis plant to guarantee the sustainability of both biomass sourcing and the pyrolysis process, compliance of biochar properties with relevant regulations and the availability of precise and load-specific data on biochar characteristics like carbon content and hydrogen to carbon ratio, which requires representative sampling and recurring analysis in accredited laboratories.

High investment and maintenance costs of industrial pyrolysis plants and low profitability in markets with low prices for thermal energy and biochar explain why no such industrial biochar production facilities exist in most tropical countries. However, biochar can also be produced with low-cost methods, e.g., Kon-Tiki type kilns (see chapter 3). Here, the biochar is produced manually e.g., from farm residues like straw, leaves, kernels, husks, prunings, or shade tree biomass. The process is less controlled than in industrial facilities and not mechanized, but when done correctly, the resulting biochar is of high quality, and emissions tend to be low compared to biomass decay or uncontrolled combustion. (Cornelissen et al., 2016; Karananidi et al., 2020; Smebye et al., 2017). Such low-tech artisanal biochar can be certified as a carbon sink under the following conditions:

1. The biomass was procured sustainably e.g., farm residues or derived from biomass processing waste streams (chapter 6).
2. It was dried and/or aerated to avoid decomposition during storage and subsequent greenhouse gas emissions (chapter 8).
3. The pyrolysis was done with care to reduce the formation of non-CO_2-greenhouse gas emissions during pyrolysis to a minimum (chapter 4 and 5)
4. The methane emissions caused during production are compensated through tree plantations or equivalent emission reductions (chapter 12).

5. The biochar was applied to the soil or C-sink eligible materials and not burnt or sold for burning (chapter 7).
6. The carbon sink was registered in a public carbon registry (chapter 10).
7. The participating **artisan biochar producers** are paid directly for the climate service, and the amount the artisans receive is transparently communicated.
8. The country where the biochar was produced counts among the Low-Income, Lower Middle Income and Higher Middle Income countries as defined by the World Bank classification of countries.

If proven that the above principles and conditions are met, the carbon sink capacity of the produced biochar can be assessed, certified, and traded as an asset.

2. Definition of an Artisan Biochar Producer, C-Sink Farmer, and Artisan Pro

The biochar artisan prepares and controls the biomass feedstock and produces biochar manually. The artisan biochar producer himself or an external auditor appointed by the C-Sink Manager documents feedstock provision, biochar production and application via a smartphone App.

The artisan (she or he) selects the feedstock and feeds the pyrolysis kiln manually. He/she controls the biochar making process, maintains the temperature, avoids the evolution of smoke, proceeds the quenching and post-pyrolysis treatments. The artisan or a dedicated auditor registers all necessary data and images into the Artisan App.

Artisan production is further defined by the fact that the biomass feedstock used for biochar production are either crop residues from a farm (e.g., straw, prunings, leaves, empty fruit bunches, shells, etc.), dedicated biomass production sites (e.g., bamboo plantation), biomass feedstock from fallow crop rotations, natural disaster biomass (e.g. after a tornado), or residues from crop processing (e.g., nut shells, coffee parchments, saw dust, pomace, etc.).

Artisanal produced biochar is preferentially used on the farm from where the biomass feedstock originated. When direct application is not feasible or useful, the biochar or biochar-based materials may be packaged for selling. If the biochar is applied and sold outside of the farm, the biochar trader needs to become certified as trader to track the biochar with an App to the eventual carbon sink.

The biochar application must be documented with georeferenced photos. This is no longer necessary if the biochar is already incorporated into a non-combustible matrix like compost, liquid fertilizer, digestate, or manure (except where manure is dried for fuel use) and documented as such. If untreated biochar (i.e., biochar that still could be dried and burned) is sold as biochar fertilizer on the market and the biochar trader does not document the biochar application, the C-sink cannot be certified.

An artisan is an artisan as long as he/she excels in his/her craft which means he/she prepares the biomass, pyrolyzes it, stores the biochar, packages it, labels it, registers it. We consider that an artisan can produce at maximum 5 m3 biochar per day on 300 days per year which adds to a maximum of 1500 m3 of biochar per year. Exceeding the production of 1500 m^3 biochar per year already reaches industrial scale, and more professional production equipment should be considered.

Within this regulatory framework, the Global Artisan C-Sink distinguishes two options for artisanal biochar production:

(1) **C-Sink Farmer:** The C-Sink Farmer is an Artisan Biochar Producer who produces himself up to 100 m^3 of biochar per year from residues of her/his farm and applies this biochar back to his/her soil.

Exceptionally, biomass from neighboring farms or debris can be used, and biochar can be sold to other farmers when correctly tracked. C-Sink Farmers are grouped in certification networks with a maximum of 1000 participating farmers that underly a simplified certification procedure for C-Sink Farmers.

A group of more than 1000 farmers is hardly manageable in the internal control system. A farmer **C-sink network** with 1000 farmers each producing 100 m3 would produce a total of 20,000 t biochar per year which is significantly more than most fully EBC certified industrial companies.

(2) **Artisan Pro:** Artisan Pro biochar is professionally produced by a company, an association, or an individual using residual farm biomass, biomass from processing industries, controlled fallow rotations, or disaster debris. Artisan Pro biochar is not necessarily applied back to the fields where the biomass was grown but is mostly traded to other farms and industries. Artisan Pro biochar is produced at a registered production site with registered production equipment. It can be produced by several trained artisan biochar producers (i.e., employees of the certified company) though they work at the same site with the same equipment. The maximum annual biochar production still considered artisanal is 1500 m3 per year. Artisan Pro production sites and entities cannot be certified under the simplified certification procedure for C-Sink Farmers but need individual certifications.

If they expect to produce more than 1500 m3 of biochar per year, they must submit a justification, why no industrial pyrolysis plant (burning pyrolysis gases under controlled and monitored conditions with heat usage or electricity production or pyrolysis oil recovery) can be installed yet. This must include a timeline for the development towards industrialization of the biochar production. The justification must be approved by the certifier; the approval may include deadlines for re-evaluation.

3. Basic Principles of Certification

The basic principles of certification are the same as for the EBC-Guidelines for the Certification of Biochar Based Carbon Sinks (EBC, 2020) that are applied to industrial biochar production:

- All emissions occurring due to biomass sourcing, biochar production and application must be accounted and need to be adequately compensated by carbon sinks.
    - In the case of methane emissions, the increase of standing biomass and the avoidance of methane emission from crop residue burning or decomposition may be used for offsetting.
    - Other emissions need to be converted into CO_2eq and must be subtracted from the amount of carbon stored in the final biochar C-sink to achieve climate neutral biochar and a certified net C-sink.
- Individual farmers producing less than 100 m^3 of biochar per year can be grouped into artisan biochar producer networks for simplified certification (**C-Sink Farmer**).
- Artisan biochar producers with an annual production exceeding 100 m^3 per year have to be certified individually (**Artisan Pro**).
- The production of biochar and the establishment of the final, physical C-sink must be verified by the certified **C-Sink Manager**. The C-Sink Manager must follow the present guidelines and be certified through the Certifier.
- The trading of biochar and the issuance of C-sink certificates or tokens must equally be verified by the certified C-Sink Manager.

Creating biochar-based C-sinks is a negative emission technology. It is not considered a certified emission reduction (CER) or verified emission reduction (VER). However, the production and application of biochar can lead to significant emission reductions (e.g., reduction of methane emissions from rice fields or from the uncontrolled decomposition of farm residues, nitrous oxide emissions from fertilizer applications). Those emission reductions are not accounted for in the present C-sink assessment. The individual artisan biochar producer or the C-Sink Manager may take advantage and monetize these co-benefits of biochar production and application when scientific evidence and/or suitable controlling is available for the specific case, but not under the umbrella of the C-Sink Artisan standard. However, if the monetization of these co-benefits is done negligently and without sufficient evidence, the certifier may withdraw the Global Artisan C-sink certification.

4. Eligible technology

While industrial biochar making is slowly picking up in some countries (mainly in North America, Middle and Northern Europe and Australia), most of the biochar used worldwide is made using flame curtain pyrolysis e.g., in Kon-Tiki type pyrolysis kilns. The Kon-Tiki flame curtain pyrolysis combines the simplicity of the traditional kiln with sufficient combustion of pyrolysis gases and avoids the need of external fuel for start-up.

The Kon-Tiki was developed in 2014 by the Ithaka Institute in Switzerland and spread rapidly by open-source technology transfer to farmers in more than 80 countries (www.ithaka-institut.org/en/ct/113). However, the Ithaka Institute did not invent flame curtain pyrolysis (i.e., the Kon-Tiki), which is a simple method that ancient people most probably used already thousands of years ago. Also, Kelpie Wilson had presented on her most valuable Backyard Biochar website examples of the Japanese Moki-Kiln, the Australian Moxham Kiln, Kelpie Wilson's own Pyramid Kiln and new cone and pyramid designs by Michael Wittman, Gary Gilmore, Josiah Hunt, and others before Ithaka's open access promotion and scientific investigation of flame curtain pyrolysis under the generic name of Kon-Tiki (Schmidt and Taylor, 2014). Other names like ring of fire, trough kiln, or fire cap are also commonly used.

