Trust Creation with Blockchain and Distributed Ledger Technology (DLT) for Carbon and Biodiversity Credit Management

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Abstract *– Climate action and biodiversity conservation rely on market-based instruments like carbon and biodiversity credits to track and incentivise their impacts. Carbon credits compensate the carbon dioxide emissions, while biodiversity credits support ecosystem restoration. However, issues like double-counting and limited interoperability prevent their effectiveness. Blockchain and distributed ledger technology (DLT) enhance transparency, traceability and trust creation in credit management through smart contracts, tokens, DLT oracles and decentralised identifiers (DID). This article explores the role of blockchain and DLT in strengthening credit markets and proposes a technical architecture that is intended to feed ISO/TC307 standardisation efforts to improve trust and scalability in carbon and biodiversity credit management.*

Keywords *– Biodiversity Conservation, Biodiversity Credit, Blockchain, Carbon Credit, Climate Action, Credit Management, Credit Market, Distributed Ledger Technology, Sustainable Development*

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INTRODUCTION

A previous article showed that blockchain and distributed ledger technology (DLT) are now mature and viable in terms of scalability, sustainability and sovereignty, and detailed how they can now support the sustainable development efforts thanks to their inherent characteristics such as decentralisation, transparency, traceability or certification thus helping reaching the United Nations Sustainable Development Goals (SDGs) globally, and finally how blockchain and DLT perfectly fit with the European Green Deal and associated regulation in particular the circular economy action plan (CEAP), including the digital product passport (DPP), and the corporate sustainability reporting directive (CSRD) and associated reporting (ESRS E1, E4, E5) **[1]**.

The present article further studies the trust creation with blockchain and DLT for the specific use case of carbon and biodiversity credit management, which answers some of the United Nations Sustainable Development Goals, in particular UN SDG 13 (climate action), 14 and 15 (life below water and life on land).

This article introduces **climate action and biodiversity conservation challenges** (e.g. climate change adaptation, climate change mitigation, biodiversity loss), **data** (e.g. greenhouse gas (GHG) emissions, species abundance decline, land use change), **targets** (set in Paris Agreement, refined by IPCC and followed by UNFCCC, set in Kunming-Montreal Global Biodiversity Framework, refined by IPBES and followed by CBD) **and means** (e.g. GHG emission reduction and removal, biodiversity protection and restoration) (cf. **section I**).

Then, the article details the **carbon and biodiversity credit management concepts** (e.g. offset, credit, certificate, project, credit market), **processes** (i.e. credit management including project development and registration, project measurement, monitoring, reporting and verification (MRV), project validation, verification and certification, credit issuance, transfer and trading, claiming and credit retirement), **stakeholders** (including project developer, regulatory authority and standardisation body, registry, data and technology providers, project validator and verifier, auditor, credit issuer, marketplace, buyer and seller), **standards and regulations** (cf. **section II**),

Finally, the article explores **blockchain and DLT application to carbon and biodiversity credit management** including the **mechanisms behind trust creation**, the **use cases for sustainable development** (i.e. climate action, life below water and life on land), the **specific concepts for credit management** (e.g. asset, token, fungible token, non-fungible token (NFT), credit token, DLT oracle), the **technical architecture** (architecture elements e.g. blockchain and DLT, smart contract, token, MRV tools, DLT oracle, user interface and wallet, decentralised identifier (DID) and verifiable credential (VC)), **and blockchain and DLT-enabled credit management processes** (cf. **section III**).

I. INTRODUCTION TO CLIMATE ACTION AND BIODIVERSITY CONSERVATION: CHALLENGES, DATA, TARGETS AND MEANS

I.1. Climate Action: Challenges, Data, Targets and Means

I.1.a. Climate Action Challenges

Previous article listed some definitions for climate action **[1]** that are completed in present article. The **climate action terms** receiving some definitions are highlighted in **blue bold**, the **biodiversity conservation terms** in **green bold**, the **credit management terms** in **gold bold** and the **blockchain and DLT terms** in **dark red**.

Climate action is defined as a "human intervention to achieve climate change measures or goals based on mitigation or adaptation priorities under climate change policies" (ISO 14050:2020) **[2a]**. Climate action thus refers to climate, reacts to climate change, is given two means for this purpose with climate change adaptation and climate change mitigation and is guided by climate change policies.

In this context, **climate** is defined as a "statistical description of the weather in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years", **climate change** as a "change in climate that persists for an extended period, typically decades or longer", **climate change adaptation** (or adaptation to climate change) as the "process of adjustment to actual or expected climate and its effects" and **climate change mitigation** as some "human intervention to reduce greenhouse gas emissions or enhance greenhouse gas removals" (ISO 14050:2020). The climate change mitigation introduces the greenhouse gas and associated reduction or removal.

Greenhouse gas (GHG) is defined as "gaseous constituent of the atmosphere, both natural and anthropogenic [i.e. human-originated], that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019) **[2b] [2o] [2i]**, **greenhouse gas emission** (GHG emission) as the "release of a greenhouse gas into the atmosphere" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019) and **greenhouse gas removal** (GHG removal) as the "withdrawal of a greenhouse gas from the atmosphere by a greenhouse gas sink" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019). GHG emission and removal processes introduce the GHG source and sink.

The greenhouse gas emission refers to the **greenhouse gas source** (GHG source), which is defined as the "process that releases a GHG into the atmosphere" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019) whereas the greenhouse gas removal introduces the **greenhouse gas sink** (GHG sink), defined as the "process that removes a greenhouse gas from the atmosphere" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019), the **greenhouse gas reservoir** (GHG reservoir), defined as a "component, other than the atmosphere, that has the capacity to accumulate GHGs, and to store and release them", noting that "oceans, soils and forests are examples of components that can act as reservoirs" and noting that "GHG capture and storage is one of the processes that results in a GHG reservoir" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-3:2019), and the **greenhouse gas storage** (GHG storage) as the "process for retaining captured GHGs so that they do not reach the atmosphere" (ISO 14064-3:2019).

The **Kyoto Protocol** was adopted on December 11th 1997 and entered into force on February 16th 2005. The Protocol "operationalizes the United Nations Framework Convention on Climate Change [UNFCCC] by committing industrialized countries and economies in transition to limit and reduce greenhouse gases (GHG) emissions in accordance with agreed individual targets" and brings "the establishment of flexible market mechanisms, which are based on the trade of emissions permits. […] the Protocol also offers them an additional means to meet their targets by way of three market-based mechanisms: International Emissions Trading, Clean Development Mechanism (CDM) and Joint implementation (JI)" **[3a]**.

In particular, the "Clean Development Mechanism (CDM), defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO2, which can be counted towards meeting Kyoto targets" **[3b]**, thus introducing the concept of **carbon credit**.

Additionally, the Annex A of the Kyoto Protocol lists the types of greenhouse gas under focus: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6) **[3c]**.

To compare the greenhouse gas emissions, the **carbon dioxide equivalent** (CO2e) is defined as a "unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019). The carbon dioxide equivalent is measured in **metric tonne of CO2e** (tCO2e), typically in kilo tonnes of CO2e (ktCO2e) for individuals, in million tonnes of CO2e (MtCO2e) for companies or billion tonnes of CO2e (GtCO2e) for some countries and continents. The carbon dioxide equivalent introduces the radiative forcing of a GHG.

The **radiative forcing of a GHG** is defined as "the difference between incoming solar radiation on the Earth and outgoing thermal radiation from the Earth [noting that] a positive radiative forcing tends to warm the surface and a negative radiative forcing tends to cool the surface" (ISO 22948:2020) **[2c]**.

When carbon dioxide (CO2) and methane (CH4) gases, which are composed with carbon (C) atoms, are released or removed from the atmosphere, the GHG emission are referred to as **carbon dioxide emission** (CO2 emission) and **methane emission** (CH4 emission) respectively whereas GHG removal is referring to **carbon dioxide removal** (CO2 removal or CDR). Similarly, GHG source and GHG sink are referred to as **carbon source** and **carbon sink** respectively.

The oceans, soils and plants are examples of carbon sinks that depend on the **land**, defined as a "solid surface of the earth that is not permanently covered by water" (ISO 14050:2020) and **land use** (LU), defined as the "human use or management of land within the relevant boundary [i.e.] the **reporting boundary**" (ISO 14050:2020, ISO 14064-1:2018).

Examples of land use are **arable land** and **cropland** (for agricultural activities such as plant cultivation in rural areas), **grassland** and **grazing land** (for natural reserves or for agricultural activities such as pasture management for animal breeding e.g. livestock), **peatland** and **wetland** (for natural reserves or for market gardening in rural areas), **forest land** (for natural reserves or for forestry activities) and **settlements** and **built-up area** (for housing, industrial and services activities in urban areas) **[4]**. An **arable land** is defined as a "land capable of being ploughed and used to grow crops" (ISO 14050:2020) and is thus referred to as cropland.

A change in land use, or **land use change** (LUC), which is defined as a "change in the use or management of land by humans, which can lead to a change in land cover" (ISO 13065:2015) **[2d]**, can turn a carbon sink (e.g. forest land) into a carbon source (e.g. settlements after deforestation) and *vice versa*. As a result, a land use by human activities determines whether a land acts as a carbon sink or as a carbon source.

The **carbon footprint** (CF) is defined as a "sum of greenhouse gas (GHG) emissions and GHG removals of the subject expressed as carbon dioxide equivalents", the **subject** being an "**organisation** or a **product**" (ISO 14068-1:2023) **[2e]**.

In particular, the **carbon footprint of an organisation** is defined as "the sum of the direct GHG emissions, indirect GHG emissions and GHG removals, if applicable, within the boundary of the subject quantified in accordance with ISO 14064-1" (ISO 14068-1:2023). In details, **direct greenhouse gas emission** (direct GHG emission) is defined as "greenhouse gas emission from greenhouse gas sources owned or controlled by an organization" (ISO 14050:2020, ISO 14064-1:2018) whereas **indirect greenhouse gas emission** (indirect GHG emission) is defined as "greenhouse gas emission that is a consequence of an organization's operations and activities, but that arises from greenhouse gas sources that are not owned or controlled by the organization" (ISO 14050:2020, ISO 14064-1:2018).

The **carbon footprint of a product** (CFP) is defined as the "sum of greenhouse gas emissions and greenhouse gas removals in a product system, expressed as carbon dioxide equivalents and based on a life cycle assessment using the single impact category of climate change" (ISO 14050:2020, ISO 14064-3:2019).

I.1.b. Climate Action Data

The **climate action data** are mainly the **greenhouse gas emissions per subject** (in billion tonnes of CO2 equivalent) that are provided, beyond an organisation or a product, for additional subjects such as the **World** (e.g. 53.82 GtCO2e in 2023), a **continent** (e.g. 29.99 GtCO2e for Asia and 726.78 MtCO2e for Oceania in 2023) or a **country** (e.g. 13.97 GtCO2e for China and 334.28 MtCO2e for France in 2023) (cf. **Table I**) **[5a]**.

TABLE I. CLIMATE ACTION DATA – GREENHOUSE GAS EMISSIONS PER SUBJECT (IN BILLION TONNES OF CO2 EQUIVALENT)

GHG Emissions per Subject (in billion tonnes of CO2e)		1850	1950	1990	2000	2010	2015	2019	2020	2021	2022	2023
World		4.22 Gt	16.67 Gt	37.34 Gt	40.73 Gt	49.80 Gt	52.44 Gt	52.80 Gt	50.79 Gt	52.94 Gt	53.33 Gt	53.82 Gt
Continent	Africa	0.31 Gt	1.89 Gt	2.86 Gt	3.70 Gt	4.75 Gt	4.70 Gt	4.67 Gt	4.47 Gt	4.60 Gt	4.65 Gt	4.66 Gt
	Asia	1.31 Gt	4.06 Gt	12.46 Gt	15.43 Gt	23.68 Gt	27.21 Gt	28.26 Gt	27.64 Gt	28.70 Gt	29.06 Gt	29.99 Gt
	Europe	1.31 Gt	4.10 Gt	10.43 Gt	7.61 Gt	7.85 Gt	7.40 Gt	7.07 Gt	6.69 Gt	7.02 Gt	6.97 Gt	6.73 Gt
	North America	1.02 Gt	4.65 Gt	7.96 Gt	9.08 Gt	8.50 Gt	8.27 Gt	8.21 Gt	7.49 Gt	7.88 Gt	8.00 Gt	7.85 Gt
	Oceania	0.07 Gt	0.34 Gt	0.64 Gt	0.87 Gt	0.99 Gt	0.78 Gt	0.77 Gt	0.75 Gt	0.75 Gt	0.75 Gt	0.73 Gt
	South America	0.21 Gt	1.63 Gt	2.99 Gt	4.02 Gt	4.03 Gt	4.08 Gt	3.81 Gt	3.75 Gt	3.98 Gt	3.89 Gt	3.86 Gt
Country	Brazil	0.05 Gt	0.68 Gt	1.85 Gt	2.61 Gt	2.35 Gt	2.46 Gt	2.28 Gt	2.36 Gt	2.55 Gt	2.44 Gt	2.38 G
	Canada	0.08 Gt	0.47 Gt	0.79 Gt	0.90 Gt	0.79 Gt	0.86 Gt	0.84 Gt	0.76 Gt	0.77 Gt	0.81 Gt	0.80 Gt
	China	0.43 Gt	1.22 Gt	4.21 Gt	5.31 Gt	10.57 Gt	11.93 Gt	12.61 Gt	12.84 Gt	13.43 Gt	13.40 Gt	13.97 Gt
	France	0.11 Gt	0.32 Gt	0.56 Gt	0.49 Gt	0.44 Gt	0.40 Gt	0.38 Gt	0.35 Gt	0.37 Gt	0.36 Gt	0.33 Gt
	India	0.35 Gt	0.80 Gt	1.53 Gt	2.02 Gt	2.87 Gt	3.33 Gt	3.69 Gt	3.52 Gt	3.78 Gt	3.95 Gt	4.20 Gt
	Indonesia	0.10 Gt	0.48 Gt	1.07 Gt	1.39 Gt	1.56 Gt	2.50 Gt	2.10 Gt	1.68 GT	1.65 Gt	1.82 Gt	1.92 Gt
	Poland	0.05 Gt	0.15 Gt	0.50 Gt	0.40 Gt	0.39 Gt	0.35 Gt	0.37 Gt	0.35 Gt	0.38 Gt	0.36 Gt	0.34 Gt
	Russian Fed.	0.42 Gt	0.99 Gt	3.41 Gt	1.89 Gt	2.44 Gt	2.48 Gt	2.42 Gt	2.40 Gt	2.53 Gt	2.67 Gt	2.69 Gt
	UK	0.20 Gt	0.69 Gt	0.80 Gt	0.71 Gt	0.61 Gt	0.52 Gt	0.46 Gt	0.42 Gt	0.43 Gt	0.40 Gt	0.39 Gt
	USA	0.87 Gt	3.67 Gt	6.21 Gt	7.07 Gt	6.56 Gt	6.25 Gt	6.22 Gt	5.65 Gt	6.01 Gt	6.07 Gt	5.89 Gt

Source: Our World in Data (GHG emissions, including CO2, CH4 and N2O from all sources, including land use change)

A previous article **[1]** reminded that the United Nations defined 17 **Sustainable Development Goals** (SDGs) and 169 targets to be fulfilled by 2030 within the scope of the 2030 Agenda for Sustainable Development, which was adopted in 2015 **[6a] [6b]**. In particular, UN SDG 13 (climate action) refers to **climate action** whereas UN SDG 14 (life below water) and UN SDG 15 (life on land) refer to **biodiversity conservation** (marine and terrestrial biodiversity respectively).

