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Review of Biochar Standards: Can Biochar Contribute to Net Zero?

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Luka Štrubelj and Dr Sue Rodway-Dyer

About the authors

Luka Štrubelj is Research Fellow in Environmental Law at CO_2RE, based at the Faculty of Law, University of Oxford.

Dr Sue Rodway-Dyer is Senior Research Fellow on Monitoring, Reporting and Verification at CO_2RE, based at the School of Geographical Sciences, University of Bristol.

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Review of Biochar Standards: Can Biochar Contribute to Net Zero?

Biochar can drawdown atmospheric greenhouse gas emissions by sequestering some of the carbon dioxide for centennial or millennial bases. Several standards already exist that seek to certify biochar as a product or as a climate change mitigation method. This report analyses the state of the biochar standards landscape, identifies their alignments and divergences, and highlights gaps where improvements could be introduced.

Abbreviations

BQM	- Biochar Quality Mandate;
EBC	- European Biochar Certificate;
GGR	- Greenhouse gas removal;
GHG	- Greenhouse gas;
$H:C_{org}$	- Hydrogen to organic carbon molar ratio;
IBI	- International Biochar Initiative;
IPCC	- Intergovernmental Panel on Climate Change;
ISO	- International Organisation for Standardisation;
LRWP	- Low risk waste position;
MIR	- Mid-infrared;
MRT	- Mean residence time;
MRV	- Monitoring, reporting, verification;
$O:C_{org}$	- Oxygen to organic carbon molar ratio;
PAC	- Persistent aromatic carbon;
PAH	- Polycyclic aromatic hydrocarbon;
PAH_8	- 8 most carcinogenic polycyclic aromatic hydrocarbons (as recognised by EU Food and Safety Agency);
PAH_{16}	- 16 polycyclic aromatic hydrocarbons (as recognised by US Environment Protection Agency);
PCB	- Polychlorinated biphenyls;
PCDD/Fs	- Dioxins and furans;
PM	- Particulate matter;
PTE	- Potentially toxic element;
PTLAR	- Potential toxicant limiting application rate;
QA	- Quality assurance;
QC	- Quality control;
TGA	- Thermogravimetric analysis;
WBC	- World Biochar Certificate.

Executive summary

The UK is required to reach net zero greenhouse gas (GHG) emissions by 2050. Biochar, a charcoal-like substance, can function as a recalcitrant carbon-rich material which stores carbon that was previously captured from the air by its biomass predecessors, making it a potentially useful climate mitigation tool. Simultaneously, biochar soil application can introduce nutrients to plants and improve soil features, potentially bringing agricultural benefits. Specific biochar-related activities are governed by standards which can be national, regional, or international. The standards are generally privately led and enforced, with some publicly led. They vary regarding the biochar characteristics that they govern, in particular with some limited to appraising biochar as a product as opposed to offering a GHG removal (GGR) service (Table 1). This report reflects the state of biochar certifications before November 2023.

Table 1: Comparison of scope differences between the analysed standards. The table indicates characteristics of their formal (territory, sphere) and substantive scope (feedstock, production, toxicants, quantifying emissions, permanence, soil application MRV). A characteristic gets a ✓ sign if it is within substantive scope of the standard and an ✗ sign if outside of its scope. The table concludes on standards' overarching focus that is deducted from their substantive characteristics (GHG-focused, product-focused standards).

Scope	Puro. earth	Verra	C-Sink	Artisan C-Sink	EBC	WBC	BQM	IBI	EU Regulation
Territory	Inter national	Inter national	Regional	Inter national	Regional	Inter national	National	Regional	Regional
Sphere	Private	Private	Private	Private	Private	Private	Private	Private	Public
Feedstock	✓	✓	✓	✓	✓	✓	✓	✓	✓
Production	✓	✓	✓	✓	✓	✓	✓	✓	✓
Toxicants	✗	✗	✗	✗	✓	✓	✓	✓	✓
Quantifying emissions	✓	✓	✓	✓	✗	✗	(✓)[1]	✗	✗
Permanence	✓	✓	✓	✓	✗	✗	(✓)[1]	✗	✗
Soil application	✓	✓	✓	✓	(✗)[2]	✗	✓	✗	✗
MRV	✓	✓	✓	✓	✓	✓	✓	✓	✓
Focus	**GHG**	**GHG**	**GHG**	**GHG**	**Product**	**Product**	**Product**	**Product**	**Product**

However, biochar standards are aligned in some aspects of governance:

- They allow types of feedstock, in which there is generally less risk for contamination, and some types of domestically collected waste, either separately collected bio waste or biological fraction of mixed solid waste, combined with a limit on contamination.
- Except for requiring treatment of off gases, production parameters are not controlled directly but through biochar output, reporting, and compliance with local and national regulations. They abstain from explicitly including certification of high-carbon ash and putting emission limits on biochar production.
- To tackle environmental hazards of biochar applications, standards require testing for most heavy metals, 16 polycyclic aromatic hydrocarbons as recognised by US Environment Protection Agency (PAH16), dioxins and furans (PCDD/Fs) and polychlorinated biphenyls (PCBs), but range in the allowed limit values, especially for

[1] BQM provides methods to quantify emissions and estimate permanence but uses them to meet specific requirements thus not quantifying them in general.
[2] Limited to the country-specific Annex for Denmark.

heavy metals. In general, they do not require specific tests for certain organic (benzo[e]pyrene and benzo[j]fluoranthene) and inorganic contaminants (Co, B, Cl, Na) as well as for germination inhibition of biochar.

- Standards deduct GHG project emissions from the stable carbon content of biochar, account beyond just biochar production process emissions, and cover biochar production emissions and transport emissions. They do not explicitly account lifecycle stages of manufacture, use, and disposal of each component activity.
- They consider biochar as 'permanent' if the material can withstand 100 years in soil which is most commonly estimated through hydrogen to organic carbon molar ratio ($H:C_{org}$). Other methods of estimating permanence are used less and are encompassed in specific standards only.
- In terms of soil application factors, standards only passively align in factors that they do not consider.
- Monitoring, reporting, and verification (MRV) protocols generally require records management, chain of custody mechanisms, accredited laboratory testing and evidencing biomass supply through sustainable biomass sourcing schemes. GHG-focused standards generally stop monitoring biochar-related activities when acceptable utilisation is reached in which it can be assumed that biochar will avoid combustion.

The biochar standard landscape has several gaps which need addressing to improve confidence in biochar contribution to the UK net zero emissions target. First, quantification of GHG emissions and removals within the standards can be ambiguous and incomplete due to obfuscating system boundaries and GHG emission sources. Overall, the analysed standards neglect GGR baseline assessment, increasing concerns about confounding GGR with avoided emissions. Second, biochar standards focus on biochar production omitting soil application requirements, and even when standards introduced soil application requirements they are generally not monitored. Finally, robustness of data governance procedures diverges substantially between product-focused standards and GHG-focused standards, with the latter being less well equipped to assure high data quality. Namely, GHG-focused standards are predominantly relying on estimates instead of measurements which in several instances abstain from providing any detail regarding testing or GHG emission quantification. Biochar standards, in particular GHG-focused ones, contain few quality assurance (QA) and quality control (QC) safeguards to ensure high quality data governance and are lacking provisions on robust verification of their findings.

Despite these gaps, biochar standards play an important role in facilitating biochar's contribution to the UK net zero emissions target. In absence of a publicly administered approach to biochar that would utilise regulatory mechanisms available to the public authority, these standards act as crucial regulatory enablers, filling the void by providing a standardised way of utilising biochar as a GGR and giving certainty to biochar operators and investors.[3] Furthermore, considering the limits of biochar regulation adopted to date, analysed standards remain the only comprehensive guidelines for environmental protection of biochar production and use. For instance, the Environment Agency's Low Risk Waste Positions (LRWPs) for biochar focus on a narrow and limiting waste framing for biochar. Therefore, it is the analysed standards that offer some confidence to the public as to the environmental integrity of biochar that is input into the UK soil.

Biochar could help support climate change mitigation objectives such as the net zero emissions target whilst offering co-benefits for climate adaptation and agricultural resilience. In order to do so, the UK regulatory frameworks pertaining to biochar must be calibrated in a way to control potentially harmful repercussions of biochar production and deployment and maximise its beneficial characteristics whilst allowing space for its further development. The UK

[3] Department for Energy Security and Net Zero has announced a delivery of a GGR Standard for GGR Business Model funding. Should a strategic decision be taken to support biochar through such funding, then a biochar methodology could be developed therein. Department for Energy Security and Net Zero, 'Greenhouse gas removals (GGR): business model' (HM Government, 20.12.2023) <https://www.gov.uk/government/publications/greenhouse-gas-removals-ggr-business-model> accessed 29.1.2024.

regulators can utilise the significant knowledge base present in existing private governance mechanisms and in foreign jurisdictions such as the EU, upgrading it where needed.

Introduction

The Climate Change Act 2008 requires the net UK carbon account to be “100% lower than the 1990 baseline” by 2050.[4] Reaching the net zero target requires ensuring GHG emissions are diminished. Additionally, in its 2021 Net Zero Strategy, the UK Government recognised the need to deploy GGR to compensate for emissions from hard-to-abate sectors where emissions reductions are particularly challenging, such as agriculture and some forms of transport and industry.[5] It targets the removal of 5 $MtCO_2$ per year by 2030, around 23 $MtCO_2$ by 2035, and projects between 75 and 81 $MtCO_2$ by 2050 through deploying engineered GGRs.[6] The UK Government plans to deliver them with a portfolio-based approach including an array of varying ways of removing GHG from the atmosphere and seawater.[7]

GGR approaches encompass a removal method that is called biochar. A charcoal-like substance that is produced by heating biomass whilst preventing or restricting the flow of oxygen, which in turn, averts biomass from burning.[8] Biochar, when not used for energy production or as a reductant, can function as a recalcitrant carbon-rich material that stores carbon that was previously captured from the air by its biomass predecessors, making it a potentially useful climate mitigation tool (Figure 1). Simultaneously, biochar can introduce nutrients to plants and has the potential to improve soil features when applied to the soil, increasing primary productivity and bringing valuable agricultural benefits.[9]

