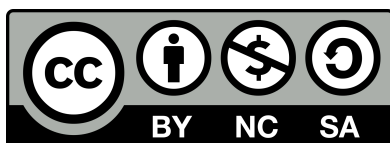


Responsible Finance and Web3

From Impact Statement
to Cryptographic Proof
REPORT N°2 | 2026



TheBlockchainforGood.org



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About



THE BLOCKCHAIN FOR GOOD is a non-profit organization (governed by the French law of 1901) whose purpose is to build bridges between the blockchain and crypto-asset ecosystem and stakeholders in development that respects future generations. Since 2018, it has brought together researchers and civil society in an open and participatory science approach through three means of action: (1) Collecting data on impactful projects built on blockchains through a global directory, (2) Analyzing these projects by sector through accessible reports, and (3) Sharing, exchanging, and debating through original events.

(1) Directory

 A screenshot of a web browser displaying the "Impact Blockchain Projects Open Directory". The page shows a complex table with multiple columns, including project names, descriptions, and various data points. The table is organized into sections, with a "Related to SDG" section visible at the bottom. The interface includes a search bar and navigation tabs at the top.

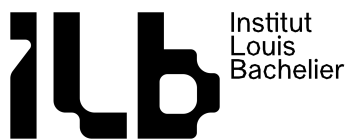
(2) Reports



(3) Events



Our Partners



The Louis Bachelier Institute (ILB) is a non-profit organization established in 2008 under the auspices of the French Treasury and the Caisse des Dépôts et Consignations (French Deposits and Consignments Fund). The core mission of the Louis Bachelier Group (ILB, FdR, IEF) is scientific research that promotes sustainable development in economics and finance. Currently, over 60 programs are hosted at the ILB, focusing on four societal transitions: environmental, digital, demographic, and financial. Its activities aim to engage academics, businesses, and public authorities in research programs, scientific events, and other forums for exchange.



Bpifrance, the French public investment bank, is the leading partner for French entrepreneurs. From creation to stock market listing, it supports companies at every stage of their development through financing, guarantee, and investment solutions.

A key player in innovation, Bpifrance also supports projects with a strong technological and societal impact, particularly in emerging fields such as blockchain and the ecological transition. Through its programs and partnerships, Bpifrance fosters sustainable business growth and strengthens the competitiveness of the French economy.



The Fintech Chair of the University of Paris Dauphine - PSL, and its Founding Partners FORVIS MAZARS, and Crédit Agricole CIB, supports research and focuses on two priority areas, blockchain and the role of Artificial Intelligence in finance.

A pool of high-level specialists (researchers, scientific advisors, doctoral students, Tech environment actors, etc.) are involved in developing these areas through three types of actions: research, teaching and valorization.



Ethereum France is a non-profit association (law of 1901) founded in 2016, whose purpose is to promote and develop the use of the Ethereum blockchain among the general French-speaking public.

The Blockchain for Good Association publishes independent analysis and the opinions expressed in this report are solely those of the authors and do not represent the views of the individuals or organizations consulted, nor our partners.

RESPONSIBLE FINANCE & WEB3

FROM IMPACT STATEMENT TO CRYPTOGRAPHIC PROOF

According to the United Nations Environment Program, “\$7.3 trillion has been invested in activities harmful to nature, compared to only \$200 billion for nature-based solutions. The private sector is responsible for the majority of negative financial flows to nature, \$4.9 trillion, but contributes only \$23 billion to nature-based solutions¹”. This imbalance, however, is not new. Why, after half a century of reforms, is responsible finance still struggling to gain traction?

Beyond cyclical trends and the current climate of distrust, is this a risk problem, which can be managed with better models, or a trust problem, which can be restored with evidence? What fundamentally distinguishes an impact statement from proof of impact, recorded on a public blockchain and verifiable by anyone? Would it be possible to replace the annual audit by an accredited third party with real-time verification, based on heterogeneous data streams, without previous biases simply reappearing in a new form? These questions raise others, more political ones. Is decentralizing finance enough to democratize it, or does it reproduce, in a new form, the same power asymmetries as in the traditional system? Does the tokenization of a natural ecosystem make it a better-protected common good, or an even more exposed speculative asset? And how can a system designed to empower unbanked populations, if poorly designed, reinforce their dependence rather than reduce it?

The transition to a life-oriented financial model could, according to some estimates², generate up to \$10.1 trillion in annual commercial value by 2030. This figure says less about what Web3 can achieve than it measures the magnitude of what remains to be decided: between promise and proof, between innovation and inclusion, between decentralization and regulation. These are some of the questions this report seeks to address and, where possible, to document.

¹ König-Sykorova, M., Olsen, N., Grimm, M., Bertello, H., et al. (2026). *State of Finance for Nature 2026 : Nature in the Red – Powering the Trillion Dollar Nature Transition Economy*. United Nations Environment Programme (UNEP). <https://wedocs.unep.org/items/a4a8edaa-3896-4811-b527-1583dfce7201>

² World Economic Forum. (2026). *50 investible opportunities for a new nature economy* [Insight report]. <https://www.weforum.org/publications/50-investible-opportunities-for-a-new-nature-economy-insight-report/>

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Key: A, C, or R stands for Author, Contributor, and Reviewer, followed by Status / Part / Chapter.

Ex.: [R P1, 2] reads Reviewer, Part 1, Chapter 2. I and C stand for Introduction and Conclusion.

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LIST OF THE 73 WEB3 PROJECTS CITED

AAVE, AGUA, AgriDex, Algorand, Alpha Bonds, Amply, Anzi Finance, Arbol, AthenaDAO, Big Green DAO, Blink, Carbons, Centrifuge, Chainlink, Change Code, CirclesUBI, Clixpesa, Compound, CryoDAO, dClimate, Dowgo, EcoBridge, Ejara, Empowa, EthicHub, Etherisc, GainForest, Gitcoin, Giveth, Glo Dollar, GoodDollar, Grassroots Economics, Haraka, Helium, HesabPay, HiveOnline, Hypercerts, ImpactMarket, Iniciativ/InEx, Inuk, IXO Protocol, Jia, JusToken, KlimaDAO, Kolektivo, M3tering Protocol, MakerDAO / Sky, Mento Labs/Celo, MiniPay, Molecule, Morpho, MultiKnip, Octant, Optimism Collective, PACT Protocol, Penomo, Pleno, PsyDAO, Quipu, Rahat, Regen Network, Shamba Network, Solana, Tadamon, terra0, Toucan Protocol, Untangled Finance, Uniswap, ValleyDAO, Worldcoin.

Executive Summary

Finance has always been as much a political issue as a technical one. Who decides what to finance, according to what criteria, and for whose benefit: these choices have shaped the trajectories of economies, societies, and territories far beyond what rates of return can measure.

This report starts from a simple observation. The instruments that our societies have built to direct capital towards the common good, from the ethical exclusion of Quaker portfolios to the carbon credit of the Kyoto Protocol, from microcredit to labeled impact investing, are failing to deliver on their promise.

The reasons for this are numerous, including chronic underfunding, short-term horizons, and institutional conflicts of interest, and this report does not claim to address them all. It focuses on one in particular, perhaps the least visible because it is the most structural: the verification architecture on which these instruments are based. As long as proof of impact depends on self-reporting or intermediaries whose integrity can only be verified by trusting them, even the best-intentioned systems remain vulnerable to abuses, which are widely documented. It is within this space, that of verification, traceability, and transparency, that the new digital architectures built on Distributed Ledger Technologies (DLTs*) are situated.

This report is neither a plea for nor an indictment of Web 3.0. It does not seek to pit a failing traditional financial system against a miraculous technological solution. Rather, it examines, with the rigor required by a subject so laden with political and commercial implications, what these tools actually enable, what they cannot do, and under what conditions their deployment can serve a transition to a so-called regenerative economy, that is, an economy that no longer merely limits its damage, but actively

strengthens the capacity of living systems to reproduce.

This report is addressed to three communities that everything seems to separate, but which the question of impact verification ultimately brings together.

For traditional finance professionals (TradFi*), it offers a genealogy of concepts and a mapping of impactful Web3 tools, without assuming any prior familiarity with cryptography or decentralized protocols. For decentralized finance (DeFi*) players, it provides a grounding in the long history of responsible finance and a critical assessment of the promises of their own ecosystem, without sparing any blind spots or promotional rhetoric. For centralized finance (CeFi*) players, who have mastered the codes of TradFi* while already having heavily invested in DeFi*, it offers a framework for analyzing their unique position at the interface of a convergence whose conditions and risks this report documents.

These three perspectives are inseparable, and the issues they share cannot be understood or resolved within the silos of each of these communities. The first part examines the limitations of conventional sustainable finance and the new infrastructures that Web3 proposes to overcome them. The second explores the possibility of gradually replacing simple impact statements with cryptographic proofs, at what cost, under what conditions, and with what systemic risks.

It is these questions, and not just its promotional aspects, that the following developments seek to answer.

Report structure

In order to make a subject that is both technical and institutional accessible, this report adopts a two part plan structured around a central question: under what conditions do new digital infrastructures allow us to move from the declaration of impact to its cryptographic proof?

The first part establishes the structural diagnosis and maps the architectural responses of Web3. The second part subjects these responses to rigorous examination by adopting a posture of analytical neutrality.

The report is aimed at two audiences. Traditional finance professionals will find the conceptual foundations of regenerative economics and the technical tools that enable its decentralized implementation. Decentralized finance (DeFi*) and Web3 practitioners will find an institutional and regulatory perspective that shapes the adoption of their architectures by established capital markets.

We prefer to explain using use cases, indicated in grey boxes and by this pictogram:



and we can also rely on the directory of impact projects built on public blockchains, which the Blockchain for Good association has been working on since 2018.

This report documents 73 operational projects, distributed across all sections according to the theme they illustrate.

Si vous n'êtes pas familier avec les Technologies de registre distribué (DLT) vous trouverez sur la version numérique un glossaire couvrant l'ensemble de leur terminologie. Sur une version imprimée, vous pouvez y accéder en scannant le QR Code figurant en annexe.



This report is available online. If you wish to discuss, annotate, or correct information within the text, please visit the collaborative version. Select the word, phrase, or paragraph you wish to discuss and write your comment.

As mentioned at the end of the book, we used artificial intelligence tools to facilitate certain writing tasks. [A dedicated chatbot, whose responses are based on this report and its bibliography, is available in digital format](#) (in French).

Introduction

The idea that investment can and should be responsible is not a contemporary invention. It predates the rise of Web 3.0, the first non-financial rating agencies, and even the Brundtland³ Report of 1987. As early as the 17th and 18th centuries, Quakers refused to finance slavery and gambling, not through risk calculation, but out of moral conviction. This precedent is instructive and reveals that the question of the purpose of finance is as old as finance itself, and that the idea that money has no smell, *pecunia non olet*, according to the phrase attributed to Emperor Vespasian, has never been a reality, but a convention. Societies have collectively chosen, on numerous occasions throughout history, to pretend that capital does not smell of what it finances. This report starts from the premise that this convention has become untenable and examines what new technological architectures can contribute to its dismantling.

Before going any further, a clarification of terminology is necessary, as confusion between three related concepts pervades a significant portion of public debate on digital finance. Traditional finance, referred to in this report by the English acronym TradFi* (Traditional Finance), encompasses all conventional financial institutions and markets, commercial banks, asset managers, stock exchanges, and insurance companies, whose infrastructure relies on centralized ledgers, accredited intermediaries, and national or supranational regulatory frameworks. Centralized finance, or CeFi*, refers to the platforms and operators that allow the purchase, holding, or exchange of crypto-assets, but while retaining custody of the funds in centralized structures whose risk

architecture is not fundamentally different from that of a traditional bank, apart from currently much less stringent regulations. Finally, decentralized finance, or DeFi*, refers to all financial services, loans, borrowings, asset exchanges, and liquidity management, built directly on public blockchains *via* smart contracts*, without institutional intermediaries and accessible to any holder of a digital wallet, regardless of nationality or banking status. Within decentralized finance, regenerative finance, or ReFi*, has emerged, which this report examines in detail. This approach seeks to direct the liquidity and structural properties of DeFi* toward projects with measurable environmental and social impact, or even toward projects for the regeneration of living systems. These four concepts are not opposed but coexist, and their partial convergence is precisely one of the key issues addressed in the following sections.

This report does not seek to pit a "*failing, traditional system*" against a "*new, life-saving solution from Web 3*". This opposition is as convenient as it is misleading. Traditional finance has produced remarkable instruments for mobilizing capital and remains essential for any ambition to finance at scale. Decentralized protocols have generated real innovations in transparency, automation, and access, as well as a massive wave of pure speculation, documented fraud, and broken promises. Neither system holds a monopoly on virtue or rationality. What this report examines is a question of architecture: which tools, combined in what ways, and under what governance conditions, can bring responsible finance closer to its original function, directing capital toward what creates value for all living things, not just the shareholder?

A question often posed as a preliminary matter deserves to be addressed here, so as not to have to revisit it: the ecological footprint of blockchain technology itself. The criticism is valid for certain protocols.

³ The Brundtland Report, published in 1987 by the World Commission on Environment and Development of the United Nations, under the title *Our Common Future*, is the founding text of sustainable development, whose *raison d'être* is supposed to "*meet the needs of the present without compromising the ability of future generations to meet their own needs*".

| RESPONSIBLE FINANCE & WEB3

The Proof of Work consensus mechanism used by the Bitcoin network is inherently energy-intensive, and it is precisely this energy expenditure that underpins its security. However, most of the protocols used by the Regenerative Finance applications examined in this report, and in particular the public blockchains Ethereum (since its migration to Proof of Stake in 2022), **Celo**, **Solana**, and **Algorand**, operate using consensus mechanisms with energy consumption several orders of magnitude lower than that of their Proof of Work predecessors. Ethereum's transition alone resulted in an estimated 99.95% reduction in its electricity consumption, bringing it down to approximately 0.0026 TWh per year⁴, according to the Cambridge Centre for Alternative Finance, this is equivalent to the annual consumption of several thousand European households, and comparable to that of a medium-sized⁵ bank *data center*. The energy argument, valid when applied to proof-of-work protocols*, therefore no longer applies to the on-chain infrastructures* examined here.

A distinctly legal issue underpins this entire report and deserves to be explicitly stated in the introduction. Corporate liability law, in the vast majority of jurisdictions, is currently based on a fundamental distinction between an obligation of means, whereby the company commits to making reasonable efforts to achieve an objective, and an obligation of result, whereby the company commits to producing a specific and verifiable effect. Companies' environmental and social commitments almost universally fall into the first category.