About UN SDG 13, the United Nations SDG Report 2024 stated that "climate records were shattered in 2023, with the world watching the climate crisis unfold in real time. Communities around the world are suffering the effects of extreme weather, which is **destroying lives and livelihoods** on a daily basis. The roadmap to **limit the rise in global temperature** to 1.5°C and avoid the worst of climate chaos […] demands immediate action for drastic **reductions in global greenhouse gas emissions** in this decade and the achievement of net zero by 2050" **[6c]**.

I.1.c. Climate Action Targets

The **climate goals** are defined as "international long-term goals based on mitigation and adaptation priorities", noting that **international climate goals** were defined in the Paris Agreement (ISO 14097:2021) **[2f]**.

Indeed, **climate action targets** were set in the **Paris Agreement** during the United Nations Climate Change Conference of Parties (COP21) held in Paris, France. This Agreement was reached on Dec. 12th 2015 and entered into force on Nov. 4th 2016. The Agreement "sets long-term goals to guide all nations to:

1) substantially **reduce global greenhouse gas emissions** to **hold global temperature increase to well below 2°C** above pre-industrial levels [**goal 1**] and **pursue efforts to limit it to 1.5°C** above pre-industrial levels [**goal 2**], recognizing that this would significantly reduce the risks and impacts of climate change,
2) **periodically assess the collective progress** towards achieving the purpose of this agreement and its long-term goals,
3) **provide financing to developing countries to mitigate climate change**, strengthen resilience and enhance abilities to adapt to climate impacts" **[7a]**.

The Paris Agreement is a **legally binding international treaty**, under the United Nations Framework Convention on Climate Change (UNFCCC), which was signed by 195 parties including 194 states and the European Union (as of March 22nd 2025) **[7b]**. In order to assess the countries progresses, "every five years, each country is expected to submit an updated national climate action plan known as **Nationally Determined Contribution** (NDC). In their NDCs, countries communicate actions they will take to reduce their greenhouse gas emissions in order to reach the goals of the Paris Agreement. Countries also communicate in the NDCs actions they will take to build resilience to adapt to the impacts of rising temperatures" **[7a]**.

The Intergovernmental Panel on Climate Change (IPCC) published a special report in 2018 that provided two **CO2 emission reduction pathways** for limiting the global warming **[8a]**:

- Below **1.5°C**: CO2 emissions decline by about **45% from 2010 levels by 2030** and reach **net zero around 2050**,
- Below **2°C**: CO2 emissions decline by about **25% by 2030** and reach **net zero around 2070**".

Then, the IPCC published their sixth assessment report (AR6) in 2023, stating that "all global modelled pathways that limit warming to **1.5°C** with no or limited overshoot and those that limit warming to **2°C**, involve rapid and deep and, in most cases, **immediate greenhouse gas emissions reductions** in all sectors **this decade**. Global **net zero CO2 emissions** are reached for these pathway categories, in the **early 2050s** and around the **early 2070s**, respectively". The report reminded that GHG emissions were 12% higher in 2019 compared to 2010 and refined **GHG and CO2 emission reduction pathways** from 2019 emission levels with more recent data, also evaluating that net zero CO2 emissions will be reached before net zero GHG emissions (including CH4 emissions) (cf. **Table II**; IPCC) **[8b]**.

TABLE II. GREENHOUSE GAS EMISSION REDUCTION PER PATHWAY (IN PERCENT FROM 2019 EMISSION LEVELS)

GHG Emission Reduction per Pathway (in percent from 2019 emission levels)		2030	2035	2040	2050
1.5°C	GHG Emission Reduction	43%	60%	69%	84%
	CO2 Emission Reduction	48%	65%	80%	99%
2°C	GHG Emission Reduction	21%	35%	46%	64%
	CO2 Emission Reduction	22%	37%	51%	73%

Source: IPCC Sixth Assessment Report (SPM)

For this, the IPCC report detailed that "global modelled mitigation **pathways reaching net zero CO2 and GHG emissions** include transitioning from fossil fuels without carbon capture and storage (CCS) to very low- or zero-carbon energy sources, such as renewables or fossil fuels with CCS, demand-side measures and improving efficiency, reducing non-CO2 GHG emissions, and CDR. **In most global modelled pathways, land-use change and forestry** (via reforestation and reduced deforestation) **and the energy supply sector reach net zero CO2 emissions earlier** than the buildings, industry and transport sectors."

Furthermore, the IPCC report pointed out that "global GHG emissions in 2030 implied by nationally determined contributions (NDCs) announced by October 2021 make it likely that warming will exceed 1.5°C during the 21st century and make it harder to limit warming below 2°C. There are **gaps between projected emissions from implemented policies and those from NDCs** and finance flows fall short of the levels needed to meet climate goals across all sectors and regions".

Indeed, every five years (i.e. by 2020, 2030, 2035), the NDCs are submitted by parties to the UNFCCC secretariat **[9a]** and are recorded in the **NDC registry**, which is publicly available and maintained by the secretariat **[9b]**. These NDCs are used by the UNFCCC to prepare the **NDC synthesis report** that feeds e.g. the IPCC report or the UNEP emissions gap report. In particular, the 2024 release of the report concluded that global GHG emissions (including the latest NDCs, excluding land use change) are "estimated to be around 53.0 GtCO2e in 2025 and 51.5 GtCO2e in 2030, which are in 2025, 54.0 % higher than in 1990 (34.4 GtCO2e), 11.3% higher than in 2010 (47.6 GtCO2eq) and approximately the same as in 2019 (52.9 GtCO2e) and in 2030, 49.8 % higher than in 1990, 8.3 % higher than in 2010 and 2.6 % lower than in 2019, as well as 2.8 % lower than the estimated level for 2025, indicating the **possibility of global emissions peaking before 2030**" (UNFCCC NDC 2024) **[9c]**.

The IPCC report introduced the net zero CO2 emission that can be generalised. The **net zero greenhouse gas emission** (net zero GHG emission) is defined as a "condition in which metric weighted anthropogenic greenhouse gas (GHG) emissions are balanced by metric-weighted anthropogenic GHG removals over a specified period" (IPCC, sixth assessment report, annex I) whereas the **net zero greenhouse gas** (net zero GHG) is defined as a "condition in which human-caused residual GHG emissions are balanced by human-led removals over a specified period and within specified boundaries", noting that "human-led removals include ecosystem restoration, direct air carbon capture and storage [DACCS], reforestation and afforestation, enhanced weathering, biochar and other effective methods" (ISO IWA 42:2022) **[2g]**.

In particular, the **net zero carbon dioxide emission** (net zero CO2 emission) is defined as a "condition in which anthropogenic carbon dioxide (CO2) emissions are balanced by anthropogenic CO2 removals over a specified period" (IPCC, sixth assessment report, annex I) whereas the **net zero carbon** (NZC) is also defined as a "state in which a quantity of greenhouse gas (GHG) emissions is balanced by the same quantity of GHG removals", noting that "NZC can be applied within boundaries specified by the organization over a defined period of time", that "the GHG removals can be achieved by clean renewable energy generation" and that "the difference between CO2 and GHGs can be small or negligible for buildings but can be significant for industrial facilities" (ISO/PAS 50010:2023) **[2h]**.

I.1.d. Climate Action Means

In order to tackle the climate action challenges and to meet the climate action objectives, countries and organisations deploy some actions on a project basis. In this context, a **greenhouse gas project** (GHG project) is defined as an "activity or activities that alter the conditions of a GHG baseline and which cause GHG emission reductions or GHG removal enhancements" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019), the **greenhouse gas baseline** (GHG baseline) being defined as "quantitative reference(s) of GHG emissions and/or GHG removals that would have occurred in the absence of a GHG project and provides the baseline scenario for comparison with project GHG emissions and/or GHG removals" (ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019) and the **baseline scenario** as a "hypothetical reference case that best represents the conditions most likely to occur in the absence of a proposed GHG project" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019).

Beyond the GHG project, a **greenhouse gas programme** (GHG programme) is defined as a "voluntary or mandatory international, national or subnational system or scheme that registers, accounts or manages GHG emissions, GHG removals, GHG emission reductions or GHG removal enhancements outside the organization or GHG project" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019).

Two types of climate action means are derived with the greenhouse gas emission reduction and the greenhouse gas removal enhancement.

The **greenhouse gas emission reduction** (GHG emission reduction) is defined as a "quantified decrease in GHG emissions between a baseline scenario and the GHG project" (ISO 14050:2020, ISO 14064-2:2019, ISO 14064-3:2019) whereas the **carbon dioxide emission reduction** (CO2 emission reduction) is defined as a "calculated net decrease of CO2 emissions between a baseline scenario and the CCS [carbon dioxide capture and storage] project output", noting that "in most cases, a CO2 emission reduction may be referred to as CO2 avoided [which] may also refer to CO2 removals from the atmosphere" (ISO 27917:2017) **[2j]**. The carbon dioxide capture and storage (CSS) is one of the means for carbon dioxide emission reduction.

The **greenhouse gas removal enhancement** (GHG removal enhancement) is defined as a "quantified increase in GHG removals between a baseline scenario and the GHG project" (ISO 14050:2020, ISO 14064-2:2019, ISO 14064-3:2019), and the **carbon dioxide removal enhancement** is a specific case.

The IPCC report defined the **carbon dioxide removal** (CDR) as "technologies, practices, and approaches that remove and durably store carbon dioxide (CO2) from the atmosphere", reminded that "CDR is required to achieve global and national targets of net zero CO2 and greenhouse gas (GHG) emissions" and warned that "CDR cannot substitute for immediate and deep emissions reductions" (IPCC, sixth assessment report, annex III) **[8d]**.

The IPCC report classifies the **CDR methods** and their **applications** (i.e. land and ocean) and details some **methods** (i.e. afforestation, reforestation, improved forest management, soil carbon sequestration, biochar, carbon capture and storage (CCS), enhanced rock weathering, peatland and wetland restoration for land; blue carbon management, ocean alkalinity enhancement, ocean fertilisation for ocean), **implementation options** (e.g. agroforestry, tree planting, agricultural practices, pasture management, purpose-grown biomass crops, rewetting, revegetation for land; coastal revegetation for ocean), **storage timescale** (e.g. decade, century, millennium, more than 10 000 years), **financial cost** (in $ per tonne of CO2) and **trade-offs and risks** (IPCC, sixth assessment report, annex III; cf. **Table III**, which does not detail trade-offs and risks).

TABLE III. CLASSIFICATION OF CARBON DIOXIDE REMOVAL (CDR) METHODS

Application	Method	Implementation Option	Storage Timescale	Financial Cost ($ per tonne of CO2)
Land	Afforestation, Reforestation, Improved Forest Management	Agroforestry; Tree Planting, Silviculture; Timber in Construction; Bio-based Products	Decades to centuries (in vegetation, buildings, soils)	Afforestation and Reforestation: 0 to 240 $ / tCO2; Agroforestry and Forest Management: not enough data
	Soil Carbon Sequestration	Agricultural Practices; Pasture Management	Decades to centuries (in soils, sediments)	45 to 100 $ / tCO2
	Biochar	Cropping and Forestry Residues; Urban and Industrial Organic Waste; Purpose-grown Biomass Crops	Centuries to millennia (in soils, sediments)	10 to 345 $ / tCO2
	Bioenergy with Carbon Capture and Storage (BECCS)		More than 10 000 years (in geological formations)	50 to 200 $ / tCO2
	Direct Air Carbon Capture and Storage (DACCS)	Solid Sorbent; Liquid Solvent	More than 10 000 years (in geological formations)	100 to 300 $ / tCO2
	Enhanced Rock Weathering	Spreading Crushed Silicate Rock	More than 10 000 years (in minerals)	50 to 200 $ / tCO2
	Peatland and Wetland Restoration	Rewetting; Revegetation	Decades to centuries (in vegetation, soils, sediments)	Not enough data
Ocean	Blue Carbon Management	Rewetting; Coastal Revegetation (e.g. mangroves, seagrass, saltmarsh)	Decades to centuries (in vegetation, soils, sediments)	Not enough data
	Ocean Alkalinity Enhancement	Adding Alkaline Materials such as Carbonate or Silicate Rock	More than 10 000 years (in minerals)	40 to 260 $ / tCO2
	Ocean Fertilisation	Iron Fertilisation; Nitrogen and Phosphorus Fertilisation; Enhanced Upwelling	Centuries to millennia (in marine sediment)	50 to 500 $ / tCO2

Source: IPCC, sixth assessment report, Annex III (CDR)

The IPCC report detailed that “there are potential synergies between sustainable development and, for instance, **energy efficiency** and **renewable energy**. Similarly, depending on the context, **biological CDR** methods like reforestation, improved forest management, soil carbon sequestration, peatland restoration and coastal blue carbon management can **enhance biodiversity and ecosystem functions**, employment and local livelihoods. However, afforestation or production of biomass crops can have adverse socio-economic and environmental impacts, including on biodiversity, food and water security, local livelihoods and the rights of Indigenous Peoples, especially if implemented at large scales and where land tenure is insecure. Modelled pathways that assume using resources more efficiently or that shift global development towards sustainability include fewer challenges, such as less **dependence on CDR** and **pressure on land and biodiversity**” (IPCC, sixth assessment report, annex I).