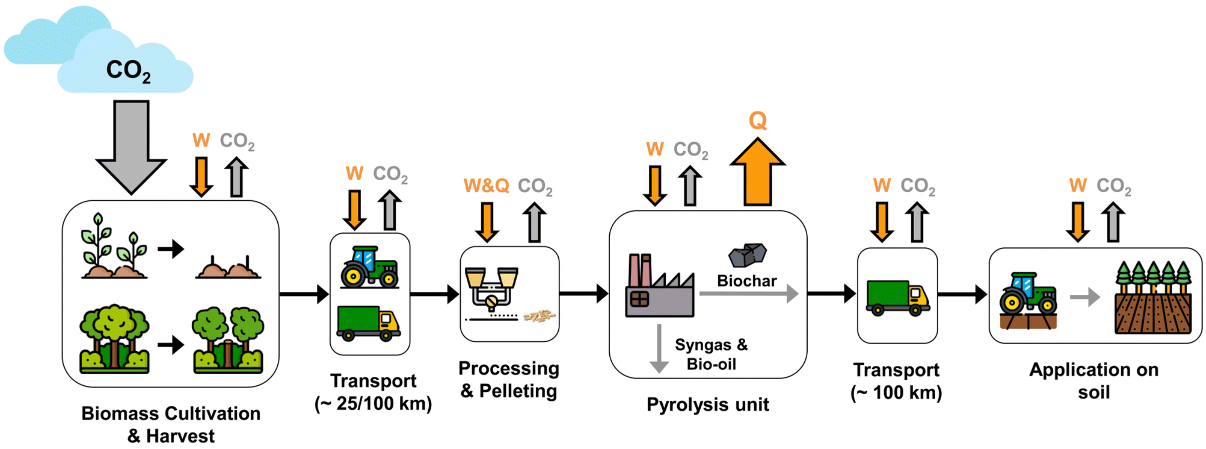

Figure 1: Value chain of biochar starting with biomass cultivation and harvesting, its short-distance transport to the processing plant and pre-treatment of biomass such as drying and pelleting. Biochar is then produced in a pyrolysis or gasification unit together with syngas and bio-oil. Finally, biochar is distributed to a place of application and applied on soil. Grey arrows track the CO_2 and its leakage whilst the yellow arrows follow the energy flow where W stands for power and Q for heat.[10]

[4] Climate Change Act 2008 s 1(1).
[5] HM Government, ‘Net Zero Strategy: Build Back Greener’ (HM Government, 19.10.2021) <https://www.gov.uk/government/publications/net-zero-strategy> accessed 20.10.2023.
[6] Ibid.
[7] Department for Energy Security and Net Zero, ‘Engineered Greenhouse Gas Removals, Government response to the consultation on a GGR Business Model’ (HM Government, June 2023) <https://assets.publishing.service.gov.uk/media/64955096831311000c296222/engineered-ggrs-government-response.pdf> accessed 8.1.2024.
[8] Stephen Michael Ogle and others, ‘Appendix 4 Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development’ in E Calvo Buendia Calvo and others (eds), ‘2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use’ (2019, Intergovernmental Panel on Climate Change).
[9] Jim Hammond and others, 'Biochar field testing in the UK: outcomes and implications for use' (2013) Carbon Management 4 159.
[10] The figure is taken from Solene Chiquier and others, ‘A comparative analysis of the efficiency, timing, and permanence of CO_2 removal pathways’ (2022) Energy Environ Sci 15 4395.

There is considerable interest in the potential of biochar to provide long-term carbon sequestration as well as agricultural benefits. For example, relative to other GGR methods, 91% of all known and realised GGR purchases from the first half of 2023 were delivered by biochar.[11] However, quantification of agricultural and GGR benefits is complex and the properties of biochar – and in turn its carbon stability and environmental impacts – are highly affected by specific factors such as biomass feedstock type and pyrolysis temperature. Robust evidence and suitable regulatory frameworks are required before biochar can confidently be deployed at scale in the UK. This must include robust standards and guidelines to produce safe, sustainable, and high-quality biochar that can deliver stable carbon storage and improved soil health.

This report aims to review the leading international biochar standards to identify alignment and divergence in definitions of safe and high-quality biochar. This will enable policymakers to understand the degree of international consensus on the type of biochar that (1) is safe to deploy from an environmental standpoint and (2) provides stable carbon storage over centennial timescales. Convergence between standards in biochar governance, however, does not necessarily result in practices that are desirable. They can support the formation of a working position on best practices for biochar which in turn may inform future policy, research, and regulation, with a view toward ensuring biochar contributes to the net zero emissions target.

The scope of the review shall cover prominent biochar standards that govern biochar worldwide. These include standardisations and studies for use in the voluntary carbon market and in the agricultural sector that were developed prior to November 2023 when the exploratory mapping was undertaken. The study emanates from data mapping of the standards' governance with regard to seven prominent features of biochar that is destined for soil application: feedstock, production, limits on toxicants, emission measurement, permanence estimations, soil application factors, and MRV.[12] Additionally, the mapping points to private biochar-specific governance structures for other biochar uses, such as in construction-building, long-lived materials, and animal feed but excludes their further analysis to ensure comparability between assessed governance structures. The mapping also considers the approach to biochar carbon sequestration as suggested by Schmidt and others in the 'Permanence of soil applied biochar' paper that was published in advance of the Global Biochar Carbon Sink Certification approach.[13] The paper only comprises an assessment of biochar permanence. Therefore, the mapping considers it solely under the permanence section. The guiding idea behind this review is not finding flaws in any one methodology or standard but rather to create an overarching sense of the state of the art in biochar certification by identifying varying approaches and gaps.

This report is structured as follows. It starts by introducing the existing landscape of biochar standards, their scopes, and interactions. Then the report makes a high-level comparison of these standards, identifying commonalities and divergences. It does so by reference to specific biochar features that were analysed in the mapping and that apply to biochar deployed on the soil. Standards' features are compared in separate sub-sections and their alignments and misalignments are illustratively summarised in the tables at the end of each respective sub-section (Tables 2-8). Comparative assessment then leads to a discussion about current gaps in the standards for ensuring robust and sustainable deployment of biochar. The report concludes by summarising the findings and reflecting upon them in the context of the domestic UK regulatory setting.

Existing biochar standards

Biochar production and application are currently governed by diverse standards ranging in the jurisdiction of application as well as in the nature of the entity standing behind them. These comprise national, international, and

[11] CDR.fyi, CDR.fyi Mid-Year Progress Report (Medium, 9.8.2023) <https://medium.com/@cdr_fyi/cdr-fyi-2023-mid-year-progress-report-656826b7e4cb> accessed 20.10.2023
[12] Appendix I.
[13] Hans-Peter Schmidt and others 'Permanence of soil applied biochar' (The Biochar Journal, 23.12.2022) <https://www.biochar-journal.org/en/ct/109-Permanence-of-soil-applied-biochar> accessed 6.11.2023.

regional standards (Table 1). Mostly, they are privately led and enforced, except for the EU Regulation on fertilising products which is a legislative act adopted by the EU to enable single market access for fertilising products comprising biochar. The Regulation enables compliant biochar products to freely circulate within the single market between different member states. Crucially, existing standards vary greatly regarding the biochar characteristics that they govern. They can broadly be grouped into GHG-focused and product-focused standards.

Table 1: Comparison of scope differences between the analysed standards. The table indicates characteristics of their formal (territory, sphere) and substantive scope (feedstock, production, toxicants, quantifying emissions, permanence, soil application MRV). A substantive characteristic gets a ✓sign if i t is within scope of the standard and a ✗ sign if outside its substantive scope. The table concludes on standards' overarching focus that is deducted from their substantive scope (GHG-focused, product-focused standards).

Scope	Puro. earth	Verra	C-Sink	Artisan C-Sink	EBC	WBC	BQM	IBI	EU Regulation
Territory	Inter national	Inter national	Regional	Inter national	Regional	Inter national	National	Regional	Regional
Sphere	Private	Private	Private	Private	Private	Private	Private	Private	Public
Feedstock	✓	✓	✓	✓	✓	✓	✓	✓	✓
Production	✓	✓	✓	✓	✓	✓	✓	✓	✓
Toxicants	✗	✗	✗	✗	✓	✓	✓	✓	✓
Quantifying emissions	✓	✓	✓	✓	✗	✗	(✓)[1]	✗	✗
Permanence	✓	✓	✓	✓	✗	✗	(✓)[1]	✗	✗
Soil application	✓	✓	✓	✓	(✗)[2]	✗	✓	✗	✗
MRV	✓	✓	✓	✓	✓	✓	✓	✓	✓
Focus	**GHG**	**GHG**	**GHG**	**GHG**	**Product**	**Product**	**Product**	**Product**	**Product**

GHG-Focused Standards

GHG-focused methodologies quantify the effects of biochar deployment on climate change mitigation (Table 1). Besides specifying rules on allowed feedstock materials and outlining some requirements as to biochar production, they focus on quantifying emissions and estimating permanence of removals and they are more likely to consider soil application factors. On the other hand, they avoid stipulating requirements to ensure sufficient wider environmental performance (e.g., pollution prevention by excessive content of toxicants).

These standards, simultaneously, facilitate additional co-benefits provided that they guarantee sufficient robustness of carbon storage. Allowed biochar uses in goods for carbon sequestration span from products that result in biochar ending up in the soil (e.g., greenhouse substrates, fertilisers and feed supplements) to long-lived products that support the recalcitrant nature of biochar such as cement, asphalt, insulation material, and bioplastics. The standards generally take a more cautious approach to the use of biochar in products that may result in the loss of biochar. For example, C-Sink's positive list (and the Artisan C-Sink too) imposes a controlling period spanning their lifetime for materials such as composite, plastics, tissues, and paints, and introduces a larger security margin that is deducted from the carbon storage potential of biochar concerned. Likewise, Puro.earth stipulates that care should be exhibited when the end use of biochar will not result in the incorporation of biochar into a mineral matrix (soil or construction).

GHG-focused standards generally do not prevent the co-application of different GGRs or emission reduction approaches.[14] However, Verra, C-Sink, Artisan C-Sink, restrict biochar application in wetland settings, consequently limiting its application in peatland restoration projects due to uncertainties regarding increased mineralisation of wetland carbon stocks.[15] Moreover, they avoid carbon crediting for biochar application if there is an existing soil organic carbon enhancement project on the same plot of land to ensure that its GHG mitigation effect is not double counted. This could happen due to difficulties between distinguishing biochar effects from other soil organic carbon enhancements.