One run of a 2 m^3 conical flame curtain kiln with an upper diameter of 2.4 m produces 500 kg of biochar (dry matter basis) and close to 2 MWh of heat from shrubs, husks, straw, prunings and other organic farm waste in about three hours needing one worker to maintain and control the process. The cost per kiln varies with design, construction material and country but is within a range of 30 € (soil pit shield) to 5,000 €. The cheapest way is a mere conically shaped soil pit which would essentially be for free.

The principle of the flame curtain pyrolysis consists of pyrolyzing biomass layer by layer in a conically, polygonal, rectangular, or cylindrical formed metal, concrete, or soil kiln. A fire is started in the kiln, and the embers spread to form a first layer on the bottom of the kiln. A thin layer of biomass is then added on top of the embers, heats quickly and starts outgassing. The rising pyrolysis gas is caught in the flame curtain and reacts with combustion air entering the kiln from the top. When ash appears on the outside of the carbonizing biomass, the next layer of biomass is homogenously spread on top. Convective and radiant energy from the flames above and from the hot pyrolyzing layers below heat-up the fresh biomass layer, which starts to pyrolyze (Schmidt et al., 2015).

The biochar below the upper pyrolysis layer is shielded from oxygen access by the fire curtain itself. The combustion zone thus forms a flame curtain that protects the underlying biochar from oxidizing and cleanly burns all pyrolysis smoke and gases as they pass through this hot fire front. It is important to spread each new biomass layer at the right time and rate determined by monitoring the flame, smoke, and ash formation. Too much feedstock will smother the flame (producing smoke and gas emissions), and too little feedstock will not maintain a full curtain of flame to protect the biochar from oxidizing (forming ash) and to completely combust the pyrolysis gases (avoiding smoke). The manual layering of biomass is repeated until the metal kiln or soil pit is filled. The pyrolysis process is then actively ended by quenching with water or a nutrient solution (e.g., diluted urine, dissolved fertilizer) which is fed into the kiln from below if possible or, where water is not easily available, by snuffing with a layer of soil.

The temperature in the main pyrolysis zone just below the flame curtain is 680°C to 750°C (Schmidt and Taylor, 2014) and cools down slowly below the main pyrolysis zone when new feedstock layers are added to 150–450°C depending on the duration of a production load before final quenching. When snuffed with a metal lid and soil, biochar temperature may be maintained at above 400°C for more than 24h depending how tight the snuffing layer and kiln are (Cornelissen et al., 2016).

There is no restriction to the size of the kiln. Small backyard kilns with a volume of less than 100 liters or giant 15 m3 kilns can all make high quality biochar if the artisan biochar maker knows his/her trade.

The Kon-Tiki type pyrolysis is well investigated today (Bursztyn Fuentes et al., 2020; Dahal et al., 2021; Flesch et al., 2019; Kalderis et al., 2020; Karananidi et al., 2020; Kiong Kong and Sing Sii, 2019) in regard to biochar quality, organic contaminants, and emissions. Other low-tech devices to produce biochar exists but are less well investigated regarding emission data, biochar characterization, and consistency of biochar quality using various feedstock. Often, pyrolysis gases are released in such devices without proper combustion into the atmosphere (Kajina et al., 2019), causing significant GHG emissions. When using such methods, the total amount of greenhouse gases, expressed in CO_2 equivalents (CO_2e) of the charcoal/biochar production outweighs the C-sink potential of the resulting biochar.

The present certification guideline does not exclude any particular (low) technology but requires that no uncombusted pyrolysis gases are emitted from the device. Biochar from traditional charcoal piles and retorts where pyrolysis gases are released not passing a combustion zone or burning chamber cannot be certified under the present method. Biochar from top lit updraft (TLUD) gasifiers could be certified, however, the small quantities of biochar produced per production run, makes the certification procedure challenging and would need additional specification about the organization of artisan biochar producer networks. For TLUD, retorts with gas combustion or other non-mentioned types of pyrolysis equipment an application must be submitted to Carbon Standards International including biochar analysis from an EBC accredited lab and accredited emission analysis following national or international standards.

The Kon-Tiki type production of biochar is considered a bridge technology towards more carbon efficient and lower emission technologies. While High Income industrial countries have already today the financial means to invest in higher tech low emission pyrolysis plants of scale, farmers in lower income countries do simply not have the means of investment for such large-scale pyrolysis plants and corresponding biomass collection and logistics. While Kon-Tiki type pyrolysis is less C-efficient, the overall climate balance is positive when coupled with active methane compensation and has thus an overall positive short- and long-term climate effect. It is a bridge towards higher efficiency devices but with a large positive effect already today, and is, therefore, acknowledged and certified as negative emission technology. However, the C-Sink certification for biochar made with Kon-Tiki type pyrolysis is limited to Low-Income, Lower Middle Income and Higher Middle Income countries as defined by the World Bank classification of countries to incentivize High Income countries to invest into pyrolysis development and industrial production of pyrolysis plants.

5. Production of biochar, training of the biochar artisans, and exams

Flame curtain pyrolysis (Kon-Tiki) can cleanly burn the pyrolysis gases so that no or little smoke arises, particulate matter emissions keep low, and the emission of methane stays low compared to other low tech pyrolysis or combustion methods (Cornelissen et al., 2016). However, to reduce the environmental impact of the Kon-Tiki method to an unavoidable minimum, it needs qualified artisans having enjoyed a proper qualification. For this reason, it is not the Kon-Tiki technology as such that can be certified but only the combination of the technology and the executing artisan – the artisan biochar producer.

Therefore, the C-Sink Manager has to prove how the artisan biochar producers were qualified to produce high-quality biochar with low emissions. The artisan biochar producer must follow a biochar production training given by a qualified trainer and prove their proficiency in an exam. The training must include principles of feedstock selection and biomass drying (chapter 8), basic Kon-Tiki operation principles, the volume measurement of the produced biochar, a biochar sampling procedure, and the proficient use of the Artisan smartphone App.

The training must further cover the post pyrolytic treatment to refine the biochar for material and agronomic uses. The preparation and application of biochar-based fertilization should be taught and demonstrated in the trainings.

Producer training and verification of the producers competence is an essential part of the C-Sink Manager's duties.

Each artisan biochar producer must be registered in the Artisan App, and a proof about their successful participation in the training has to be uploaded.

6. Biomass feedstock

The present certification standard assumes that the biochar is made from biomass feedstock that originated from the artisan's farm or from biomass processing such as cocoa mills, coffee pealing, rice thrashing, sawmills, and comparable industries. The biomass may also come from disaster debris, maintenance of fallow fields, or dedicated biomass production like bamboo or switch grass plantations.

It is not permitted to use forest biomass and to slash forest wood. The only exceptions are residues from sustainable and, as such certified forest management. Woody residues from fallow fields are eligible when the fallow period does not exceed 15 years. Selected biomass from forest gardens, agroforestry, short rotation coppice, and fallow rotations are authorized. It is not allowed to pyrolyze food or feed products.

The restriction of eligible biomass for biochar production is explained by the intention to avoid by all means the overexploitation of ecosystems for the sake of C-sink maximation.

For Artisan Farmers, the farm size and available biomass need to be reported. For residues from crop processing units, the annually available amount of biomass should be estimated. With this data, the maximum amount of biochar that can be produced by a given farmer or a company can be estimated. Overuse of available biomass or fraud through misreporting can thus efficiently be avoided.

Under the present Global Artisan Artisan guidelines, it is not permitted to use primary forest biomass. The only exceptions are residues from sustainable and, as such certified forest management. Still, use of the latter needs written permission from the Certifier.

7. Application and trade of biochar

While C-sink Farmers are expected to apply the biochar in their own farm to improve their soil and increase farm resilience to climate change, Artisan Pro producer may intend to sell the biochar, which needs to be tracked either by the producer or a certified biochar trader.

The following exceptions to the above standard cases are possible:

- A farmer could pyrolyze residues from a neighboring farm or produce a biochar-based fertilizer to be sold in the respective region.
- A service provider comes with a mobile Kon-Tiki to farmers to pyrolyze residues and market the biochar on their own behalf.
- A farmer collects disaster debris or other occasionally available biomass and transforms it into biochar to be applied on his/her own land or to be sold on a not regular base to other farmers.

The C-Sink Manager is obliged to document all those production scenarios and present them for acceptance to Carbon Standards International.

In any case, the biochar producers must document the biomass used, the production process and the final application of the biochar as described in chapters 5, 6, 7, and 9. The obligation to keep proper proofs and records of application may be transferred to a certified biochar trader.