Among the CDR methods, the **carbon dioxide capture and storage** (CCS), covering bioenergy with CCS (BECCS) and direct air CCS (DACCS), is defined as the “long-term removal, capture or reduction of carbon dioxide from the atmosphere to slow or reverse CO2e saturation and to mitigate or reverse global warming” and **carbon sequestration** is defined as a “process by which carbon dioxide is removed from the atmosphere and incorporated as biogenic carbon in biomass, through photosynthesis and other processes associated with the carbon cycle” (ISO 6707-3:2022) **[2k]**, the **biomass** being defined as a “material of biological origin excluding material embedded in geological formations and material transformed to fossilized material” noting that “biomass includes organic material (both living and dead), e.g. trees, crops, grasses, tree litter, algae, animals, manure and waste of biological origin” (ISO 14050:2020, ISO 14064-1:2018).

I.2. Biodiversity Conservation: Challenges, Data, Targets and Means

I.2.a. Biodiversity Conservation Challenges

Previous article listed some definitions for biodiversity **[1]** that are completed in present article.

Biodiversity conservation is defined as the "active management of the ecosystem to ensure the survival of the maximum diversity of species and the maintenance of genetic variability within them" (ISO 23405:2022) **[2l]**.

Biodiversity conservation directly refers to the **biodiversity**, literally the biological diversity, defined as the "variability among living organisms on the earth, including the variability within and between species, and within and between ecosystems" (ISO 14050:2020) and inherent components i.e. **ecosystem diversity**, **species diversity** and **genetic diversity**.

The United Nations Convention on Biological Diversity (CBD) distinguishes **in-situ conservation**, defined as "the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties", and **ex-situ conservation**, defined as "the conservation of components of biological diversity outside their natural habitats" **[10a]**.

The biodiversity conservation applies to ecosystems, habitats and species. An **ecosystem** is defined as a "dynamic complex of communities of plants, animals and microorganisms and their non-living environment, interacting as a functional entity" (CBD, ISO 14050:2020), a **habitat** as "the place or type of site where an organism or population naturally occurs" (CBD, ISO 14055-1:2017) **[2m]** and a **species** as "a group of organisms capable of interbreeding freely with each other but not with members of other species" (CBD) **[10b]**.

Biodiversity conservation reacts to **biodiversity loss**, described as "the reduction of any aspect of biological diversity (i.e. diversity at the genetic, species and ecosystem levels) [is] lost in a particular area through death (including extinction), destruction or manual removal; it can refer to many scales, from global extinctions to population extinctions, resulting in decreased total diversity at the same scale" (IPBES) **[11a]**.

According to the United Nations Environment Programme (UNEP), the five drivers of the nature crisis, i.e. the five **causes of biodiversity loss**, are **invasive alien species**, **changes in land and sea use, climate change**, **pollution** and **direct exploitation of natural resources** (i.e. overexploitation) **[12a]**.

I.2.b. Biodiversity Conservation Data

The **biodiversity conservation data** are based on several indicators. Among them, the **Living Planet Index** (LPI) measures the **species abundance decline** for 34 836 wildlife populations across 5 495 native species relative to the year 1970 (i.e. 1970 is associated to the index value of 100%) for the **World** (e.g. 27.1% in 2020) or per **Continent** (cf. **Table IV**) **[5b]**.

TABLE IV. BIODIVERSITY CONSERVATION DATA – LIVING PLANET INDEX (LPI)

Living Planet Index (LPI)		1970	1980	1990	2000	2010	2015	2016	2017	2018	2019	2020
World		100%	78.4%	60.1%	44.4%	31.1%	28.6%	27.8%	27.4%	27.1%	27.3%	27.1%
Continent	Africa	100%	61.5%	43.6%	40.7%	31.5%	26.0%	25.6%	25.6%	25.3%	24.6%	24.0%
	Asia & Pacific	100%	101.2%	90.7%	60.8%	42.0%	47.2%	45.7%	45.3%	43.2%	41.9%	39.6%
	Europe & Central Asia	100%	111.8%	128.2%	97.3%	85.4%	68.2%	66.2%	63.7%	62.7%	63.5%	64.7%
	Latin America & Caribbean	100%	63.4%	35.6%	19.0%	9.5%	6.5%	6.0%	5.6%	5.6%	5.7%	5.4%
	North America	100%	91.4%	85.1%	72.7%	72.1%	69.8%	69.4%	68.7%	66.5%	64.2%	61.0%

Source: Our World in Data (Living Planet Index (LPI), central estimate)

This index is completed with the **land use change due to human activities in billion hectares** (Gha) for **forest land**, **settlements** and **built-up area**, **grassland** and **grazing land** as well as **cropland** for the **World**, per **Continent** or per **Country** (cf. **Tables V**; Our World in Data, FAO) **[5c] [5d] [13]**.

TABLE V. BIODIVERSITY CONSERVATION DATA –LAND USE CHANGE DUE TO HUMAN ACTIVITIES (IN BILLION HECTARES)

Human Land Use over the long-term (in billion hectares)			-10000	-5000	1700	1900	1950	2000	2010	2018	2020	2021	2022	2023
World		Built-up Area	0.00 Gha	0.00 Gha	0.00 Gha (1% (1))	0.01 Gha (1%)	0.02 Gha (1%)	0.05 Gha	0.07 Gha	0.08 Gha (1%)	0.08 Gha	0.08 Gha	0.08 Gha	0.08 Gha
		Crop-land	0.00 Gha	0.00 Gha	0.33 Gha (3%)	0.90 Gha (8%)	1.20 Gha (12%)	1.49 Gha	1.51 Gha	1.59 Gha (15%)	1.60 Gha	1.61 Gha	1.62 Gha	1.63 Gha
		Forest land	6 Gha (57%)	No data (55%)	No data (52%)	No data (48%)	No data (44%)	4.16 Gha	4.10 Gha	4.07 Gha (38%)	4.06 Gha	4.05 Gha	4.05 Gha	No data
		Grass-land (2)	4.6 Gha (42%)	No data (44%)	No data (38%)	No data (27%)	No data (12%)	No data	No data	1.74 Gha (14%)	No data	No data	No data	No data
		Grazing Land	0.00 Gha (<1%)	0.01 Gha (1%)	0.60 Gha (6%)	1.57 Gha (16%)	2.49 Gha (31%)	3.32 Gha	3.26 Gha	3.20 Gha (31%)	3.21 Gha	3.20 Gha	3.20 Gha	3.20 Gha
Conti-nent	Africa	Built-up Area	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha
		Crop-land	0.00 Gha	0.00 Gha	0.05 Gha	0.08 Gha	0.13 Gha	0.23 Gha	0.26 Gha	0.28 Gha	0.28 Gha	0.28 Gha	0.29 Gha	0.29 Gha
		Forest land	No data	No data	No data	No data	No data	0.68 Gha	0.65 Gha	0.64 Gha	0.64 Gha	0.63 Gha	0.63 Gha	No data
		Grazing Land	0.00 Gha	0.00 Gha	0.22 Gha	0.38 Gha	0.67 Gha	0.88 Gha	0.87 Gha	0.85 Gha	0.86 Gha	0.86 Gha	0.86 Gha	0.86 Gha
	Asia	Built-up Area	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.01 Gha	0.02 Gha	0.02 Gha	0.02 Gha	0.02 Gha	0.02 Gha	0.03 Gha
		Crop-land	0.00 Gha	0.00 Gha	0.17 Gha	0.35 Gha	0.45 Gha	0.58 Gha	0.58 Gha	0.61 Gha	0.62 Gha	0.63 Gha	0.63 Gha	0.64 Gha
		Forest land	No data	No data	No data	No data	No data	0.59 Gha	0.61 Gha	0.62 Gha	0.62 Gha	0.62 Gha	0.62 Gha	No data
		Grazing Land	0.00 Gha	0.01 Gha	0.25 Gha	0.64 Gha	0.71 Gha	1.06 Gha	1.05 Gha	1.04 Gha	1.04 Gha	1.04 Gha	1.04 Gha	1.04 Gha
	Europe	Built-up Area	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.02 Gha	0.02 Gha
		Crop-land	0.00 Gha	0.00 Gha	0.10 Gha	0.29 Gha	0.32 Gha	0.30 Gha	0.29 Gha	0.29 Gha	0.29 Gha	0.29 Gha	0.29 Gha	0.29 Gha
		Forest land	No data	No data	No data	No data	No data	1.00 Gha	1.01 Gha	1.02 Gha	1.02 Gha	1.02 Gha	1.02 Gha	No data
		Grazing Land	0.00 Gha	0.00 Gha	0.10 Gha	0.16 Gha	0.17 Gha	0.18 Gha	0.18 Gha	0.17 Gha	0.17 Gha	0.17 Gha	0.17 Gha	0.17 Gha
	North America	Built-up Area	0.00 Gha	0.00 Gha	0.00 Gha	0.01 Gha	0.01 Gha	0.02 Gha	0.02 Gha	0.02 Gha	0.03 Gha	0.03 Gha	0.03 Gha	0.03 Gha
		Crop-land	0.00 Gha	0.00 Gha	0.00 Gha	0.17 Gha	0.25 Gha	0.26 Gha	0.24 Gha	0.24 Gha	0.25 Gha	0.25 Gha	0.25 Gha	0.25 Gha
		Forest land	No data	No data	No data	No data	No data	0.75 Gha	0.75 Gha	0.75 Gha	0.75 Gha	0.75 Gha	0.75 Gha	No data
		Grazing Land	0.00 Gha	0.00 Gha	0.02 Gha	0.19 Gha	0.34 Gha	0.35 Gha	0.36 Gha	0.36 Gha	0.36 Gha	0.36 Gha	0.35 Gha	0.35 Gha
	Oceania	Built-up Area	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha
		Crop-land	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.03 Gha	0.03 Gha	0.03 Gha	0.03 Gha	0.03 Gha	0.03 Gha	0.03 Gha
		Forest land	No data	No data	No data	No data	No data	0.18 Gha	0.18 Gha	0.18 Gha	0.18 Gha	0.18 Gha	0.18 Gha	No data
		Grazing Land	0.00 Gha	0.00 Gha	0.00 Gha	0.10 Gha	0.33 Gha	0.40 Gha	0.34 Gha	0.32 Gha	0.31 Gha	0.32 Gha	0.32 Gha	0.31 Gha

	South America	Built-up Area	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha
		Crop-land	0.00 Gha	0.00 Gha	0.00 Gha	0.01 Gha	0.04 Gha	0.09 Gha	0.11 Gha	0.13 Gha	0.13 Gha	0.13 Gha	0.13 Gha	0.13 Gha
		Forest land	No data	No data	No data	No data	No data	0.92 Gha	0.87 Gha	0.85 Gha	0.84 Gha	0.84 Gha	0.84 Gha	No data
		Grazing Land	0.00 Gha	0.00 Gha	0.02 Gha	0.11 Gha	0.27 Gha	0.45 Gha	0.46 Gha	0.46 Gha	0.46 Gha	0.46 Gha	0.46 Gha	0.46 Gha
Coun-try	Brazil	Forest land	No data	No data	No data	No data	No data	0.55 Gha	0.51 Gha	0.50 Gha	0.50 Gha	0.50 Gha	0.49 Gha	No data
	Canada	Forest land	No data	No data	No data	No data	No data	0.35 Gha	0.35 Gha	0.35 Gha	0.35 Gha	0.35 Gha	0.35 Gha	No data
	China	Forest land	No data	No data	No data	No data	No data	0.18 Gha	0.20 Gha	0.22 Gha	0.22 Gha	0.22 Gha	0.22 Gha	No data
	France	Forest land	No data	No data	No data	No data	No data	0.02 Gha	0.02 Gha	0.02 Gha	0.02 Gha	0.02 Gha	0.02 Gha	No data
	India	Forest land	No data	No data	No data	No data	No data	0.07 Gha	0.07 Gha	0.07 Gha	0.07 Gha	0.07 Gha	0.07 Gha	No data
	Indonesia	Forest land	No data	No data	No data	No data	No data	0.10 Gha	0.10 Gha	0.09 Gha	0.09 Gha	0.09 Gha	0.09 Gha	No data
	Poland	Forest land	No data	No data	No data	No data	No data	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	0.01 Gha	No data
	Russian Fed.	Forest land	No data	No data	No data	No data	No data	0.81 Gha	0.82 Gha	0.82 Gha	0.82 Gha	0.82 Gha	0.82 Gha	No data
	UK	Forest land	No data	No data	No data	No data	No data	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	0.00 Gha	No data
	USA	Forest land	No data	No data	No data	No data	No data	0.30 Gha	0.31 Gha	0.31 Gha	0.31 Gha	0.31 Gha	0.31 Gha	No data

Sources: Our World in Data (Land use, (1) in percent of a total of 10.6 Gha; Forest area, including (2) wild grassland and shrubs), FAO (Global Forest Resources Assessment 2020)

About UN SDG 14, the United Nations (UN) SDG report 2024 stated that “oceans cover over 70% of the Earth’s surface and play a crucial role in providing food and livelihoods for more than 3 billion people as well as combating the effects of climate change. Yet, alarming trends from **declining fish stocks, marine pollution, ocean acidification and habitat destruction** threaten marine ecosystems and the livelihoods of coastal communities worldwide. Urgent action is needed to address these challenges and ensure the long-term health and sustainability of the ocean through sustainable fishing practices, **marine conservation efforts**, **pollution reduction** and global cooperation to safeguard marine life and ecosystems for future generations” **[6c]**.