Product-Focused Standards

Product-focused biochar standards are seeking to ensure quality of certified biochar with respect to their function as a product (Table 1). An important aspect is ensuring that biochar products have sufficient environmental integrity for diverging uses. For example, they do that by differentiating heavy metals and organic pollutant contents requirements depending on the use. Nevertheless, product-focused standards generally omit GHG quantification considerations except when used to meet specific requirements stipulated within the standard. For instance, BQM mandates a net GHG life cycle assessment of biochar production, not to quantify climate effects of biochar but to ensure that net GHG emissions per unit of feedstock are lower than in a modern bioenergy facility. Similarly, its durability considerations are not targeted toward quantification of GGR but are in place to guarantee that biochar contains at least a 10% fraction of stable carbon that can persist in soil for more than 100 years.

Product-focused biochar standards range in the types of appraised biochar uses and the granularity of such use types. BQM and IBI only govern biochar for soil application. In terms of environmental performance, BQM differentiates between “Standard” and “High” grade biochar by requesting lower toxicant limit values for the “High” grade but they both apply only to the input of biochar in agricultural and horticultural soils. The EU Regulation on fertilising products merely controls biochar production that is used as a fertilising product, i.e., for the purpose of providing the plants or mushrooms with nutrients or to improve their nutrition efficiency” which would normally end up in the soil.[16] The EBC and WBC, on the other hand, certify biochar for utilisations beyond direct soil application, several certification classes stipulate conditions depending on the utilisation purpose of biochar, including uses for animal feed, consumer materials, in urban settings, and in basic materials such as in construction-building. Whilst the WBC covers these uses in three diverging classes, the EBC specifically appraises biochar use cases having a separate category for each utilisation.[17] EBC and WBC certification requirements vary between certification classes concerning basic properties, such as $H{:}C_{org}$, allowed feedstock types and limit values of toxicants present in the biochar.

Landscape of Biochar Standards

The diverse standards’ landscape reflects the multiplicity in the umbrella term of biochar that ranges in features and enables different certification options depending on the place of biochar production and application, and the purpose for which biochar is being used. Overarchingly, the standards diverge in whether they quantify biochar’s contribution to climate change mitigation or if they aim to ensure its environmentally sound utilisation. Despite their discrepancies,

[14] See, for example, Verra stating this in biochar methodology FAQs. Verra, ‘Biochar Methodology FAQs’ (Verra) <https://verra.org/methodologies-main/biochar-methodology-faqs/> accessed 6.11.2023.
[15] Carbon Standards, ‘Positive list of permissible matrices for the establishment of biochar C-sinks’ (European Biochar Certification) <https://www.european-biochar.org/media/doc/139/matrix_list_ebc.pdf> accessed 6.11.2023.
[16] EU Fertilising Products Regulation Art 2 (1).
[17] WBC provides three classes: WBC-Premium for all applications (including consumer products), WBC-Agro for agricultural applications, and WBC-Material which allows only the use of biochar in business-to-business trade and prevents use in consumer products or in soil application. EBC enables use in conventional agriculture (EBC-Agro) and organic agriculture (EBC-AgroOrganic), in urban settings (EBC-Urban), animal feed (EBC-Feed and EBC-FeedPlus), consumer materials (EBC-ConsumerMaterials), and for all other non-soil applications, including construction-building (EBC-BasicMaterials).

standards are linking into a more complex and complete biochar governance framework. The GHG-focused standards, such as Puro.earth and Verra, in absence of specific national regulations, require compliance with IBI or EBC standards when it comes to toxicant limits to minimise risk of environmentally adverse effects of biochar application. The C-Sink certification similarly presupposes EBC or WBC certification. The product-focused standards thus provide the backbone for further utilisation of biochar as a GGR, for which GHG-focused biochar standards impose restrictions on biochar production and use in order to encapsulate their overall climate performance.

Whilst their overall different scopes make them complementary, it simultaneously makes them less comparable. Therefore, several substantive comparisons in the next section can only be made between product-focused (e.g., toxicant assessment) and GHG-focused standards (e.g., quantification of GHG emissions and removals, estimation of permanence). Other feature comparisons must consider what the specific biochar standard focuses on. For instance, aspects of MRV approaches such as sampling and verification procedures have a crucial role for GHG-focused standards but are important for ensuring compliance with product-focused standards too. They, however, diverge fundamentally in what type of data they are governing. Product-focused standards govern the quality of physical biochar material whereas GHG-focused standards assess achievement of GHG savings and removals provided by biochar. This results in a different MRV emphasis given by each standard.

Comparison of biochar standards

Feedstock Types

The assessed standards align in the inclusion of most varieties of biomass. This encompasses biomasses from agricultural production, forestry operations, landscape management, urban green cuttings, aquaculture plants, food processing that are on a vegetable basis and biogenic residues from defined industrial sources such as sawmills and paper production. The Artisan C-Sink diverges from this by explicitly excluding food and feed feedstock and limiting the use of agricultural and forestry biomass and residues from some of the related industries (cocoa mills, coffee pealing, rice thrashing, sawmills). This can be attributed to Artisan C-Sink that focuses on the use of feedstock from the artisan's own farm. Puro.earth and C-Sink reference all feedstock types stipulated in the EBC's positive list, but C-Sink requires their individual authorisation.

Standards diverge in including feedstocks that could contain bigger concentrations of contaminants but their use is nonetheless enabled. For instance, sewage sludge or biosolids, textiles, digestates, residues from industrial biomass processing, such as production of bioethanol or biodiesel and kitchen waste are all enabled by several standards. Many of these biomass sources must meet additional requirements stipulated in the respective standards, such as provided by the EBC's positive list or in the EU Regulation on fertilising products. The IBI characterises such feedstock streams as processed biomass feedstocks. Most standards, however, align in allowing the use of animal by-products including manure.

Furthermore, most of the investigated standards enable some form of utilisation of collected waste. They include some types of separately collected bio-waste, such as paper waste, untreated or treated wood waste without PVC treatment or heavy metal enrichment, or wood preservatives (Puro.earth, C-Sink, EBC, WBC). EU Regulation on fertilising products allows use of all separately collected bio-waste whereas BQM and IBI allow the utilisation of the biogenic fraction of municipal solid waste. In order to ensure that these waste streams only comprise biogenic material, the product-focused standards provide ranging requirements as to the allowed levels of feedstock contamination. EU Regulation on fertilising products does not allow any contamination, BQM less than 0.25% (dry weight basis), EBC and WBC under 1%, and the IBI 2% of dry weight.

Table 2: Comparison summary of biochar feedstock materials that are allowed by analysed standards. ✓ symbol represents which standard feature is represented by the standard and ✗ symbol identifies which is not. Green lines represent commonalities between standards whereas yellow lines illustrate where general alignments between standards cannot be identified. More than 75% of analysed standards must treat the feedstock material similarly in order to be identified as an alignment. The lines are organised from top to bottom in the order of standard features that are most commonly represented in the analysed standards by proportion. This does not apply for standard characteristics when the colour-coding scheme is not applied. N/A signals that the identified characteristic is out of scope of the specific standard. This legend applies to all summary tables (Table 2-8).

Table 2: In this table, the N/A values are attributed to Artisan C-Sink which only governs farm-specific materials present in the global south and closely related industrial sources whilst specifically preventing pyrolysis of foodstuffs. Furthermore, contaminant levels are generally excluded from the consideration of GHG-focused standards.

Trends & divergences	Puro. earth	Verra	C-Sink	Artisan C-Sink	EBC	WBC	BQM	IBI	EU Regulation
Agricultural biomass	✓	✓	✓	✓	✓	✓	✓	✓	✓
Forestry biomass	✓	✓	✓	✓	✓	✓	✓	✓	✓
Residues from defined industrial sources (e.g., sawmills, paper industry)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Biomass from landscape management	✓	✓	✓	N/A	✓	✓	✓	✓	✓
Urban green cuttings	✓	✓	✓	N/A	✓	✓	✓	✓	✓
Aquaculture plants	✓	✓	✓	N/A	✓	✓	✓	✓	✓
Food processing (vegetables)	✓	✓	✓	✗	✓	✓	✓	✓	✓
Animal by-products (including manure)	✓	✓	✓	✗	✓	✓	✓	✓	(✓)[18]
Sewage sludge or biosolids	✓	✓	✓	N/A	✓	✓	✗	✓	✗
Separately collected bio-waste	✓	✗	✓	N/A	✓	✓	✗	✗	✓
Digestates	✓	✗	✓	N/A	✓	✓	✗	✓	✗
Residues from industrial biomass processing	✓	✗	✓	N/A	✓	✗	✗	✗	✓
Textiles	✓	✗	✓	N/A	✓	✓	✗	✗	✗
Kitchen waste	✓	✗	✓	✗	✓	✗	✗	✗	✗
Biomass fraction of solid municipal waste	✗	✗	✗	N/A	✗	✗	✓	✓	✗
Contaminant levels allowed	N/A	N/A	N/A	N/A	1%	1%	0.25 %	2%	0

[18] The EU regulation on fertilising products enables the use of animal by-products and derived products as feedstock provided that the end of manufacturing of such products is determined and that other conditions from the Animal by-products regulation are met (Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002).

Production methods

The biochar standards allow the use of production processes in which the biomass is heated in an oxygen-limited environment. This can be further specified to include pyrolysis or gasification (Puro.earth, EBC, WBC) or is left unspecified (BQM, IBI). Verra, EBC, and WBC explicitly prevent certification of chars from torrefaction and hydrothermal carbonisation. Apart from Verra and IBI, standards generally do not include certification of high-carbon ash from biomass boilers.

Biochar standards contain some provisions as to the biochar production core features such as processing temperature, time, or production equipment. The EU Regulation on fertilising products determines the required production temperature and time, i.e., to exceed 180°C for at least 2 seconds. Whilst EBC and WBC require the heat treatment to exceed 500°C for at least three minutes only in case of treating animal by-products. The Artisan C-Sink requires the production of biochar in simple Kon-Tiki-type kilns which consists of biochar production methods that create a flame curtain which protects the pyrolysis zone from combusting. It does not impose restrictions on the metal of the kilns nor on their shape. The Artisan C-Sink standard assumes that the temperature will be consistently above 650°C to produce sufficiently recalcitrant biochar.

Rather than putting requirements on the use of production methods, the standards focus predominantly on appraising the output of such process. For assessing sufficient carbonisation of biomass through the production process, and therefore correct pyrolysis, the standards, for example, require measurement of $H:C_{org}$ (Puro.earth, Verra, EBC, WBC, IBI, EU Regulation) and oxygen to organic carbon molar ration ($O:C_{org}$) (EBC and WBC) which must be below 0.7 and 0.4, respectively. Differently, BQM includes this as an optional testing parameter. Several standards, however, require consideration of pyrolysis temperature. If the temperature of the production process deviates significantly from previously stated (20% for EBC and WBC and 50°C for IBI) or if the thermochemical residence time changes in excess of 10% (IBI) biochar sampling must be repeated and these features assessed anew. EU Regulation on fertilising products requests additional testing if changes occur to any product quality relevant characteristic of the production process. In the case of Verra, pyrolysis temperature is recorded to assess durability of the produced biochar.