8. Feedstock preparation and storage

To limit emissions and avoid smoke during biochar production, the feedstock needs to be pre-dried and must be bulky. Usually, three days of sun drying is sufficient if the feedstock is not piled but thinly layered. The feedstock must not be used freshly cut or from a feedstock pile where it rained upon.

Feedstock needs to be stored airy and protected from rain.

To avoid methane emissions from feedstock storage, wet feedstock must not be piled higher than a meter. Otherwise, the humid feedstock will self-heat, consume the oxygen inside the pile and decompose anaerobically, which produces significant amounts of methane.

When feedstock got exposed again to rain, a new period of at least three days of thinly layered sun drying has to start.

Touching the feedstock must not feel humid.

The water content of feedstock should be below 30% when used in the Kon-Tiki. Simple, low-cost digital devices (+/− 60 €) exist to measure feedstock humidity which must be used at the biochar trainings so that artisans get the experience how to test the feedstock for humidity also without digital devices. Producers of more than 100 m^3 biochar per year are required to measure the feedstock humidity with an appropriate device and record it in the production protocols. Here, the average humidity is recorded using five measurements with the handhold device per m^3 of feedstock.

The Kon-Tiki can consume lots of different feedstock and mixing of feedstock during one run is possible. However, most of the feedstock needs to be bulky to allow the continues release of pyrolysis gases and unrestricted passage through the flame curtain. Smaller portions of e.g., rice husks, saw dust, coffee parchment, empty corn cobs can be added slowly in thin layers if the pyrolysis zone is sufficiently hot.

Both, feedstock drying and correct bulkiness of the feedstock blend, is an essential part of the initial artisan training.

9. C-sink monitoring, reporting and verification

Technically, the C-sink artisan certification procedure is based on a dedicated smartphone application. The main database and backbone for the Artisan App will be provided by Carbon Standard International to automatize data exchange and centralize the carbon registration. C-Sink Managers may develop their own Artisan App to manage their Artisan biochar production and trade. Until September 2023, production documentation can also be done on paper and be transferred later to a computer database. However, photo and video documentation of the biochar making, and GPS data (georeferencial coordinates of biomass origin, biochar production and biochar soil application) that also necessitates a smartphone are required.

The following data need to be recorded/uploaded using the dedicated smartphone application:

9.1 Creating an account for each biochar artisan:

1.1 Registering each biochar artisan (name, address, phone number)

1.2 Upload of the proof for successful participation in a biochar craft workshop

9.2 Registration of biomass for C-Sink Farmers (< 100 m^3 biochar per year)

2.2 GPS data of the cultivated land (creating a vector file for each field > 1 ha using the kml-filetype of Google maps, for all smaller fields, at least one GPS-point within the field and a list including the name of field and surface areas). Each field receives a unique identification number.

2.3 The crop rotation, harvest data, and harvest amount of biomass feedstock need to be recorded annually for each registered field (the C-Sink Manager correlates the biomass potential and the amount of biochar produced).

9.3 Registration of processed biomass for Artisan Pro

3.1 Short description how biomasses are processed (e.g., pealing of pineapples) – as predefined by the C-Sink Manager

3.2 Description of biomass preparation (e.g., sun drying, chopping)

3.3 Quantification of biomass residues used for biochar making usually in m^3

9.4 Registration of pyrolysis technology

4.1 Documentation of the technology used (Kon-Tiki type) including a picture, the upper surface area and depth of the kiln.

4.2 Register the volume measuring device and respective volume (e.g., 10 l buckets, 60 l bags, 200 l barrels, etc.)

9.5 Registration of each biochar production load

5.1 A biochar production load within Global Artisan C-sink is defined as the amount of biochar produced with a single run of one Kon-Tiki. For deviating technologies, the production load must be defined appropriately.

5.2 Registering the biochar feedstock type (e.g., 40% rice straw, 60% cocoa pods)

5.3 Artisan Pro must register the humidity of each feedstock component and the average feedstock size.

5.4 Artisan Pro must register the location of the pyrolyzer (address and GPS coordinates)

5.5 In the case of a new feedstock type or feedstock blend that is not registered in the Ithaka feedstock database (https://farmtool.ithaka-institut.org/en/biochar-database), the C-content and bulk density of the resulting biochar must be analyzed in an accredited laboratory (see chapter 16). The app guides the user how to take the sample, provides an ID for the sample, informs the user on how to proceed with the sample and communicates to the C-Sink Manager the necessity for analysis.

5.6 Documentation of the biochar making (registering a minimum of two photos from the middle and the end of production with georeferencing and date of picture). If the C-Sink Manager accompanies the respective process with approved auditors for the biochar making, this step is not necessary.

5.7 Accounting of the biochar produced (measured on a volume base)

9.6 Tracking and documentation of the mixing and application of biochar

6.1 Documentation of the biochar mixing to compost, manure, fertilizer, etc. (in text and photo with georeferencing and date)

6.2 Registration of the volume applied to each respective matrix.

6.3 Registration of biochar amount, application date, and the reference to the registered field of the farm (for C-Sink Farms)

9.7 Selling of the biochar

7.1 If the biochar is sold to a third party, a certificate of the carbon sink potential of the biochar can be issued. However, the carbon sink potential is not a C-sink certificate and cannot be traded as such before the biochar is not applied to soil or to persistent materials. For this purpose, a production quantity may be split into defined sub-units for selling (e.g., 60 L bags) and the Artisan App generates IDs for these units that can also be traced on a mobile device of a certified biochar trader.

7.2 The buyer of the biochar, i.e., a biochar user or trader, can become certified and deliver verified documentation and tracking of the biochar's end use so that C-sink certificates can be issued.

7.3 If the traded biochar is mixed to compost, manure, fertilizer, feed etc., the biochar cannot be burned or decompose anymore. For that reason, a C-sink certificate for a such a non-localized C-sink could be established in case that tracking of individual amounts is not possible (e.g., selling small packages via garden markets).

10. C-Sink Registry

The Artisan App and its link to the Artisan biochar data base and the Carbon Standards C-Sink Registry is the backbone of monitoring, reporting and verification in the Global Artisan C-Sink standard.

The C-Sink Manager must ensure that the following data are transmitted regularly to the CSI C-Sink Registry. Verification of correct data transfer is part of the regular monitoring of the C-Sink Manager trough the certifier.

1. Feedstock of biochar production
2. Technology of production
3. Date of production
4. C-content and H/C ratio of biochar (taken from the Ithaka database)
5. Matrix into which the biochar was mixed (compost, manure, feed, cement etc.)
6. Location of the C-sink (vector file of land or at least one GPS point for fields < 1000 m2)
7. Amount of biochar applied in tons (dry matter tons)
8. Date of application

The C-Sink Manager may keep a regional C-sink register where all individual C-sink Farmer sinks are registered with the above information (1 to 8). The C-Sink Manager may group then the C-sinks of the C-sink Farmers of a network of max. 1000 C-sink farmers into a grouped C-sink to be registered as such in the CSI C-Sink Registry.

The amount of biochar produced is measured volumetrically by the artisan biochar producer. By selecting the feedstock or feedstock blend used to produce the biochar, the applicable bulk density of the biochar can be identified in the Ithaka database. The applicable bulk density is then used to convert the biochar volume into mass (tons dry matter) with an accuracy of at least +/- 20%. Then the respective C-content of the biochars from the Artisan biochar database is used to calculate the amount of carbon contained in a given volume of biochar.

Example: 320 liter of biochar was produced from rice straw in a Kon-Tiki kiln. The density of non-milled biochar made from rice straw is registered with 220 g per liter and a C-content of 62%. The amount of carbon that can be sequestered in C-sink would then be calculated as

$320\ l * 0.2\ kg\ l^{-1} * 62\%\ C = 39.7\ kg\ C$.

In case of death of a farmer or lease of the registered land, the C-Sink Manager must inactivate the participant from the system. In case of inheritance or lease of land, the new owner or farmer must be re-registered, sign the respective declarations, and follow the required trainings.

11. On-site and remote control

The present guidelines regulate the management, inspection, and certification. Carbon Standards International is in the role of the Accrediting Agent of the Certifier. The list of accredited "Artisan Certifiers" is published on CSIs homepage. The certifier may conduct announced and unannounced inspections to verify compliance of the C-Sink Manager's duties that include visits at individual Artisan Biochar Producers (C-Sink Farmers or Artisan Pro) and traders.

11.1 Control and payment of C-Sink Farmers grouped in C-sink networks

The C-Sink Manager is responsible for the monitoring of the individual C-Sink Farmers producing less than 100 m^3 biochar per year and participating in C-Sink Farmer networks. It is not necessary to do a regular on-site inspection for each individual farmer. Instead, after the artisan training, the smartphone app used by the C-Sink Famer is the key for monitoring, reporting, and verification (MRV). The C-Sink Manager takes the full responsibility for the correctness of the declared C-sinks. They need to assure with measures that go beyond the declaration in the app that the C-sinks declared by the participating C-sink farmers were set-up in the declared quality and quantity. Various control methods such as triad peer groups, farmer leaders, or independent inspections can be applied to improve the data quality. Which additional control method is best adapted to a given region and mentality can be decided by the C-Sink Manager.