About UN SDG 15, the UN report stated that “SDG 15 underscores the critical importance of biodiversity as humanity’s life-support system. Yet, the relentless **depletion of forests,** coupled with an alarming rate of **species extinction** and **stagnation in safeguarding key biodiversity areas**, jeopardizes the delicate balance of our ecosystems. To address the pressing global environmental challenges and crises, including climate change, **biodiversity loss**, and pollution, as well as desertification, **land and soil degradation**, drought and **deforestation**, it is imperative to intensify efforts in fulfilling our global environmental and biodiversity commitments” (UN, SDG Report 2024).

I.2.c. Biodiversity Conservation Targets

The **biodiversity conservation targets** were set in the **Kunming-Montreal Global Biodiversity Framework** (GBF) during the United Nations Biodiversity Conference of Parties (COP15) held in Montreal, Canada. This agreement was adapted on Dec. 19th 2022 and sets **4 goals** for 2050 (CBD) **[10c]**:

- “**Goal A**: the integrity, connectivity and resilience of all ecosystems are maintained, enhanced, or restored, substantially increasing the area of natural ecosystems by 2050; **human induced extinction of known threatened species is halted**, and, **by 2050, the extinction rate and risk of all species are reduced tenfold** and **the abundance of native wild species is increased to healthy and resilient levels**; The genetic diversity within populations of wild and domesticated species, is maintained, safeguarding their adaptive potential.
- **Goal B**: biodiversity is sustainably used and managed and **nature’s contributions to people** [NCP], **including ecosystem functions and services, are valued, maintained and enhanced** […].

- **Goal C**: the **monetary and non-monetary benefits from the utilization of genetic resources** and digital sequence information on genetic resources, and of traditional knowledge associated with genetic resources, as applicable, **are shared fairly and equitably** […].
- **Goal D**: **adequate means of implementation**, including financial resources, capacity-building, technical and scientific cooperation, and access to and transfer of technology to fully implement the Kunming-Montreal Global Biodiversity Framework **are secured and equitably accessible to all Parties** […]".

The Kunming-Montreal GBF sets "**23 action-oriented global targets** for urgent action over the decade to 2030. **The actions set out in each target need to be initiated immediately and completed by 2030**. Together, the results will enable achievement towards the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the [United Nations] Convention on Biological Diversity […]" (cf. **Table VI**).

TABLE VI. KUNMING-MONTREAL GLOBAL BIODIVERSITY FRAMEWORKS (GBF) PURPOSES & TARGETS

Purpose	Number of targets	Target
Reducing threats to biodiversity	8	1 **Ensure that all areas are under participatory, integrated and biodiversity inclusive spatial planning and/or effective management processes** addressing land- and sea-use change, to bring the loss of areas of high biodiversity importance, including ecosystems of high ecological integrity, close to zero by 2030, while respecting the rights of indigenous peoples and local communities.
		2 **Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and marine and coastal ecosystems are under effective restoration**, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.
		3 **Ensure and enable that by 2030 at least 30 per cent of terrestrial and inland water areas, and of marine and coastal areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved** […] Note: this target is also known as "30x30"
		4 **Ensure urgent management actions to halt human induced extinction of known threatened species and for the recovery and conservation of species, in particular threatened species**, to significantly reduce extinction risk, as well as to **maintain and restore the genetic diversity** within and between populations of native, wild and domesticated species to maintain their adaptive potential, including through in situ and ex situ conservation and sustainable management practices, and effectively manage human-wildlife interactions to minimize human-wildlife conflict for coexistence.
		5 **Ensure that the use, harvesting and trade of wild species is sustainable, safe and legal**, preventing overexploitation, minimizing impacts on non-target species and ecosystems, and reducing the risk of pathogen spillover, applying the ecosystem approach, while respecting and protecting customary sustainable use by indigenous peoples and local communities.
		6 **Eliminate, minimize, reduce and or mitigate the impacts of invasive alien species on biodiversity and ecosystem services** […].
		7 **Reduce pollution risks and the negative impact of pollution from all sources by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services, considering cumulative effects** […]
		8 **Minimize the impact of climate change and ocean acidification on biodiversity and increase its resilience** through mitigation, adaptation, and disaster risk reduction actions, including through nature-based solutions and/or ecosystem-based approaches, while minimizing negative and fostering positive impacts of climate action on biodiversity.
Meeting people's needs through sustainable use and benefit-sharing	5	9 **Ensure that the management and use of wild species are sustainable**, thereby providing social, economic and environmental benefits for people […].
		10 **Ensure that areas under agriculture, aquaculture, fisheries and forestry are managed sustainably**, in particular through the sustainable use of biodiversity, including through a substantial increase of the application of biodiversity friendly practices, such as sustainable intensification, agroecological and other innovative approaches, contributing to the resilience and long-term efficiency and productivity of these production systems, and to food security, conserving and restoring biodiversity and maintaining nature's contributions to people, including ecosystem functions and services.
		11 **Restore, maintain and enhance nature's contributions to people**, including ecosystem functions and services, such as the regulation of air, water and climate, soil health, pollination and reduction of disease risk, as well as protection from natural hazards and disasters, through nature-based solutions and/or ecosystem-based approaches for the benefit of all people and nature.
		12 **Significantly increase the area and quality, and connectivity of, access to, and benefits from green and blue spaces in urban and densely populated areas sustainably** […].
		13 **Take effective legal, policy, administrative and capacity-building measures at all levels**, as appropriate, **to ensure the fair and equitable sharing of benefits that arise from the utilization of genetic resources** and from digital sequence information on genetic resources, as well as traditional knowledge associated with genetic resources, and facilitating appropriate access to genetic resources, and by 2030, facilitating a significant increase of the benefits shared, in accordance with applicable international access and benefit-sharing instruments.

Tools and solutions for implementa-tion and main-streaming	7	14 **Ensure the full integration of biodiversity and its multiple values into policies, regulations, planning and development processes**, poverty eradication strategies, strategic environmental assessments, environmental impact assessments and, as appropriate, national accounting, within and across all levels of government and across all sectors, in particular those with significant impacts on biodiversity, progressively aligning all relevant public and private activities, and fiscal and financial flows with the goals and targets of this framework.
		15 **Take legal, administrative or policy measures to encourage and enable business, and in particular to ensure that large and transnational companies and financial institutions**: (a) **Regularly monitor, assess, and transparently disclose their risks, dependencies and impacts on biodiversity** […]; (b) Provide information needed to consumers to promote sustainable consumption patterns; (c) Report on compliance with access and benefit-sharing regulations and measures, as applicable; […]
		16 **Ensure that people are encouraged and enabled to make sustainable consumption choices** […]
		17 **Establish, strengthen capacity for, and implement in all countries, biosafety measures** as set out in Article 8(g) of the Convention on Biological Diversity and measures for the handling of biotechnology and distribution of its benefits as set out in Article 19 of the Convention.
		18 **Identify by 2025, and eliminate, phase out or reform incentives**, including subsidies, harmful for biodiversity, in a proportionate, just, fair, effective and equitable way, while substantially and progressively reducing them by at least $500 billion per year by 2030, starting with the most harmful incentives, and scale up positive incentives for the conservation and sustainable use of biodiversity.
		19 **Substantially and progressively increase the level of financial resources from all sources**, […] to implement national biodiversity strategies and action plans, mobilizing at least $200 billion per year by 2030, including by: (a) **Increasing total biodiversity related international financial resources from developed countries**, […] to at least $20 billion per year by 2025, and to at least $30 billion per year by 2030; (b) Significantly increasing domestic resource mobilization […]; (c) Leveraging private finance, promoting blended finance, implementing strategies for raising new and additional resources, and encouraging the private sector to invest in biodiversity, including through impact funds and other instruments; (d) **Stimulating innovative schemes such as payment for ecosystem services**, green bonds, **biodiversity offsets and credits**, and benefit-sharing mechanisms, with environmental and social safeguards; (e) Optimizing co-benefits and synergies of finance targeting the biodiversity and climate crises; (f) Enhancing the role of collective actions […]; (g) Enhancing the effectiveness, efficiency and transparency of resource provision and use.
		20 Strengthen capacity-building and development, access to and transfer of technology, and promote development of and access to innovation and technical and scientific cooperation […].
Mother Earth Centric Actions […]	3	21 **Ensure that the best available data, information and knowledge are accessible** to decision makers, practitioners and the public to guide effective and equitable governance, integrated and participatory management of biodiversity, and to strengthen communication, awareness-raising, education, monitoring, research and knowledge management […].
		22 **Ensure the full, equitable, inclusive, effective and gender-responsive representation and participation in decision-making**, and access to justice and information related to biodiversity […].
		23 **Ensure gender equality in the implementation of the Framework through a gender-responsive approach** […].

Source: CBD (Kunming-Montreal GBF)

In particular, target 19 encourages "stimulating innovative schemes such as payment for ecosystem services, […] biodiversity offsets and credits", thus introducing the concepts of **ecosystem service**, defined as "benefit people obtain from one or several ecosystems" (ISO 14050:2020) and **biodiversity credit**.

The Kunming-Montreal GBF is a **legally binding international treaty** under the United Nations Convention on Biodiversity (CBD). To assess the progresses for each COP, countries are expected to submit their updated **National Biodiversity Strategies and Action Plans** (NBSAP) through the **Online Reporting Tool** (ORT) **[10d]**.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) published in 2019 their global assessment report. This report precedes the Kunming-Montreal Global Biodiversity Framework and relies on the Aishi Biodiversity Targets for evaluating the progress of actions in favour of biodiversity conservation and sustainable use of nature **[11b]**.

The **Aishi Biodiversity Targets** were a set of **5 strategic goals** and **20 global biodiversity targets** that were adopted by the CBD in 2010 at the COP10 held in Aichi, Japan. These targets influenced and were replaced with the 4 goals for 2050 and the 23 targets for 2030 of the Kunming-Montreal GBF e.g. the Aishi target 11 (protect 17% of land and 10% of oceans by 2020) was replaced with the GBF target 3 (also known as "30x30" i.e. protect 30% of land and 30% of oceans by 2030), the Aishi target 20 (increase financial resources for biodiversity conservation) with the GBF target 19 (mobilise $200 billion per year for biodiversity and introduce biodiversity credits) and the Aishi target 15 (restore at least 15% of degraded ecosystems) with the GBF target 2 (restore at least 30% of degraded ecosystems by 2030).

I.2.d Biodiversity Conservation Means

In order to tackle the biodiversity conservation challenges and meet the biodiversity conservation targets, countries and organisations deploy some actions on a project basis.

The WWF provides the latest status on biodiversity conservation. Firstly, "over the past 50 years (1970–2020), **the average size of monitored wildlife populations has shrunk by 73%**, as measured by the Living Planet Index (LPI). This is based on almost 35,000 population trends and 5,495 species of amphibians, birds, fish, mammals and reptiles. Freshwater populations have suffered the heaviest declines, falling by 85%, followed by terrestrial (69%) and marine populations (56%). At a regional level, the fastest declines have been seen in Latin America and the Caribbean – a concerning 95% decline – followed by Africa (76%) and the Asia and the Pacific (60%). Declines have been less dramatic in Europe and Central Asia (35%) and North America (39%), but this reflects the fact that large-scale impacts on nature were already apparent before 1970 in these regions: some populations have stabilized or increased thanks to conservation efforts and species reintroductions. **Habitat degradation and loss, driven primarily by our food system**, is the most reported threat in each region, followed by overexploitation, invasive species and disease. **Other threats include climate change** (most cited in Latin America and the Caribbean) **and pollution** (particularly in North America and Asia and the Pacific)" (WWF, Living Planet Report 2024) **[14a] [14b]**.

Secondly, "despite the alarming overall decline in wildlife populations shown in the LPI, **many populations have stabilized or increased as a result of conservation efforts**. […] **Protected areas have been the cornerstone of traditional conservation efforts, and currently cover 16% of the planet's lands and 8% of its oceans** […]. Target 3 of the Kunming-Montreal Global Biodiversity Framework (GBF) calls for 30% of lands, waters and sea to be protected by 2030, while Target 2 aims to restore 30% of degraded areas by 2030" (WWF, Living Planet Report 2024).

Thirdly, "**food production is one of the main drivers of nature's decline**: it uses **40% of all habitable land**, is the **leading cause of habitat loss**, accounts for **70% of water use** and is **responsible for over a quarter of greenhouse gas emissions**" (WWF, Living Planet Report 2024).

The **biodiversity loss** covers many aspects such as species loss (e.g. species extinction), genetic loss (e.g. genetic erosion) and ecosystem loss (e.g. forest loss due to deforestation, habitat loss due to habitat fragmentation or habitat degradation).

As illustrations, the **species extinction** is defined as "a population, species or more inclusive taxonomic group [that] has gone extinct when all its individuals have died", in particular "a species may go extinct locally (population extinction), regionally (e.g., extinction of all populations in a country, continent or ocean) or globally". For this, "the **IUCN Red List** categories and criteria require there to be no reasonable doubt that all individuals have died, before a species is formally listed as Extinct" (IPBES) **[11b]**. The **IUCN Red List categories** are Extinct (EX), Extinct in the Wild (EW), threaten which embeds the 3 sub-categories Critically Endangered (CR), Endangered (EN) and Vulnerable (VU), Near Threaten (NT) and Least Concerned (LC) species **[15a]**.

The **Genetic erosion** is defined as "the loss of genetic diversity, including the loss of individual genes or particular combinations of genes, and loss of varieties and crops" (IPBES) **[11b]**.

Forest loss may be due to **wildfire** or **deforestation**, which is defined as the "permanent and intentional clearing of forested land by humans, often for agricultural expansion, timber harvesting for fuel or building materials, mining, and human settlement. Huge areas of forest can also become rapidly deforested during natural disasters like wildfires, tornadoes, and cyclones" (IUCN) **[15b]** whereas **habitat loss** is defined as "the outcome of a process of land use change in which a 'natural' habitat-type is removed and replaced by another habitat-type, such as converting natural areas to production sites. In such process, flora and fauna species that previously used the site are displaced or destroyed […]" (CBD) **[10b]** and is due to **habitat fragmentation** defined as "the breaking apart of continuous habitat into distinct pieces" or **habitat degradation** defined as "a general term describing the set of processes by which habitat quality is reduced. Habitat degradation may occur through natural processes (e.g. drought, heat, cold) and through human activities (forestry, agriculture, urbanization)" (IUCN) **[15b]**.