The standards provide more guidance on the configuration of the biochar production process beyond the core biochar production parameters. Most standards require adequate post-production processing of output gases to minimise methane emissions and ensure the efficiency of processing. The EBC and WBC mandate trapping of pyrolysis gases for utilisation and prohibit their release into the atmosphere. In case these are combusted, they require the use of at least 70% of the so-produced excess heat. Use of bio-oil, a third co-product of pyrolysis process besides biochar and pyrolysis gas, and utilisation of products made from pyrolysis gases must reach 70% carbon efficiency. Verra, on the other hand, labels this kind of biochar processing configuration as “high-technology production facility” and whilst not excluding certification of lesser biochar production options, adopts a more favourable carbon accounting approach for a high-technology production facility which assumes methane emissions have been avoided. Differently, C-Sink standard, despite requiring adherence to EBC production efficiency criteria, demands additional certification of the production facility regarding its methane emissions.

Other biochar production requirements are enacted only through reference to keeping in line with local and national regulations whilst avoiding additional emission criteria. This is the case for all standards besides Artisan C-Sink and EU Regulation on fertilising products. In the case of the latter, however, such requirements are nonetheless imposed by other legislative acts that comprise part of EU legal order, such as the Industrial Emissions Directive.[19] Only BQM self-imposes environmental safeguards e.g., to guarantee sufficient emissions opacity, limit particulate

[19] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (recast).

matter emissions and volatile organic carbon emissions. BQM also inputs upper limits to emission per GJ in the fuel content of biomass feedstock.

Table 3: Comparison summary of biochar production method requirements from analysed standards.

In this table, the N/A values are attributed to EU Regulation on fertilising products which avoids requirements pertaining to emissions, output gases, or regulations due to the existence of other applicable legal regimes that already control industrial emissions within EU law.

Trends & divergences	**Puro. earth**	**Verra**	**C-Sink**	**Artisan C-Sink**	**EBC**	**WBC**	**BQM**	**IBI**	**EU Regulation**
Production parameters controlled through resultant biochar properties	✓	✓	✓	×	✓	✓	(✓)[20]	✓	✓
Treating output gases	✓	✓[21]	✓	✓	✓	✓	✓	×	N/A
Requiring compliance with local and national regulations	✓	✓[21]	✓	×	✓	✓	✓	✓	N/A
Reporting crucial production parameters or their changes	✓	✓	✓	×	✓	✓	×	✓	✓
Torrefaction and hydrothermal carbonisation specifically excluded	×	✓	✓	×	✓	✓	×	×	×
Pyrolysis and gasification specifically included	✓	×	×	×	✓	✓	×	×	×
Temperature or production residence time requirements	×	×	×	×	✓[22]	✓[22]	×	×	✓
Use of Kon-Tiki (low-tech production) specifically allowed	✓	✓[23]	×	✓	×	×	×	×	×
Biomass boilers specifically included (high-carbon ash)	×	✓	×	×	×	×	×	✓	×
Imposing additional emission criteria	×	×	×	×	×	×	✓	×	N/A

Limits on toxicants

Biochar standards align on several toxicants that must be assessed prior to application. This, in all cases of product-focused biochar standards, encompasses testing for heavy metals and organic pollutants whilst GHG-focused standards omit this consideration and instead refer to product-focused standards (Puro.Earth, Verra to IBI and EBC, C-Sink to EBC). In terms of heavy metals, all product-focused standards include testing for lead, cadmium, copper, nickel, mercury, zinc, chromium, and arsenic. Furthermore, they all measure the content of PAH_{16} as well as the content of PCDD/Fs, and most assess the quantity of PCBs.

Biochar standards, however, diverge in their additional testing requirements. EBC and WBC introduce a more granular assessment of the most relevant persistent organic pollutants. Both include an assessment of the list of 8 most carcinogenic polycyclic aromatic hydrocarbons as recognised by EU Food and Safety Agency (PAH_8) whilst only

[20] $H:C_{org}$ is an optional biochar parameter for testing in the BQM.
[21] For high-technology production facilities.
[22] For treatment of animal by-products.
[23] As low-technology production facilities.

EBC assesses the contents of benzo[e]pyrene and benzo[j]fluoranthene. WBC, however, does not impose a limit on PAH_{16} contents but only requires their disclosure. In contrast, BQM and IBI impose additional limits on heavy metals such as molybdenum, and selenium. Except for IBI, no standard tests biochar for cobalt or for germination inhibition.

Instead of testing every batch, several biochar standards are more pragmatic and do the assessment of PCBs and PCDD/Fs more sparingly. EBC and WBC will only undertake it in the first year of the production unit (EBC and WBC) due to its close connection with the operation of the unit. Afterward, they test it only when the risk of chlorine contamination of the feedstock has been identified. Differently, BQM will generally omit and solely test if the feedstock is in danger of having excessive levels of chlorine.

Simultaneously, biochar standards range profusely in the levels of toxicants that they allow biochar to have. The overall strictest biochar standardisation in this regard is the EBC which follows compliance with the EU Regulation on fertilising products. The IBI, on the other hand, requires the biochar producer to primarily follow the applicable limits in the jurisdiction of application and/or production, but if there are no such limits, they should follow another jurisdiction's requirements within the range given by the IBI. The resultant IBI range is considerable, thus appearing to have the highest allowable levels of toxicants for soil applicable biochar.

Table 4: Comparison summary of biochar testing requirements for toxicants required by analysed standards.

In this table, the N/A values are attributed to GHG-focused standards (Puro.earth, Verra, C-Sink, Artisan C-Sink) which generally do not deal with toxicant assessments.

Trends & divergences	Puro. earth	Verra	C-Sink	Artisan C-Sink	EBC	WBC	BQ-M	IBI	EU Regulation
Testing for heavy metals (Pb, Cd, Cu, Ni, Hg, Zn, Cr, As)	N/A	N/A	N/A	N/A	✓	✓	✓	✓	✓
Testing for PAH_{16}	N/A	N/A	N/A	N/A	✓	✓	✓	✓	✓
Testing for PCDD/F	N/A	N/A	N/A	N/A	✓[24]	✓[24]	✓[25]	✓	✓
Testing for PCBs	N/A	N/A	N/A	N/A	✓[24]	✓[24]	✓[25]	✓	×
Testing for Se	N/A	N/A	N/A	N/A	×	✓	✓	✓	×
Testing for Mb	N/A	N/A	N/A	N/A	×	×	✓	✓	×
Testing for PAH_8 and Ag	N/A	N/A	N/A	N/A	✓	✓	×	×	×
Testing for benzo[e]pyrene and benzo[j]fluoranthene	N/A	N/A	N/A	N/A	✓	×	×	×	×
Testing for Co, B, Cl, Na	N/A	N/A	N/A	N/A	×	×	×	✓	×
Germination inhibition assay	N/A	N/A	N/A	N/A	×	×	×	✓	×
Limit values severity overall	N/A	N/A	N/A	N/A	1	3	4	(5)[26]	2

[24] Testing is required in the first year of the operation of the production unit and then after an identification of chlorine contamination of the feedstock.
[25] In the case of using feedstock which contains excessive amounts of chlorine.
[26] Severity of IBI toxicant limit values hinges on the jurisdiction of production or soil application in question.

Quantifying life cycle emissions

Quantifying life cycle emissions is predominantly in the domain of the GHG-focused standards and generally out of scope of product-focused ones. For biochar to be used as a GGR, one must demonstrate its overall effect on climate-relevant factors. In general, standards do so by accounting the stable proportion of carbon present in the biochar[27] deducting from it the biochar-related GHG emissions. As mentioned above, the exception from product-focused standards not encompassing a GHG assessment, is the BQM, which imposes specific restrictions on GHG intensity of biochar production, hence, requiring emission quantification from its production. Due to the requirement in question, the BQM expresses GHG intensity per unit of feedstock, but nevertheless uses a similar calculation, in which the stable carbon fraction comprising biochar decreases the emission intensity of production.

All GHG-focused standards and the BQM state the requirement to quantify life cycle GHG emissions expanding assessment beyond just the specific biochar production processes, however, they differ in their system boundaries. Puro.earth sets the system boundary cradle-to-grave, spanning across the production and supply of biomass, its transformation into biochar, distribution of biochar, and final use up to the incorporation into the matrix. Verra imposes similar spatial boundaries. Differently, the BQM includes accounting for biomass sourcing and biochar production setting the end of GHG emissions accounting explicitly at the biochar factory gate, therefore excluding subsequent distribution and use phases. The C-Sink and Artisan C-Sink mandate project proponents to account for GHG emissions caused by the biochar-related processes spanning biomass cultivation, biochar production and soil or product incorporation. However, the C-Sink only calculates emissions up to the factory gate, and thus, contains guidance only on how to calculate C-Sink potential and not the final C-Sink. The C-Sink trader would track and record emissions that occur prior to incorporation into the matrix and deduct them from the overall GHG balance.

Biochar standards consider different GHG sources and thus include biochar supply chains to a ranging extent. BQM includes direct and indirect land use change from dedicated biomass production. However, it exempts project proponents from accounting carbon contained within the feedstock, consequently focusing on fossil emissions in the subsequent production process without providing more detail about included GHG emissions. C-Sink accounts emissions from cultivation and harvest of biomass due to use of fertiliser as well as biomass transport emissions.[28] Differently than BQM, it includes methane emissions from biomass decay if the biomass is not appropriately stored. Furthermore, it considers methane emissions from the pyrolysis equipment whilst accounting for other emissions related to biochar production (biomass transport and pre-treatment, use of energy and fossil fuels for production and post-production processes and transport to distribution depot). From all the analysed standards, only Puro.earth explicitly accounts life cycle stages of manufacturing, use, and disposal for each component activity. However, in the use of biochar. Puro.earth only incorporates GHG emissions that are known to the producer inclusive of, at minimum, transport and matrix incorporation. Verra, on the other hand, only allows the use of biomass waste feedstock that would otherwise be left to decay or be combusted for non-energy-related purposes, therefore excluding consideration of biomass sourcing emissions altogether. It accounts for energy-related emissions and fossil fuel emissions from biomass preparation procedures, such as drying and chipping, and from biochar production. It also includes methane emissions from biochar production processes. The application stage considers scope 1[29] and scope 2[30] emissions from further processing of biochar but excludes emissions from applying biochar. Verra includes emissions from the transport of biomass and biochar provided that each exceeds 100 km in one direction. Likewise, Artisan C-Sink

[27] For more on this, see the following sub-section titled "Estimating permanence of removal".
[28] Note that these are dealt within the production process emissions category.
[29] We use the term scope 1 emissions as defined in The GHG Protocol's Corporate Accounting and Reporting Standard: "Direct GHG emissions occur from sources that are owned or controlled by the company.". See more in The GHG Protocol, 'A Corporate Accounting and Reporting Standard' (The GHG Protocol) <https://ghgprotocol.org/corporate-standard> accessed 14.11.2023.
[30] We use the term scope 2 emissions as defined in The GHG Protocol's Corporate Accounting and Reporting Standard: "GHG emissions from the generation of purchased electricity consumed by the company." See more in ibid.

includes transport emissions if the biochar is used farther than 100 km from the place of production but leaves all other GHG emissions unspecified.