Except for benefit corporations⁶, a company can legally claim that it "aims" for carbon neutrality, that it "seeks to" reduce its impact on biodiversity, or that it "strives to" guarantee fair working conditions in its supply chain, without these statements implying verifiable liability in the event of a discrepancy between the stated intention and the observed reality. However, the instruments examined in the second part of this report, smart contracts* for conditional financing, Impact Tokens, and continuous digital verification systems, structurally pave the way for a shift from an obligation of means to an obligation of results, verifiable through computer code. Should this shift become entrenched in practices and regulatory frameworks, it would fundamentally redefine corporate civil liability with respect to their non-financial commitments, which is perhaps the most significant, and least discussed, transformation that distributed ledger technologies could bring to law and finance.

This report targets three interdependent audiences: professionals in traditional finance (TradFi*) and centralized finance (CeFi*) for an introduction to impactful Web3 and decentralized tools; and actors in Web3 and decentralized finance (DeFi*) for a historical grounding in responsible finance and a critical assessment of their ecosystem. First and foremost, it is important to recall the perspective within which this report is situated. It is not that of the 17 Sustainable Development Goals (SDGs), considered as a list of equivalent ambitions, but rather that proposed by Karl Polanyi and adopted by the Stockholm Resilience Centre, where the economy is embedded within society, itself embedded within the biosphere.

⁴ Neumüller, A. (2023, April 26). Ethereum's climate impact: a contemporary and historical perspective. Cambridge Center for Alternative Finance, Cambridge Digital Assets Programme, Cambridge Judge Business School, University of Cambridge.

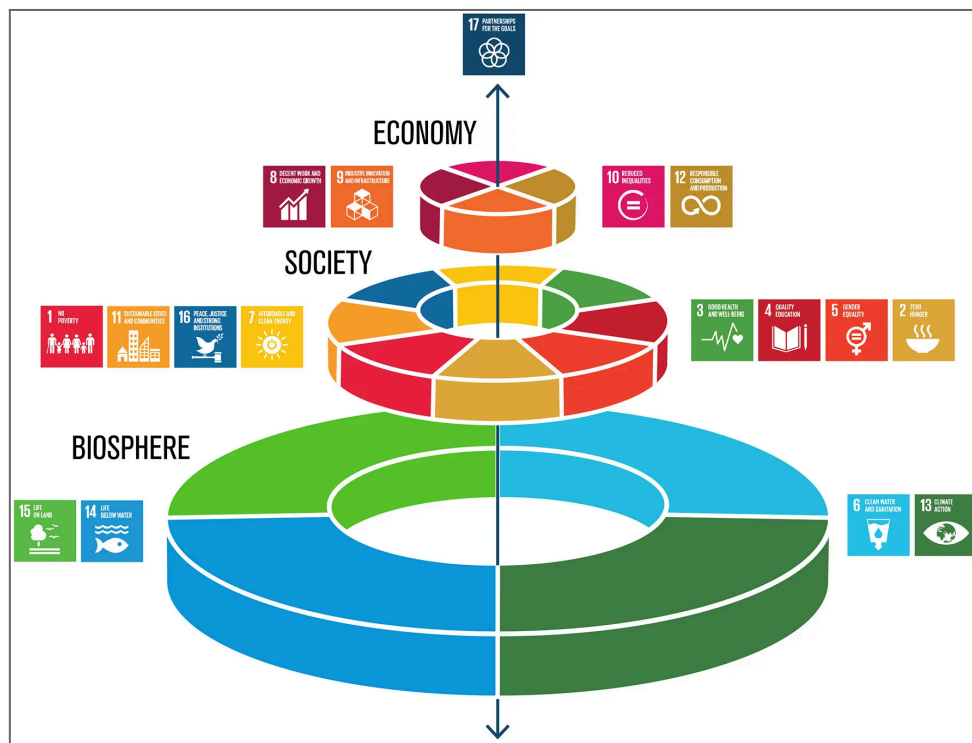
<https://www.ibs.cam.ac.uk/2023/ethereums-climate-impact-a-contemporary-and-historical-perspective/>

⁵ Sedlmeir, J., Buhl, H. U., Fridgen, G., & Keller, R. (2020). The energy consumption of blockchain technology: Beyond myth. *Business & Information Systems Engineering*, 62(6), 599–608. <https://doi.org/10.1007/s12599-020-00656-x>

⁶ Quality introduced by the law of May 22, 2019 relating to the growth and transformation of businesses, known as the PACTE law. The social and environmental objectives included in the articles of association of a mission-driven company are subject to periodic verification by an independent third-party organization (OTI) accredited by the French Accreditation Committee (COFRAC), and failure to comply with them may lead, upon referral by the public prosecutor or any interested party, to the judicial removal of the designation by the president of the commercial court.

| RESPONSIBLE FINANCE & WEB3

This analytical framework, which applies not only at the global level but also at the territorial and community levels, is the one in which the instruments examined in this report find their greatest relevance.



[F] The Sustainable Development Goals Wedding cake

Source⁷

⁷ Simpson, G. B., & Jewitt, G. P. W. (2019). The development of the water-energy-food nexus as a framework for achieving resource security: A review. *Frontiers in Environmental Science*, 7, 8. <https://doi.org/10.3389/fenvs.2019.00008>. The Sustainable Development Goals framework is another way of understanding the Sustainable Development Goals and their interconnections, where the economy and society are embedded within the biosphere. Azote for Stockholm Resilience Centre, Stockholm University CC BY-ND 3.0.



PART 1. The limitations of ESG finance in light of a new technological infrastructure

For more than half a century, a question has been circulating through global financial and economic systems without yet finding a satisfactory answer: how to sustainably direct capital towards creating value for all living things, and not just for the shareholder?

1.1 The genesis of an economy at the service of life

This question is neither new nor unique to Web 3.0; it runs throughout the history of economic thought, from the first ethical exclusions of Quaker portfolios in the 18th century to the dual materiality requirements now enshrined in European law. It has progressively forced finance to broaden its horizons, from maximizing short-term profit to considering stakeholders, then to measuring social and environmental impact, and finally to the even more ambitious idea of a so-called regenerative economy, that is, an economy that no longer merely limits or neutralizes its

damage, but actively strengthens the capacity of living systems to regenerate.

This trajectory, however, is not linear, and at each stage, the instruments created to serve the common good have revealed their limitations. Socially responsible investing (SRI) has produced empty labels, carbon credits have created a rigged market, and microfinance has sometimes worsened the situation of the poorest. It is not so much the bad faith of the actors that explains these excesses, but rather the structural fragility of the evaluation systems on which they relied, systems based on self-declaration, manual auditing, and trust placed in centralized intermediaries, just as fallible as the institutions they were supposed to oversee. The current context, in which states are abandoning their obligations of solidarity, is finally placing a particular pressure on the private sector in general, and finance in particular, to fill a growing void, in the name of social justice and fairness.

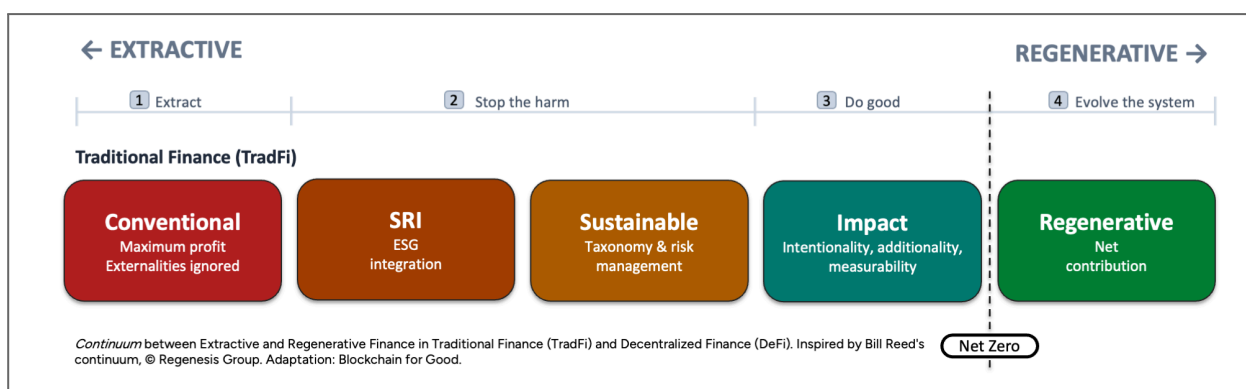
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This first chapter traces this genealogy. It starts from the intellectual foundations of responsible finance, from stakeholder theory to the notion of dual materiality, to show how a movement of thought has gradually been formed demanding an economy oriented towards life – an economy which enshrines the preservation of natural capital not as a regulatory constraint, but as a condition of its own sustainability.

He then examines how this movement, initially led by accountants, biologists, and

1.1.1 What kind of finance serves whom and what?

Finance is not monolithic. Under this generic term coexist profoundly heterogeneous practices, logics and ambitions, which are distinguished not only by their instruments but by the fundamental question they claim to answer: what should finance be used for, and according to what rules?



economists, produced new tools for measurement and governance, long before Web 3 came into being. And it finally analyzes why the current centralized system, despite decades of reforms, has failed to deliver on its promise, due to the lack of a verification infrastructure capable of transforming stated intent into legally binding evidence.

It is in this space, that of verification, transparency, and traceability, that new decentralized digital architectures come into play. Not as a miracle solution, but as a set of tools whose promises and limitations must be constantly and rigorously evaluated.

[F] The continuum between extractive and regenerative Finances

Source⁸

To account for this heterogeneity without caricaturing it, it is necessary to map it. Between extractivist finance, which maximizes monetary return while ignoring its ecological and social costs, and regenerative finance, which claims to actively strengthen the living systems on which it depends, there extends a "continuum of finance" in between, each representing a growing demand for intentionality, measurement, and accountability.

⁸ The "Trajectory of Ecological Design" (Bill Reed, © Regenes Group) represents the continuum from degenerative (reductionist thinking, siloed development) to regenerative (integrated development, thinking in terms of living systems). Adapted by: Blockchain for Good.
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This continuum is not a linear progression towards progress but a mapping of the compromises that each era has deemed acceptable between the logic of efficiency and consideration of the world from which that efficiency is extracted.

This analytical framework is valid first of all for traditional finance, which took more than half a century to conceptualize and is still struggling to build it, and is also valid, albeit at a different time and in a much less developed way, for Decentralized Finance (DeFi*), with a striking asymmetry which this section will return to.

1.1.1.1 The continuum of fiduciary duty to the regeneration of life

Every map presupposes a starting point, and in finance, that starting point is the paradigm that dominated capital markets for most of the 20th century: maximizing shareholder returns within the existing legal framework, without any other considerations. Milton Friedman gave it its canonical formulation in 1970, stating in the *New York Times* that *"there is only one corporate social responsibility [...] to increase its profits to the extent that it plays by the rules"*⁹.

This doctrine was not merely an ideological position and crystallized into fiduciary duty, accounting standards, and criteria for evaluating managers.

In this context, the social or environmental effects of an economic activity fell under what economists euphemistically call externalities, that is to say, effects that were outside the scope of the market and that it did not have to account for.

And this paradigm remains, in terms of volume, the dominant one in global finance. The World Economic Forum estimated in 2023 that *"\$7.3 trillion was invested in activities*

*harmful to nature, compared to only \$200 billion for nature-based solutions."*¹⁰ and that *"the private sector is responsible for the majority of negative financial flows to nature, \$4.9 trillion, but contributes only \$23 billion to nature-based solutions"*¹¹.

Even though this paradigm has been progressively challenged, from within the financial markets themselves, by a series of approaches that have each, in their own way, shifted the boundary between what finance must consider and what it can continue to ignore, this fiduciary duty that prioritizes financial profitability at all costs has been progressively questioned within the financial markets themselves, using various methods.

Each of these methods has redefined, in its own way, what finance must consider and what it can still disregard.

Beyond conventional finance, the first layer of this continuum is socially responsible investing (SRI), whose roots lie in the religious convictions of Quakers and Methodists in the 17th and 18th centuries, but which only became formalized as an institutional practice in the 1960s and 1970s, particularly driven by the movements against the Vietnam War and against apartheid in South Africa.

By massively withdrawing their capital, universities, churches, and pension funds established a fundamental precedent, demonstrating that capital could be mobilized for moral and political reasons, and no longer solely for considerations of return.

⁹ Friedman M. (1970) "A Friedman Doctrine – The Social Responsibility of Business is to Increase its Profits" *New York Times*, September 13, 1970

¹⁰ World Economic Forum. (2026). 50 investible opportunities for a new nature economy [Insight report]. <https://www.weforum.org/publications/50-investible-opportunities-for-a-new-nature-economy-insight-report/>
¹¹ Ibid.

[B] From stakeholder theory to the 3P matrix

It was in the context of the 1970s that academia began to formalize what activist practice had already sensed. In 1984, the philosopher R. Edward Freeman published *Strategic Management: A Stakeholder Approach*¹² and introduced stakeholder theory. His thesis is simple in principle, but radical in its implications. For Edward Freeman, the management of a company cannot simply serve the shareholder and bears the responsibility of *"giving due consideration to the interests of other stakeholders, including employees, customers, suppliers, communities, financiers, government bodies and the environment."*¹³ *This conceptual shift does not deny the necessity of profit but redefines its conditions of legitimacy. Profitability ceases to be an end in itself and becomes the result of governance that is attentive to all stakeholders.*

This theoretical break was completed thirteen years later by John Elkington, who introduced the concept of the Triple Bottom Line in his 1997 book *Cannibals with Forks*.¹⁴ His "3P" matrix – Profit, People, Planet – proposes measuring an organization's performance according to three inseparable pillars: economic profitability, social impact, and environmental impact. The idea is less to replace financial logic than to add two dimensions previously invisible in balance sheets. This shift in organizational theory finds an unexpected echo in the field of corporate finance. In 2002, Michael Jensen, co-author with William Meckling of the

seminal article on agency theory¹⁵, who had established shareholder primacy as an axiom of modern governance, recognizes that the objective of maximizing shareholder value cannot be achieved in the long term by ignoring the interests of stakeholders. He proposes an "informed maximization of value."¹⁶ (enlightened value maximization) integrates stakeholders not as legitimate ends in themselves, as Freeman does, but as operational constraints whose satisfaction conditions sustainable performance (Jensen, 2002). The gap between the two positions reveals the limits of this apparent consensus: Freeman grounds stakeholder consideration in an ethic of responsibility; Jensen grounds it in a logic of optimization. The question of whether this shift is normative or simply instrumental, whether the company should consider its stakeholders because they have rights or because it maximizes its value, remains the unresolved point of contention that sustainable finance instruments, from ESG to impact bonds, inherit without having addressed it.