The **biodiversity protection** covers many aspects such as species protection (in particular threaten species), genetic resources maintenance and protection (e.g. crop protection) and ecosystem protection (e.g. coastal and seascape protection, freshwater and mountain ecosystems protection, forest protection, habitat protection such as natural and protected areas, land and landscape protection, ocean protection, soil protection).

As illustrations, a **protected area** is defined as “an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means […]” and a **marine protected area** (MPA) as “an area of sea (or coast) especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means” (CBD) **[10b]**.

The **biodiversity restoration** is defined as “the return of an ecosystem or habitat to its original community structure, natural complement of species, and natural functions” (CBD) **[10b]** and only covers ecosystem restoration (e.g. forest restoration through natural regeneration, afforestation or reforestation, habitat restoration, land restoration, native plant restoration, nature restoration, soil restoration, wetland restoration).

In particular, **forest restoration** is managed through **natural regeneration**, which is defined as “the process by which woodlands are restocked by trees that develop from seeds that fall and germinate in situ […]”, **afforestation** as “the process of establishing and growing forests on bare or cultivated land, which has not been forested in recent history” and **reforestation** as the “process [that] increases the capacity of the land to sequester carbon by replanting forest biomass in areas where forests have been previously harvested” (IUCN) **[15b]**, whereas “**soil restoration** is defined as “actions to restore soil functions for intended uses or to protect man and the environment from dangers” (ISO 11074:2015) **[2n]**.

II. CARBON AND BIODIVERSITY CREDIT MANAGEMENT: CONCEPTS, PROCESSES, STAKEHOLDERS, STANDARDS AND REGULATIONS

II.1. Carbon and Biodiversity Credit Management Concepts

II.1.a. Introduction to Carbon Offset, Credit and Credit Markets

In the specific case the carbon footprint of a product (CFP) cannot be reduced anymore, the **carbon offsetting** is defined as a “mechanism for compensating for all or for a part of the carbon footprint of a product or the partial carbon footprint of a product through the prevention of the release of, reduction in, or removal of an amount of greenhouse gas emissions in a process outside the product system under study” (ISO 14050:2020).

More generally, a **carbon offset** is defined as “a method of allowing companies and individuals to compensate for their own carbon emissions through contributing to reduced emissions of carbon dioxide of greenhouse gases elsewhere. This usually involves payment for **carbon credits** each representing one ton of carbon equivalent [i.e. 1 tCO2e]” (IUCN) **[15b]**.

The **carbon credit** was introduced within the **Kyoto Protocol** and is defined as a “verifiable quantity of climate mitigation for which the [credit] **buyer** can claim an offset as a result of financing either reduction or avoidance of carbon emissions or the removal or sequestration of CO2 in the atmosphere” (IUCN) **[15b]**. The alternative name for carbon credit is **carbon certificate**.

Typical **climate action projects** involving carbon credits are renewable energy and energy efficiency projects, afforestation and reforestation projects, methane capture from landfills or agriculture and avoided deforestation projects (within the **REDD+** (Reducing Emissions from Deforestation and Forest Degradation Plus) **Framework** led by the UNFCCC **[3d]**).

A **carbon market** is defined through the **emissions trading**, which was set in Article 17 of the Kyoto Protocol as a mechanism that “allows countries that have emission units to spare […] to sell this excess capacity to countries that are over their targets. Thus, a new commodity was created in the form of emission reductions or removals. […] Carbon is now tracked and traded like any other commodity. This is known as the **carbon market**" (UNFCCC) **[3e]**.

According to UNEP, “carbon markets are carbon pricing mechanisms enabling governments and non-state actors to trade greenhouse gas emission credits. The aims is to achieve climate targets and implement climate actions cost effectively” and “there are two types of carbon markets: compliance and voluntary. In **compliance [or regulatory carbon] markets** such as national or regional emissions trading schemes participants act in response to an obligation established by a regulatory body. In **voluntary carbon markets**, participants are under no formal obligation to achieve a specific target. Instead, non-state actors such as companies, cities or regions seek to voluntarily offset their emissions, for example, to achieve mitigation targets such as climate neutral, net zero emissions” **[12b]**.

II.1.b. Introduction to Biodiversity Offset, Credit and Credit Markets

Similarly, a **biodiversity offset** is defined as "a quantified **environmental benefit** that is designed to compensate for any adverse impacts to habitat, environmental functions, or ecosystem services that cannot be avoided, minimised, and/or restored. Offsets can take the form of positive management interventions such as **restoration** of degraded habitat or preventing continued degradation [i.e. **protection**]. Offsets can be implemented by either the party directly responsible for adverse impacts or a third part" (IUCN) **[15b]**. An **environmental benefit** is defined as an "internal or external gain related to the environment" (ISO 14050:2020).

The **biodiversity credit** (sometimes referred as a **biocredit**) was introduced within the Kunming-Montreal GBF and is defined as "an economic instrument that can be used to finance actions that result in measurable positive outcomes for biodiversity (e.g. species, ecosystems, natural habitats) through the creation and sale of biodiversity units" (WEF, IIED) **[16] [17]** or as "a **certificate** that represents a measured and evidence-based unit of positive biodiversity outcome that is durable and additional to what would have otherwise occurred" (BCA) **[18a]**. Thus, the alternative name for biodiversity credit is **biodiversity certificate**.

A BCG study noticed that "**biodiversity credits differ from biodiversity offsets**" and detailed that "biodiversity credits are related to biodiversity offsets but are different in intention and use along the mitigation hierarchy. At this stage of market maturity, credits should not be used as offsets. The mitigation hierarchy is a tool that guides users on how to limit potential negative impacts on biodiversity from development projects. Following this hierarchy is fundamental to achieving **no net loss** or being **nature positive**. The **steps of the mitigation hierarchy** should be followed sequentially: 1) avoid negative impacts […], 2) minimise impacts […], 3) restore and regenerate habitats based on unavoidable impacts, 4) [compensate i.e.] take responsibility by offsetting residual impact via biodiversity offsets to ensure there is no net loss […], and 5) go beyond [through] additional voluntary contributions […] via biodiversity credits beyond offsetting direct impacts and dependencies" **[19]**.

The **biodiversity gain** is defined as "the result of a positive effect on biodiversity generated by favourable actions. These gains relate to practices implemented or maintained in a given area (**restoration** or conservation [i.e. **protection**]), the **biodiversity certificate [or credit]** as "a certified quantity of biodiversity gain. This gain value can be claimed by an end-buyer through a **claim**". The study clarified that "the term **certificate [is used] rather than credit** because a credit is implicitly associated with a debit, and therefore suggests a system of compensation (or offsetting), where biodiversity gains enable to cancel out (or offset) negative impacts generated elsewhere. A certificate refers only to a certified unit of biodiversity gain, regardless of its use and the type of associated claims" (MNHN / Carbone4 / FRB) **[20]**.

Typical **biodiversity conservation projects** involving biodiversity credits are forest protection and restoration, coral reef restoration, sustainable agriculture and pollinator conservation, wetland and peatland restoration or wildlife corridor and habitat connectivity.

A **biodiversity market** is defined, among **nature markets**, as a market "in which credits that reflect efforts to enhance [i.e. **restoration**] or conserve ecosystem assets or services [i.e. **protection**] are traded", where "the term credit is broadly used to imply that the [**credit**] **owner** can make a **claim** regarding something they have done or that is embodied in a credit (or **certificate**) that they have purchased" (MNHN / Carbone4 / FRB) **[20]**.

The same MNHN / Carbone4 / FRB study defined a **biodiversity certificate mechanism (or biodiversity market)** as "a scheme framing the generation, trading and use certificates", clarified that "the term **mechanism [is used] rather than market** to emphasise that the primary objective of such a mechanism is to contribute to the global goals for biodiversity, with the generation of financial flows being a means to this end", that "the **mechanism may be voluntary or regulatory, local or global**" and then distinguished **regulatory (or compliance) biodiversity mechanism (or market)**, where "the certificates can be part of a regulatory framework, for example that of ecological offsetting, existing in several countries. In these countries, certain stakeholders are obliged to purchase biodiversity credits to compensate for existing or future destruction caused by a project", and **voluntary biodiversity mechanism (or market)**, where "organisations may wish to purchase certificates independently of the regulations in force" **[20]**.

For biodiversity conservation projects, the International Advisory Panel on Biodiversity Credits (IAPB) published in August 2024 the results of a survey that reported **[22a]**:

- three **types of project developers** among 60 projects with private companies (36 out of 60 projects), non-governmental organisations (29 out of 60) and indigenous peoples and local communities (IPLC) organisations (9 out of 60), knowing that the types of projects developers were not exclusive;
- two **types of project interventions** with ecosystem conservation (i.e. ecosystem protection) (~50 out of 60) and ecosystem restoration (~45 out of 60), knowing that projects could mix both interventions;

- two **types of intervention targets** with terrestrial environment (e.g. terrestrial habitat, terrestrial species) and marine environment (e.g. marine habitat, marine species). The conservation and restoration projects addressed terrestrial habitats such as forest habitat (49 out of 60 projects), grassland habitat (24 out of 60) and wetland habitat (15 out of 60), marine habitats (10 out of 60), terrestrial species (43 out of 60) and marine species (9 out of 60);
- six **categories of intervention sites** with community-managed protected areas (22 out of 60), government-managed protected areas (16 out of 60), indigenous lands (2 out of 60), private lands (30 out of 60), public / state land (3 out of 60) and other (4 out of 60);
- several **environmental standards** with 23 frameworks such as Plan Vivo [Biodiversity] Standard (10 out of 60), Global Biodiversity Standard (GBS; 7 out of 60), Biodiversity Net Gain (BNG; 1 out of 60) and own methodologies (6 out of 60);
- two **types of biodiversity credits** with credits for conservation outcome (i.e. protection) (10 out of 60) and biodiversity uplift (i.e. restoration) (11 out of 60) or both of them (36 out of 60);
- two **types of credit markets** with voluntary credit market (45 out of 60), compliance credit market (6 out of 60) or both of them (11 out of 60);
- several **types of credit buyers** with private companies (49 out of 60), governments (28 out of 60), individual consumers (3 out of 60), asset managers (1 out of 60) or NGO (1 out of 60);
- **use of verification and validation processes prior to credit issuance** (56 out of 60).

Following previous study, the **IAPB Framework** was published in October 2024 to refine **[22b]**:

- the definitions of **biodiversity credits** that "represent the biodiversity outcomes linked to a project and can be sold and issued throughout the project lifecycle" and **biodiversity certificates** that "provide validated proof that inputs, outputs and outcomes have been achieved";
- the **differences between biodiversity and carbon credits** in terms of goals ("biodiversity conservation and restoration" vs. "carbon sequestration and emissions avoidance"), measurement ("multiple units of measurement, including abundance and richness of species, habitat extent and condition, and ecosystem integrity among others" vs. "single unit of measurement […] in tonnes of CO2[e] removed from the atmosphere"), purpose of use ("voluntary contribution, local compensation for direct impact and supply chain insetting" vs. "avoided emissions or enhanced removals"), locality ("higher (local-to-local and like-for-like biological equivalence must be demonstrated – international, non-local compensation should not be allowed)" vs. "lower (CO2 emissions have the same impact no matter where or how that CO2 is released)" in particular the fact that "biodiversity credits are highly location-specific and not easily interchangeable" i.e. non-fungible) and tradability ("very low" vs. "high");
- the **project lifecycle and associated processes in 10 steps**: "1) engagement with IPLC […], 2) feasibility assessment, 3) project design, 4) validation and project registration, 5) *ex ante* sale of credits (claims are not allowed at this stage), 6) project delivery, 7a) periodic third-party verification, 7b) certification of verified outcomes, 8) *ex post* sale of credits (only claims about verified outcomes can be made), 9) profits / benefits shared with those involved in local conservation efforts, including IPLC […], 10) Retirement of biodiversity credits [i.e.] the biodiversity benefit it represents has been claimed by the entity that bought it";
- the **project use cases** with contribution ("making Nature improvements beyond won organisation or value chain"), which is a voluntary contribution, and compensation ("addressing material Nature impacts and risks within own organisation and value chain"), which may be a voluntary compensation or a compliance compensation;
- the **mitigation hierarchy pathway**: cumulating the following actions from biodiversity impact (i.e. doing nothing), then avoid, minimise, restore and compensate (i.e. offset, leading to at least "no net loss" or better "net gain").

II.2. Carbon and Biodiversity Credit Management Processes

Credit management relies on **several processes** (cf. **Table VII**): 1) project development and registration, 2) project measurement, monitoring and reporting, 3) project validation, verification and certification, 4) credit issuance, 5) credit trading and transfer, and 6) claiming and credit retirement. Monitoring, reporting and verification processes are referred to as **MRV processes**.

The **project development** covers the submission by the project developer of a project, including the project details, to the registry provider for further **project registration**. The project development is defined as the "the first stage of a [biodiversity] credit project in which the size and scope are defined, and finance [i.e. funding] is secured for implementation" (IAPB) **[22a]**. **Project details** include various **project metadata** such as the size, scope, funding plan, boundaries, location, goals, expected outcome, activities, methodologies, environmental metrics, environmental impact / benefits and environmental standards.

A **field project** (e.g. reforestation) is followed up thanks to MRV tools. For this, the **project measurement, monitoring and reporting** cover the provision by the data provider of **MRV tools** that are used for data collection of **environmental metrics**. **MRV tools** may be IoT sensors, IoT digital twin, satellite imagery, drone imagery, AI-driven tools (e.g. analytics) and blockchain-driven tools (e.g. DLT oracle). **Environmental metrics** are used to monitor, track and assess the project progress / performance and its environmental impact.