The assessed standards either do not provide a baseline assessment, or provide it but adopt it as being zero. Verra assumes zero GHG emissions under the baseline on the basis of only allowing biomass left to decay or combustion for non-energy-related purposes and being conservative in doing so. Differently, Puro.Earth generally demands a counterfactual assessment to be project-specific, conservative and periodically updated but puts default baseline emission scenario for biochar production to zero. The project proponent can submit a non-zero counterfactual assessment but Puro.earth does not specify any further what such a counterfactual assessment ought to include. Finally, C-Sink and Artisan C-Sink do not introduce any specific considerations of baseline assessment.

Artisan C-Sink levies a flat 3% “margin of security” against the total carbon content of biochar in order to avoid missing unspecified emissions. Similarly, C-Sink imposes a “margin of safety” to avoid under accounting scope 3[31] emissions from biochar production. This encompasses 10% of GHG emissions on top of accounted GHG project emissions. Other standards do not include any such buffers to avoid GHG emissions under accounting. Furthermore, only these two standards treat methane emissions similarly by accounting for them in their 20-year global warming potential and then enabling their offsetting by enhancing short-term carbon sinks that guarantee carbon storage for at least 20 years. Artisan C-Sink also enables C-Sink Farmers to “offset” methane emissions by pledging avoidance of harmful practices such as crop burning or leaving biomass to decomposition.

[31] We use the term scope 3 emissions as defined in The GHG Protocol’s Corporate Accounting and Reporting Standard: consequence of the activities of the company, but occur from sources not owned or controlled by the company. See more in ibid.

Table 5: Comparison summary of GHG emissions quantification approaches required by analysed standards.

In this table, the N/A values are attributed to product-focused standards which generally do not cover GHG quantification except for BQM (see sub-section "Product-focused standards"). Moreover, some elements of GHG quantification within GHG-focused standards are omitted due to their varying assumptions. BQM avoids a comparable baseline consideration due to limiting its GHG emission quantification on fulfilling a specific emission level criterion. Verra and C-Sink do not quantify land use change emissions, the first due to only enabling the use of waste biomass which does not invoke cultivation emissions, and the second for its evidencing requirements regarding carbon neutral biomass sourcing.

Trends & divergences	Puro. earth	Verra	C-Sink	Artisan C-Sink	EBC	WBC	BQM	IBI	EU Regulation
Deduct GHG emissions from the stable carbon content	✓	✓	✓	✓	N/A	N/A	✓	N/A	N/A
Accounting beyond biochar production process emissions	✓	✓	✓	✓	N/A	N/A	✓	N/A	N/A
Emissions source: Transport	✓	✓	✓	✓	N/A	N/A	✓	N/A	N/A
Emissions source: Fossil emissions from biomass treatment and biochar production	✓	✓	✓	×	N/A	N/A	✓	N/A	N/A
Emissions source: Methane emissions from biochar production	✓	✓	✓	✓	N/A	N/A	×	N/A	N/A
Emissions source: Direct land use change	✓	N/A	N/A	×	N/A	N/A	✓	N/A	N/A
Emissions source: Cultivation and harvesting	✓	N/A	✓	×	N/A	N/A	(✓)[32]	N/A	N/A
System boundary: Biomass sourcing, biochar production, distribution, use	✓	✓	×	✓	N/A	N/A	×	N/A	N/A
Baseline emissions consideration	✓	✓	×	×	N/A	N/A	N/A	N/A	N/A
Buffer	×	×	✓	✓	N/A	N/A	×	N/A	N/A
Offsetting methane emissions	×	×	✓	✓	N/A	N/A	×	N/A	N/A
System boundary: Factory gate	×	×	(✓)[33]	×	N/A	N/A	✓	N/A	N/A
Emissions source: Use	(✓)[34]	×	(✓)[33]	×	N/A	N/A	×	N/A	N/A
Emissions source: Indirect land use change	×	N/A	N/A	×	N/A	N/A	✓	N/A	N/A
Explicit consideration of manufacture, use, disposal of each component activity	✓	×	×	×	N/A	N/A	×	N/A	N/A

[32] Covered by the consideration of biomass production emissions.
[33] Calculation only up to the factory gate but the C-Sink Trader ought to deduct subsequent emissions.
[34] Depending on the knowledge of producer.

Estimating permanence of removals

All biochar standards that assess permanence of biochar take 100 years as a reference period. As a sufficiently long carbon sequestration period, most standards utilise the $H:C_{org}$ as a proxy to estimate the levels of sufficient recalcitrance.

Schmidt and others state that $H:C_{org}$ below 0.4 leads to at least 74% of persistent aromatic carbon (PAC) content in biochar, i.e., polycyclic aromatic carbon that can persist in soil under any climatic condition for millennia. The rest (26%) is composed of semi-persistent carbon pool with mean residence time (MRT) of 50-100 years. Quantification of PAC is possible through hydrogen pyrolysis but is said to be unpractical due to cost. Other testing methods are also being investigated, for instance, Raman spectroscopy, mid-infrared (MIR) spectroscopy or Rock-Eval method.[35] Still, standards that are following the approach as described by Schmidt and others (C-Sink, Artisan C-Sink) resort to imposing a threshold for $H:C_{org}$ that must be below 0.4 in order to show sufficient recalcitrance. The C-Sink Positive list of permissible matrices, however, stipulates that carbon remaining in soil after 100 years amounts to 82% and thus exceeds the assumed content of PAC.

Other methods to estimate permanence (including the ones derived from the $H:C_{org}$ method) are used more sparingly and only by specific standards. Puro.earth, does not impose a threshold on $H:C_{org}$ to estimate permanence but multiplies it with regression coefficients that reflect temperature of the soil where biochar is applied and the timescale of storage assessed.[36] This equation would thus enable, on the basis of coefficients from Woolf and others, a calculation of how much biochar will be left in the soil after 100 years.[37]

Additionally to using $H:C_{org}$ ratio, BQM enables the use of other methods such as ensuring $O:C_{org}$ is low enough to sufficiently demonstrate permanence, and estimating biochar recalcitrance index relative to volatilisation of graphite through the use of Thermogravimetric analysis (TGA).[38] The preferred method for BQM to estimate permanence, however, is accelerated aging, which encompasses using a solution of hydrogen peroxide to simulate environmental conditions of carbon storage in soil, thus, causing decay but in an amplified manner.[39] After the treatment, in approximately 10 days, the biochar sample gets weighed with remaining carbon being assumed as sufficiently recalcitrant to withstand 100 years in soil avoiding decomposition.

Only Verra which estimates permanence of biochar through production temperature as suggested by the Intergovernmental Panel on Climate Change's (IPCC).[40] Verra assumes that high-temperature pyrolysis and gasification (> 600 °C) produces biochar that retains 89% of organic carbon after 100 years. Medium-temperature pyrolysis (450 – 600 °C) makes biochar in which 80% of organic carbon can withstand decay whereas low-temperature pyrolysis (350 – 450 °C) only enables recalcitrance of 65% of organic carbon. Pyrolysis temperature is measured per biochar batch as an average annual production temperature. If biochar is made in a low-technology production facility, a default permanence percentage is used. In this case, Verra accounts for 15% standard error and assumes 56.22% of organic carbon is retained after 100 years of storage in soil.

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[35] Schmidt and others (n 12).
[36] Dominic Woolf and others, 'Greenhouse Gas Inventory Model for Biochar Additions to Soil' (2021) Environmental Science and Technology 55 14795.
[37] Ibid.
[38] Omar R Harvey and others, 'An Index-Based Approach to Assessing Recalcitrance and Soil Carbon Sequestration Potential of Engineered Black Carbons (Biochars)' (2012) Environtal Science and Technology 46 1415.
[39] Andrew Cross and Saran P. Sohi, 'A method for screening the relative long-term stability of biochar' (2013) GCB Bioenergy 5 215.
[40] Stephen Michael Ogle and others, (n 7).

Table 6: Comparison summary of approaches to estimating permanence of biochar from analysed standards.

In this table, the N/A values are attributed to product-focused standards which generally do not consider permanence except for BQM (see sub-section "Product-focused standards"). This table also contains biochar permanence considerations as contained in Schmidt and others (2022).

Trends & divergences	Puro. earth	Verra	C-Sink	Artisan C-Sink	EBC	WBC	BQM	IBI	EU Regulat-ion	Schmidt et al (2022)
100 years as reference	✓	✓	✓	✓	N/A	N/A	✓	N/A	N/A	✓
Measure H:C_{org} to estimate permanence	✓	×	✓	(✓)[41]	N/A	N/A	(✓)[42]	N/A	N/A	✓
Estimating PAC through H:C_{org} (H:C_{org} < 0.4 = 74% SPAC ∧ 26% semi-persistent C pool with MRT of 50-100 years)	×	×	✓	(✓)[41]	N/A	N/A	×	N/A	N/A	✓
H:C_{org} < 0.4 = 82% remaining after 100 years	×	×	✓	(✓)[41]	N/A	N/A	×	N/A	N/A	×
Soil temperature	✓	×	×	×	N/A	N/A	×	N/A	N/A	×
Accelerated aging	×	×	×	×	N/A	N/A	✓	N/A	N/A	×
Production temperature	×	(✓)[21]	×	×	N/A	N/A	×	N/A	N/A	×
O:C_{org} to estimate permanence	×	×	×	×	N/A	N/A	(✓)[42]	N/A	N/A	×
TGA	×	×	×	×	N/A	N/A	(✓)[42]	N/A	N/A	×

Soil application factors

The mapping of biochar standards has shown that soil application factors are left commonly ungoverned in the biochar standard landscape. Puro.earth, Verra, C-Sink, EBC contain marginal consideration regarding soil application. Only BQM approaches soil application factors more comprehensively, for example by considering soil conditions and controlling soil application approaches. Hence, no active alignments can be identified. Standards only converge in what they do not do. They do not govern place of application to control runoff or explicitly prevent application in places where abundant soil organic carbon stocks are present.