A C-sink farmer network should not group more than 1000 individual farmers. However, a C-Sink Manager can coordinate several C-sink farmer networks.

Payments for the establishment and maintenance of carbon sinks at small holder farmers need to be transparent. All income from and costs for carbon sink certificates of C-sink farmers must be publicly declared.

11.2 Control of Artisan Pro biochar production

Artisan Pro biochar producers with a production capacity of more than 100 m^3 per year must be controlled by an annual on-site inspection from the C-Sink Manager.

The C-Sink Manager must:

- Verify the data declaration in the smartphone app
- Check the supply chain of the biomass feedstock, feedstock storage and preparation

- Inspect on-site at least one Kon-Tiki production per year.
- Check storage, packaging, and labelling of biochar
- Control the sample taking and retention sample storage (see chapter 15)
- Check the tracking of the biochar from the production facility to soil, to the trader, and/or to the incorporation into a matrix that cannot be burnt. This is a plausibility and process check using the app; there is no physical check of each tracking step required.

Artisan Pro companies need to estimate their annual production. If they expect to produce more than 1500 m3 of biochar per year, they must submit a justification, why no industrial pyrolysis plant (burning pyrolysis gases under controlled and monitored conditions with heat usage or electricity production or pyrolysis oil recovery) can be installed yet. This must include a timeline for the development towards industrialization of the biochar production. The justification must be approved by the certifier; the approval may include deadlines for re-evaluation.

12 Methane emissions

During biochar production, small but relevant methane emissions occur, especially with Kon-Tiki and similar devices (Cornelissen et al., 2016). Based on emission data gained with various types of Kon-Tiki and various fresh biomass feedstock containing up to 50% humidity, Cornelissen et al. (2016) calculated an average of 30 kg CH_4 emissions occurring during the production of one ton of biochar in a Kon-Tiki type kiln, which equals an emission factor of 4.2±1.2 kg CH_4 t^{-1} biomass considering 14±3% conversion factor of biomass to biochar (Karananidi et al., 2020). The methane emissions in Kon-Tiki type kilns depend mainly on the craft to fire the kiln and on the humidity of the feedstock. The dryer the feedstock, the hotter and more homogenous the flame curtain that oxidizes the combustible gases rising from the kiln. If the feedstock is not layered with care and the flame curtain is disrupted, smoke may arise from the kiln and within the smoke CH_4. For that reason, the training and proof of expertise of the artisan biochar producers are of utter importance.

Once emitted to the atmosphere, methane is oxidized to CO_2 and H_2O within less than 15 years (Lelieveld et al., 1993; Prather et al., 2012; Skytt et al., 2020). However, during those 15 years the climate forcing effect the methane is more than 80 times stronger than an equal CO_2 emission. Following the natural decay of methane in the atmosphere, the resulting CO_2 is in balance with the CO_2 that was originally assimilated by the eventually pyrolyzed biomass and can thus be considered climate neutral. However, the water vapor (H_2O) which is the other decay product of methane in the higher atmospheric layers, has a climate forcing effect for many more decades.

Despite fundamentally different dynamics of CH_4 and CO_2 in the atmosphere, a single overarching metric for the climate forcing of those two main greenhouse gases was suggested. For this purpose, the global warming potential (GWP) was defined to convert the impact of non-CO_2 greenhouse gas emissions into CO_2 equivalent emissions (CO_2eq) (Balcombe et al., 2018). Usually, for these calculations the time horizon of 100 years (i.e., GWP100) is chosen. However, looking at the quick decay of methane, a "dilution" of its integrated radiative forcing to 100 years is hard to justify with physics. Moreover, the decades up to 2050 are the decisive period for limiting anthropogenic global warming. Since methane emissions have a particularly severe impact during this period, the calculation of methane's climate impact should not be diluted by setting a reference frame of 100 years. Therefore, the EBC chooses the 20-year reference frame (GWP20) for methane to promote actions that help avoid these critical GHG emissions (Schmidt et al., 2020). The GWP20 for methane is provided by the IPCC with a value of 86 t CO_2eq t^{-1} CH_4 (IPCC 2022).

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At emissions of 30 kg CH4 per ton of biochar, the GWP20 of 1 t biochar is thus calculated as (0.03 t * 86 CO_2eq =) 2.6 t CO_2eq. To compensate for the climate forcing effect of 30 kg Methane (caused by the Kon-Tiki production of 1 ton of biochar (dry matter)), the extraction or avoidance of 2.6 t CO_2e is necessary.

Today, the 30 kg CH_4 per ton of biochar (on a dry matter base) is considered the average for different feedstock and kiln geometries. However, many common feedstocks like rice straw, cocoa pods, husks, and leaves have not yet been investigated regarding potential CH_4 emissions. Also, the effect of using very dry biomass compared to humid biomass was not yet analyzed. In the next years, more precise data and production guidelines can be expected and will be used to update the suggested CH_4-copensation method. In the meantime, we are confident that using the average CH_4 emission value accounts reliably for the climate forcing that has to be compensated.

12.1 The principle of methane compensation by negative emissions

Unfortunately, there is no technology ready to directly remove methane from the atmosphere (Jackson et al., 2019). Equally, no method is available to accelerate methane elimination in the atmosphere. Thus, to balance the global warming effect of a given methane emission, another greenhouse gas such as CO_2 could be removed from the atmosphere (i.e., carbon dioxide removal – CDR). The principal of methane compensation is to create a climate cooling effect equal to the climate warming effect of the emission during a defined period of time.

As the climate warming effect of methane over a period of 20 years is 86 times higher than the effect of the same amount of CO_2, 86 times more CO_2 must be removed from the atmosphere for those 20 years. Due to the limited lifetime of methane in the atmosphere (< 20 y), there is no need for a long-term carbon sink such as biochar that sequesters carbon for many centuries. Instead, carbon sinks such as the first 20 years of a growing tree can be accounted for as a short-term carbon sink to compensate for the equally short-term climate warming effect of methane emissions.

Considering the urgency of limiting radiative forcing and climate warming until 2050, the compensation of methane emissions that occur once as a single pulse (running a Kon-Tiki for 2-3 h) needs to be performed within a short time frame. **Therefore, methane emissions occurring during biochar production must be fully compensated within 20 years after emission.** This period was chosen to use the widely acknowledged GWP20 of methane with a value of 86 t CO_2eq t^{-1} CH_4 (IPCC 2022) and to account for average 20y-tree growth as climate cooling activity compensating methane emissions.

Trees grow over an extended period and slowly build up a natural C-sink. The C-sink is thus accumulative, i.e., the climate effect of a tree in the first, second, third…, twenties year sums up to the accumulative effect. In the first year, the very small tree extracts only a tiny amount of CO_2 from the atmosphere, in the fifth year the extraction amount is already substantial, in the 20^{th} year it is a multiple of the fifth year's amount. The climate cooling effect is thus the highest towards the end of the 20-years period, while in the case of a methane emission, the global warming effect is highest in the first years after the emission because the atmospheric decomposition of methane is fastest in the beginning and slows down towards the end of the fifteenth year when eventually all CH_4-molecules of the emission decayed to CO_2 and H_2O. To balance the one-time methane emission with the accumulative C-sink of a growing tree, the effect of the methane emission and the C-sink are both converted into an amount of CO_2 (CO_2eq) that enable the calculation of the equivalent climate forcing (warming or cooling) during the convened time horizon. To calculate the climate cooling effect of a nature-based solution like a growing tree, we do not consider the carbon removal at the end of the selected period, but the **average annual C-sink in t CO_2eq** over the entire period under consideration.

Calculating the climate warming effect of a CH_4-emission as done by the IPCC with the GWP20, and then calculating the climate cooling effect of an incremental CO_2 removal from the atmosphere over the same 20 years, allows to establish a balance of the two effects at the end of the 20 years. Using this method, it can be determined how many of what type of trees are necessary to grow over 20 years to compensate or annul the climate warming effect of a given methane emission. The necessary metric and calculations are defined as follows:

> *The climate warming effect of an GHG emission and the climate cooling effect of a GHG removal from the atmosphere is given by the cumulative radiative forcing over a given short-term time horizon (< 50 years) of a unit mass of GHG released to or removed from the atmosphere. The unit of the accumulated climate warming effect over a given period of time is ton-years (t CO_2 * y) and is used to generate equivalency factors between emissions of different GHGs as well as between GHG emissions and carbon sinks. The annual average of the climate warming and cooling effect is given in CO_2eq and is convertible to the time dependent GWP (e.g., GWP20 or GWP100 which are the annual averages of the climate warming effect during the years written right of the GWPxx).*
> *Methane compensation within Global Artisan C-Sink is defined as creating a* ***carbon sink for 20 years that*** *has a climate cooling effect equal to the climate warming effect of a methane emission over the same 20 years after the emission occurred.*

The global warming caused by the one-time methane emission is considered compensated by the equivalent 20-year C-sink as only a minor global warming effect of the methane-borne H_2O persists after those 20 years.
The methane compensation concept defined here is a robust and scientifically reliable tool to enable the C-sink economy to implement pyrogenic carbon capture and storage (PyCCS) using the Kon-Tiki and similar low-tech pyrolysis methods. Nevertheless, it is subject to further fundamental scientific work on offsetting methane emissions with short-term C-sinks and details of the calculation method might be adjusted in the coming years.