In particular, the **(project) measurement** is defined as the "process to determine a value" (ISO 14050:2020), the **(project) monitoring** is defined as "determining the status of a system, a process or an activity" (ISO 14050:2020) and as the "continuous or periodic assessment of GHG emissions, GHG removals or other GHG-related data" (ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019). Within MRV processes, project monitoring "includes the measurement of emissions data" (UNECE) **[20]** whereas the **(project) reporting** "facilitates accurate and expeditious reporting and distillation of the data into formats that can be understood by reporting facilities and users of the data. The reporting system allows stakeholders, including the emitting facilities, to track changes in emissions and emission reductions over time" (UNECE).

The **project validation, verification and certification** cover the review by an independent third-party such as project validator, project verifier or auditor of the collected data and the assessment, audit and/or certification of the project **environmental impact / benefits** by verifying their compliance with established **environmental standards** and **environmental regulations**.

In particular, the **(project) validation** is defined as the "process for evaluating the reasonableness of the assumptions, limitations and methods that support a statement about the outcome of future activities" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019) or as the "confirmation through the provision of objective evidence that the requirements for a specific intended use or application have been fulfilled" (ISO 14050:2020).

Then, the **(project) verification** is defined as the "process for evaluating a statement of historical data and information to determine if the statement is materially correct and conforms to criteria" (ISO 14050:2020, ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019) and as the "confirmation through the provision of objective evidence, that specified requirements have been fulfilled" (ISO 14050:2020). Within MRV processes, the (project) verification "is the final and necessary step to ensure the veracity of reported data as well as its consistency and compliance with reporting requirements […]" (UNECE).

Furthermore, an **audit** may apply to the organisation behind the project and is defined as a "systematic and independent process for obtaining evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled" (ISO 14050:2020).

And finally, the **(project) certification** is defined as a "third-party attestation related to an object of conformity assessment, with the exception of accreditation" (ISO 14050:2020).

The **credit issuance** covers the issuance by the credit issuer of a predefined number of credits representing the **verified project environmental impact / benefits**, then the allocation of a **unique identifier** to each credit, then the recording of credits on the registry, then the allocation of credits to the project developer and/or to credit marketplace(s). The unique identifier is used for tracking and trading and avoids **double-counting**, defined as the "accounting for the inputs or outputs of a process more than once" (ISO 14050:2020).

The **credit trading and credit transfer** cover the selling of credits directly by the credit issuer or project developer to a credit buyer (through bilateral agreements) or the trading by a credit seller to a credit buyer via a **credit marketplace**. The credit marketplace may be a **voluntary credit marketplace** or a **compliance credit marketplace**, a **decentralised marketplace** (also known as a decentralised exchange (DEX)) or a **centralised marketplace** (also known as a centralised exchange (CEX).

The **claiming and credit retirement** cover the claiming by the credit buyer that environmental goals are met within an **environmental claim**, then the recording of the **credit retirement status** by the credit issuer in the registry. The credit retirement status avoids re-selling, re-use, re-trading and double-counting.

An **environmental claim** is defined for a product as a "statement, symbol or graphic that indicates an environmental aspect of a product, including any associated components and packaging" (ISO 14050:2020) and distinguishes a **self-declared environmental claim** "that is made, without an independent third-party certification, by manufacturers, importers, distributors, retailers or anyone else likely to benefit from such a claim" and a **qualified environmental claim** "that is accompanied by an explanatory statement to describe the limits of the claim" (ISO 14050:2020).

An **(environmental) claim** is specifically defined for biodiversity credit as "a statement that enables the end [credit] **buyer** to claim the biodiversity benefits associated with the certificate" and distinguishes a **compensation claim** "when the biodiversity gain cancels out, i.e. offsets, a negative impact generated elsewhere by the entity claiming the gain" and a **contribution claims** "when the biodiversity gain is distinguished from the negative impacts. The entity that claims this gain then claims a contribution to restoring or conserving biodiversity, and accounts for it separately from its negative impacts" (MNHN / Carbone4 / FRB) **[21]**.

TABLE VII. Carbon and Biodiversity Credit Management Processes

Process	Action	Carbon Credit Implementation	Biodiversity Credit Implementation
1 Project Development and Registration	submission by the **project developer** of a **project**, including the **project details**, to the **registry provider** for further **project registration**	**project** e.g. GHG (e.g. CO_2) emission reduction, carbon sequestration, methane capture, GHG (e.g. CO_2) emission offsetting through e.g. reforestation **project details** e.g. goals such as estimated GHG (e.g. CO_2) emission reduction	**project** e.g. biodiversity conservation such as threaten species protection, biodiversity restoration such as forest restoration (improving habitat quality for endangered species), land restoration (e.g. wetland restoration), habitat restoration, species restoration (e.g. native plants) **project details** e.g. methodology for measuring biodiversity enhancement / biodiversity gains such as improvements in wildlife populations
2 Project Measurement, Monitoring, and Reporting	provision by the **data provider** of **MRV tools** that are used for data collection of **environmental metrics**	**MRV tools for compliance market** e.g. EU ETS Reporting Tool (ERT) **MRV tools for voluntary market** e.g. DigitalMRV by IOTA Foundation (DLT-based) **environmental metrics** e.g. GHG (e.g. CO_2) absorption rate **project progress / performance** e.g. GHG (e.g. CO_2) emission reduction calculation	**monitoring and reporting tools for voluntary market** e.g. Biodiversity MRV by Natural Solutions (blockchain-based) **environmental metrics** e.g. biodiversity indices
3 Project Validation, Verification and Certification	review by an independent third-party such as **project validator**, **project verifier** or **auditor** of the collected data and the assessment, audit and/or certification of the **project environmental impact / benefits** by verifying their compliance with established **environmental standards and regulations**	**environmental regulations for compliance market** e.g. EU Emissions Trading System (EU ETS), UK Emissions Trading Scheme (ETS), UNFCCC Clean Development Mechanism (CDM) **environmental standards for voluntary market** e.g. BioCarbon Standard, Climate Action Reserve (CAR), Gold Standard (GS), ISO 14064 Series, Plan Vivo Carbon Standard (PV Climate), Puro Standard, Verified Carbon Standard (VCS) by Verra	**environmental regulations for compliance market** e.g. UK Biodiversity Net Gain (BNG) **environmental standards for voluntary market** e.g. Biodiversity Credits Alliance (BCA), Plan Vivo Biodiversity Standard (PV Nature), Sustainable Development Verified Impact Standard (SD VISta) by Verra
4 Credit Issuance	issuance by the **credit issuer** of a predefined number of credits representing the **verified project environmental impact / benefits**, then allocation of a **unique identifier** to each credit, then recording of credits on the **registry**, then allocation of credits to the **project developer** and/or to **credit marketplace(s)**, and finally recording of the **credit retirement status** in the registry	**verified project environmental impact / benefits** e.g. 1 carbon credit for 1 metric tonne of CO_2 equivalent (tCO_2e) sequestered	**verified project environmental impact / benefits** e.g. 1 biodiversity credit for 1 hectare of restored forest habitat with improved species diversity
5 Credit Trading and Transfer	selling of credits directly by the **credit issuer** or **project developer** to a **credit buyer** (through bilateral agreements) or trading by a **credit seller** to a **credit buyer** via a **credit marketplace**	**credit** e.g. compliance carbon credit for offsetting an environmental impact	**credit** e.g. voluntary biodiversity credit for supporting conservation efforts
6 Claiming and Credit Retirement	claiming by the **credit buyer** that environmental goals are met within an **environmental claim**, then the recording of the **credit retirement status** by the **credit issuer** in the **registry**	**environmental claim** e.g. sustainability goals met i.e. offsetting an environmental impact	**Environmental claim** e.g. sustainability goals met i.e. conservation benefits

II.3. Carbon and Biodiversity Credit Management Stakeholders

Credit management involves **several stakeholders** (cf. **Table VIII**): project developer, regulatory authority and standardisation body, registry provider, data provider, technology provider, project validator, project verifier and auditor, credit issuer, credit marketplace provider, credit seller, credit buyer.

A **project developer** initiates, details and implements the project and is specifically defined in the case of **greenhouse gas project proponent** (GHG project proponent) as an "individual or organization that has overall control and responsibility for a GHG project" (ISO 14050:2020, ISO 14064-2:2019) and can be generalised as an "individual or organization that has overall control and responsibility for a project".

A **regulatory authority** defines and oversees the compliance with local, regional or global **environmental regulations** whereas a **standardisation body** defines and oversees the compliance with the **environmental standards**.

A **registry provider** allows the project developer to submit a project, collects data from data provider(s), retrieves assessment from project validator(s), project verifier(s) and/or auditor(s), and, upon validation, verification and certification, requests the credit issuer to issue credits. The registry provider may be a **compliance registry provider** or a **voluntary registry provider** whereas a **registry** may be a **centralised registry** (i.e. a traditional registry), a **decentralised registry** or a **distributed registry**. A **data provider** offers MRV tools for data collection of environmental metrics to the registry provider(s) and/or to the project validator(s), project verifier(s) and/or auditor(s) whereas a **technology provider** develops and offers the registry technology to the registry provider(s) and/or to the credit issuer(s) and maintains the registry technology. A **registry technology** may be a centralised database, a blockchain or a DLT.

A **project validator**, **project verifier** or **auditor** is an independent third-party who reviews the collected data and assesses / audits / certifies the **project environmental impact / benefits** by verifying their compliance with established environmental standards.

In particular, a **(project) validator** assesses whether a proposed project meets the eligibility criteria before it is implemented and is defined as a "competent and impartial [or independent] person [or persons] with responsibility for performing and reporting [on the results of the] on a validation" (ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019, ISO 14050:2020), a **(project) validation team** as "one or more validators conducting a validation, supported if needed by technical experts" (ISO 14050:2020) and a **(project) validation body** as an "organization that performs validations" (ISO 14050:2020).

Then, a **(project) verifier** confirms that a project has achieved the claimed environmental / benefits before credits are issued and is defined as a "competent and impartial [or independent] person [or persons] with responsibility for performing and reporting on a verification [process]" (ISO 14064-1:2018, ISO 14064-2:2019, ISO 14064-3:2019, ISO 14050:2020), a **(project) verification team** as "more verifiers conducting a verification, supported if needed by technical experts" (ISO 14050:2020), a **(project) verification body** as an "organization that performs verifications" (ISO 14050:2020) whereas a **(project) client** is defined as an "organization or person requesting verification or validation" (ISO 14064-1:2018, ISO 14064-3:2019).
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A **(project) verification / validation team** is defined as a "person or persons conducting verification / validation activities" (ISO 14064-3:2019), a **(project) independent reviewer** is defined as a "competent person, who is not a member of the verification/validation team, who reviews the verification or validation activities and conclusions" (ISO 14064-3:2019). The **validation and verification body** is referred to as VVB.

And finally, an **auditor** leads periodic assessments of project performance ensuring continued compliance with standards and is defined as a "person who conducts an audit" (ISO 14050:2020), an **audit team** as "one or more persons conducting an audit, supported if needed by technical experts" (ISO 14050:2020) whereas an **audit client** is defined as an "organization or person requesting an audit" (ISO 14050:2020), an **auditee** as an "organization being audited" (ISO 14050:2020).

A **credit issuer** issues a predefined number of credits representing the verified environmental impact of the project, allocates a unique identifier to each credit (for tracking, trading and avoiding double-counting), records credits on the registry and each credit receives a unique identifier, allocates credits to the project developer and/or to credit marketplace(s) and finally records the credit retirement status in the registry (for avoiding re-trading and double-counting).

A **credit marketplace provider** offers the credit marketplace that allows the credit seller to trade a credit to a credit buyer. A **credit seller** sells credits to a credit buyer via a credit marketplace whereas a **credit buyer** purchases credits to a credit seller via a credit marketplace or directly to a project developer or credit issuer (through a bilateral agreement).

TABLE VIII. CARBON AND BIODIVERSITY CREDIT MANAGEMENT STAKEHOLDERS

Stakeholder	Stakeholder Function	Carbon Credit Implementation	Biodiversity Credit Implementation
Project Developer	**project developer** initiates, details and implements the project	**project developer** e.g. company (e.g. private company)	**project developer** e.g. company (e.g. private company), individual, IPLC, organisation (e.g. NGO)
Regulatory Authority and Standardisation Body	**regulatory authority** defines and oversees the compliance with local, regional or global **environmental regulations**; **standardisation body** defines and oversees the compliance with the **environmental standards**	**regulatory authority** e.g. European Union, UNFCCC, UK Government **standardisation body** e.g. Climate Action Reserve (CAR), Gold Standard (GS), ISO, Plan Vivo Foundation, Puro.earth, Verra	**regulatory authority** e.g. UK Government **standardisation body** e.g. Biodiversity Credit Alliance (BCA), Plan Vivo Foundation, Verra
Registry Provider	**registry provider** allows the **project developer** to submit a project, collects data from **data provider(s)**, retrieves **assessment** from **project validator(s)**, **project verifier(s)** and/or **auditor(s)**, and, upon validation, verification and certification, requests the credit issuer to **issue credits**	**registry provider for compliance market** e.g. EU Union Registry (formerly Transaction Log (EU TL)), UK Emissions Trading registry, UNFCCC Clean Development Mechanism (CDM) **registry provider for voluntary market** e.g. BioCarbon Registry (BCR) (blockchain-based), Climate Action Reserve (CAR) Public Registry, Global Carbon Council (GCC) Carbon Registry, Gold Standard (GS) Impact Registry, Plan Vivo (PV) Climate Registry, Puro Registry, Regen Registry (blockchain-based) by Regen Network Development, Verra Registry	**registry provider for compliance market** e.g. UK Biodiversity Gain Site Register **registry provider for voluntary market** e.g. Regen Registry by Regen Network Development (blockchain-based), Verra Registry
Data Provider	**data provider** offers **MRV tools** for data collection of **environmental metrics** to the **registry provider(s)** and/or to the **project validator(s)**, **project verifier(s)** and/or **auditor(s)**	**data provider** e.g. Climate, Community & Biodiversity Standards (CCBS) by Verra, ESA Copernicus, Emissions Database for Global Atmospheric Research (EDGAR), FLINTpro, Global Carbon Atlas, NASA Carbon Monitoring System (CMS)	**data provider** e.g. Climate, Community & Biodiversity Standards (CCBS) by Verra, ESA Copernicus, Digital Observatory for Protected Areas (DOPA), FLINTpro, Global Biodiversity Information Facility (GBIF), Global Forest Watch (GFW), IUCN Red List, IUCN Species Information Service (SIS), JICA-JAXA Forest Early Warning System in the Tropics, NASA Earth Data, NOAA Atmospheric Carbon Dioxide, OpenET
Technology Provider	**technology provider** develops the registry technology, offers the **registry technology** to the **registry provider(s)** and/or to the **credit issuer(s)**, and maintains the registry technology	**technology provider** e.g. community of developers for open-source technology, private company for a solution	**technology provider** e.g. community of developers for open-source technology, private company or consortium for a solution
Project Validator, Project Verifier and Auditor	**project validator**, **project verifier** or **auditor** is an independent third-party who reviews the collected data and assesses / audits / certifies the **project environmental impact / benefits** by verifying their compliance with established **environmental standards**; **project validator** assesses whether a proposed project meets the eligibility criteria before it is implemented; **project verifier** confirms that a project has achieved the claimed environmental / benefits before credits are issued; **auditor** leads periodic assessments of project performance ensuring continued compliance with standards	**project validator / project verifier** e.g. AENOR (e.g. UNFCCC CDM, Verra VCS), Det Norske Veritas (DNV) (e.g. EU ETS), Earthood (V=e.g. Verra VCS), Société Générale de Surveillance (SGS) (e.g. UNFCCC CDM) **auditor** e.g. KPMG, PwC, EY	**project validator / project verifier** e.g. Preferred by Nature, Rainforest Alliance
Credit Issuer	**credit issuer** issues a predefined number of credits representing the **verified environmental impact** of the project, allocates a **unique identifier** to each credit, records credits on the **registry**, allocates credits to the **project developer** and/or to **credit marketplace(s)** and finally records the **credit retirement status** in the **registry**	**credit issuer for compliance market** e.g. EU Union Registry (formerly Transaction Log (EU TL)), UK Emissions Trading registry, **credit issuer for voluntary market** e.g. Climate Action Reserve (CAR) Public Registry, Global Carbon Council (GCC) Carbon Registry, Gold Standard (GS) Impact Registry, Plan Vivo (PV) Climate Registry, Puro Registry, Verra Registry	**credit issuer for compliance market** e.g. UK Biodiversity Gain Site Register **credit issuer for voluntary market** e.g. Verra Registry