Puro.earth's biochar methodology gives soil application temperature a role in determining the durability of such carbon storage. C-Sink, in its positive list, distinguishes soil application regarding the calculation of emissions and removal and related MRV depending on the place of application. For instance, biochar application in forests may lead to higher mineralisation of soil organic carbon, thus potentially leading to a larger margin of security deducted from carbon storage (up to 20%). Puro.earth and C-sink, thus, use soil application conditions as a factor of GHG quantification. Conversely, Verra and EBC provide some controlling requirements. Verra requires biochar users to apply biochar on cropland, grassland, vegetated urban land, or in the forest by placing it in the subsurface, to a minimum of 10 cm depth, or mixed with substrates on the soil surface. EBC, in a country-specific Annex 7, stipulates

[41] Artisan Pro biochar producer must measure and calculate it.
[42] A secondary method.

requirements for biochar made from manure and aquaculture sludge for soil application in Denmark, including maximum application rates and consideration of heavy metal contents already present in the soil.

Compared to other biochar standards, the BQM represents the most comprehensive approach to governing soil application for biochar. First, the advocated method to estimating permanence (accelerated aging) can simulate climatic conditions of the place of application. Second, deployment of Standard-grade biochar is limited by the potential toxicant limiting application rate (PTLAR) which limits the application rate of biochar considering the presence and introduction of toxicants in soil. PTLAR assesses soil limit values of each relevant toxicant, their quantity in biochar and their already established levels in the soil. The application of biochar can either meet 20% of PTLAR each year (with testing being done prior to each subsequent biochar application) or an average annual rate of toxicant addition over a 10-year period. Third, biochar application must comply with good agricultural and handling practices, such as ensuring sufficient moisture content during application and deployment on soil where there is no fear of leeching in the waterways which precludes application in the wetlands. Finally, BQM does not enable any type of biochar to be used in soils with over 10% of soil organic carbon.

Table 7: Comparison summary of soil application factors from analysed standards.

In this table, the N/A values are attributed to product-focused standards which generally do not contain consideration of soil application for their product focus except in the case of BQM which contains soil application factors. Moreover, EBC comprises some soil application factors in a country-specific Annex. Differently, GHG-focused standards do not have a toxicant assessment in their scope and the EU law may provide for such safeguards within other legal regimes.

Trends & divergences	Puro. earth	Verra	C-Sink	Artisan C-Sink	EBC	WBC	BQM	IBI	EU Regulation
Place of application affects carbon storage potential	✓	×	✓	×	N/A	N/A	(✓)[43]	N/A	N/A
Toxicants already present in soil are considered	N/A	N/A	N/A	N/A	(✓)[2]	×	✓	×	N/A
Allowed land for application is limited	×	✓	×	×	N/A	N/A	✓	N/A	N/A
Modes of application are determined	×	✓	×	×	N/A	N/A	✓	N/A	N/A
Quantity of application is controlled	×	×	×	×	(✓)[2]	N/A	✓	N/A	N/A
Place of application is limited to prevent runoff	×	×	×	×	N/A	N/A	✓	N/A	N/A
Abundant soil organic carbon restricts biochar application	×	×	×	×	N/A	N/A	✓	N/A	N/A

[43] The use of accelerated aging technique for estimating permanence is capable of simulating the conditions in the place of application.

MRV protocols

The different foci of assessment between biochar standards brings generally diverging requirements as to the requested MRV protocols. First, product-focused standards rely heavily on biochar material testing to ensure biochar has acceptable physical properties and does not exceed prescribed toxicant limits. Second, GHG-focused standards besides testing a couple of GHG-relevant biochar features (organic carbon content, hydrogen content, dry weight) additionally encompass MRV related to GHG emissions across the life cycle of biochar. Third, their MRV protocols engender ranging requirements due to the assessment focusing on different parts of biochar life cycle (see section “Quantifying life cycle emissions”). Finally, this is made more convoluted by difference in employed terminologies. Nevertheless, some general active alignments can be identified between standards in requiring accredited laboratory testing, evidencing compliant biomass supply, management of records, limiting monitoring and reporting until acceptable use of biochar can be assumed, and requesting a chain of custody mechanism.

Basic monitoring procedures for biochar material properties are fairly divergent. Often, biochar sampling and testing is done at least yearly for every biochar batch when re-audits take place. Such an approach is adopted by EBC, WBC IBI, C-Sink, and Verra which require sampling and testing biochar once a year provided that no material changes of the main production parameters occur (feedstock, temperature, residence time). EBC and WBC allow adopting a stricter sampling schedule depending on the producer and require continuous retention sampling for QC purposes whilst IBI differentiates sampling frequency depending on the use of processed and unprocessed feedstock. C-Sink additionally requires continuous sampling and testing for dry matter content due to large fluctuations in biochar moisture content. Verra, allows use of IPCC estimates for organic carbon content for validation and for low-technology production facilities. Artisan C-Sink relies on constant retention sampling by Artisan Pro biochar producers where representative samples are tested annually during the inspection visit by the C-Sink Manager. In contrast, producers that make less than 100 m^3 of biochar annually (C-Sink Farmers) do not need to sample and test biochar. BQM and Puro.earth allow biochar producers to propose their own sampling plans depending on their production processes without any provided limits, such as annual testing. The EU Regulation on fertilising products is the sole standard that demands sampling and testing depending on the amount of biochar produced but can amount up to 48 samplings a year. Where the standards actively align regarding biochar testing is in requiring their analysis being undertaken by an accredited laboratory.

Biochar standards monitor and report on wider elements beyond the material testing, spanning from biomass sourcing, through biochar production, and post-production. The assessed standards treat biomass supply monitoring similarly. This is most typically done through sustainable biomass sourcing schemes, in particular for forest biomass, but diverge in which concrete sustainability schemes they mandate. BQM leaves biochar producers with freedom to trace biomass in a manner suiting to the individual project but provides outlines on international certification schemes as possible ways to ensure good management. Verra, conversely, due to allowing only waste biomass destined for specified purposes (decay, non-energy related combustion) does not mandate fulfilling sustainability requirements, but requests evidencing of feedstock via receipts, historical management data, signed attestations and satellite data.

Biochar standards must also monitor what happens throughout the biochar production process. Their common baseline is in some form of records management, and mostly they require imposition of a chain of custody mechanism. Product-focused standards impose control mechanisms in order to ensure traceability of feedstock, production parameters, and quality of biochar. EBC, WBC and C-Sink create a QR code and ID number to identify the biochar batch with features available online and requires documenting each posterior production step in a processing journal. Similarly, EU Regulation on fertilising products requests the producer to assign a unique identification code to each batch and requires managing technical documentation. IBI and Puro.earth requires a chain of custody tracking mechanism with documentation, whereas BQM vaguely requires record management regarding feedstock, production, and supply. Artisan C-Sink, tracks biochar-related processes through a provided mobile application. This comprises reporting of information by biochar producers such as the type of feedstock and kiln used, quantity of biochar produced, and georeferenced photo of the production process. This is further combined by MRV obligations of the C-Sink Manager who must have an MRV plan in place that stipulates the scope of activities covered, protocols for conveyance of information to the C-Sink registry, procedures for on-site control and monitoring strategy. Verra, on the other hand, requires utilisation of a chain of custody tracking mechanism and outlines the main data that must be monitored and reported but leaves it to the project proponent to develop and apply a monitoring plan that would evidence GHG emissions.

GHG-focused standards, as opposed to product-focused ones, must evidence beyond the production and sourcing process and monitor use in order to increase integrity of biochar as a climate change mitigation tool. Most commonly, standards require evidencing of biochar use that does not lead to CO_2 release. Puro.earth evidences that through, for example, offtake agreements. Verra and C-Sink demand the use of above mentioned chain of custody mechanisms that track biochar to the point where acceptable use can be assumed (incorporation into the product, soil application). C-Sink and Verra also require tracking of the geo location of biochar application and storage but C-Sink does not require it when locating the place of application is “not possible or practicable.”[44] Artisan C-Sink requires geo referencing in a mobile app when biochar is added directly to the soil.

Standards diverge in their emphasis on QA and QC procedures. Product-focused standards are generally better equipped in this manner, for example, EBC and WBC require biochar producers to prepare a company specific QA plan that gets approved by the certification body. Moreover, they demand a qualified quality manager to lead on internal quality procedures and act as the main reference point for the certification body. Quality managers must undertake sampling and ensure that testing is undertaken by an accredited laboratory within the company certification scheme. External verification audits must be undertaken on an annual basis by one of the two specifically determined entities and the project provider must ensure relevant documentation is duly managed and kept. EU Regulation on fertilising products imposes substantial requirements for internal quality management procedures such as identifying quality objectives and assigning responsibilities for them, having a management representative in charge for them, allocation of resources and training, and conducting regular internal audits. Whether these procedures are adequately followed and sufficient biochar quality is indeed assured, is assessed by periodic audits of the conformity assessment body. The body also monitors testing approaches and can undertake its own sampling and testing. Differently, IBI and BQM ground QA in sound record management and by relying on accredited laboratories which undertake biochar testing. IBI, furthermore, checks compliance of the biochar producer and is subsequently empowered to undertake randomised sampling of certified biochar products to ensure sufficient quality. BQM requires compliance of biochar producers to be checked by an UKAS accredited body.

In the case of GHG-focused standards, the provisions dedicated to QA and QC procedures are fewer. They are specifically addressed within Verra and Artisan C-Sink. The former mandates adoption of a QA/QC plan comprising activities which protect monitoring instruments and records, the checking of data integrity on regular and periodic basis, comparing and improving estimates and the provision of staff training. The latter empowers the C-Sink Manager to adopt measures to improve data quality, e.g., triad peer groups, naming farmer leaders, or undertaking inspections. Other GHG-focused standards, beyond requesting verification of their claims and generally referencing product-focused standards regarding testing requirements do not provide much details on these processes.

[44] Section 8 of the C-Sink standard.

Table 8: Comparison summary of approaches to MRV from analysed standards.