12.2 Compensation of methane emissions by growing additional biomass

To compensate methane emissions, the Global Artisan C-Sink accepts the plantation of trees to create forest gardens on fallow land, silvo-pastures on pastures, agroforestry on annual and perennial crop land, re- and afforestation. Replacing existing older trees in a tree-crop or forest garden cultivation cannot be accounted for methane compensation. However, the active management of natural regeneration of eroded, deforested steppe land where natural regrowth of trees is promoted through measures such as scrub removal, weeding, irrigation, pruning, etc. can equally be accepted for methane compensation.

Young natural sprouting or newly planted trees grow slowly in the first five or so years and continuously increase the annual growth rate for the next twenty to thirty years, depending on the tree species, the soil, and climate. For most tropical trees, the growth rate follows an exponential function over the first 20 years (see figure 1). The tree's extraction of CO_2 from the atmosphere follows the growth rate and underlies the same exponential function. If methane emissions are compensated by newly planted trees over 20 years, as suggested above, the amount of compensated CO_2eq is not the amount of carbon accumulated at the end of the 20th year (the yellow square in figure 1) but the incremental effect of each years CO_2-extraction. To compensate for the effect that the methane emission has on global warming, we need to calculate the tree's impact on global cooling, which means estimating the effect of CO_2 extracted from the atmosphere every year and summing up every year's effect over the 20 years. In the first five years, the climate effect is minimal, and then it increases rapidly every year.

To demonstrate the calculation, we choose a *Michelia champaca* tree planted in the tropics with sufficient precipitation and average soil quality. The tree grows quickly and will reach after twenty years the capacity to remove annually 1.3 t CO_2 from the atmosphere. However, as the CO_2-removal capacity of the tree is much lower in the preceding years, the tree's average CO_2-removal (climate cooling effect) over those 20 years is only 0.38 t CO_2. This is calculated as follows (Fig. 1):

- The growth of the tree is described by the exponential function: $f(x) = 0.04664 * e^{0.1676*x}$
- Integrating year 0 to year 20 of the tree's growth function (dark green area in Fig. 1) shows that the *Michelia champaca* tree removes $\int_0^{20} 0.04664 * e^{0.1676*x}\ dx$ = 7.67 t CO_2 * y. The result is given in ton-years.
- The annual average C-sink for 20 years which equals the climate cooling effect during this time horizon is calculated by dividing the total amount of CO_2 ton-years by the envisage time horizon of the tree's growth, i.e., 20 years in our example: 7.67 t CO_2 * y / 20 y = 0.38 t CO_2
- The methane emission of the Kon-Tiki (30 kg CH_4 per ton of biochar) has to be converted into CO_2eq using the GWP20, i.e., multiplying it with the factor 86 t CO_2 per t CH_4 which results in (30 kg * 86 t CO_2 t^{-1} CH_4 =) 2.58 t CO_2.
- To compensate the climate warming effect of the methane, produced during the production of one ton of biochar, (2.58 t CO2 / 0.38 t CO_2 = 6.79), seven Michelia champaca trees need to be planted and maintained at a healthy growth for 20 years.
- Further climate relevant effects of the tree such as change in albedo, evapotranspiration, and increase in soil organic carbon is not considered here.

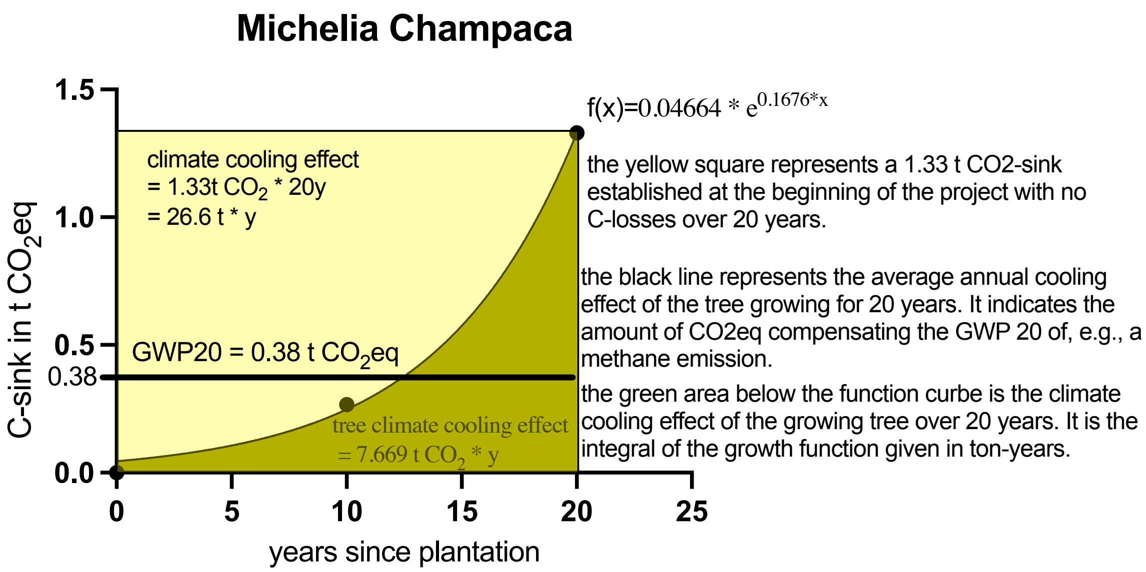

Figure 1: Climate cooling effect of a Michelia Champaca tree growing for 20 years. The GWP20-line refers to the annual averaged carbon sink over 20 years, i.e., the integral of the growth curve (0-20 years, dark green) divided by 20 years.

The Ithaka Institute develops an open-access database collecting the growth curves and corresponding sequestration functions and annual average C-sinks over the first twenty years since the plantation. Depending on the tree species used in the methane compensation plantations, the actual climate cooling effect over 20 years since the plantation must be calculated by the C-Sink Manager and submitted to Carbon Standard International for verification.

Example of a methane compensation using cinnamon tree (Fig. 2) and bamboo (Fig. 3) plantations:

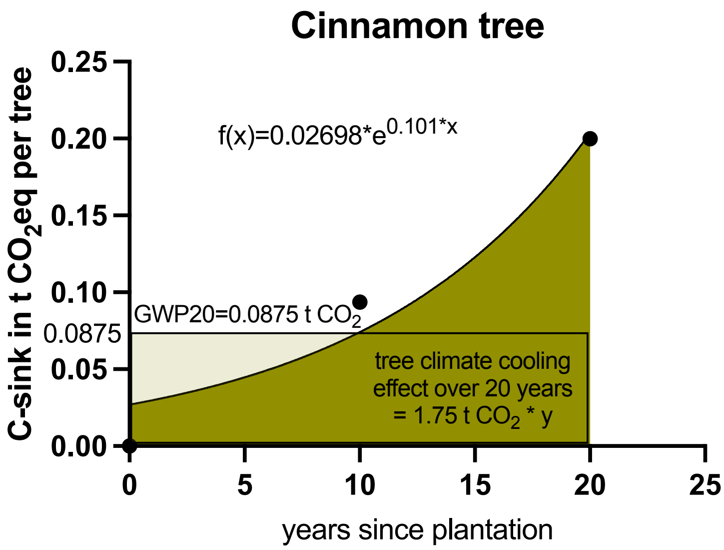

Figure 2: The function of the climate cooling of a cinnamon tree over the first 20 years after plantation. The GWP20 refers to the time-weighted averaged carbon sink over 20 years, i.e., the integral of the growth curve (0-20 years, dark green) divided by 20 years.