Credit Marketplace Provider	**credit marketplace provider** offers the **credit marketplace** that allows the **credit seller** to trade a credit to a **credit buyer**	**credit marketplace provider for compliance market** e.g. EU Emissions Trading System (ETS) **credit marketplace provider for voluntary market** e.g. AirCarbon Exchange (ACX) (blockchain-based), ClimateTrade Market, Gold Standard Marketplace, Moss Carbon Credit Marketplace Infrastructure (blockchain-based)	**credit marketplace provider for compliance market** e.g. BNGx **credit marketplace provider for voluntary market**
Credit Seller	**credit seller** sells credits to a **credit buyer** via a **credit marketplace**	**credit seller** e.g. company, individual (e.g. trader), organisation	**credit seller** e.g. company, individual, organisation
Credit Buyer	**credit buyer** purchases credits to a **credit seller** via a **credit marketplace** or directly to a **project developer** or **credit issuer**	**credit buyer** e.g. company, government, individual (e.g. trader), organisation	**credit buyer** e.g. company, government, individual, organisation

II.4. Carbon and Biodiversity Credit Management Standards

The **main environmental standards for voluntary market** applying to **carbon credit** are e.g. the Climate Action Reserve (CAR) **[23]**, Gold Standard (GS) **[24]**, ISO 14064 Series **[2b] [2o] [2i]**, Plan Vivo Carbon Standard (PV Climate) **[25a]**, Puro.earth **[26]** and Verified Carbon Standard (VCS) by Verra **[27a] [27c] [27d]**. And the ones applying to **biodiversity credit** are e.g. the Biodiversity Credits Alliance (BCA) **[18b]**, Plan Vivo Biodiversity Standard (PV Nature) **[25b]**, Sustainable Development Verified Impact Standard (SD VISta) by Verra **[27b] [27c] [27d]**.

II.5. Carbon and Biodiversity Credit Management Regulations

The **main environmental regulations for compliance market** applying to **carbon credit** are e.g. the UNFCCC Clean Development Mechanism (CDM) **[9d]**, EU Emissions Trading System (EU ETS) **[28a] [28b] [28c] [28d] [28e]** and UK ETS **[29a]**. And the ones applying to **biodiversity credit** are e.g. the UK Biodiversity Net Gain (BNG) **[29b]**.

III. BLOCKCHAIN AND DLT APPLICATION TO CARBON AND BIODIVERSITY CREDIT MANAGEMENT

III.1 Blockchain and DLT Mechanisms behind Trust Creation

Blockchain is defined as a “distributed ledger with confirmed blocks organized in an append-only, sequential chain using hash links” and is a type of **distributed ledger technology** (DLT), which is defined as a “technology that enables the operation and use of distributed ledgers”, whereas a **distributed ledger** is defined as a “ledger that is shared across a set of distributed ledger technology (DLT) nodes and synchronized between the DLT nodes using a consensus mechanism” (ISO 22739:2024) **[2p]**.

Previous article **[1]** pointed out how the cryptographic innovations behind blockchain and DLT (e.g. hash function, RSA encryption, Merkle tree, proof of work) contributed to strengthen their characteristics including **decentralisation**, **distribution**, **disintermediation**, **transparency** (including monitoring, reporting and verification (MRV)), **traceability** (including accountability, monitoring and tracking), **trust creation** (including security), **certification** (including labelling, timestamping) and **contract automation**.

Additional inherent characteristics of the distributed ledger are **immutability**, defined as a “property of a distributed ledger wherein ledger records cannot be modified or removed once added to that distributed ledger” and **interoperability**, defined as the “ability of two or more systems or applications to exchange information and to mutually use the information that has been exchanged”, noting that “interoperability is possible between applications on a single distributed ledger technology (DLT) system, between DLT systems, or between a DLT system and external systems” (ISO 22739:2024) such as DLT oracles.

Contract automation relies on a **smart contract**, defined as a “computer program stored in a distributed ledger technology (DLT) system wherein the outcome of any execution of the program is recorded on the distributed ledger” (ISO 22739:2024).

Then, previous article came up with a first conclusion that **blockchain and DLT are now mature and viable** since new architectures have improved their **scalability** (e.g. ~100 000 transactions per second for Ethereum 2.0), **sustainability** (in terms of electricity consumption e.g. ~35 Wh for an Ethereum 2.0 transaction, carbon footprint, water footprint, electronic waste and land footprint) and **sovereignty** (no particular person, legal entity or country controls the system); and to a second conclusion that **blockchain and DLT can now support the sustainable development efforts [1]**.

Carbon and biodiversity credit management can now benefit from blockchain and DLT characteristics. Firstly, **decentralisation**, **distribution**, **scalability** and **sustainability** characteristics help developing reliable, sustainable and resilient infrastructure and strengthening resilience and adaptive capacity against climate-related hazards and natural disasters whereas **disintermediation** reduces the reliance on intermediaries and lowers the operational costs.

Secondly, **transparency**, when offered by public blockchain, provides access to the transactions history and allows validation and verification processes thus avoiding **greenwashing**, **traceability** allows audit process and **contract automation** brings fluidity and efficiency.

And finally, **immutability** ensures that data cannot be altered once recorded, which is a critical factor in credit issuance, credit trading and credit retirement processes, thus avoiding **double-counting**, whereas **interoperability** guarantees that various systems such as centralised registries and credit marketplaces may be interconnected.

III.2. Blockchain and DLT Use Cases for Sustainable Development

Previous article **[1]** analysed the coverage of the 17 United Nations Sustainable Development Goals (UN SDGs) by blockchain and DLT in terms of use cases and solutions (cf. **Table IX**, reduced to carbon and biodiversity credit management, then updated with additional solutions).

TABLE IX. UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS COVERAGE BY BLOCKCHAIN AND DLT USE CASES

Sustainable Development Goal	**Blockchain and DLT Use Cases and Solutions** Disclaimer: this list is not exhaustive and some solutions may be defunct
13 Climate Action	**Use cases**: **Climate action certificate and credit management** (including issuance, measurement, monitoring, reporting and verification (MRV), transparency, traceability, accountability, tracking), **Climate action certificate and credit tokenisation and trading marketplace** (e.g. cryptocurrency, token) **Solutions**: Allinfra Climate by Allinfra - Astral Protocol by Astral – Atem (Polygon) - Bitmo by Blockchain for Climate (Ethereum) - Blockchain Triangle - Cambridge Centre for Carbon Credits (4C) - Carbon Bridge by Toucan (Polygon or Celo / Ethereum) – Carbon Credit by Carbonland Trust - Carbon Credit by Open Forest protocol (OFP) (NEAR) - Carbon Credit by Regen Network Development – Carbon Credit by ReSeed (Polygon) - Carbon Credit by Solid World (Alchemy) – Carbon Token by 2Tokens - Carbon Offsets To Alleviate Poverty (COTAP) – Carbonbase - CarbonClear – CarbonPath - Climate Accounting Infrastructure (CAI) by KPMG - Climate Action Data (CAD) Trust with Climate Change Coalition, Climate Check, Open Earth Foundation & al - Climate Ledger Initiative (CLI) – ClimateCoin - DAO IPCI by Russian Carbon Foundation – dClimate – DigitalMRV by IOTA Foundation with ClimateCHECK (IOTA) – Earthchain - ECO2 Ledger by ECO2 Foundation - ECOTA with Earthchain & al. - ELV Carbon Credits by Meta Materials Circular Markets (MMCM) – Evercity,- Ethereum Climate Platform (ECP) by Ethereum Climate Alliance (Ethereum) - First Carbon Corp. by DeepMarkit – Flowcarbon (Celo) –Goodcarbon (Polygon) – Hiphen by Hyphen Global - Hyperledger Climate Action & Accounting SIG (CA2SIG) by Linux Foundation – Klima Infinity by KlimaDAO (Polygon) - Kolektivo - Moss - Nested Climate Accounting by Open Earth Foundation - Nori (Polygon) - Project Genesis 2.0 – Rebalance Earth – SavePlanetEarth (SPE) (Phantasma) - Senken (Polygon) – Spirals Protocol by Spirals (Celo) – Sushi Carbon Offset by Sushi with KlimaDAO (Polygon) – Thallo - Universal Protocol by Universal Protocol Alliance
14 Life Below Water (Biodiversity)	**Use cases**: **Life below water credit management** (including issuance, transparency, measurement, monitoring, reporting and verification (MRV), traceability, accountability, monitoring, tracking), **Life below water credit tokenisation and trading marketplace** (e.g. cryptocurrency, token) **Solutions**: Biodiversity Credit by Regen Network Development - Biodiversity Offset Scheme for marine resources by BioDiversity Solutions Australia (BDS)
15 Life On Land (Biodiversity)	**Use cases**: **Life on land credit management** (including issuance, measurement, monitoring, reporting and verification (MRV), transparency, traceability, accountability, monitoring, tracking), **Life on land credit tokenisation and trading marketplace** (e.g. cryptocurrency, token) **Solutions**: Biodiversity Credit by BIOTA - Biodiversity Credit by Regen Network Development – Biodiversity MRV by Natural Solutions - Biodiversity Offset Scheme for land resources by BioDiversity Solutions Australia (BDS) - CarbonCoin – Carbon Tokens by TreeCoin – EthicHub - GainForest (Solana) – Green Forest Project (GFP) with InvestConservation (Solana) - Hedera Guardian by Hedera (Hedera Hashgraph) – Hiveonline in Africa - NARIA by Credit Nature - Preservaland – Nature-Based Solutions by Veritree – TreeCycle (Ador) - Wildchain by WildDAO - Wildlife Credits in Namibia

Source: DiCoDaMo.org

Some solutions such as Carbonland Trust, Open Forest protocol (OFP), ReSeed or Solid World propose **carbon credits** associated with various projects such as carbon sequestration with forests, afforestation / reforestation, regenerative agriculture and nature restoration respectively. Climate change is one of the causes of biodiversity loss. In return, climate action supports biodiversity conservation based on the expenditure of carbon credits in favour of life below water and life on land actions, like communicating vessels. In addition, some solutions such as Regen Network Development propose **biodiversity credits**.

Blockchain and DLT apply to credit management and particularly the voluntary markets, where they intrinsically improve the transparency, traceability and contract automation in the trading of credits. According to Blockchain for Good Association, blockchain and DLT-based carbon credit solutions, proposed by e.g. Toucan, Nori, KlimaDAO, Cambridge Centre for Carbon Credits, Moss or ClimateTrade, tend to fluidify and increase the efficiency of the centralised voluntary carbon markets (VCM). These solutions are completed with blockchain and DLT-based reforestation solutions as proposed by e.g. Open Forest Protocol **[30] [31]**.

III.3. Blockchain and DLT Specific Concepts for Credit Management

Blockchain and DLT introduce the concept of **tokenisation** or **token creation** that, applied to credit management, consists in associating a token to a digital or physical asset such as a credit. An **asset** is defined as a “anything that has value to a stakeholder” and a **token** as an “asset that represents a collection of entitlements”. A smart contract is used to create two types of tokens: the **fungible token** (FT), defined as a “token that is **fungible**”, meaning “capable of mutual substitution among individual units”, and the **non-fungible token** (NFT), defined as a “token that is **non-fungible**”, meaning “not capable of mutual substitution among individual units” (ISO 22739:2024).

The IAPB reported that contrarily to the carbon credits, the biodiversity credits are “not easily interchangeable” **[22b]** i.e. non-fungible. Similarly, two types of **credit tokens** exist and are associated with **fungible tokens** and / or **non-fungible tokens**. Tokens are recorded on a distributed registry which implements blockchain technology.