Socially responsible investing (SRI) operates strictly within the framework of traditional finance, without questioning its market structures, and where financial performance remains the primary evaluation criterion. It does not claim that capital should "do good" but only that it "should not finance certain evils," relying mainly on three strategies: exclusion, which consists of removing entire sectors such as weapons, tobacco, or, increasingly, fossil fuels; the "best-in-class" approach, which selects the companies with the best environmental, social, and governance (ESG) performance within each sector, without excluding any sector a priori; and shareholder engagement, which consists

¹² Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman.

¹³ *Ibid.*

¹⁴ Elkington, J. (1997). *Cannibals with forks: The triple bottom line of 21st century business*. Capstone.

¹⁵ Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, 3(4), 305–360.

¹⁶ Jensen, M. C. (2002). Value maximization, stakeholder theory, and the corporate objective function. *Journal of Applied Corporate Finance*, 14(3), 8–21.

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of using voting rights at general meetings to influence the company's governance and sustainability practices. These three strategies share the common feature of relying on ESG analysis as an extra-financial evaluation tool. It is important to note that SRI, as a labeled investment practice, is by design limited to assets listed on financial markets. In the field of private equity and unlisted assets, the same analytical criteria apply, but under the sole term ESG, without the approach being designated as socially responsible in the institutional sense of the term.

The second layer is that of so-called sustainable finance in the regulatory sense of the term, the institutional formalization of which accelerated in 2004, driven by the United Nations Global Compact¹⁷, which formally introduced the acronym into the vocabulary of institutional finance. The ESG approach no longer relies on exclusion but on the integration of extra-financial criteria, which are incorporated into the analysis of investment risks and opportunities.

This shift is real, but limited in scope. As the specialized literature points out, ESG remains fundamentally a *"risk reduction approach, which focuses on processes"*¹⁸, an outside-in perspective which asks how climate or social risks threaten the profitability of the company, and not the other way around.

Virtue, in this context, is presented as profitable, which is an elegant way of never having to choose between the two.

The third layer is that of so-called sustainable finance in the regulatory sense of the term, such as the European Taxonomy¹⁹, which came

into force in 2020, seeks to define sustainability. The requirement is higher in that an activity can only be considered sustainable if it contributes substantially to one of the six environmental objectives defined by the regulation, without significantly harming the other five, according to the principle of Do Not Significantly Harm (DNSH). For example, a renewable energy project that severely destroys local biodiversity cannot be considered sustainable finance. This principle acts as a safety net and marks the end of siloed approaches by stipulating that the pursuit of positive performance never exempts investors from managing the occurrence of negative externalities.

Dual materiality, as enshrined in the Sustainable Finance Disclosure Regulation (SFDR), adopted in November 2019²⁰ This adds a further requirement. Companies must account not only for the risks that climate and biodiversity pose to their activities, but also for the impact their activities have on climate and biodiversity. The company *"is no longer merely exposed to climate or social risks but generates them and must be held accountable"*²¹. This represents a significant conceptual shift, from managing financial risk to ecological accountability, but it remains rooted in a logic of damage limitation, not restoration.

The fourth layer is that of impact finance, which focuses more on unlisted asset classes, the conceptualization of which accelerated at the end of the 2000s, and which Finance for Tomorrow defines as an *"investment approach that aims to generate, in addition to a financial return, measurable positive impacts on society and the environment"*.²²

¹⁷ ESG, 20 years later: from intuition to global transformation

<https://pactemondial.org/2024/12/19/esg-20-ans-apres-de-lintuition-a-la-transformation-globale/>

¹⁸ See in particular the Institute for Sustainable Finance.

¹⁹ Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on a framework to promote sustainable investment and amending Regulation (EU) 2019/2088 (Text with EEA relevance)

<https://eur-lex.europa.eu/legal-content/FR/ALL/?uri=cele x:32020R0852>

²⁰ *Ibid.* and Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability disclosure in the financial services sector. <https://eur-lex.europa.eu/legal-content/fr/ALL/?uri=CELEX%3A32019R2088>

²¹ *Ibid.*

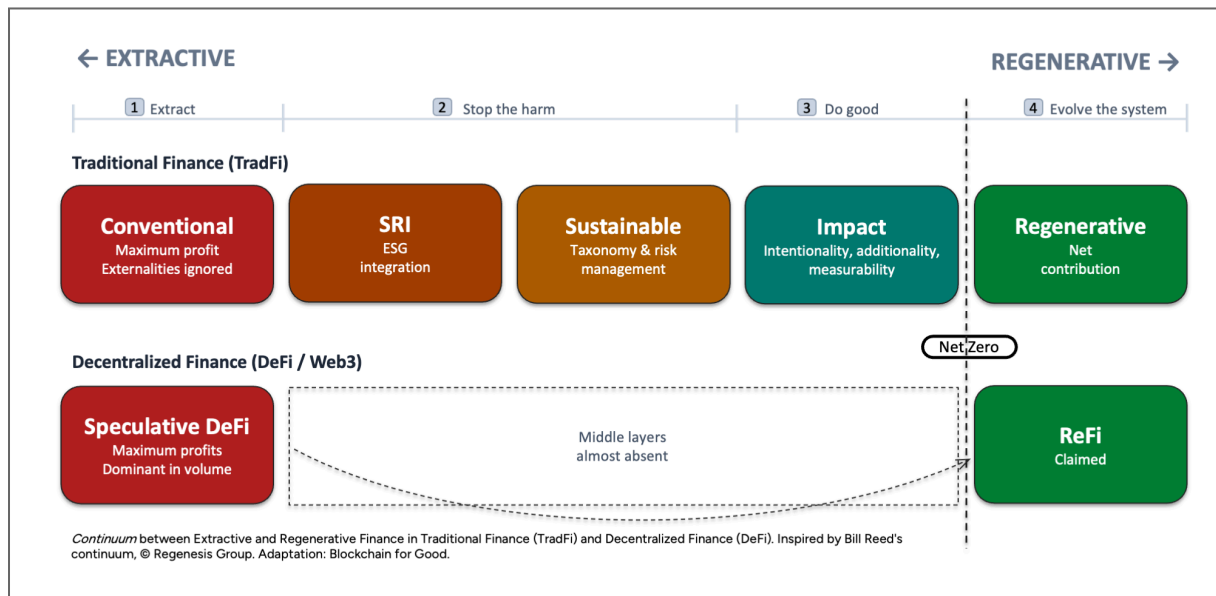
²² Becquey, P., Boric, N., & Clerc, P. (2021). Definition of impact finance. Finance for Tomorrow. <https://institutdelafinancedurable.com/wp-content/uploads/2023/09/Finance-for-Tomorrow-Definition-de-la-finance-a-impact-Septembre-2021-5.pdf>

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Impact finance introduces two new and cumulative requirements not found in previous frameworks: intentionality, meaning that the investment must have the explicit objective of producing a positive impact, not simply avoiding a negative one; and additionality, meaning that the impact must be demonstrable and would not have occurred without the investment in question.

available on preferential terms²⁴ and private capital within the same structure in order to reduce the risk profile of an investment to the point of making it acceptable for actors who would not have been able to bear it alone.

At the end of the continuum lies what is beginning to be called regenerative finance, a concept that will be examined in detail in the



[F] The continuum between extractive, regenerative, traditional and decentralized finance

Source²³

These two criteria considerably raise the level of evidentiary requirement and presuppose an a priori measurement of objectives, ongoing monitoring and an ex post evaluation of results.

Among the operational mechanisms that impact finance has developed to reach structurally underfunded sectors or geographies, blended finance occupies a notable place. It combines capital made

following section, but whose outlines should be sketched here. Whereas impact finance measures a net positive impact, finance serving the regenerative economy argues that capital must actively strengthen the capacity of living, ecological, social, and territorial systems to reproduce and thrive. This is no longer a logic of damage limitation, nor even of compensation, but a logic of net positive contribution to life.

This continuum we have just presented is not a progression toward an ideal but a description of different types of finance at work within the global financial system, in which practices coexist that differ not only in their instruments but also in their fundamental relationship to the question of what capital should produce, and for whom.

²³ The "Trajectory of Ecological Design" (Bill Reed, © Regenes Group) represents the continuum from degenerative (reductionist thinking, siloed development) to regenerative (integrated development, thinking in terms of living systems). Adapted by: Blockchain for Good.
<https://online.flippingbook.com/view/443409299/25/>

²⁴ such as subsidized rates or guarantees or absorption of initial losses, provided by public actors, development finance institutions, or philanthropic actors.

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The gap between financial flows that degrade life and those that claim to serve it is considerable.

1.1.1.2 The parallel with Decentralized Finance (DeFi): a biased continuum

The continuum between extractive and regenerative finance can also be interpreted in the decentralized finance (DeFi*) ecosystem and constitutes a relevant angle of analysis to understand both the ambitions and the weaknesses of Web3 in terms of impact.

Decentralized Finance (DeFi*), as it unfolded from 2017-2018, and especially during what the sector dubbed the "DeFi* Summer" of 2020, functionally corresponds to the extractive end of the spectrum. The dominant protocols in terms of volume are designed to maximize financial returns through the circulation of capital between different capitals.

Liquidity enters the system to generate returns on other liquidity, in cycles whose value relies more on the continuous influx of new participants than on the creation of productive value. Raphaël Haupt, in an analysis published by Curve Labs in 2022, describes this ecosystem as designed a priori for "optimizing financial returns without being anchored in real activities."²⁵ This is not a moral judgment but a description of the incentive architecture at the heart of speculative decentralized finance, which is not intended to finance the real economy because it was not designed for that purpose.

What is striking, however, is the next step within the Web3 ecosystem. Starting in 2021, the Regenerative Finance (ReFi) movement emerged with the ambition of directing the liquidity accumulated in Decentralized Finance (DeFi) towards projects with measurable

environmental and social impact. Regenerative Finance (ReFi) seeks to combine the structural properties of DeFi, transparency, programmability, and accessibility, with the objectives of impact finance.²⁶ But when viewed in light of the aforementioned continuum, it presents a striking structural asymmetry. Between speculative DeFi* and ReFi*, the intermediate layers that traditional finance took more than half a century to build – the equivalent of socially responsible DeFi*, ESG DeFi*, sustainable DeFi* – are almost entirely absent.

These categories do not exist as established fields within the Web3 ecosystem. They lack measurement standards, reporting obligations, and bodies of doctrine. The spectrum has been bypassed. In traditional finance, each intermediate layer fulfilled a specific function, enabling the forging of definitions, the imposition of increasingly stringent measurement and evidence requirements, and the development of specialized professional bodies. Errors, pitfalls, and scandals led to the following corrective measures. Socially responsible investing (SRI) has generated greenwashing.²⁷ *which gave rise to the environmental, social, and governance (ESG) approach; ESG produced its own excesses, which in turn led to impact finance; impact finance is now encountering its own limitations in terms of measurement and systemic transformation. Each layer served as a learning ground for the next, whereas Regenerative Finance (ReFi*) within Web3 did not have this groundwork. It claimed the regenerative end of the continuum without having gone through the intermediate stages that, in traditional finance, allowed for greater substance in the subsequent layers.*

This observation is not an indictment of Web3 Regenerative Finance (ReFi*). Researcher Kate Bennett establishes, in a study of forty ReFi* initiatives published in *Frontiers in Blockchain*

²⁵ Haupt, R. (2022, February 23). The Promises and Pitfalls of Regenerative Finance: Towards a Critical Yet Constructive Dialogue. CurveLabs. <https://web.archive.org/web/20241201222452/https://blog.curve labs.eu/the-promises-and-pitfalls-of-regenerative-finance-4910f0f6f690?qi=44616d45ec9a>

²⁶ *Ibid.*

²⁷ Communication from an organization about its environmental commitments that exceeds, embellishes, or contradicts the reality of its practices.

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in 2025, that the design of protocols determines whether they "serve regeneration or are limited to optimizing existing markets without changing their underlying logic."²⁸ Some protocols have produced real innovations in traceability, community governance, and access to capital for actors overlooked by traditional finance. Bennett also identifies an internal divide within the movement, between a ReFi* oriented towards the financialization of natural assets and a ReFi* rooted in territories and communities, a divide that precisely reflects the absence of a stable, intermediate conceptual framework. **Penomo**²⁹ is a renewable energy infrastructure tokenization platform that allows digital tokens to be linked to solar or wind projects to facilitate their financing through decentralized markets. The project explicitly conditions the selection of its renewable energy assets on an impact criterion for the energy transition, just as much as on financial return. Another example is **Dowgo**³⁰. **Dowgo**, a French B2B platform for green bond tokenization that connects renewable energy suppliers and investors by offering entry tickets starting at one euro per token, and **Dowgo**, which structures its access to private markets around dual financial and environmental performance aimed at European institutional investors, illustrate this attempt to occupy the missing intermediate strata, although it is not yet possible to speak, at this stage, of a fully established category.

It is in this space, that of missing layers, absent standards, and unformalized evidentiary requirements, that one of the central issues of this report lies. Not to ask Web3 to rebuild in ten years what traditional finance (TradFi*) took fifty years to construct, but to identify what each of the two systems can contribute to the other. Traditional finance (TradFi*) possesses the institutional architecture of accountability.

Decentralized finance (DeFi*) possesses the technical tools for verification. Their convergence, if it occurs under certain conditions, could allow us to collectively cross the net zero threshold, that point on the continuum where financial activity ceases to degrade and begins to give back.



The Initiative platform³¹ **Initiativ**, whose trading product is called **InEx**, offers trading of European emission allowances (EUAs), both spot and futures, via a programmable digital trading infrastructure. While traditional platforms like the Intercontinental Exchange (ICE) require a standard lot of 1,000 EUAs, **Initiativ** allows trading from a single allowance, representing one tonne of CO₂. This lower entry threshold makes the carbon compliance market accessible to mid-sized industrial operators and new entrants who were previously excluded by transaction costs. The platform is open to both compliance entities (industrial operators subject to the EU ETS) and other entities.³² and to financial participants (banks, brokers, funds), subject to qualification as a professional client within the meaning of the MiFID II directive³³.