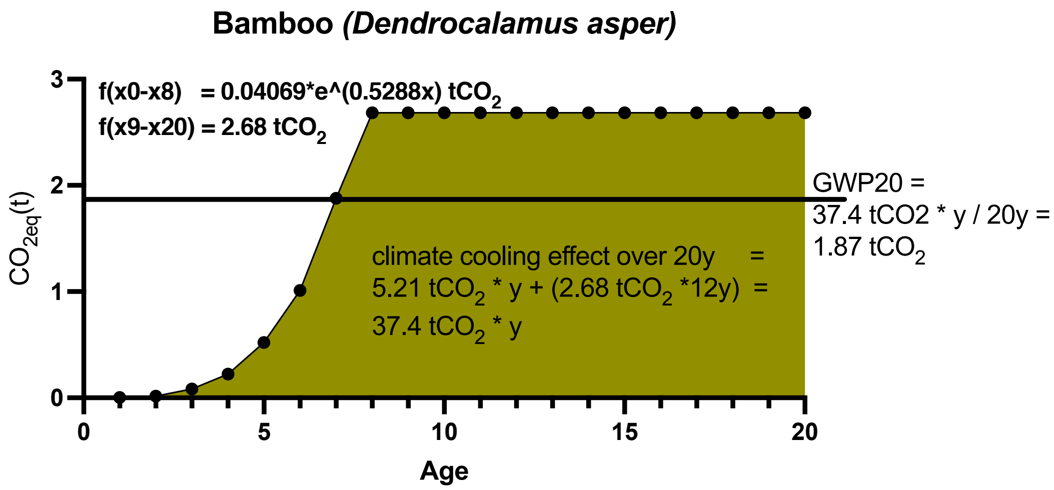

Figure 3: Climate cooling effect of a fast-growing tropical Bamboo plant that grows exponentially over the first eight years and maintains thereafter its atmospheric carbon accumulation at a stable rate.

Assuming a 1 m^3 Kon-Tiki produces 820 l of biochar from pruning wood. The biochar has a density of 190 kg m^{-3}. The dry weight of biochar would thus be (0.82 m^3 * 190 kg m^{-3} =) 156 kg. At 30 kg CH_4 t^{-1} biochar, the Kon-Tiki would produce (30 kg * 0.156 t =) 4.67 kg CH_4 which equals (4.67 kg CH_4 * 86 t CO_2eq t^{-1} CH_4 =) 402 kg CO_2eq as converted with the GWP20.
A twenty-year-old cinnamon tree creates a climate cooling effect with an annual average 88 kg CO_2 for 20 years. To compensate for the CH_4-emissions of one Kon-Tiki producing 820 l biochar (402 kg CO_2eq / 88 kg CO_2eq =), 4.6 Cinnamon trees would have to be planted and maintained growing for 20 years. As *Michelia champaca* trees accumulate more carbon and have a climate cooling effect of 380 kg CO_2e over 20 years, only about one *Michelia champaca* tree (402 kg CO_2eq / 380 kg CO_2eq = 1.06) would have to be planted to compensate for the methane emission.
All trees planted to compensate for methane emissions must be registered, and the tree growth should be controlled at least every five years by the C-Sink Manager. The farmers have to sign a declaration of honor that they care for the compensation trees for at least 20 years and that they replace all trees that die or suffer from growth difficulties. C-Sink Managers must establish detailed rules, adapted to local conditions, that take into account the respective cultivation practices and are based on a risk analysis on possible partial or total loss of trees (e.g., prolonged drought, fire). These rules shall comprise a local selection of tree species, tree cultivation practices, biodiversity guidelines and the monitoring, reporting and verification of biomass growth. The establishement of agro-foresty is encouraged.

After the compensation period of 20 years, the trees can be used without any further restrictions, i.e., the carbon contained in the tree can be assessed as carbon removal. If, for example, the tree is cut after the 20 years and the trunk is used as a beam in a building, the beam-carbon could be considered a C-sink for as long as the beam stays in place.

A proper guideline for the tree plantation and monitoring is in preparation. In the meantime, the C-Sink Manager must submit the plantation plan and monitoring program to Carbon Standard International for approval.

12.3 Avoiding GHG-emissions from burning crop residues

In many tropical countries, crop residues are burnt directly in the fields. While it has some positive effects on farming (ash fertilization, some pyrogenic carbon, elimination of pests), emissions of such practices are massive. Besides significant emissions of particulate matter that cause smog (the main reason for air pollution, e.g., in Delhi (Shyamsundar et al., 2019), methane and carbon monoxide emissions are very high due to the uncontrolled combustion of mostly wet or humid residues (Lin and Begho, 2022).

Based on the published data summarized below, it is assumed that the overall climate impact of pyrolysis within Global Artisan C-sink is in any case not worse than direct burning of crop residues in the field. Therefore, abandoning crop residue burning can be accounted as an offset for emissions of Kon-Tiki-pyrolysis within the limits specified below and in chapter 12.5.

Today, there are only few scientific publications about emissions from the Kon-Tiki and from crop burning in open fields. Both, crop residue burning and the Kon-Tiki release particulate matter, carbon monoxide, nitrogen oxides (NO_x), methane, and some other gases to the atmosphere. While the effect of methane on climate warming can be stated with certainty, the climate effect of those other gases is less clear, and the IPCC does not provide a global warming potential for conversion into CO_2eq.

It is technically challenging to measure methane emissions from crop waste burning in open fields. The few available data include data from airplane sampling, remote sensing, and small-scale lab trials, which do not allow precisely relating the emissions to the amount of burnt crop waste. Based on a review of 20 emission studies, the burning of agricultural residues causes 5.7±6.0 kg of methane emissions per ton of feedstock (Andreae, 2019), which is similar compared to the data measured for the biochar production in a Kon-Tiki (Cornelissen et al., 2016). 30 kg methane per ton of biochar corresponds to 4.2±1.2 kg methane per ton feedstock considering typical Kon-Tiki biochar yields of 14±3% of feedstock dry matter (Karananidi et al., 2020).

However, the pyrolysis of agricultural residues in a Kon-Tiki system emits seven times less CO, four times less particulate matter, and 33 times less NO_x (Andreae, 2019; Cornelissen et al., 2016). Treating agricultural residues with a Kon-Tiki significantly reduces the environmental burden of crop residue burning and does not increase total GHG emissions. Carbon monoxide is not a greenhouse gas, but its emission contributes to ozone changes in the troposphere and slows down atmospheric methane degradation (Prather, 1996; Prather et al., 2012). Carbon monoxide, NO_x, and particulate matter, reduce air quality and contribute to respiratory diseases.

Thus, despite complex atmospheric physics and chemistry and very limited data, replacing crop residue burning with pyrolysis in a Kon-Tiki is a sound approach to contribute to climate change mitigation and improvement of air quality that should be promoted by accounting this measure as an offset for greenhouse gas emissions occurring during Kon-Tiki pyrolysis. Changing agricultural habits is always tricky and switching from burning the fields to pyrolyzing the residues is not a slight change of tradition. To perpetuate the abandonment of field burning (including crop residue burning, gras and stubble burning), farmers must sign a declaration of honor to not burn harvest residues anymore. The exact wording of this declaration of honor must be defined by the C-Sink Manager depending on the prevailing tradition of crop waste treatment in the region. The C-Sink Manager must define separate control mechanisms for compliance with the declaration of honor. Only when the farmer or farming company or organization signed the declaration, the compensation of Kon-Tiki emissions by avoiding field burning emissions can be accepted for a limited time horizon of 10 years (see chapter 12.5). **If a farmer or farming company or organization recommences burning one of its fields, they lose the entitlement to generate C-sink certificates with Kon-Tiki pyrolysis on their land.**

During a transition phase of maximal three years, farmers may stop crop residue burning in some of their fields and continue the traditional practice in other clearly separated fields. We allow such a transition phase to facilitate the decision-making process as it is never easy to change a traditional practice. The transition phase needs to be clearly documented though.

12.4 Avoiding GHG-emission from biomass decomposition

When biomass is pyrolyzed that otherwise would decompose uncontrolled, the avoided emissions from biomass decomposition can equally be used to compensate for CH_4 emissions of the Kon-Tiki. Examples are cocoa pods, sawdust from sawmills, pulp from coffee, oil palm residues, and sugar cane filter cake. Uncontrolled decomposition, especially in the humid tropics, can cause significant methane emissions in the same or higher range than CH_4 emissions during Kon-Tiki pyrolysis. However, data allowing the calculation of emission factors is scarce and not all crop residues left in the fields or at production sites cause methane emissions, and there are plenty of other methods to avoid methane emissions from uncontrolled decomposition. Spreading the biomass on the soil exposed to sunlight for drying and aeration to prevent anoxic conditions is equally efficient. However, in many cases, the tradition of leaving crop residuals or processing waste carelessly behind is so strong that it needs strong incentives to change the habits. In such situations, the compensation of methane emission from the Kon-Tiki with the avoidance of uncontrolled biomass decomposition can be accepted.

If avoided emissions from biomass decomposition can be accepted for methane compensation, must be decided case by case by Carbon Standards International. A flowchart of the current practice has to be submitted by the C-Sink Manager for evaluation. A well-founded estimate of current methane emissions can be submitted to support the proposal. If accepted by CSI, the contracted farmer must sign a declaration of honor to stop the uncontrolled decomposition of crop residues in the fields cultivated by him. The exact wording of this declaration of honor must be defined by the C-Sink Manager. A written form with original signature is mandatory. The C-Sink Manager must define separate control mechanisms for compliance with the declaration of honor. **If a farmer recommences to leave crop residues in his fields decomposing uncontrolled, he loses the entitlement to generate C-sink certificates with Kon-Tiki pyrolysis compensated by emission avoidance.** Mulching with crop residues is not considered as uncontrolled decomposition nor is composting or anaerobic digestion.