As illustrations of **carbon credits**, in *Carbon Bridge* by Toucan, a carbon credit from the Verra Registry is associated with a Toucan CO2 (TCO2) non-fungible token, which is then fractionalised into Base Carbon Tonne (BCT) and Nature Carbon Tonne (NCT) fungible tokens (based on ERC-20 Ethereum standard) that are recorded on Polygon or Celo layer 2 solutions relying on the Ethereum blockchain **[30] [31] [32] [33]**. Note that a layer 2 solution allows both increasing the scalability and reducing the transaction costs of a (layer 1) blockchain system such as Ethereum **[1]**.

In Nori solution, a carbon credit is associated with the Nori Carbon Removal Tonne (NRT) non-fungible token and a regenerative agriculture project is associated with the Carbon Removal Credit (CRC) non-fungible token (based on ERC-721 and ERC-777 Ethereum standards). The NORI fungible token is introduced for credit trading on a second market and for credit retirement. All tokens are recorded on Polygon layer 2 solution and Ethereum blockchain and are traded on the Nori marketplace. The project details are fed with the data collected through MRV tools (IoT censors, satellite and drone imagery, AI-driven tools) **[30] [31] [34]**.

In KlimaDAO solution, a carbon credit from e.g. *Carbon Bridge* by Toucan is associated with KLIMA fungible tokens (based on ERC-20 Ethereum standard) that are recorded on Polygon layer 2 solution and Ethereum blockchain and are traded on the *Sushi Carbon Offset* marketplace by Sushi **[30] [31] [35]**.

In *Carbon Credit* by Open Forest Protocol, an agroforestry project is associated with a non-fungible token that is recorded on NEAR blockchain. The NFT metadata scheme and project details (e.g. name, duration, type, boundaries, description, goals, stakeholders, co-benefits, tree species, average tree density, additional project documentation) are stored on the IPFS distributed storage system and are updated based on the data collected through MRV tools (IoT censors, satellite and imagery, AI-driven tools) **[30] [31] [36]**.

As illustrations of **biodiversity credits**, in GainForest solution, some forest projects are associated with *NFTrees* non-fungible tokens that are recorded on Solana blockchain. The project details are fed with the data collected through MRV tools (satellite and drone imagery, AI-driven tools) **[30] [37]**.

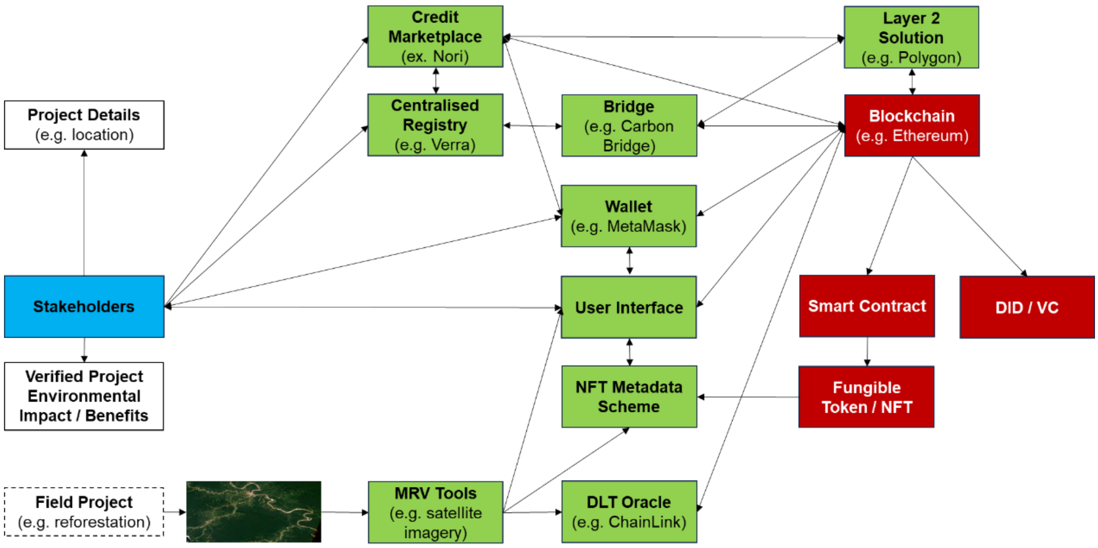
In TreeCycle solution, 10 million trees are associated with 10 million TREE security tokens, each of them being fragmented into 100 TreeCoin fungible tokens, leading to 1 billion TreeCoins, that are recorded on Ador blockchain **[12c] [38]**.

To interconnect external sources (e.g. data sources) with a distributed ledger, a **distributed ledger technology oracle** (DLT oracle; also referred to as **data oracle**) is defined as a "service that updates a distributed ledger using data from outside of a DLT system", noting that "DLT oracles can be used by smart contracts to access data from sources external to the DLT system" (ISO 22739:2024). This concept is helpful for connecting the data provider to the registry provider for carbon and biodiversity credit management.

III.4. Blockchain and DLT Technical Architecture for Credit Management

The blockchain and DLT **technical architecture** for credit management relies on **several architecture elements** that provide functions that are implemented on various blockchain and DLT systems (cf. **Figure 1** and **Table X**): blockchain and DLT, smart contract, token, MRV tools, DLT oracle, user interface and wallet, Decentralised Identifier (DID) and Verifiable Credential (VC).

FIGURE 1. BLOCKCHAIN AND DLT TECHNICAL ARCHITECTURE FOR CREDIT MANAGEMENT



A **wallet** is defined as an "application or mechanism used to generate, manage, store or use private keys and public keys or other digital assets", noting that "digital assets stored in wallets can include, for example, non-fungible tokens" (ISO 22739:2024).

A **decentralised identifier** (DID) is defined as an "identifier that is issued or managed in a decentralized system and designed to be unique within a context" (ISO 22739:2024) and as "a globally unique persistent identifier that does not require a centralized registration authority and is often generated and/or registered cryptographically […]" (W3C DID) **[39] [40a]**. And a **verifiable credential** (VC) is defined as "a standard data model and representation format for cryptographically-verifiable digital credentials" **[40a] [40b]**.

TABLE X. BLOCKCHAIN AND DLT TECHNICAL ARCHITECTURE FOR CREDIT MANAGEMENT

Architecture Element	Blockchain and DLT Function	Blockchain Implementation
Blockchain and DLT	records **credits** via a **transaction** on the **distributed ledger**	**blockchain**: e.g. Ethereum, Solana, Tezos **layer 2 solution**: e.g. Celo, Polygon
Smart Contract	automates **credit issuance**, **credit trading**, **credit transfer** and **credit retirement** between the credit stakeholder **wallets**	**smart contract**: e.g. token smart contract
Token	associates (tokenises) a **credit** to a **token** (e.g. fungible token, non-fungible token (NFT) that represents one unit of verified and traceable **environmental benefit / impact**	**token**: e.g. fungible token (ERC-20 on Ethereum blockchain), non-fungible token (ERC-721 on Ethereum blockchain)
MRV Tools	records the update of the environmental metrics within the **smart contract** or within the **NFT metadata scheme**	**NFT metadata scheme**: e.g. JSON metadata file that describes the NFT and may be updated
DLT Oracle	connects **data providers** to the **blockchain**	**DLT oracle**: e.g. ChainLink blockchain oracle
User Interface and Wallet	provides a **user interface** (e.g. dashboard, mobile application) to **stakeholders** to track and monitor the project status and performance / progress, provides a **wallet** to trade and transfer credits	**wallet**: e.g. MetaMask on Ethereum blockchain
DID and VC	provides a **unique identifier** to the **project** or **credit** and **identity** to **stakeholders**; provides **verifiable credential** for **credit verification** and **credit retirement**	**identifier**: e.g. W3C DID **verifiable credential**: e.g. W3C VC

III.5. Blockchain and DLT-enabled Credit Management Processes

The blockchain and DLT-enabled credit management processes involve several stakeholders, architecture elements and blockchain and DLT functions (cf. **Table XI**).

TABLE XI. BLOCKCHAIN AND DLT-ENABLED CREDIT MANAGEMENT PROCESSES

Process	Stakeholder	Architecture Element	Blockchain and DLT Function
1 Project Development and Registration	Project Developer, Registry Provider	Blockchain and DLT, Smart Contract, DID, User Interface	**blockchain** records some **project details** (or a hash of project details) with a **unique** and **decentralised identifier** (DID) within a **smart contract** and / or the **NFT metadata scheme**
2 Project Measurement, Monitoring and Reporting	Data Provider	Blockchain and DLT, DLT Oracle, MRV Tools, User Interface	**blockchain** collects some **measurement metrics** through **DLT oracles** and records them within the **smart contract** and / or **NFT metadata scheme**
3 Project Validation, Verification and Certification	Project Validator, Project Verifier, Auditor	Blockchain and DLT, User Interface, VC	**blockchain** records the **verified project environmental impact / benefits** (or a hash) through a **verifiable credential** (VC) that made available through a user interface
4 Credit Issuance	Credit Issuer, Registry Provider, Project Developer	Blockchain and DLT, DID, Smart Contract, Token, User Interface, Wallet	**smart contract(s)** create(s) the **token(s)** associated with the **credit** that are assigned to the **project developer wallet** or transferred to the **credit issuer wallet**; **project metadata** may be linked to the **NFT metadata scheme**
5 Credit Trading and Transfer	Credit Buyer, Credit Issuer, Credit Marketplace Provider, Credit Seller, Project Developer	Blockchain and DLT, Smart Contract, Token, Wallet	**smart contract** automates the trading and transfer of **tokens** from a **credit seller wallet** to a **credit buyer wallet** in exchange for payment
6 Claiming and Credit Retirement	Credit Buyer, Credit Issuer	Blockchain and DLT, Smart Contract, Token	**smart contract** and / or **NFT metadata scheme** records the **credit retirement status**

CONCLUSION

Section I of this article introduced climate action and biodiversity conservation challenges, data, targets and means. For climate action, the Kyoto Protocol introduced the concepts of carbon credit and carbon dioxide equivalent (CO2e). The later measures greenhouse gas (GHG) emissions that have reached 53.82 billion tonnes of CO2e in the World in 2023. Following the Paris Agreement and according to IPCC latest report, these emissions shall be reduced by 43% in 2030 from 2019 levels and by 84% in 2050 to limit the global warming to 1.5°C above preindustrial levels. Countries efforts, i.e. nationally determined contributions (NDC), are collected by the UNFCCC through NDC reports that allow following the progress of GHG emission reduction and removal enhancement.

For biodiversity conservation, the species abundance decline was evaluated to 73% in the World between 1970 and 2020 and forest land decreased from 6 to 4.05 billion hectares in the World between -10 000 and 2022 due to land use change to built-up area, cropland or grazing land. The Kunming-Montreal Global Biodiversity Framework (GBF) targets 30% of ecosystem conservation and restoration by 2030 by mobilising 200 billion dollars per year by 2030 in order to implement national biodiversity strategies and action plans (NBSAP), based e.g. on biodiversity credit. Countries efforts are collected by the CBD through NBSAP reports that allow following the progress of biodiversity protection and restoration.

Then, **section II** detailed the carbon and biodiversity credit management concepts, processes, stakeholders, standards and regulations. For climate action, a carbon credit typically represents the emission reduction of one tonne of CO2e. Carbon credits are associated with a climate action project (e.g. afforestation, reforestation) and allows credit buyers to compensate their GHG emissions. For biodiversity conservation, a biodiversity credit represents various biodiversity gains for species, ecosystems and natural habitats. Biodiversity credits are associated with a biodiversity conservation project (e.g. forest restoration) and allows credit buyers to compensate their pressures on the nature.

Carbon and biodiversity credits are traded and exchanged on compliance and voluntary markets that rely on centralised credit registries and credit marketplaces. Credit marketplaces allow project developers to propose some projects that become credits that are then purchased and reported by credit buyers as environmental claims at national level (thus feeding the NDC and NBSAP reports). Despite the existence of environmental standards for the voluntary market (e.g. Verified Carbon Standard by Verra, Gold Standard, Plan Vivo Biodiversity Standard) and environmental regulations for the compliance market (e.g. UNFCCC Clean Development Market, EU Emission Trading System, UK Biodiversity Net Gain), centralised credit registries and credit marketplaces do not prevent from double-counting of credits.

And finally, **section III** explored blockchain and DLT application to carbon and biodiversity credit management including the mechanisms behind trust creation, the use cases for sustainable development, the specific concepts for credit management, the technical architecture, as well as the blockchain and DLT-enabled credit management processes. Indeed, carbon and biodiversity credits can take advantage of new architectures in blockchain and DLT (e.g. Ethereum 2.0) that improved their scalability, sustainability and sovereignty and support the sustainable development efforts. In particular credit registries and credit marketplaces can benefit from blockchain and DLT inherent characteristics such as transparency for credit validation and verification, traceability for audit, immutability of data for credit issuance, credit trading and credit retirement, which is a critical factor for eliminating double-counting of credits, and interoperability for the interconnection of various credit registries and marketplaces.

Blockchain and DLT bring powerful tools such as the fungible and the non-fungible token, which are created through a smart contract and associated with carbon and biodiversity credits, the DLT oracle, which interconnects collected data between MRV tools and the blockchain, but also the decentralised identifiers for credit and stakeholder identification, and the verifiable credentials for credit verification. Some credit management solutions exist for carbon credit (e.g. Toucan, Nori, KlimaDAO, Open Forest Protocol) and biodiversity credit (e.g. GainForest, TreeCircle), especially for the voluntary market, and can even interconnect with centralised registries (e.g. *Carbon Bridge* by Toucan with the Verra Registry).

Beyond their inherent characteristics, blockchain and DLT bring a technical architecture for supporting the credit management processes in a backward-compatible way. This article proposed a technical architecture for credit management that is intended to feed, in a second step, some standardisation efforts at the ISO/TC307 technical committee, in charge of blockchain and DLT standardisation. In particular, the following standards under development in various standardisation groups were already identified: "ISO/AWI TR 24878 New and emerging DLT/Blockchain Use Cases" and "ISO/AWI PAS 24874 Guidebook on the Use of Smart Contracts in Contributing to the Sustainable Development Goals" within ISO/TC307/WG6, "ISO/CD 20435.2 A Framework for Representing Physical Assets Using Tokens" within ISO/TC307/WG8 and "DLT and Carbon Markets" preliminary work item within ISO/TC307/AHG4.

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