Initiativ/InEx does not belong to Regenerative Finance (ReFi*) and does not claim to regenerate natural ecosystems. It occupies an intermediate stratum that this report identifies as

³¹ <https://www.takeinitativ.com/>

³² EU Emissions Trading System, https://climate.ec.europa.eu/eu-action/carbon-markets/eu-emissions-trading-system-eu-ets_en

³³ MiFID II – Markets in Financial Instruments Directive II – is European Directive 2014/65/EU, which entered into force in January 2018 and regulates markets in financial instruments within the European Union. It imposes strict obligations on trading platforms regarding pre- and post-trade transparency, investor protection, transaction reporting, and participant qualification (distinguishing between retail clients, professional clients, and eligible counterparties). Source: <https://eur-lex.europa.eu/legal-content/FR/TXT/?uri=CELEX%3A32014L0065>

²⁸ Bennett, K. (2025b). An evaluation of the regenerative claims of Web3's ReFi* movement. *Frontiers in Blockchain*, 8, 1564083. <https://doi.org/10.3389/fbloc.2025.1564083>

²⁹ <https://penomo.com/>

³⁰ <https://www.dowgo.com/fr>

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virtually absent in the Web3 ecosystem: that of regulatory compliance, directly linked to the dual materiality imposed by European law. Companies subject to the EU ETS are indeed required to simultaneously measure their climate impact (impact materiality) and the financial risk posed by their quota obligations (financial materiality). **Initiativ/InEx** translates this regulatory framework into granular digital infrastructure, without claiming to go beyond or fall short of what the law requires. This model illustrates that a carbon compliance FinTech, the digital equivalent of regulatory ESG finance, is technically feasible and commercially operational, even if it remains marginal in volume compared to the overall EU ETS market. As such, it foreshadows the convergence between digital infrastructure and the compliance market examined in section 2.3.3.

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1.1.2 The regenerative economy, a paradigm pre-existing Web3

The mapping of the financial spectrum presented in the previous section concluded with a finding of a gap between the promise of the regenerative pole and the capital actually mobilized toward it. Before examining why financial instruments struggle to bridge this gap, it is essential to understand what the regenerative pole truly represents and where it originates. The regenerative economy is not an invention unique to Web 3.0 but an established intellectual and practical movement, whose roots go back to the 1980s, and which has produced, over the decades, a body of academic literature, territorial experiments, and robust conceptual frameworks, well before decentralized protocols adopted the term. If regenerative finance, whether traditional or decentralized, claims to serve the regenerative economy, it is still necessary to understand what it is supposed to serve.

1.1.2.1 From "do no harm" to triple profitability

The intellectual turning point that distinguishes regenerative economics from its conceptual predecessors lies in a question of orientation, not just degree. Since the publication of the Brundtland Report in 1987³⁴ The dominant thinking in sustainable development aims to limit negative externalities, that is, to do less harm without necessarily doing more good. In the 2010s, this logic was extended with the rise of the circular economy, notably promoted by the Ellen MacArthur Foundation from 2015 onwards, based on the idea that closing material loops would make it possible to

decouple economic growth from resource depletion.

But the circular economy is facing increasing academic criticism. Biologist Keith Ronald Skene, in a 2018 publication³⁵ he emphasizes that this approach relies on a mechanistic vision that ignores fundamental thermodynamic realities, according to which recycling and circulating matter inevitably requires energy expenditure and generates entropic losses. He concludes, deliberately provocatively, that "*the circular economy cannot work*"³⁶. In the same vein, Life Cycle Assessment methods applied to so-called green infrastructures, such as the floating offshore wind farms studied by researcher Gaia Brussa and her colleagues, demonstrate that all technologies, even decarbonized ones, generate a material and extractive footprint³⁷ simply limiting the damage proves mathematically insufficient to reverse the degradation of the biosphere.

Facing the entry into the Anthropocene³⁸ researchers are calling for a fundamental reconfiguration of the relationship between the economy and its environment. In 2021, Carl Folke and researchers from the Stockholm Resilience Centre stated that it is no longer just a question of mitigating climate change, but that it has become essential to «improve the regenerative capacity of the biosphere, and its diversity, to support and

³⁴ In 1987, the United Nations Commission on Environment and Development (WCED) published the Brundtland Report, named after its chair, Gro Harlem Brundtland, and entitled "Our Common Future." This document became the guiding principle of sustainable development as we still understand it today. A French version is available here: <https://www.are.admin.ch/fr/1987-le-rapport-brundtland>

³⁵ Skene, K. R. (2018). Circles, spirals, pyramids and cubes: why the circular economy cannot work. *Sustainability Science*, 13, 479–492. <https://doi.org/10.1007/s11625-017-0443-3>

³⁶ *Ibid.*

³⁷ Brussa, G., Grosso, M., & Rigamonti, L. (2023). Life cycle assessment of a floating offshore wind farm in Italy. *Sustainable Production and Consumption*, 39, 134–144. <https://doi.org/10.1016/j.spc.2023.05.006>

³⁸ The Anthropocene is one of the scientifically supported narratives describing the ongoing shifts in the relationship between human societies and their environments. Within the Holocene, the last geological epoch of the Quaternary period, which began after the last ice age and has lasted for 12,000 years, the Anthropocene can be considered the epoch in Earth's history during which human activities have a significant and global impact on the planetary system. Geography resources for teachers, Eduscol, ENS Lyon, <https://geoconfluences.ens-lyon.fr/glossaire/anthropocene>

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maintain *societal development*³⁹» and it is this shift that gives rise to the concept of a regenerative economy.

The break is significant. The work of Joern Fischer and his colleagues, published in 2025 in *Ambio*, scientifically distinguishes three logics of action that correspond to the successive strata of the continuum presented previously⁴⁰. Sustainability seeks to "do less harm"⁴¹, assuming that the damage is reversible.

Resilience seeks to "*persist, adapt, and transform*"⁴² in the face of shocks. Regeneration, on the other hand, aims to "*renew and contribute positively*"⁴³ this is not a rhetorical gradation but a systemic shift. In the field of business strategy, Tobias Hahn and Maja Tampe defined regenerative businesses in 2021 as "*businesses that strengthen the health of socio-ecological systems while thriving thanks to them, in a co-evolutionary process*"⁴⁴. **This definition marks a break with the intermediate layers of the continuum; ecosystem health is no longer perceived as an external constraint to be managed or a risk variable to be integrated, but as the very foundation of value creation.** The objective is no longer to mitigate damage but to strengthen the living systems upon which all economic activity depends.

This ambition was formalized on a macro level by the economist John Fullerton, who in 2015 proposed the eight principles of "Regenerative

Capitalism".⁴⁵in which natural, social, and financial capital reinforce each other rather than opposing each other. The regenerative approach relies on what researchers conceptualize as "upward spirals," positive feedback loops where each ecological or social strengthening action generates the momentum needed to catalyze the next strengthening of the system.⁴⁶This paradigm, it should be emphasized, was established well before the term "regenerative finance" appeared in the Web 3 vocabulary. The Regenes Group⁴⁷, founded in the 1990s by Bill Reed, had already developed a theory of regenerative design applied to territories and communities.

[B] Carol Sanford's four paradigms and the "Outside-in" perspective⁴⁸

To design a truly regenerative strategy, Hahn and Tampe emphasized in 2021 that business objectives must adopt an outside-in perspective.⁴⁹Strategy should no longer be dictated by internal financial logic and then applied to the environment, but should be formally derived from the limits and needs of local socio-ecological systems. This cognitive shift echoes the work of Carol Sanford, who distinguishes four historical approaches: (1) **Extract Value**: Nature is a resource to be exploited (neoclassical approach). (2) **Arrest Disorder**: Sustainable development (Do Not

³⁹Folke, C., Polasky, S., Rockström, J., Galaz, V., Westley, F., Lamont, M., Scheffer, M., Österblom, H., Carpenter, S. R., Chapin, F. S., Seto, K. C., Weber, E. U., Crona, B. I., Daily, G. C., Dasgupta, P., Gaffney, O., Gordon, L. J., Hoff, H., Levin, S. A., ...Walker, B. H. (2021). Our future in the Anthropocene biosphere. *Ambio*, 50, 834–869. <https://doi.org/10.1007/s13280-021-01544-8>

⁴⁰See 1.1.1.1 The continuum of fiduciary duty to the regeneration of life

⁴¹Fischer, J., Farny, S., Pacheco-Romero, M., & Folke, C. (2025). Resilience and regeneration for a world in crisis. *Ambio*, 55, 24–34. <https://doi.org/10.1007/s13280-025-02287-6>

⁴²Ibid.

⁴³Ibid.

⁴⁴Hahn, T., & Tampe, M. (2021). Strategies for regenerative business. *Strategic Organization*, 19(3), 456–477. <https://doi.org/10.1177/1476127020979228>

⁴⁵Fullerton, J. (2015). *Regenerative Capitalism, How Universal Principles and Patterns Will Shape Our New Economy*. Capital Institute. <https://capitalinstitute.org/wp-content/uploads/2015/04/2015-Regenerative-Capitalism-4-20-15-final.pdf>

⁴⁶Fischer, J., Farny, S., Abson, D.J., et al. (2024). *Mainstreaming Regenerative Dynamics for Sustainability*. Nature Sustainability. <https://doi.org/10.1038/s41893-024-01368-w>

⁴⁷Regenes Group, Inc.

<https://regenesgroup.com/team/bill-reed>

⁴⁸Sanford, C. (2017). *The regenerative business: Redesign work, cultivate human potential, achieve extraordinary outcomes*. Nicholas Brealey Publishing.

⁴⁹Hahn, T., & Tampe, M. (2021). Strategies for regenerative business. *Strategic Organization*, 19(3), 456–477. <https://doi.org/10.1177/1476127020979228>

Significantly Harm/DNSH principle), which seeks to slow down damage. (3) **Do Good:** The philanthropy and restoration approach, which seeks to repair without changing the underlying model. (4) **Evolve Inherent Potential:** The regenerative approach, where economic activity co-evolves with living systems. Another way to represent the different spectra of finance could be interpreted in light of this graph, in order to distinguish conventional finance, green finance, sustainable finance, impact finance and regenerative finance.

1.1.2.2 New grammars of ecological value

The regenerative paradigm posits the primacy of life as the foundation of all economic activity. This assertion elicits two types of responses that are too often presented as opposing forces. The first, dialogical and qualitative, rehabilitates rights, cultural practices, and local knowledge as legitimate sources of knowledge and guidance, in contrast to the preeminence of quantitative approaches that has long structured dominant economic thought. This approach prioritizes strengthening governance, building countervailing powers, and fostering alignment among stakeholders rather than proliferating indicators. The second response, accounting-based and technical, seeks to make life visible in capital allocation tools, based on the observation that as long as the degradation of the biosphere does not appear anywhere as a loss on balance sheets, the regenerative paradigm remains a statement of intent without any real impact on financial decisions.

This report focuses primarily on this second approach, not because it is superior, but because it is the one that new digital infrastructures seek to support. It is important, however, to bear in mind that quantification without governance produces precisely the risk of narrative inflation that practitioners refer to as "regen-washing", the tendency to

claim to be part of a regenerative approach without respecting its substantive requirements. The accounting tools presented in this section, however rigorous they may be, operate within a logic of assigning value to natural entities that remains foreign to, or even contradictory to, the regenerative paradigm in its most demanding form. The latter does not seek to better measure nature; it seeks to reconfigure the relationship between organisms and the living systems on which they depend. According to Pierre Musseau-Milesi, a political science researcher at the University of Paris 1 Panthéon Sorbonne/CESSP, *"these methods are instruments of transition when deployed without governance of their measurement tools, and can become instruments of embodiment of regeneration when this governance is put in place."*⁵⁰.

But while the theoretical framework of regenerative economics posits the primacy of living systems, its application to finance encounters a structural obstacle that cannot be understood without going back to its accounting foundations. Finance is not neutral in its categories: it is governed by ratios, return on equity, debt, asset value, which are themselves constructs stemming from a particular accounting ontology, historically and politically determined. This is the ontology of the post-war General Accounting Plan, whose architecture is based on a model distinguishing between equity and debt capital, but excluding natural capital from any accounting representation.

As Jacques Richard demonstrated as early as 1988⁵¹ This choice was not technical and decisively settled a then-active debate between monist and dualist accounting, favoring a model that would permanently structure how our capitalist economies

⁵⁰ Interview Blockchain for Good x Pierre Musseau-Milesi, CIFRE PhD student in Political Science at Metapolis, University Paris 1 Panthéon Sorbonne/CESSP.

⁵¹ Jacques Richard. Towards a French monistic accounting plan. Proceedings of the ninth congress, May 1988, France. pp. CD-ROM. Hal-00823789.

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account for, or fail to account for, nature. It is from this legacy that the structural obstacle inherited from the post-war period stems, notably the standardization of national accounts by the United Nations (UN) in 1953 and the invisibility of nature in accounting balance sheets.

In classical economics, the degradation of the biosphere does not appear anywhere as a loss of capital.⁵² This risk of accounting invisibility is not new, and as early as the 1970s, researchers identified the limitations of what would be called corporate social responsibility (CSR) in accounting for environmental and social externalities. It is this critique, extended in the 1990s by work on the integrative approach, particularly the correlation between financial performance, business model, and environmental impacts, that has led to this shift.⁵³ The field of multi-capital accounting emerged well before regenerative rhetoric became prevalent in academic and institutional discourse. From the 2010s onwards, several institutional and accounting frameworks emerged to translate these dynamics into actionable data.