12.5 Time horizon for methane compensation by emission avoidance

Compensation of methane emissions with avoided emissions from crop residue burning (chapter 12.3) or decomposition (chapter 12.4) requires a "reference scenario" in which crop residues are burned and/or biomass is subject to uncontrolled decomposition. As avoided emissions cannot be measured physically, their benefit to the climate solely depends on socio-economic assumptions. Still, they are a useful tool to stop unsustainable practices.

In this context, Global Artisan C-sink defines a time horizon of 10 years after the first issuance of a Biochar Artisan C-sink certificate. After these 10 years the new practice is considered common practice and cannot be used to compensate the climate warming of any emissions anymore. By then, methane emissions can only be compensated through the removal of CO_2, e.g., via the plantation of trees. The time horizon must be included in the contract between the C-Sink Manager and the farmer, farming company, or organization. It must also be part of the declaration of honour.

13 Margin of Security and calculation of the carbon sink potential

The carbon sink potential is defined in EBC-Guidelines for the Certification of Biochar Based Carbon Sinks (EBC 2020) as follows:

> *The C-sink potential of a packaging unit of biochar is defined as the amount of carbon it contains minus the carbon expenditure of its production, i.e., all GHG- emissions caused by its production. It thus includes the complete carbon footprint of the biochar at the factory gate, i.e., when it leaves the production site.*

As the biochar production in Kon-Tiki kilns does not consume any electricity or fuel, the carbon footprint of the biochar production with this technology is very low. However, the occurrence of some minor emissions is possible. This could be the fuel for transportation of the biomass feedstock to the kiln or of the biochar to the field, displacement of the kiln, a pump for quenching water, fuel for a chain saw for pruning, milling, and blending of the biochar, and/or application to the soil. In some cases, none of those operations cause GHG emissions because everything is executed manually; in most cases, however, some of those emissions occur. To keep the certification procedures reasonably lean, artisan biochar producers are not required to provide a detailed account of these potential emissions, but a safety margin of 3% of the C content of the biochar is levied. However, if a biochar producing company or network prefers to calculate exactly the carbon footprint of the production and if this calculation is verified and approved by CSI, the more exact carbon footprint can be provided on the certificate though it does not replace the 3% margin that covers all sorts of further uncertainties.

If a farmer produces e.g., 800 l of biochar with a density of 0.19 t m^{-3} and a C-content of 75% according to the Artisan biochar database, the margin would be (0.8 m3 * 0.19 t m^{-3} * 75% C * 3% margin * 44/12 =) 21 kg CO_2eq. The safety margin is calculated or rounded to the nearest whole kg CO_2eq. This margin equals the consumption of (21 kg CO_2e / 3.2 kg CO_2eq per l diesel =) 6.5 l diesel which is largely sufficient to account for the possible handling of about one ton of biomass and (0.8 m3 * 190 kg m^{-3}=) 0.15 t biochar. The amount of biochar is calculated in tons of dry matter and given with two decimal places, i.e., to the nearest 10 kg, and thus used in further calculations. The carbon sink potential of one ton of biochar (dry matter) with a C-content of 75% is (1,00 t* 75% C * (100% - 3% margin) * 44/12 =) 2.67 t CO_2e t^{-1}. The included margin is 83 kg CO_2e. The carbon sink potential is calculated in tons CO_2e per ton dry matter biochar and given with two decimal places, i.e., to the nearest 10 kg, and thus used in further calculations.

14 Carbon persistence and calculation of the final carbon sink

Biochar-based carbon sinks differ from natural carbon sinks like afforestation and soil organic matter in presenting a very persistent carbon pool once the biochar is applied to soil or other such materials that prevent the biochar from burning. A total loss of a biochar-based C-sink in soil is practically impossible. Still, biochar will slowly degrade when applied to soil which can be calculated with a generally applicable degradation formula. Biochar consists of a labile carbon pool that degrades within the first century after soil application and a persistent carbon pool that will stay for several centuries to millenaries in soil or sediments. Depending on the properties of biochar (mainly on the H/C ratio) the persistent carbon pool is smaller or larger (Bowring et al., 2020, 2022; Zimmerman and Gao, 2013). The range of the persistent carbon pool is likely between 60 and 95% of the carbon content of the biochar. Today, however, there is no widely accepted analytical method to distinguish between the labile and persistent carbon pool in biochar. For this reason, the persistent fraction can only be assumed by a conservative approach based on experimental data.

If biochar is applied directly to soils or indirectly into agricultural soils via its use in animal feed, livestock bedding, slurry management, compost, or anaerobic digesters, we assume a conservative average degradation rate of 26% over the first 100 years for Kon-Tiki made biochars presenting an HTT > 650°C with an H/C ratio below 0.4 (following: Budai et al., 2013; Camps-Arbestain et al., 2015). If the Artisan biochar producer follows the procedures as learned during the trainings, the pyrolysis temperatures are consistently higher than 650°C and thus the H/C-ratio is below 0.4. There is no need for C-Sink Farmers to analyze the H/C-ratio of his biochar. However, due to the larger quantities, Artisan Pro biochar must be analyzed for its H/C-ratio.

100 years after soil application, 74% of the original carbon in biochar could still be accounted for as sequestered carbon. When C-sinks are sold to compensate CO_2-emissions that have a very long mean residence time in the atmosphere, it is, therefore, recommended to trade as C-sink certificate only that part of a carbon sink that is persistent for more than 100 years (C_{100} = 74%). The part of the biochar carbon that is persistent for less than 100 years (i.e., the 26%) can be considered as short-term carbon sink with a mean residence time below 50 years and used, e.g., for C-sink portfolios or for the compensation of CH_4-emissions.

The 100-years degradation rate of 26% is based on the most conservative metanalytical estimate for biochar carbon degradation published to date. Other sources determined significantly lower degradation rates depending on the degree of pyrolysis and the experimental design (IPCC, 2019; Kuzyakov et al., 2014; Lehmann et al., 2015; Woolf et al., 2021; Zimmerman and Gao, 2013). The time horizon of 100 years was chosen because it is common in assessing Negative Emission Technologies. The assumed rate of decomposition is very conservative. However, in the absence of more reliable methods and long-term field experiments, it is appropriate to use these conservative projections and calculate the climate-relevant effect of C sinks with a sufficient safety margin.

We expect to publish the latest analytical methods to distinguish between the labile and persistent carbon pool of biochar by 2023. This new method will most likely correct the currently used rate of carbon persistency at the 100-year time horizon (C_{100} = 74%). If the biochar carbon sink is geo-localized, the expected increase of the 100-year persistency rate can be applied retroactively and farmers could retroactively receive a bonus payment.

When applied to soil, the persistence factor of 74% must be included to calculate the carbon sink value which can then be traded as C-sink certificate. In the previous chapter we calculated the carbon sink potential of 1 t biochar with a C-content of 75% as (1.00 t* 75% C * (100% - 3% margin) * 44/12 =) 2.67 t CO_2e t^{-1}. When this biochar is applied to soil, the carbon sink value be calculated as (2.67 t CO_2eq * 74% persistence over 100 years =) 1.97 t CO_2eq. The potential emissions for transporting of biochar to the field site, milling, blending with other substrates, and application are included in the 3% margin. However, when the transport distance from the production site to the final field site exceeds 100 km, the transport emissions have to be subtracted from the carbon sink value of the biochar.

15 How to prepare the analytical and retention samples

15.1 Analytical samples

If the biochar feedstock is already listed in the Artisan biochar database and if the annual production does not exceed 100 m^3, no retention and analytical samples are required. The technology of flame curtain pyrolysis allows the production of biochar with rather constant properties when the same type of feedstock is used. The main parameters influencing the biochar properties in Kon-Tiki type kilns when using the same feedstock are the water content of the feedstock and the craft of the artisan biochar producer. For this reason, particular attention is paid to the education of the artisan biochar producers and the pre-drying of the feedstock, especially during the rainy seasons.

If the feedstock or feedstock mixture is not listed in the Artisan biochar database, a biochar sample must be sent to an accredited laboratory (see chapter 16) to analyze at least the carbon content and include it in the Artisan biochar database according to the following protocol:

1. After biochar production, the entire Kon-Tiki needs to be emptied on a clean floor to take a sample.
2. To obtain a biochar sample sufficiently representative for the production load, the biochar needs to be shovelled two times from one pile to another pile.
3. Take then 12 samples of about three litres at twelve different pile spots. Put all 12 subsamples in a bucket or vat or pile them again on a clean floor.
4. Mix the biochar of the 12 subsamples thoroughly and take then three litre and seal it in a clean airtight bag to be sent to the laboratory.