In this table, the N/A values are attributed to product-focused standards when considering MRV procedures past the factory gate due to their focus on testing biochar as a product. Furthermore, they do not require MRV plans because their analysis is focused on testing the produced material whereas MRV plans are aimed to offer a solution for a more flexible and diverse process appraisal. EU Regulation on fertilising products does not impose data requirements on sustainability of feedstock sourcing because there is no such requirement in place. Similarly, Verra does not require it because it only allows the use of residues.

Trends & divergences	Puro. earth	Verra	C-Sink	Artisan C-Sink	EBC	WBC	BQM	IBI	EU Regulation
Records management	✓	✓	✓	✓	✓	✓	✓	✓	✓
Monitoring up to the point when acceptable use can be assumed	✓	✓	✓	✓	N/A	N/A	N/A	N/A	N/A
Evidencing biomass sourcing via sustainable biomass sourcing schemes	✓	N/A	✓	✓	✓	✓	×	✓	N/A
Accredited laboratory testing of biochar material	(✓)[45]	(✓)[46]	✓	(✓)[47]	✓	✓	✓	✓	×
Chain of custody mechanism	✓	✓	✓	×	✓	✓	(✓)[48]	✓	×
Sampling depends on the producer	✓	✓	✓	×	✓	✓	✓	×	×
Yearly sampling	×	✓	✓	(✓)[47] [49]	✓	✓	×	✓	×
Sampling depends on main production parameters	×	✓	✓	×	✓	✓	×	✓	×
Locating place of application	×	✓	(✓)[50]	(✓)[51]	N/A	N/A	N/A	N/A	N/A
QA and QC procedures in place	×	✓	×	(✓)[49]	✓	✓	×	×	✓
MRV plans required	×	✓	×	(✓)[49]	N/A	N/A	N/A	N/A	N/A
Continuous sampling	×	×	(✓)[52]	(✓)[47] [49]	(✓)[53]	(✓)[53]	×	×	×
Evidencing sustainable biomass sourcing depends on producer's system	✓	N/A	×	×	×	×	✓	(✓)[54]	N/A
Sampling depends on production volume	×	×	×	×	×	×	×	×	✓

[45] No specific standards.
[46] Excluded for validation and for low-technology production facilities.
[47] For Artisan Pro.
[48] In biomass sourcing.
[49] Role of the C-Sink Manager.
[50] If possible and practicable.
[51] Georeferenced photos.
[52] Testing dry weight.
[53] Retention sampling.
[54] If compliance with sustainable biomass sourcing scheme is not shown.

Gaps

Quantification of GHG emissions and removals depends on unclear and often lacking protocols

Biochar offers significant potential to mitigate climate change on a global scale. The IPCC estimates its global technical potential of removing 2.6 Gt CO_{2eq} per year.[55] However, in order to do so, its contribution to atmospheric GGR must clearly outweigh the GHG emissions emitted as a consequence of biomass sourcing, biochar production and use. Only a net negative GGR account, inclusive of clear consideration of project emissions and recalcitrance of removal, represents a worthwhile contribution to climate change mitigation. This requires robust methodologies that align with International Organisation for Standardisation's (ISO) six fundamental accounting principles: account for GHG relevantly, completely, consistently and accurately, in a transparent and conservative manner.[56] The analysed biochar methodologies that account for GHG emissions related to biochar (GHG-focused standards and BQM) commonly lack a transparent and complete approach to GHG project accounting. They do not always clearly delineate system boundaries, disclose GHG sources, and quantification often lacks GGR baseline accounting. These gaps cause concern as to the completeness, consistency, and transparency of the existing GHG accounting standards for biochar.

System boundaries of analysed biochar standards are often not very clearly defined. Whilst it is clear that product-focused standards concentrate on assessment of biochar material properties, it is much less clear what scope of assessment GHG-focused standards take. They generally stipulate that they encompass a life cycle based assessment of biochar (and biomass feedstock in the case of BQM) throughout the stages of biomass sourcing, biochar production and use. On several occasions, however, it is unclear, what component activities they span. C-Sink, for instance, stipulates the requirement to account for the biochar-related processes until integration into the relevant matrix but it does not provide any material guidance on how to do so. Rather, the C-Sink guidelines provide guidance on how to account for GHG emissions up until the factory gate (see section "Quantifying life cycle emissions"), leaving it to the C-Sink trader to account GHG emissions accordingly. This raises questions on what is the role of the guidance, what freedom of accounting is left to the trader, and how robust will the final outcome be. From the assessed standards, only Puro.earth and Verra include a system boundary diagram to illustrating the borders of their assessment and increasing accuracy and transparency of GGR quantification.

Analysed biochar standards can obfuscate which GHG sources they cover, resorting to vague stipulations as to what is included in their GHG emission equation, often contradicting with other provisions of the standard. With regards to GHG emissions from biomass supply, C-Sink, for instance, initially provides GHG emissions estimates for fertilisation, use of diesel and pesticides, and requires these calculated emissions to be subtracted as carbon expenditures.[57] Simultaneously, C-Sink states that emissions for cultivation, harvest and plant protection are included in the margin of safety but that fertilisation and transport emissions must still be included. In the later text, when considering different feedstock sources, only fertilisation emissions are considered, making it unclear what the standard actually demands should be included in the calculation of GHG emissions from biomass sourcing.

The standards also hazily account for GHG emissions from biochar application. Puro.earth, for instance, includes GHG emissions related to biochar use, but only if the producer has this knowledge, which makes final outcome of certification fundamentally divergent. Verra, on the other hand, clearly outlines in a table which GHGs and

[55] Gert-Jan Nabuurs and others, 'Agriculture, Forestry and Other Land Uses (AFOLU)' in Climate Change 2022: Mitigation of Climate Change, Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press 2022), Chapter 7.
[56] For instance, International Organisation for Standardisation, Greenhouse gases, Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements (ISO 14064-2:2019).
[57] Section 2 of the C-Sink standard.

from which sources comprise the emissions from biochar application. However, when inspecting final emission calculation, Verra includes only GHG emissions from post-production treatment and excludes emissions from final application. Some other standards leave the consideration of included GHG sources entirely out of their scope. For example, BQM stipulates general component activities that must be covered but withholds any detailed provisions regarding GHG sources that are covered with the exception of direct and indirect land use change. Such a lack of clarity leads to potential inconsistencies and endangers completeness of the GHG accounting and reduces transparency of methodologies.

Completeness of assessment is also prejudiced by a general absence of baseline consideration relevant for GHG removal. Baseline accounting is necessary to show what would have been the state of GGR in the absence of the project and thus encompass the climate benefit of the activity. In the case of biochar specifically, a baseline assessment is required to compare the quantity of GGR from biochar to that which would have occurred without biomass feedstock harvesting and production. Only Verra and Puro.earth include a baseline consideration within its assessment and only Verra provides a baseline scenario, on which it grounds its analysis: use of waste biomass feedstock destined for decay or combustion (see section “Quantifying life cycle emissions”).

Both Puro.earth and Verra assume baseline value being zero. Furthermore, neither would clearly include consideration of GGR under the baseline and thus only indicate accounting life cycle emissions arising from the baseline scenario. Thereby, they are in danger of confounding GGR for avoided emissions, in particular when a non-zero baseline scenario is submitted (Puro.earth). This is less worrisome when only waste biomass feedstock is used which was destined to release its carbon content in the atmosphere, and providing that the underlining assumption regarding regrowth of utilised biomass is accepted. More problematic is a lack of GGR accounting under the baseline when dedicated biomass and forestry materials are used with a potential to sequester carbon by themselves or in combination with the use of other GGR approaches. A zero baseline approach can be useful when there is a pervading lack of understanding regarding emissions and removals under the baseline and the baseline is set to be accommodated with the rising level of knowledge. Nevertheless, if such a dynamic approach is taken, it must be transparent, unambiguous, and accurately explained in the standard. Overall, accounting for avoided emissions and presenting them as GGR must be prevented to ensure no misunderstanding ensues regarding the value of an activity complying with the standard.[58]

Soil application governance is absent

Soil offers a large storage potential for biochar with a view to maximising its climate mitigation contribution. Concurrently, biochar storage in soil offers potential co-benefits including soil improvement, fertilisation, and increased soil organic carbon stabilisation. Having a recalcitrant material such as biochar being input in soil in large volumes invokes some persistent environmental threats, such as risks of soil contamination with heavy metals, polycyclic aromatic hydrocarbons (PAHs) and PCDD/Fs. Applying biochar on soil in excessive volumes with an inappropriate approach can lead to water runoff and wind dispersion, raising environmental concerns beyond the immediate soil environment. This can include risks for human health due to an increase in airborne particulate matter (PM) particles. Type and place of application typically affect recalcitrance of carbon storage and affect the mineralisation of carbon present in the soil.[59] Thus, where and how biochar is stored forms an important aspect of retaining control and managing environmental effects. Despite presenting an important element in biochar governance, soil application is currently out of scope of most analysed biochar standards, therefore leaving this space largely ungoverned. Where standards include such considerations, they lack in measures to monitor and enforce such requirements.

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[58] Samantha Eleanor Tanzer and Andrea Ramírez, ‘When are negative emissions negative emissions?’ (2019) Energy & Environmental Science 12 1210.

[59] Alexandre Tisserant and Francesco Cherubini, ‘Potentials, Limitations, Co-Benefits, and Trade-Offs of Biochar Applications to “Quantifying life cycle emissions Soils for Climate Change Mitigation’ (2019) Land 8 179.

The analysed standards control application scantly and in a piecemeal manner. Puro.earth and C-Sink consider the soil application as affecting the carbon storage potential, whilst Verra and EBC have some limited requirements to facilitate safe and secure storage. Only the BQM approaches this more comprehensively by considering the toxicants present in biochar and in soil (see section "Soil application factors"). When soil application requirements limit biochar producers and users, in practice the standards refrain from imposing mechanisms to ensure that they are being followed. Understandingly, the analysed standards generally focus on governing biochar production processes whereas limiting users of biochar would overreach their scope. Biochar standards mandate chain of custody mechanisms but these stop recording early in the distribution chain (see section "MRV protocols"). Verra assumes permanence of biochar, ignoring potential leaching of biochar outside of a system boundary e.g. via runoff. This is despite Verra requiring provision of a geographical coordinate of the storage location to enable subsequent control of biochar storage. BQM, the standard with the most comprehensive approach to governing soil application, only requires confirmation from the producer that application guidelines were provided to the customer in order to become certified. Accordingly, in most cases, no effective controls are input on soil conditions, under which the biochar is applied, or on the biochar application process. Thus, standards do not provide a wholesome and overarching governance of biochar production and use.