The **System of Environmental-Economic Accounting** (SEEA) is the statistical framework adopted by the United Nations to link environmental and economic data. Its central framework, the SEEA Central Framework (SEEA-CF), was adopted as an international statistical standard in 2012.⁵⁴

⁵² The provision for environmental risk is an amount recorded as a liability on a company's balance sheet to anticipate future expenses related to environmental damage for which it is responsible, such as the remediation of polluted sites, decontamination, etc. For an empirical analysis of the reliability of these provisions in French listed groups, see Maurice, J. (2013, April 25). Are environmental accounting provisions reliable? An institutional perspective on the case of French listed companies [Paper presented at the THEMA seminar]. University of Cergy-Pontoise.
<https://thema.u-cergy.fr/IMG/pdf/25-04-2013.pdf>

⁵³ Pérez, R. (2005). Some reflections on responsible management, sustainable development and corporate social responsibility.
<https://www.proquest.com/openview/bd96f0483e43f421eddbbc8add6ad51f/1?pq-origsite=gscholar&cbl=26544>

⁵⁴ United Nations et al. (2012). Central Framework of the System of Economic and Environmental Accounting,

It was supplemented in March 2021 by the SEEA Ecosystem Accounting (SEEA-EA), adopted at the 52nd session of the United Nations Statistical Commission, which provides a standardized methodology specifically dedicated to the assessment of ecosystem stocks and flows, combining biophysical and economic data in a spatial approach⁵⁵. The **integrated accounting model for respect for ecology**, the Comprehensive Accounting in Respect of Ecology (C.A.R.E.)⁵⁶ the approach, initiated by Jacques Richard, Alexandre Rambaud, and Hervé Gbego, integrates ecosystem preservation directly into the company's balance sheet, income statement, and accounting appendices by recording the unavoidable costs necessary for preserving natural and human entities as liabilities, in the form of "ecological debt"⁵⁷ according to Pierre Musseau-Milesi, this logic of debt is *"the movement that brings these methods closest to the regenerative paradigm, not because it is universally superior, but because its ontology, nature as creditor, not as asset, directly aligns with the central tenet of regeneration."*⁵⁸ Finally, the Limits and Foundations Towards Sustainability (LIFTS) **multi-capital accounting model**, developed by Delphine Gibassier and her teams⁵⁹ published in 2024, it allocates each

2012. United Nations.

https://seea.un.org/sites/seea.un.org/files/seea_cf_final_fr.pdf

⁵⁵ United Nations et al. (2021). System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA). United Nations Statistical Commission, 52nd session.
<https://seea.un.org/ecosystem-accounting>

⁵⁶ Circle of Environmental & Social Accountants
<https://www.cerces.org>

⁵⁷ Rambaud, A., & Richard, J. (2015). The "Triple Depreciation Line" instead of the "Triple Bottom Line": Towards a genuine integrated reporting. *Critical Perspectives on Accounting*, 33, 92–116.
<https://doi.org/10.1016/j.cpa.2015.01.012>

⁵⁸ Interview Blockchain for Good x Pierre Musseau-Milesi, CIFRE PhD student in Political Science at Metapolis, University Paris 1 Panthéon Sorbonne/CESSEP.

⁵⁹ French edition Gibassier, D. (dir.), Anthéaume, N., Carn, C., Cordano, E., Faure, E., Gaschignard, L., Hsissou, H., Pernias, M., & Taïbi, S. (2024). Multi-capital accounting: the LIFTS model (Limits and Foundations Towards Sustainability Accounting Model). Mining Press. ISBN 978-2-38542-538-8.

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organization strict budgets calculated using two complementary scientific frameworks: the planetary boundaries not to be exceeded, defined by Johan Rockström and his colleagues in 2009, and the social foundations to be achieved, derived from Kate Raworth's "Doughnut" framework.⁶⁰ This dual anchoring allows for a scientific assessment of whether an activity operates in a space that is both ecologically safe and socially just.

From a regulatory perspective, this structuring has accelerated in France with the publication in December 2024 of the AFNOR SPEC "Regenerative Economy"⁶¹ the first normative guide seeking to establish a demanding framework to avoid misinterpretations, defining regeneration around a three-pronged approach: ecological restoration, social improvement, and the creation of economic value rooted in local territories. This initiative, however, illustrates a tension that international literature has not failed to highlight. The regenerative paradigm is, by nature, pluriversal, that is to say, based on the recognition that forms of relationship with the living world are irreducibly diverse according to the ecological, cultural, and cosmological contexts in which they are rooted. Arturo Escobar, in his work on territorial ontologies and the economies of the Global South, addresses this issue⁶² argues that any attempt at universal normalization of the regenerative risks reproducing the logic of abstraction and epistemic domination inherent in the paradigm it claims to transcend.

<https://www.pressesdesmines.com/produit/la-comptabilite-multi-capitales/>

⁶⁰ What on Earth is the Donut?...

<https://www.kateraworth.com/doughnut/>

⁶¹ The regenerative economy lays a first stone in standardization

<https://www.afnor.org/actualites/economie-circulaire/economie-regenerative-premiere-normalisation/> and

AFNOR SPEC 2315, December 2024 AFNOR SPEC 2315

<https://www.boutique.afnor.org/fr-fr/norme/afnor-spec-2315/aspec-economie-regenerative/fa209119/426267>

⁶² Escobar, A. (2018). *Designs for the pluriverse. Radical interdependence, autonomy, and the making of worlds.* Duke University Press.

<https://doi.org/10.1215/9780822371649>

The AFNOR standard, useful as a framework tool in the French and European institutional context, should therefore be read for what it is, a transitional instrument in a given regulatory space, and not as a universal definition of what regeneration means.

This epistemological critique encompasses another, more immediately one: the determination of the operational baseline against which any measure of regeneration or degradation is assessed. Who sets this baseline? According to what definition of "good condition"? Through what process and with what legitimacy? These questions are not merely technical shortcomings but constitute a crucial governance issue, as the choices made at this stage shape all subsequent allocation decisions. Without the co-creation of measurement tools with local communities and the managers of the ecosystems concerned, even the most rigorous accounting frameworks risk reproducing, in a technologized form, power imbalances that digital infrastructure alone cannot correct.

These innovations demonstrate that the need to measure, verify, and value the contribution of an activity to living organisms largely predates distributed ledger technologies and blockchains. However, the large-scale application of these multi-capital methods encounters concrete limitations in terms of verification, audit costs, and data asymmetry. These operational limitations form the starting point of the following section, which examines new digital infrastructures not as a turnkey solution, but as a set of tools whose contributions and limitations deserve our full attention.

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1.1.3 The pitfall of the centralized system

The structural limitations of the centralized system, and in particular, unverifiable self-declaration, information asymmetry and systemic greenwashing, are less isolated malfunctions than symptoms of a fundamentally inadequate trust architecture.

1.1.3.1 Self-reporting and information asymmetry

The evaluation of an organization's non-financial performance has always relied on a declarative model, which generates a structural information asymmetry between the data provider, most often the company, and its recipients, i.e., the investor, and the regulator or civil society. This idea was central to the work of George Akerlof, winner of the Nobel Prize in Economics in 2001. In his seminal article, "The Market for Lemons" (1970)⁶³ He Analyzes the information asymmetries between sellers and buyers and their impact on market functioning. He shows that when sellers have superior information about the quality of the goods being traded, buyers, unable to distinguish good products from bad, are only willing to pay an average price. This mechanism leads sellers of quality goods to withdraw from the market, causing adverse selection which, in extreme cases, can lead to the total collapse of the market.

In this system, the company is most often both judge and party since it produces, selects and consolidates the information meant to assess its own impact on socio-ecological systems.

The largely voluntary nature of these reports has long created structural pressure encouraging companies to "only disclose

positive information"⁶⁴ or only share successes. A multinational agribusiness company might thus highlight the planting of 10,000 trees while failing to disclose the severe water stress caused by its water withdrawals in the same region. This inherent opacity, where the evaluator depends on information provided by the entity being evaluated, structurally limits the markets' ability to allocate capital efficiently.



The **DWS Group** case perfectly illustrates this mechanism. DWS Group is the asset management subsidiary of Deutsche Bank, listed on the stock exchange since 2018 and subject to the strictest reporting requirements in European institutional finance. In its 2020 annual report, the group states that €459 billion of its assets under management incorporate environmental, social, and governance (ESG) criteria.

This self-declaration is not peripheral to the group's strategy but forms the very basis of its market positioning, thus attracting institutional mandates focused on ESG alignment and justifying higher management fees than those of conventional funds. However, in this configuration, investors subscribing to a DWS-labeled sustainable fund have no access to the manager's internal processes and must rely solely on the company's declarations. Yet, in August 2021, Desiree Fixler, the group's former head of sustainability, publicly revealed that the internal operational reality differed substantially from the reported figures: only a fraction of the declared assets underwent substantial ESG

⁶³ Akerlof, G. (1970). The Market for "Lemons": Quality Uncertainty and the Market Mechanism", Quarterly Journal of Economics, vol. 84, no. 3, p. 488-500

⁶⁴ Becquey, P., Boric, N., & Clerc, P. (2021). Definition of impact finance. Finance for Tomorrow. <https://institutdelafinancedurable.com/wp-content/uploads/2023/09/Finance-for-Tomorrow-Definition-de-la-finance-a-impact-Septembre-2021-5.pdf>

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analysis, and the internal scoring tools were insufficient to substantiate the reported volumes. The US Securities and Exchange Commission (SEC) and the German Federal Financial Supervisory Authority (BaFin) launched parallel investigations. In September 2023, DWS accepted a fine of 19 million euros without admitting or contesting the facts.⁶⁵ What this episode illustrates is not a spectacular fraud but something more structural: a manager operating within the framework of current reporting rules can legally present an ESG performance that its own internal processes do not justify. The rules of the game allow this gap between promise and reality.

Monitoring these declarations faces equally profound operational limitations. Verification generally relies on manual audits, conducted after the fact, most often annually, by centralized trusted third parties. These audits frequently focus on the existence of internal processes such as the implementation of a corporate social responsibility (CSR) policy or the adoption of monitoring indicators, rather than on the tangible and ongoing reality of the impact generated on the ground. This results in a chronic inability to guarantee that the data produced is credible, accurate, and complete.

This fragility is compounded by the economic barrier of the "cost of trust." In the current financial architecture, impact certification runs up against the structural barrier of high verification costs. Establishing proof of impact currently relies on third-party human audits, lengthy manual processes, and expensive

certifications. This "trust tax" creates de facto exclusion because it renders small local or community projects economically ineligible for impact finance, as audit fees often exceed the value of the benefits generated. This is where blockchain protocol engineering becomes an innovative solution, as it automates proof through code and data, and drastically reduces the unit cost of proof.

According to an analysis by Reed Smith LLP citing a 2023 survey conducted by BNP Paribas among 420 institutional investors, 71% of them consider that *"inconsistent and incomplete data is the main obstacle to investing that respects environmental, social, governance (ESG) criteria"*⁶⁶. The proliferation of non-financial rating agencies exacerbates this situation. In the absence of global semantic standardization, evaluation methodologies vary considerably from one player to another, making comparisons between companies particularly risky.

Seemingly very favorable results can arise from coarse datasets or divergent calculation conventions, without the investor having the means to detect it. This fragmentation severely limits the markets' ability to direct capital towards truly transformative projects and struggles to bridge the often gaping gap between the ambition declared by senior management – who commit to carbon neutrality or even regeneration targets – and the operational reality of their globalized value chains.

New regulatory frameworks are attempting to address these shortcomings. The European directive on corporate sustainability reporting, the Corporate Sustainability Reporting Directive (CSRD), now requires documented

⁶⁵ BaFin. (2023, September 25). BaFin imposes fine of EUR 19 million on DWS Investment GmbH [Press release]. Bundesanstalt für Finanzdienstleistungssucht. https://www.bafin.de/SharedDocs/Veroeffentlichungen/EN/Pressemitteilung/2023/pm_230925_DWS_en.html

⁶⁶ ESG Ratings – the challenges of comparison and reliability, Reed Smith LLP, 4 July 2024 <https://www.reedsmith.com/our-insights/blogs/structure-d-finance-in-brief/102k6lg/esg-ratings-the-challenges-of-comparison-and-reliability/>

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evidence and subjects declarations to verification by accredited third parties. However, the bottleneck of manual verification, the opacity of supply chains, and the rising cost of auditing remain systemic challenges that regulation alone cannot resolve. It is precisely this asymmetry that new digital measurement, reporting, and verification (dMRV) architectures are now attempting to address through the automation of proof, as we will examine in section 2.1.

[B] From ESG data to impact data, a jump of complexity

To fully understand the self-reporting crisis, it's essential to distinguish between traditional environmental, social, and governance (ESG) data and impact data. On paper, the type of raw information doesn't necessarily differ between the two approaches. For example, tons of CO₂ equivalent emitted or liters of water consumed are identical metrics. But contextualization makes all the difference. A company that reports saving one million liters of water produces environmental, social, and governance (ESG) data. Specifying that this saving occurred in an area experiencing extreme water stress, that it helped restore the local water table, and that this effect is measurable and sustainable over time transforms this statement into impact data.

Impact data is not simply a static assessment. It must be comparable to a baseline scenario to demonstrate the additionality of the change, and it must allow for tracking the evolution of this impact over time in terms of its scale, depth, and duration. Providing, certifying, and maintaining this level of granular evidence far exceeds the technical and

financial capabilities of current static reporting and self-reporting audits.

1.1.3.2 Systemic greenwashing, crisis of confidence and a fool's market

This information asymmetry, coupled with a lack of continuous and independent verification, has not only produced imperfect data. It has transformed some key instruments of the ecological transition into symptoms of endemic greenwashing and social washing. Far from being isolated anomalies attributable to actors acting in bad faith, these abuses are the direct product of a structurally fallible centralized infrastructure. And they strike with all the greater intensity the closer the instrument is to the regenerative end of the continuum presented in 1.1.1, since it is precisely there that evidentiary requirements are highest and least verifiable.

To understand the shortcomings of the voluntary carbon credit market, one must go back to its institutional origins. The Kyoto Protocol, signed in 1997 at the Third Conference of the Parties to the United Nations Framework Convention on Climate Change and entering into force in 2005, was based on the fundamental idea of internalizing the cost of pollution in the global economy by establishing shared responsibility among states in the face of climate change. To achieve this, the protocol notably created the Clean Development Mechanism (CDM), which allows industrialized countries to finance emission reduction projects in developing countries and to count the reductions towards their own commitments. It thus laid the conceptual foundations of the carbon credit, a unit representing the reduction or avoidance of one tonne of CO₂ equivalent, which can be traded on a market.

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It is on this foundation that the voluntary carbon credit market developed from the 2000s onwards, distinct from the regulated market but inheriting the same compensation logic. Private certification bodies, foremost among them Verra, are key players in this sector.⁶⁷, are being established to evaluate and validate projects. This mechanism seemed elegant, as it was intended to mobilize private financing for climate projects in the Global South, while offering companies in the Global North a mechanism to offset their residual emissions.

But by entrusting the certification of projects to organizations whose independence from the parties they evaluate is not structurally guaranteed, the system has reproduced the same pitfall as traditional extra-financial reporting: the evaluator depends on the information provided by the party being evaluated. This architectural flaw is not unique to private actors. The Clean Development Mechanism (CDM), created by the Kyoto Protocol and overseen by an Executive Board under the authority of the United Nations Framework Convention on Climate Change, also falls into this category.⁶⁸ The UNFCCC provides an illustration of this. Despite its intergovernmental nature, it has been widely discredited for approving projects whose additionality was fictitious, as the governments of host countries had a direct economic interest in the approval of proposals submitted on their territory.⁶⁹ The question, therefore, is not whether the controller is private or public, but whether its independence from the controlled entity is

institutionally protected, a condition that neither Verra nor the MDP has been able to guarantee. The question is not whether the controller is private or public, but whether its independence from the controlled entity is institutionally protected, something that neither Verra nor existing regulatory frameworks fully guarantee.