Ideally, the sampling would be done by an accredited third-party sample taker.

15.2 Retention sample for Artisan Pro producers

Artisan Pro certified producers with a production capacity of more than 100 m3 biochar per year must take retention samples according to the following protocol:

1. Biochar samples are taken from each production load made with a Kon-Tiki type kiln.
2. Take four samples at four different spots of each Kon-Tiki load (middle, lower third, upper third, top of the kiln) using a sample cup of at least 100 ml.
3. If the feedstock does not vary by more than 20%, the retention samples from different loads and different kilns of the same production site can be united in the same closable container or vat for a maximum of six months. After six months the sample container or vat must be sealed and a new sample container or vat for the next series of retention samples started.
4. The sealed six-month sample container must be stored for at least 24 months.
5. At least once a year, an accredited sampler from the C-Sink Manager will take a representative sample from the six-month sample container and send it to an accredited laboratory for analysis.

6. The samples are analyzed according to the specifications of the European Biochar Certificate (EBC Version 10.1, 2012) for the following parameters: C, H, ash, pH, water holding capacity.
7. The data generated by the accredited analysis are used to certify the biochar quality and to calculate the C sink.

16 Analyses and accreditation of local laboratories

To accredit a local laboratory for the analysis of the carbon content of biochar, Ithaka will send two fully EBC analyzed standard biochar samples to the new laboratory for the analysis of C-content. The difference between the results of the new laboratory and the accredited laboratory must not exceed 6% for each respective biochar.

To accredit laboratories who analyse biochar for Artisan Pro, the above procedure must be followed for the parameters: C, H/C, ash, pH, and water holding capacity.

Laboratories are invited to participate in the official EBC interlaboratory ring trial organized every year. Passing the EBC proficiency test allows CSI to accredit the laboratory for the corresponding parameter of biochar analysis.

17 Trading and labelling of biochar

A biochar trader buys biochar from C-sink farmers, C-sink farmer networks, and/or Artisan Pro producers. He may process the biochar into biochar-based products and sell those or the pure biochar to farmers or industries (e.g., for construction materials). The traders must be certified under Global Artisan C-Sink and are not allowed to trade biochar that is not certified under Global Artisan C-Sink.

If a farmer or company produces biochar and sells it to other farmers or users, the buyer must also use the Artisan App to document and track the application to soil, compost, anaerobic digestor, or its use in animal farming systems or in any other way that preserves predictably the biochar carbon. Otherwise, the biochar cannot be certified as a carbon sink. With that level of security, it is the same as if the artisan biochar producer would have applied the biochar him/herself.

If the biochar is sold to a biochar trader, the trader must be registered and monitored by the C-Sink Manager to assure the complete tracking of the traded biochar to the eventual carbon sink. Otherwise, the biochar cannot be certified as a carbon sink.

International trade is not allowed within Global Artisan C-sink. For biochar that shall be traded across borders, the guidelines for industrial biochar production apply (EBC 2012, EBC 2020). An exception may be granted in border regions with cross-border movement of goods.

Traded biochar must be labeled containing the name and address of the trader, the feedstock the biochar was made from, the C-content, and the year of production.

18 Accreditation and Certification of the C-Sink Manager

The accreditation process contains a full application review by Carbon Standards International (in general, this implies several review rounds and may include consulting by the Ithaka Institute, and or other experienced C-Sink Managers). After being trained and accredited by Carbon Standards International, C-Sink Managers are certified by the following steps:

1. Online application for certification
2. Pre-audit interview
3. The C-Sink Manager fills in a template prepared by the certifier called “Monitoring Plan” in which he describes the measures he applies to make sure that the members of the farmer network comply with the requirements of the Artisan Standard.
4. Review of the Monitoring Plan by the certifier. Feedback to the C-Sink Manager and “corrective action loop” in case of missing or incorrect procedures.
5. On-site audit by the certifier. Definition of non-compliances and corrective actions
6. If applicable: Implementation of corrective actions by the C-Sink Manager
7. Certification decision by the certifier

Companies, non-governmental organizations, farmer unions or regional authorities may become C-Sink Manager for the Global Artisan C-sink certificate. The purpose of the pre-audit interview (online video meeting) is to clarify expectations and discuss the upcoming certification process. The ”Monitoring Plan” includes at least the following chapters:

a. Description of the applicant (type of organization, already existing local structures, etc.)
b. Scope of the activities (definition of the region, type of farming, if the activities are restricted or at least focused on farming, especially when focused on special crops or industries, e.g., coffee, cocoa, oil palm, sugar cane, etc.)
c. C-sink registry (written documentation of the local registries’ architecture including back-up and IT security, protocol for data transfer to the CSI C-sink register)
d. Biochar artisan training program, including train-the-trainers approach
e. Biochar artisan payment scheme (when, how, and at what rate the c-sink money is paid to whom)

f. Procedures for the on-site control and monitoring strategy (i.e., type and frequency of monitoring, how to measure its effectiveness, etc.)

Infrastructure and procedures to assure that biochar samples are taken correctly and reach the accredited laboratory in proper conditions.

The C-Sink Manager can delegate defined tasks of the managing and monitoring process to other organizations or persons, such as the training of making biochar, C-sink tracking, and on-site controls. However, the C-Sink Manager is entirely responsible for all activities related to the production, monitoring, and declaration of Global Artisan C-Sinks as described in the present guidelines.

19 Additionality

Despite being a century-old tradition in some parts of the world (Wiedner and Glaser, 2015), the production and application of artisanal biochar are not widespread in most tropical countries. Artisanal biochar producers do not generate income yet with biochar in most regions, there is no market for biochar-based fertilizers, and the production costs are higher than the expected agronomic benefit, or tropical smallholder farmers do not have the financial resources to pay biochar-based fertilizers. Farmers could produce their biochar from their feedstock to improve their yields, but without the training provided by the C-Sink Manager, they would hardly acquire the craft to do so.

The Global Artisan C-sink will, thus, be the decisive monetary incentive and knowledge transfer to produce climate positive biochar and thus carbon sinks. The C-Sink Manager will provide not only training on biochar production but also on the preparation and application of biochar-based fertilizers, which (a) will enable most farmers to establish this practice and (b) will avoid the adoption of unsustainable biochar production practices which could result in pollution and GHG-emissions. Moreover, methane compensation, as introduced by the Global Artisan C-sink is a key element to achieving net negative emissions with Kon-Tiki based PyCCS.

Artisan Pro will mainly sell their biochar, and one might argue that selling the biochar could fund this practice alone. However, without the income from C-sink certificates, the price for biochar would be too high to establish local markets. Moreover, Global Artisan C-sink assures the adoption of low-emission technology, methane compensation, and the use of sustainably sourced biomass. Without those boundary conditions, biochar production in countries with low purchasing power and limited financial and technical possibilities would hardly result in net negative emissions. Hence, additionality of any C-sink certificates issued under this standard is guaranteed.

20 Exclusivity

The demand for negative emissions and the generally high potential to generate negative emissions in the tropics with nature-based solutions will create numerous methodologies for certification, e.g., biomass carbon capture and use (BCCU) and soil organic carbon. Moreover, there are existing schemes for afforestation and reforestation. All approaches differ in permanence and risks of a partial or total loss of the carbon sink.

In general, farmers and biochar producers benefitting from Global Artisan C-Sink shall not be certified under any other methodology for nature-based climate services (i.e., biomass production and soil organic carbon). This needs to be assessed and controlled by the C-Sink Manager.

Biochar application will increase soil organic carbon as a co-benefit. However, a routine soil analysis cannot distinguish soil organic matter and biochar-derived carbon. It is, thus, not possible to measure soil organic carbon increases without an accurate assessment of the applied biochar, and it is, therefore, not permitted to create a C-sink certificate for soil organic carbon on the fields registered for Global Artisan C-Sink. Within Global Artisan C-Sink, increases in soil organic carbon are looked at as a co-benefit, and additionality is thus not given. The time horizon must be included in the contract between the C-Sink Manager and the farmer, farming company, or organization. It must also be part of the declaration of honor.

Planting trees to compensate for methane emissions could interfere with additional afforestation or reforestation programs. It might result in double accounting, which must be prevented through explicit registration of all cultivated land. Exceptions to the exclusivity rule are, therefore, possible if the C-Sink Manager can explain why an additional C-sink certification for a nature-based solution is meaningful and how double accounting is efficiently prevented. An example is a certification of a newly planted bamboo forest that is not used for methane compensation.

CSI must explicitly permit all exceptions.

21 Closing remark

Several finicking points and exceptions that cannot be addressed in the general guidelines with sufficient detail remain and will be solved in annexes and updates according to practical needs.

The Kon-Tiki is only seen as a bridge technology and should as soon as possible be replaced by pyrolysis technology with better control of pyrolysis gas combustion and uses of biomass energy in the form of heat/cold and electricity or as pyrolysis oil (Schmidt et al., 2019).

22 Literature

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