MRV protocols lack robust data governance

Standards that would harness biochar potential for GGR must provide confidence that claimed net removals have indeed taken place. To ensure this, MRV protocols are required that provide robust data governance ensuring veracity of claimed biochar effects. Besides the previously described specific limitations of biochar standards relating to MRV post-production parameters, data governance is lacking on several points: data requirements are lenient, predominantly relying on estimations rather than measurements, procedures for measurement are unclear or not provided at all, and QA and QC procedures are lacking, although the product-focused standards fare better than the GHG-focused counterparts.

Whilst C-Sink and Verra reference product-focused standards for measuring some biochar features, Puro.earth does not provide specific testing methodologies. Puro.earth also enables using estimated biochar permanence with a default 14.9°C soil temperature to represent the global mean soil temperature when the main region for biochar use cannot be defined. Similarly, Artisan C-Sink and Verra allow the use of estimates for organic carbon content of biochar that depends on the feedstock used and assume that the temperature from low-technology facilities is sufficient to guarantee 100-year permanence of biochar (Artisan C-Sink: 82%, Verra: 56.22%). Verra uses the organic carbon content estimate in validation for all biochar production processes. Artisan C-Sink omits direct weighting of produced biochar and requires volume measurements through which mass of biochar can be calculated.

The GHG-focused standards also have a tendency to resort to assumptions and estimations with regards to emissions thus giving precedence to pragmatic assessment over accuracy. C-Sink provides a default estimate for the use of fertiliser and diesel. It also requires use of an estimate for biomass decay when it is not stored following the C-Sink guidelines. Verra assumes zero methane emissions when biochar is produced within a high-technology production facility that appropriately combusts most of the off gases. When biochar is produced in an unknown low-technology production kiln, Verra estimates 49 kg of methane is produced per tonne of biochar. Artisan C-Sink, considers a default value for methane emissions arising from biochar production (30 kg per tonne of biochar). C-Sink and Artisan C-Sink adopt a flat margin of safety in order to avoid under accounting GHG emissions which cannot be avoided, even if emission measurements are provided (Artisan C-Sink). In many instances (e.g., fossil fuel use in transport, pre-treatment of biomass, post-treatment of biochar), the assessed standards do not provide any specification whether GHG emissions should be measured or estimated and how that should be approached. Verra and Artisan C-Sink tend toward improving accuracy through measures such as MRV plans. BQM and Puro.earth only reference the general frameworks such as ISO 14040 series and PAS 2050. This uncertainty within the biochar standards creates ambiguity as to how GHG emission accounting should be done in practice with significant divergences and threats to accuracy and consistency.

Ultimately, the QA and QC requirements of standards that would seek to improve data governance are scarce. This is particularly holding true for GHG-focused standards and BQM (see section “MRV protocols”). They do not impose requirements for project proponents on quality management despite presenting a crucial element of credible emission and removal accounting. They are lacking considerations on quality management such as responsibility allocation, employee qualification demands, and internal auditing. Furthermore, their demands for external verification can be similarly problematic as they often fail to request independent verification or abstain from an elaboration on what “independent” stands for. Product-focused biochar standards provide more robust QA and QC requirements, especially EBC, WBC, and the EU Regulation on fertilising products. However, requirements regarding independence of verification of biochar features and production facilities are not clearly guaranteed within the product-focused standards, rather they rely on testing being done by an accredited laboratory. The EBC, for instance, does not truly provide independent verification of compliance with the standard rules because the two certification bodies that assess compliance are part of the same corporate group as the certification scheme provider (Carbon Standards International). Additionally, the laboratory that is eligible to do the testing for EBC must be accredited by that same certification provider, thus putting independence of their findings under question.

Conclusions

Biochar has substantial potential for mitigating climate change and thus contributing to the UK meeting its net zero emissions obligation due to its prospective drawdown of atmospheric GHG emissions that could compensate for emissions from hard-to-abate sectors and reverse effects of climate change whilst also offering agricultural benefits. Accordingly, product and GHG-focused biochar standards can be distinguished, each category dealing with a distinct biochar feature.

This report has compared biochar standards and identified the elements, in which they align:

- Biochar standards allow types of feedstock, in which there is generally less risk for contamination, and some types of domestically collected waste, either separately collected bio waste or biological fraction of mixed solid waste, combined with a limit on contamination.
- Except for requiring treatment of off gases, production parameters are not controlled directly but through biochar output, reporting, and compliance with local and national regulations. They abstain from explicitly including certification of high-carbon ash and putting emission limits on biochar production.
- To tackle environmental hazards of biochar applications, standards require testing for most heavy metals, 16 polycyclic aromatic hydrocarbons as recognised by US Environment Protection Agency (PAH16), dioxins and furans (PCDD/Fs) and polychlorinated biphenyls (PCBs), but range in the allowed limit values, especially for heavy metals. In general, they do not require specific tests for certain organic (benzo[e]pyrene and benzo[j]fluoranthene) and inorganic contaminants (Co, B, Cl, Na) and for germination inhibition of biochar.
- Standards deduct GHG project emissions from the stable carbon content of biochar, account beyond just biochar production process emissions, and cover biochar production emissions and transport emissions. They do not explicitly account lifecycle stages of manufacture, use, and disposal of each component activity.
- They consider biochar as ‘permanent’ if the material can withstand 100 years in soil which is most commonly estimated through $H:C_{org}$. Other methods of estimating permanence are less prominent and encompassed in specific standards only.
- In terms of soil application factors, standards only align passively in what they do not consider.

- MRV protocols generally require records management, chain of custody mechanisms, accredited laboratory testing and evidencing biomass supply through sustainable biomass sourcing schemes. GHG-focused standards generally stop monitoring biochar-related activities when acceptable utilisation is reached in which it can be assumed that biochar will avoid combustion.

The report has identified important gaps in the voluntary biochar standard landscape which must be addressed in the future in order to induce transparent confidence in biochar contribution to the net zero emissions target. First, quantification of GHG emissions and removals in those standards can be ambiguous, inconsistent and incomplete due to obfuscating system boundaries and GHG emission sources. Analysed standards overall neglect GGR baseline assessment increasing concerns about confounding GGR with avoided emissions. Second, biochar standards focus predominantly on biochar production and thereby omit soil application governance entirely. Even when standards provide soil application requirements those are generally not monitored. Finally, robustness and consistency of data governance procedures diverges substantially between product-focused standards and GHG-focused standards, with the latter being less well equipped to assure high data quality. Namely, GHG-focused standards predominantly rely on estimates instead of accurate measurements which in several instances abstain from providing relevant detail regarding testing or GHG emission quantification. Biochar standards, in particular, GHG-focused ones, contain few QA and QC safeguards to ensure accuracy and high quality data governance and lack provisions on robust verification of their findings.

Despite these gaps biochar standards play an important role in facilitating biochar contribution to the UK net zero emissions target where there is an absence of specific biochar-focused regulatory measures. Within England the Environment Agency's LRWP 60[60] and 61[61] aim to alleviate the uncertainty that biochar producers and users are facing as a consequence of biochar being governed as waste.[62] These regulatory positions provide criteria for when the Environment Agency will refrain from enforcing the legal requirement to attain an environmental waste permit for biochar production and application. In essence, enables biochar producer and user to operate without a permit despite using biochar that is considered waste when they meet criteria stipulated therein. However, the LRWPs are prohibitively stringent, for instance by only allowing biochar production from conservative biomass waste feedstock, and by only allowing one tonne of biochar soil input per hectare per year which makes it unusable for GGR purposes. At the same time, the LRWPs are lenient regarding avoidance of environmental harm. For example, they do not require any testing for toxicants and do not impose a cap on total soil applications. LRWPs also contain a narrow framing of biochar in the context of the waste regime. The application of other general legal frameworks to biochar such as the environmental permitting regime for pyrolysis facilities, UK REACH for registering produced biochar, a planning regime for biochar application which exceeds agricultural purposes, and diffuse agricultural pollution rules remains highly uncertain.

Without an outlined biochar-specific approach which recognises beneficial properties of biochar for GGR and as a soil amendment, producers and users in the UK find themselves in limbo of general obligations that may or may not suit the specifics of biochar production and application.[63] In absence of specific public regulation, the analysed standards act as crucial regulatory enablers filling the void in order to provide a standardised way of utilising biochar as a GGR, and provide some much-needed certainty to biochar operators and investors. Furthermore, with the lack of

[60] Environment Agency, Guidance Storing and treating waste to make biochar: LRWP 60 (HM Government, 6 April 2021) <https://www.gov.uk/government/publications/low-risk-waste-positions-miscellaneous/storing-and-treating-waste-to-make-biochar-lrwp-60> accessed 14.11.2023.

[61] Environment Agency, Guidance Storing and spreading biochar to benefit land: LRWP 61 (HM Government, 20 August 2019) <https://www.gov.uk/government/publications/low-risk-waste-positions-landspreading/storing-and-spreading-biochar-to-benefit-land-lrwp-61> accessed 14.11.2023.

[62] For more on that in the EU regulatory context see Luka Štrubelj, Waste, Fertilising Product, or Something Else? EU Regulation of Biochar (2022) 34 529.

[63] That is excluding Northern Ireland where EU Regulation on fertilising products applies by virtue of the Protocol on Ireland and Northern Ireland and enables compliant biochar product to be used as a soil amendment.

clarity of general regulatory regimes in the UK they remain the only comprehensive materialised guidelines for environmental protection of biochar production and use, offering some confidence to the public as to the environmental integrity of biochar that is input into the UK soil.

The analysed voluntary standards, however, should not be confused with the UK regulator's approach to biochar. A detailed analysis of public regulation and policy in this area is out of scope of this report, thus precluding the report from providing actionable government recommendations. Nevertheless, the report points to a general need for the regulatory frameworks to be calibrated in a way to control potentially harmful repercussions of biochar production and deployment, in particular where gaps in the voluntary sector were identified, but leave space for its further development. The precautionary principle mandates regulation in spite of remaining scientific uncertainties to protect the environment.[64] Importantly, UK regulators can build on the knowledge base present in existing private governance mechanisms and in foreign jurisdictions such as the EU, upgrading where needed. The EU Regulation on fertilising products already applies and enables biochar soil amendment products access to the internal market and to the soil of all member states. EU Carbon removal certification framework that is currently being adopted will lead to biochar use as a GGR.

[64] Department for Environment, Food & Rural Affairs (DEFRA), 'Environmental principles policy statement' (HM Government, 31.1.2023) <www.gov.uk/government/publications/environmental-principles-policy-statement/environmental-principles-policy-statement> accessed 15.11.2023.

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