This market has long been the subject of well-founded criticism. Recent analyses show that these mechanisms can delay the real reduction of emissions by offering companies a way to continue polluting without reducing their emissions at the source, which filmmaker Martin Voill calls a "real sham" in his documentary *Carbon Neutrality: The Big Lie*⁷⁰.

A systematic review published in *Nature Communications* in 2024⁷¹ A study of 2,346 projects, covering nearly one billion tons of CO2 equivalent, found that less than 16% of the credits issued correspond to actual emissions reductions. This conclusion aligns with the findings of a joint investigation by *The Guardian*, *Die Zeit*, and *SourceMaterial*.⁷² supported by three independent scientific studies, which established that more than 90% of the tropical forest credits certified by Verra, the world's leading certifier which approves three-quarters of voluntary offsets, are very likely "phantom credits" that do not correspond to any real reduction in emissions, conclusions that Verra disputes.

⁶⁷ Verified Carbon Standard <https://verra.org>

⁶⁸ What is the UNFCCC, the United Nations Framework Convention on Climate Change? <https://unfccc.int/fr/processus-et-reunions/qu-est-ce-qu-e-la-cducc-la-convention-cadre-des-nations-unies-sur-les-changements-climatiques>

⁶⁹ Schneider, L. (2009). Assessing the additionality of CDM projects: practical experiences and lessons learned. *Climate Policy*, 9(3), 242–254. <https://doi.org/10.3763/cpol.2008.0533>

⁷⁰ Voill, M. (Director). (2024). *Carbon Neutrality: The Big Lie* [Documentary Film]. ARTE.tv

⁷¹ Probst, B. S., Toetzke, M., Kontoleon, A., Díaz Anadón, L., Minx, J. C., Haya, B. K., Schneider, L., Trotter, P. A., West, T. A. P., Gill-Wiehl, A., & Hoffmann, V. H. (2024). Systematic assessment of the achieved emission reductions of carbon crediting projects. *Nature Communications*, 15, 9562. <https://doi.org/10.1038/s41467-024-53645-z>

⁷² Greenfield, P. (2023, January 18). Revealed: more than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows. *The Guardian*. <https://www.theguardian.com/environment/2023/jan/18/revealed-forest-carbon-offsets-biggest-provider-worthless-verra-aoc>

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The mechanism in question deserves to be explained, as it illustrates the structural fragility of any system based on self-reporting. The creation of a carbon credit of the "avoided deforestation" type relies on a simulation: an estimation of the deforestation that would have occurred in the absence of the project, what practitioners call the baseline scenario. However, the choice of the baseline area is most often left to the discretion of the project developers themselves. By selecting areas where historical deforestation is particularly high and comparing them to their protected area, these developers can artificially inflate the volume of CO₂ supposedly "saved" and thus issue more revenue-generating credits.⁷³ An opaque assessment system, based on self-reporting and hypothetical models, can thus legally certify a near-zero environmental impact. Furthermore, in the absence of consistent traceability, problems of double counting and opacity in financial flows often deprive local communities of the revenues that are rightfully theirs.

On a social level, traditional microfinance offers a striking parallel. Founded by Muhammad Yunus (2006 Nobel Peace Prize laureate) and the Grameen Bank with the ambition of breaking the cycle of poverty by lending without collateral to populations excluded from the banking system, it has gradually suffered from a profound shift in its mission.⁷⁴ The cumbersome administrative processes of centralized institutions, combined with the pursuit of profitability, have generated such high operational costs that they have resulted in sometimes usurious interest rates applied to the most vulnerable

borrowers. Accompanied by coercive debt collection practices, these abuses have led to well-documented social tragedies, including the fatal over-indebtedness of thousands of farmers in India.⁷⁵

These two examples converge on the same lesson: failure is not only a matter of regulation, but of architecture.

As long as the evidence of impact relies on declaration and opaque intermediation, it remains vulnerable to capture.

Solutions are emerging on the fringes of the decentralized digital ecosystem. **Initiativ / InEx**⁷⁶, a platform providing access to regulated emissions trading markets, contrasts the chronic opacity of carbon markets with immutable on-chain* audit logs, transparent pricing with no hidden fees, and same-day settlement, making the emissions trading market as transparent as a regulated stock market. In a related vein, **Inuk**⁷⁷ imposes on its clients a "Carbon KYC" designed to ensure that carbon credits are integrated into a comprehensive and documented decarbonization plan, and not into a compensation scheme disconnected from any source reduction. These mechanisms do not eliminate the risk of systemic greenwashing, they simply shift its scope from opaque reporting to technical verifiability, the limitations of which will be examined in section 2.2.

⁷³ Voill, M. (Director). (2024). Carbon Neutrality: The Big Lie [Documentary Film]. ARTE.tv

⁷⁴ Mersland, R., & Strøm, R. Ø. (2010). Microfinance mission drift? *World Development*, 38(1), 28–36. <https://doi.org/10.1016/j.worlddev.2009.05.006>;

Acclassato, D.-H. (2008). Do interest rate caps in microfinance really serve the poor and small economic actors? *Developing Worlds*, 141(1), 93–109. <https://doi.org/10.3917/med.141.0093>

⁷⁵ Knowledge at Wharton. (2012, July 18). The dark side of microfinance: An industry where the poor play 'cameo roles'. University of Pennsylvania.

<https://knowledge.wharton.upenn.edu/podcast/knowledge-at-wharton-podcast/the-dark-side-of-microfinance-an-industry-where-the-poor-play-cameo-roles/>

⁷⁶ <https://www.takeinitativ.com/>

⁷⁷ <https://inuk.co/>

[B] The drift of intentions and the challenge of systemic immunity

The history of impact finance reveals a recurring trend: instruments initially founded on a profoundly positive philosophy end up straying from their original mission. This phenomenon of "mission drift" is not accidental but the consequence of structural opacity. It raises an architectural question that neither regulation nor the goodwill of stakeholders alone can resolve.

The Kyoto Protocol was based on the idea of shared responsibility for climate change and aimed to internalize the cost of pollution into the global economy. Microfinance, founded on the principle of unsecured loans to the most vulnerable, sought to break the cycle of poverty through direct access to capital. In both cases, the original intention was sound, and in both cases, the absence of an independent and continuous oversight framework allowed for a gradual drift toward practices contrary to the initial mission.

What these trajectories teach us is that an impact system cannot sustainably rely on trust in its operators. It must be designed in such a way that transparency is structural, not declarative – which lays the groundwork for the question this report explores in its second part.

The question is not simply what to fund, but how to design systems where data verifiability replaces trust in institutions, without assuming that technology alone can solve problems that are primarily political. This is precisely the question that structures the second part of this report.

1.2 The new financial infrastructures of Web3

The first part of this report demonstrated why responsible finance instruments, from socially responsible investing (SRI) to impact investing, have failed to deliver on their promise of transparency and verifiability. The difficulty lies not primarily in regulation or ill will on the part of stakeholders, but rather in the architecture itself. As long as proof of impact relies on self-reporting, intermittent auditing, and trust in centralized intermediaries, it remains vulnerable to capture, whether through greenwashing of carbon credits or mission drift within microfinance institutions.

It is within this space, that of verification, transparency, and disintermediation, that the new digital infrastructures built on Distributed Ledger Technologies (DLT*) are situated. This section examines three distinct applications, none of which constitutes a solution in itself, but each of which reconfigures a previously identified structural constraint.

The first is a movement within Decentralized Finance (DeFi*) that seeks to leverage the properties of distributed ledgers, particularly immutability, transparency, and automation through smart contracts*, to support projects with measurable environmental and social impact, or even regenerative projects. The second is the tokenization of real assets and natural capital, which transforms property rights over physical assets, such as carbon credits and biodiversity credits, into liquid, traceable, and unique digital instruments, preventing them from being counted more than once. The third is Decentralized Microfinance (Micro-DeFi*), which directly connects unbanked borrowers to global liquidity pools, replacing costly and difficult-to-scalable personalized

on-the-ground support⁷⁸, automated assessment and reimbursement mechanisms.

These three applications share a common limitation, which the following sections will address because they merely shift the structural problems of impact finance rather than eliminate them. The quality of the data recorded on the blockchain depends on the rigor of the verification mechanisms that precede it. Radical disintermediation remains a theoretical promise when confronted with the realities of fragile legal frameworks and populations without digital access. And the governance of decentralized protocols can recreate, in other forms, the power asymmetries it purports to eliminate. These tensions will be central to the second part of this report.

1.2.1 The emergence of ReFi* within Decentralized Finance

Decentralized Finance (DeFi) emerged from a technological breakthrough: the invention of smart contracts on the public Ethereum blockchain in 2015, which enabled the creation of financial services without institutional intermediaries. However, in its initial dominant iteration, this ecosystem remained largely self-referential. Capital circulated within it to generate returns on other capital, without any connection to the real economy.

It is in reaction to this hyper-financialization that the Regenerative Finance (ReFi) movement emerged within Web3* starting in 2021. Its ambition is to direct the liquidity of Decentralized Finance (DeFi*) towards projects presented as regenerative, although

⁷⁸ The so-called "high-touch" model, jargon specific to the consulting and financial services sectors, refers to a model based on intensive and personalized human contact between the institution and the client, as opposed to an automated model. In traditional microfinance, this means field agents who visit borrowers, assess their situation, support repayment, and manage any issues. This is what makes traditional microfinance both socially effective and operationally costly.

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most are not truly so⁷⁹. This section first examines the technological foundations that make this ambition structurally possible – public register, immutability, disintermediation by smart contracts* – and then the internal divide that runs through the movement between a Regenerative Finance (ReFi)* oriented towards the financialization of natural assets and a Regenerative Finance (ReFi)* anchored in territories and communities.

1.2.1.1 A trusted public register

The shortcomings analyzed in the previous section, the declarative model, the opacity of certification chains, and the inability to guarantee data continuity and integrity, are not primarily the product of ill will on the part of the actors. They stem largely from the very architecture of the centralized systems on which impact assessment relies. These systems include private databases controlled by the entity being assessed; intermittent audits conducted by accredited third parties, which themselves remain subject to the same structural limitations; and a reliance, for lack of a better alternative, on intermediaries whose integrity can only be verified by placing trust in them. The fundamental question lies in the system's architecture: **can we conceive of systems in which proof of impact ceases to be a declaration and becomes a verifiable record, accessible to any actor at any time?**

Distributed Ledger Technologies (DLT*) are situated within this framework. On October 31, 2008, under the pseudonym Satoshi Nakamoto, the foundational white paper of the Bitcoin network was published⁸⁰. The first block of which was generated on January 3, 2009. Whereas traditional finance relies on private, siloed databases held by single central authorities, commercial banks, central banks, or clearing houses, a public blockchain is an

open ledger, shared and synchronized in real time on a global peer-to-peer computer network. No single entity holds control, and each network participant retains a complete copy. The validation of each new entry is ensured by an algorithmic consensus mechanism, that is, by the automatic agreement of a majority of the network's nodes.⁸¹

The fundamental value proposition of this architecture rests on two complementary properties.

The first is native **transparency**, since on a public blockchain, the entire transaction history is accessible to any actor with an internet connection, without prior authorization, notably *via* public consultation tools called "block explorers*".⁸²

The second is **immutability**, meaning that each transaction is timestamped, validated by the consensus mechanism, and then cryptographically sealed in a "block" mathematically linked to the previous one, forming a continuous chain. Once data is recorded and validated by the network, it can no longer be altered, falsified, or retroactively erased without all participants detecting it.

Researchers such as Primavera De Filippi, Morshed Mannan, and Wessel Reijers conceptualized this device in 2020 as a "trust machine."⁸³ (confidence machine), in that it is structurally capable of compensating for the control failures of human institutions.

These two properties have a direct consequence on the issue of auditing: any

⁸¹ *Ibid.*

⁸² A block explorer* is an online tool that allows you to view, track, and verify in real time all the activity recorded on a distributed ledger. Mempool.space (<https://mempool.space>) fulfills this role for the Bitcoin network; Etherscan (<https://etherscan.io>) for the Ethereum blockchain.

⁸³ De Filippi, P., Mannan, M., & Reijers, W. (2020). Blockchain as a confidence machine: The problem of trust & challenges of governance. *Technology in Society*, 62, 101284. <https://doi.org/10.1016/j.techsoc.2020.101284>

⁷⁹ Bennett, K. (2025b). An evaluation of the regenerative claims of Web3's ReFi* movement. *Frontiers in Blockchain*, 8, 1564083. <https://doi.org/10.3389/fbloc.2025.1564083>

⁸⁰ Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. <https://bitcoin.org/bitcoin.pdf>

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actor, investor, regulator, or citizen can publicly and continuously verify the entire history of flows recorded on this distributed ledger. This permanent and permissionless auditability contrasts structurally with the traditional audit model, conducted after the fact, on a sample, by an accredited third party whose credibility can only be verified by other third parties. It is on this foundation that the new digital measurement, reporting, and verification tools, the dMRVs* (digital Measurement, Reporting, and Verification), operate, which we will examine in section 2.1.



Celo⁸⁴ illustrates concretely what a public blockchain accessible from an entry-level phone in an emerging country means. Initially deployed as an independent blockchain optimized for mobile phones, **Celo** migrated in 2024 to a Layer 2 architecture secured by Ethereum, reducing its block fees to less than \$0.001 per transaction (less than the cost of a text message). This infrastructure has become the backbone of dozens of impactful projects: **GoodDollar** (on-chain universal basic income), Haraka (group microcredit for African SMEs), **Grassroots Economics** (community currencies in Kenya), and **MiniPay** (mobile wallet for emerging markets, with 8 million wallets activated by the end of 2025). Its native compatibility with the USDT and USDC stablecoins and its integration with the **Chainlink** oracle make it a versatile infrastructure that allows a Kenyan farmer to access the same verifiable ledger used by an institutional asset manager from their Android phone. **Mento Labs** operates the **Celo** blockchain's decentralized monetary protocol, issuing a family of stablecoins*, including cUSD, cEUR, cREAL, and several African currencies, pegged to fiat

currencies. The unique analytical feature of this system lies in its reserve mechanism: the Mento Reserve⁸⁵ is over-collateralized at a rate of approximately 1.4 times its stablecoin issues by assets viewable on-chain* in real time by any actor with an internet connection.

This model illustrates the "permanent and permissionless auditability" made possible by a public distributed ledger and applies in this instance to a monetary policy mechanism that is usually opaque. In a traditional banking system, verifying the adequacy of a central or commercial bank's reserves requires an accredited institutional audit, conducted ex post and on a sample. On the Mento Reserve, this verification is permanent, automatic, and accessible to any third party, investor, regulator, or citizen, without prior authorization or a trusted intermediary.

A second significant development occurred in 2015 with the launch of the Ethereum network, whose technical specifications had been formalized by Gavin Wood in 2014.⁸⁶ This new generation of blockchain introduces smart contracts*, which Vitalik Buterin prefers to call "persistent scripts," and which are autonomous computer programs where the terms of an agreement are written directly into the computer code. These programs activate automatically when predefined conditions are met, without requiring human intervention or an intermediary to verify their execution. In a reforestation project, for example, a smart contract* can automatically release funds to a local community as soon as a satellite analysis confirms that the forest area has exceeded an agreed threshold,

⁸⁴ <https://docs.celo.org/legacy/overview>

⁸⁵ <https://reserve.mento.org/> and <https://www.mento.org>

⁸⁶ Wood, G. (2014). Ethereum: A Secure Decentralized Generalized Transaction Ledger. Ethereum Project Yellow Paper. <https://ethereum.github.io/yellowpaper/paper.pdf>

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without requiring a mandated organization to validate the finding.

The combination of a distributed public ledger and these smart contracts* has a structural effect on the costs and form of intermediation. Historically, a transfer of value or the execution of a financial agreement requires the remuneration of multiple trusted third parties to ensure balance verification, regulatory compliance, and delivery guarantees, all of which act as intermediaries between the source of funding and its recipient. In the decentralized ecosystem, these steps are replaced by so-called "atomic*" settlements, where the transfer of ownership is virtually instantaneous and inseparable from the condition that triggers it. As economists Yan Chen and Cristiano Bellavitis established in a 2020 study, this architecture can "reduce transaction costs, make decentralized platforms easier to use, and foster distributed trust, thus laying the foundations for new business models."⁸⁷ It is this property that structurally opens the way to new models of low-cost financial inclusion, such as Micro-DeFi*, which we will explore in section 1.2.3.

[B] The paradox of the *trustless* concept: trust without intermediaries

Decentralized infrastructures are frequently described by their designers as trustless systems – an English term literally meaning "without trust." As researchers Miscione and Kavanagh analyzed as early as 2015, the early architects of Web 3 emphasized this qualification to highlight that the system

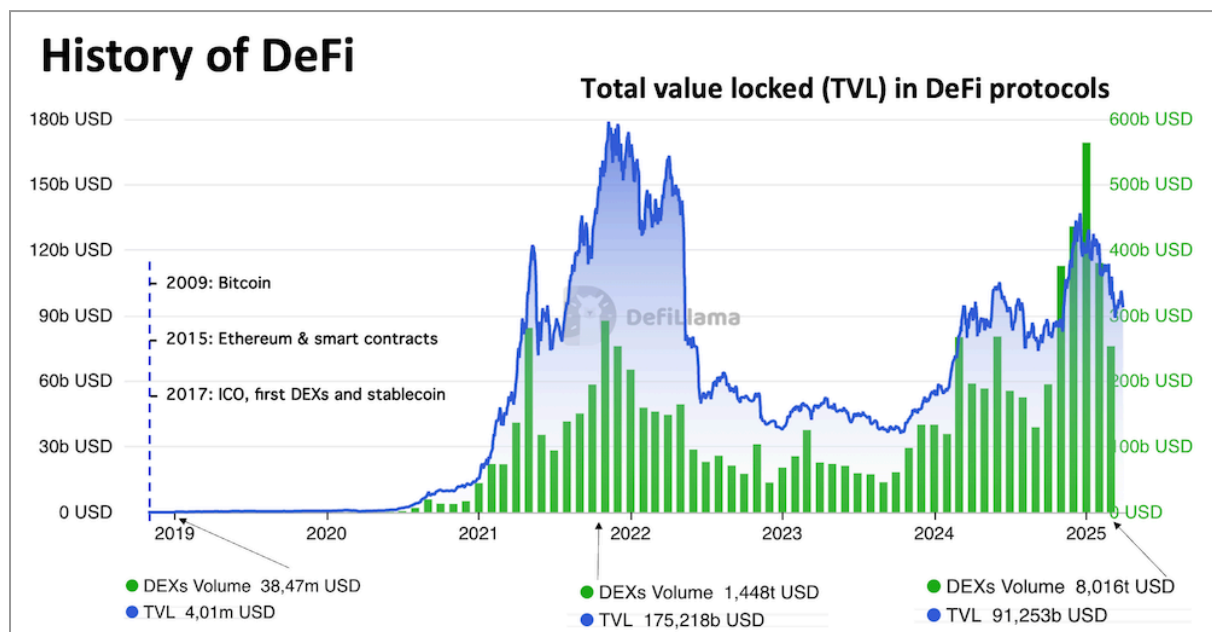
*"does not rely on central trusted intermediaries"*⁸⁸.

The term is paradoxical, however, because trust does not disappear from the transaction but changes its focus. Economists Christian Catalini and Joshua S. Gans explain that with the advent of blockchains, trust shifts from a fallible central entity to *"rules of code and consensus."*⁸⁹ The user no longer has to assume the integrity of a bank or rating agency; instead, they must place their trust in the mathematical robustness of the cryptography and the code of a smart contract*. And since this code is, in public systems, *"open and transparent so that anyone can examine it,"* trust now rests on permanent verifiability rather than on the reputation of an intermediary. This shift is not without consequence. If the code contains an error, a flaw, or logic that is misaligned with the expected objectives, automation ensures that this defect will be applied with the same rigor and immutability as any correctly formulated rule. Trustless trust is therefore not the absence of trust: it is the transfer of this trust to a different object, verifiable, but not infallible, a point we will revisit in the garbage-in, garbage-out risk analysis in section 2.2.1.

⁸⁷ Chen, Y., & Bellavitis, C. (2020). Blockchain disruption and decentralized finance: The rise of decentralized business models. *Journal of Business Venturing Insights*, 13, e00151. <https://doi.org/10.1016/j.jbvi.2019.e00151>

⁸⁸ Kavanagh, D., & Miscione, G. (2015). Bitcoin and the blockchain: A coup d'état through digital heterotopia? Paper presented at the Critical Management Studies Conference, Leicester. SSRN Working Paper. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2624922

⁸⁹ Catalini, C., & Gans, J. S. (2020). Some simple economics of the blockchain. *Communications of the ACM*, 63(7), 80–90. <https://doi.org/10.1145/3359552>



[F] A short history of Decentralized Finance (DeFi)

Source⁹⁰

1.2.1.2 From speculative decentralized finance (DeFi) to regenerative finance

The properties described in the previous section, transparency, immutability, and automatic execution *via* smart contracts, initially served as the foundation for a new type of financial infrastructure, known by the acronym DeFi (Decentralized Finance). DeFi encompasses all financial services, lending, borrowing, asset exchange, and liquidity management, built *via* smart contracts on public blockchains, without the need for institutional intermediaries. These services are accessible, with an internet connection, to anyone holding a digital wallet, without requiring account opening or prior identity verification.

The ecosystem, still very immature, has been built around three successive technological milestones. Bitcoin, whose genesis was

described previously, established the principle of a peer-to-peer digital currency, issued without a central bank. Ethereum, launched in 2015, added the programmability necessary for complex financial applications.

MakerDAO's DAI, the first decentralized stablecoin created in 2017 and pegged to the US dollar without a central issuer, provided a stable unit of account serving as the foundation for early decentralized lending and savings applications.

The growth of this ecosystem has been rapid and quantitatively significant. The total value locked (TVL) in DeFi protocols* increased from a few million dollars in 2019 to nearly \$180 billion at its peak in 2021, before contracting to around \$91 billion in 2025.

This rise to prominence, however, highlighted a structural limitation of DeFi* in its first dominant iteration: that of a deeply self-referential ecosystem. Capital entered the system to generate returns on other capital, in cycles whose value relied more on the continuous influx of new participants than on the creation of productive value. Raphaël Haupt, in an analysis published by Curve Labs

⁹⁰ <https://defillama.com/> and Blockchain for Good.

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in 2022, describes this ecosystem as designed a priori for "optimizing financial returns without anchoring them in real activities," and emphasizes that "ReFi*" will have to break with this logic to deliver on its promises⁹¹. It is indeed in this context that the Regenerative Finance (ReFi*) movement emerged from 2021, with the ambition of directing the liquidity accumulated in DeFi* towards projects with a measurable environmental and social impact.

The ReFi* movement specific to Web3 seeks to combine the structural properties of DeFi* – transparency, programmability, accessibility – with the objectives of impact finance analyzed in the first part of this report.

However, the implementation of this ambition quickly revealed an internal fracture within the movement. During the media frenzy of autumn 2021, projects such as **Toucan Protocol**⁹² and **KlimaDAO**⁹³ have focused attention by connecting voluntary carbon credit markets to public blockchains. The mechanism involved massively importing pre-existing carbon credits – often of low value on conventional markets – to convert them into digital tokens, with the aim of creating global liquidity and favorable price dynamics.

In her March 2025 publication in *Frontiers in Blockchain*, researcher Kate Bennett states that these initiatives have drawn sharp criticism due to their "focus on financialization and market efficiency rather

than on regenerative economic principles"⁹⁴. By absorbing low-cost credits, these protocols have also been accused of encouraging the resurrection of projects with questionable environmental impact (practitioners refer to them as "zombie projects") and a form of fictitious forest conservation. In his empirical evaluation of forty ReFi* initiatives published in June 2025, Bennett confirms this diagnosis, establishing that the design of the protocols determines whether they serve regeneration or merely optimize existing markets without altering their underlying logic.⁹⁵

Other projects have sought to mobilize the same tools using a different logic, starting not from financial markets but from territories. **Regen Network**⁹⁶ Initiated in 2017, with its main ledger (Regen Ledger) launched in 2021, the **Regen Network** has focused on verifying real-world ecosystem services (soil health, biodiversity, water retention) via blockchain to issue eco-credits backed by field data. Unlike pre-existing credit-importing protocols, **Regen Network** built its own verification chain, relying on a network of scientists and ecologists tasked with ensuring that the metrics used are "credible and regionally relevant."

In terms of governance, the Regen Foundation has developed Bioregional Steward Decentralized Autonomous Organizations (BSOs), associating local and indigenous communities with the management of the territories concerned, in an approach explicitly designed to counter the risk of land grabbing referred to in the literature as green grabbing.

⁹¹ Haupt, R. (2022, February 23). The Promises and Pitfalls of Regenerative Finance: Towards a Critical Yet Constructive Dialogue. CurveLabs.

<https://medium.com/m/global-identity-2?redirectUrl=https%3A%2F%2Fblog.curve-labs.eu%2Fthe-promises-and-pitfalls-of-regenerative-finance-4910f0f6f690>

⁹² <https://toucan.earth/>

⁹³ <https://www.klimaprotocol.com/>

⁹⁴ Bennett, K. (2025a). The ReFi movement in Web3: implications for the Global Commons. *Frontiers in Blockchain*, 8, 1564073.

<https://doi.org/10.3389/fbloc.2025.1564073>

⁹⁵ Bennett, K. (2025b). An evaluation of the regenerative claims of Web3's ReFi movement. *Frontiers in Blockchain*, 8, 1564083. <https://doi.org/10.3389/fbloc.2025.1564083>

⁹⁶ <https://www.regen.network/>

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In a similar vein, the **Kolektivo** protocol⁹⁷ deployed from 2019 on the **Celo** blockchain⁹⁸, has developed tools enabling local communities to create and manage circular economies rooted in their territories, by combining community currencies and locally defined economic incentive mechanisms – what its designers refer to as place-based tokenomics.

Other initiatives have taken a different path altogether, mobilizing not natural assets but the financial returns of DeFi* as a driver of impact. **Glo Dollar**⁹⁹ **GoodDollar** is a stablecoin whose seigniorage (that is, the return generated by invested reserves) is fully and automatically donated to programs fighting extreme poverty, without any additional friction for the user: simply holding this stablecoin generates a measurable social impact.¹⁰⁰ applies a similar logic on the scale of a decentralized universal basic income: the returns on reserves invested in lending protocols (**Aave**)¹⁰¹ **Compound** automatically powers a daily distribution of billions of dollars to over 500,000 beneficiaries in emerging economies, without any intermediary redistribution. These models do not tokenize nature but rather leverage the mechanics of returns from Decentralized Finance (DeFi) as a substitute for an institutional redistribution mechanism.

These examples illustrate that the distinction between decentralized finance (DeFi*) geared towards regeneration and that simply

reoriented towards green-labeled assets lies not in the underlying technology, which is essentially identical in both cases, but in the incentive architecture and the role given to communities in defining, governing, and verifying impact. This distinction, between form and substance, will be central to the discussions on the tokenization of natural capital (section 1.2.2) and on the systemic risks of ReFi* (section 2.2).

[B] The ReFi* – Carbon DeFi* divide *versus* Bioregional ReFi*

The evolution of impactful Web3 has given rise to two approaches whose presuppositions are fundamentally distinct.

The first approach, which practitioners refer to as Carbon DeFi* – exemplified by protocols like Toucan or **KlimaDAO** – starts from the premise that the climate crisis is primarily a problem of liquidity and efficiency in carbon markets. Its response consists of transforming natural assets into highly standardized, fungible, and liquid units to integrate them into global financial circuits. In doing so, it risks reproducing in the decentralized space the same pitfall identified in the traditional voluntary carbon credit market (section 1.1.3.2): the hyper-financialization of a common good whose true ecological value remains unverified at the source.

The second approach, known as Bioregional ReFi* – represented by organizations like **Regen Network** and **Kolektivo** – starts from a different diagnosis: the ecological crisis is primarily a crisis of the relationship between societies and their territories. It mobilizes Distributed Ledger Technologies (DLT*) not to abstract nature into assets tradable on global markets, but to provide local communities with tools for ecological accounting and self-organization. This approach considers that natural capital

⁹⁷<https://kolektivolabs.com/>

⁹⁸<https://celo.org/>

⁹⁹<https://www.glodollar.org>

¹⁰⁰<https://www.gooddollar.org>

¹⁰¹<https://aave.com/> It is worth noting that Aave's resilience was tested in April 2026 during the Kelp DAO hack (estimated loss of \$43 million). Although Aave's code remained intact, the attacker used the protocol to launder the stolen funds, resulting in a bad debt of approximately \$4.3 million on the WETH version 3 market. This systemic incident required governance intervention and the activation of Aave's security module to cover the losses without impacting depositors.

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cannot be separated from its material and territorial reality, and that technology must therefore be integrated with local governance rather than supplant it.

The tension between these two currents cannot be resolved on a technical level. It leads back to the question, raised in section 1.1.2, of the purpose of financial tools: are they instruments for optimizing existing markets, or vectors of a structural transformation of the relationship between capital and territory? It is this tension that we will encounter again in the analysis of the risks of hyper-financialization and green grabbing in section 2.2.

1.2.2 The tokenization of real assets (RWA*) and natural capital

Tokenization is the mechanism by which environmental assets, such as carbon credits, biodiversity rights, renewable energy certificates, or green bonds, are represented digitally to circulate, be financed, and verified on distributed ledgers. The "representability" of these assets as individualizable and transferable rights is precisely the framework that is contested by many regenerative movements, which adhere to stewardship or commons-based principles.

Tokenization also raises its own technical limitations. Applied to natural capital, it reveals two fundamental asymmetries. The first concerns carbon credits: when recorded on-chain*, they gain traceability and lose their susceptibility to double counting, but the quality of the asset remains entirely dependent on the verification mechanisms that precede its entry onto the chain. Current research, aware of this limitation, advocates integrating filtering mechanisms directly at the smart contract* level, in the form of reputation algorithms or forensic analysis strategies, to prevent the entry of redundant, manipulated, or malicious data onto the

chain¹⁰². These safeguards remain insufficient, however, when falsification occurs upstream, at the time of human entry of environmental data, even before it is submitted to the oracle*.

The second asymmetry concerns biodiversity credits: their structural heterogeneity, since biodiversity is not fungible, poses conceptual limits to any standardization, and a fortiori to any global tokenization. This section examines these two dimensions and establishes why tokenization, without robust digital verification mechanisms, merely shifts the integrity problems documented in the first part of this report to an immutable register.

1.2.2.1 Tokenization: fractionalization, liquidity and interoperability

Regenerative Finance (ReFi*), the movement specific to Web 3, seeks, as we have seen, to capture and direct liquidity from decentralized finance (DeFi*) towards projects with real impact. But for a reforestation project, a green bond, or a renewable energy certificate to be financed, traded, or tracked on a public blockchain, its ownership rights must first be represented in a digital form compatible with this infrastructure. This is the function that tokenization fulfills. "*The tokenization of financial markets is a technological revolution as significant as the one experienced in the late 1980s with the shift from the trading floor and open outcry to the computerization of financial markets*"¹⁰³. explains Hubert de Vauplane, head of Fintech activity at the law firm Morgan Lewis.

It refers to the process by which ownership rights to a real asset are converted into a digital token, recorded on a distributed and public ledger. The World Economic Forum, in

¹⁰² Al-Breiki, H., Rehman, M. H. U., Salah, K., & Svetinovic, D. (2020). Trustworthy blockchain oracles: review, comparison, and open research challenges. IEEE access, 8, 85675-85685.

¹⁰³ "#Stablecoins*? or Tokenized Deposits?", Hubert de Vauplane, LinkedIn post. April 2, 2026.

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its May 2025 report published with Accenture, defines it as the process that uses *"a programmable ledger to digitally represent ownership of an asset in a cryptographically transferable format."*¹⁰⁴ The spectrum of assets concerned is broad: classic financial instruments (bonds, shares, fund units), real assets (real estate, raw materials), or natural and environmental assets (carbon credits, biodiversity rights, renewable energy certificates).

The added value of this digital representation lies in three complementary properties that practitioners and financial institutions summarize as fractionalization, liquidity, and interoperability. Fractionalization refers to the ability to divide an asset into low-nominal-value exchange units, thereby lowering the entry barrier for individual investors and smaller players, who were previously excluded from certain asset classes by high minimum subscription amounts. A green bond issued for one million euros, or a carbon credit covering an entire plot of forest, can thus be divided into thousands of tradable tokens, each representing a fraction of the underlying ownership or right. This mechanism lowers the entry barrier for individual investors and smaller players, who were previously excluded from certain asset classes by high minimum subscription amounts. As the World Economic Forum analyst points out, fractionalization *"democratizes access to high-nominal-value assets"*¹⁰⁵ which were *de facto* reserved for institutional investment.

¹⁰⁴ World Economic Forum & Accenture. (2025, May).

Asset Tokenization in Financial Markets: The Next Generation of Value Exchange. World Economic Forum. https://reports.weforum.org/docs/WEF_Asset_Tokenization_in_Financial_Markets_2025.pdf

¹⁰⁵ *Ibid.*



Ejara, a Cameroonian savings and investment platform with several hundred thousand users in Francophone Africa and its diaspora, announced in May 2025 a partnership with the Starknet Foundation to develop a tokenization infrastructure for sovereign bonds and RWAs*. The objective would be to enable fractional ownership of African bonds, a market historically reserved for institutional investors, in amounts accessible to individual savers.¹⁰⁶

Liquidity refers to the ease with which an asset can be sold at its market value without delay or excessive cost. Real assets, such as real estate, energy infrastructure, and reforestation projects, are structurally illiquid in traditional finance. Their sale involves settlement times of several business days, multiple intermediation fees, and limited secondary markets. Tokenizing these assets allows them to be traded on decentralized, continuously operating marketplaces with settlement times reduced to seconds or minutes. This reduces the friction associated with traditional processing cycles and opens up short-term financing opportunities for projects previously constrained by their structural illiquidity.



AgriDex is an agricultural RWA* marketplace built on **Solana** that tokenizes agricultural commodity transactions, with each transaction secured by a unique token, an NFT*, recording all the contract metadata. In July 2024, the platform settled the first agricultural transaction recorded on a

¹⁰⁶ Tokenized Bond Smart Contract*

<https://github.com/keep-starknet-strange/tokenized-bond>

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public blockchain: the shipment of olive oil and wine from Oldenburg Vineyards, a South African estate, to a London importer.¹⁰⁷ The funds were received in seconds, for a fee of £5, compared to 3-6% commissions in traditional financial channels. In September 2025, **AgriDex** surpassed \$9 million in stablecoin (USDC) transactions in African markets¹⁰⁸.

This property also applies to impact infrastructure asset classes. **Penomo**¹⁰⁹ targets renewable energy and critical infrastructure assets in the \$5 million to \$100 million range, a segment structurally neglected by large infrastructure funds and inaccessible to mid-sized investors through traditional channels. Its platform combines AI-powered automation (CredOS™ system) and on-chain tokenization* to make these assets liquid and traceable. Similarly, **Dowgo** structures access to European impact private markets by providing continuous liquidity and 24/7 instant settlement for often fragmented assets, with over €300 million in identified projects awaiting distribution.

Interoperability, also known as composability by Web 3 practitioners, refers to the ability of tokens to interact between distinct protocols within the same distributed ledger ecosystem. Tokenized carbon credits can thus be used as collateral in decentralized lending protocols, integrated into structured financial products,

or transferred between ledgers via cryptographic bridges, without requiring a separate bilateral agreement for each transaction¹¹⁰. This property constitutes the technical condition for a more unified market for environmental assets, reducing the fragmentation that currently characterizes voluntary carbon and biodiversity markets.

When applied to natural and environmental assets, tokenization offers an advantage directly linked to the structural weaknesses identified in section 1.1.3.2: **traceability, which addresses the problem of double counting**. In the current configuration of voluntary carbon credit markets, nothing technically prevents the same credit from being recorded simultaneously on the balance sheet of both the project issuer and the buyer, or from being sold to two separate counterparties. Recorded on a public and immutable ledger, each tokenized credit has a unique identifier that links its issuance, successive transfers, and withdrawal, accessible and viewable by any actor with an internet connection. The definitive neutralization of a credit, meaning that it has been used to offset emissions and can no longer circulate, is permanently and irreversibly recorded in the chain.



Centrifuge¹¹¹ is one of the most mature Real-World Asset (RWA*) tokenization protocols in terms of institutional infrastructure in the DeFi* ecosystem. Founded in 2017 and operational in production since 2021,

¹⁰⁷ Manoylov, M. K. AgriDex completes first agricultural RWA* trade on Solana. The Block. July 24, 2024. <https://www.theblock.co/post/307055/agridex-completes-first-agricultural-rwa-trade-on-solana>

¹⁰⁸ The Defiant. Solana-based AgriDex sees \$9M in stablecoin trades across African markets. The Defiant. September 8, 2025. <https://thedefiant.io/news/infrastructure/solana-based-agridex-marks-usd9m-in-stablecoin-trades-across-african-markets>

¹⁰⁹ Penomo, Evolving green energy finance with on-chain RWA: Meet, penomo! Aug 7, 2024. <https://medium.com/penomo/evolving-green-energy-finance-with-onchain-rwa-meet-penomo-a02938ac800b>

¹¹⁰ AAVE Horizon (multi-chain/EVM) is a lending marketplace dedicated to tokenized RWAs*, including tokenized US Treasury bonds from Franklin Templeton and VanEck (vBILL token). AAVE V4's Hub-and-Spoke architecture, combined with the ERC-4626 standard, manages the liquidity of these institutional assets across EVM*-compatible chains. Source: Aave Horizon Supports VanEck's Tokenized Treasury Fund vBILL <https://aave.com/blog/horizon-vaneck-vbill>

¹¹¹ <https://centrifuge.io/>

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it has structured the tokenization of private credit assets such as corporate bonds, commercial receivables, or structured loans, to make them accessible as collateral in DeFi* protocols, notably **Sky**, a decentralized stablecoin* (ex-**MakerDAO**) and **AAVE**, a decentralized lending and borrowing protocol. Its V3 multichain migration in July 2025 and the LayerZero partnership in March 2026 for full asset interoperability between chains embody the concept of deRWA* (decentralized Real World Asset): complex assets, such as S&P 500 replicas or Treasury bonds, are transformed into tokens usable on all EVM*-compatible Decentralized Finance (DeFi)* platforms, without conversion or friction between ledgers. **Centrifuge** illustrates the next step in the triad of fractionalization/liquidity/interoperability described in this section. It is no longer the tokenization of an isolated asset on a single blockchain or decentralized application*, but the creation of an interoperability standard allowing a real and certified asset to circulate freely between protocols and ledgers, without loss of information about its origin or risk characteristics.

These properties, however, do not resolve the central question posed in the first part of this report: that of the **quality of the source data**. Tokenizing an overestimated carbon credit or one based on a questionable baseline scenario merely freezes this imperfect asset in an unalterable record. The robustness of tokenization as an impact finance tool remains contingent on the strength of the verification mechanisms that precede it, which we will examine in section 1.2.2.2 for carbon credits and biodiversity, and in section 2.1 for new digital proof tools.

[B] Tokenization in institutional finance – from experimentation to integration

The tokenization of financial instruments is no longer, in 2026, a marginal experiment and is being deployed in several jurisdictions, supported by a legislative framework of which France was a pioneer on a global scale.

French Ordinance No. 2017-1674 of December 8, 2017, was the first legislation in the world to explicitly authorize the registration of financial securities on a shared electronic registration system. It was this legal framework that enabled Société Générale SFH to issue €100 million of covered bonds, the OFH Tokens*, on April 18, 2019.¹¹² recorded directly on the public Ethereum blockchain. This is the first bond issue by a major global bank on a public blockchain.

In April 2021, the European Investment Bank (EIB) issued its first fully digital bond on Ethereum (€100 million), settled via a wholesale central bank digital currency (CBDC) token issued experimentally and intraday by the Bank of France as part of its experimentation program launched in 2020 – with SG Forge, Goldman Sachs and Santander as lead managers.

¹¹² OFH Tokens represent the first issuance of secured bonds in the form of security tokens on a public blockchain by a French bank. On April 18, 2019, Société Générale SFH issued €100 million of housing finance bonds directly registered on Ethereum, rated Aaa/AAA by Moody's and Fitch (Société Générale, Société Générale issues the first secured bond in the form of "security tokens" on a public blockchain, press release, April 18, 2019, available at societegenerale.com). A second issuance of €40 million followed on May 14, 2020, settled for the first time in wholesale central bank digital currency (CBDC) issued by the Banque de France on the blockchain (Société Générale, Société Générale completes the first financial transaction settled in Central Bank Digital Currency, press release, May 14, 2020, available at societegenerale.com). These operations were conducted by SG Forge, the group's digital asset entity, within the framework of the legal regime opened by Decree No. 2018-1226 of December 24, 2018 relating to the use of shared electronic recording devices (DEEP) for the representation and transmission of financial securities.

In April 2023, SG Forge launched EUR CoinVertible (EURCV), the first institutional euro-denominated stablecoin deployed in production on Ethereum. In November 2023, SG Forge issued the first digital green bond on a public blockchain: €10 million, subscribed by AXA Investment Managers and Generali Investments, with the option of direct settlement in EURCV on-chain*.

Just as information technology completely reshaped the financial infrastructure starting in the 1980s, the tokenization of financial assets will likely profoundly reshape the methods of issuance, settlement, and asset traceability. This convergence between regulated finance and distributed ledgers is precisely what we will examine in section 2.3.3, which focuses on the hybridization of traditional finance (TradFi*) and Web3.

SG-Forge completed its first digital bond issuance in the United States in November 2025, on the Canton Network blockchain¹¹³ via Broadridge Financial Solutions – one of the first transactions of its kind targeting US institutional investors. At the beginning of 2025, the same entity validated the settlement of a tokenized bond by combining its EURCV stablecoin and the SWIFT messaging infrastructure, demonstrating the interoperability between traditional finance and on-chain settlement*.

1.2.2.2 Carbon credits and on-chain biodiversity

While tokenization formally enables fractionalization, liquidity and interoperability, the question now is what it actually produces when applied to the two main classes of natural assets that environmental markets are trying to value – carbon credits and biodiversity credits – and why these two classes call for structurally different treatments.

On-chain carbon credits*: traceability and elimination of double counting

A carbon credit represents the reduction or elimination of one tonne of CO₂ equivalent, as defined by the main certification standards in force, notably Verra's Verified Carbon Standard (VCS) and the Gold Standard. Its value is based on three properties: it must be real (correspond to a verifiable reduction), additional (not having occurred without the project), and unique (can only be counted once). It is this third property that traditional voluntary markets struggle to guarantee the most. In the current configuration of centralized registries, with each certifier maintaining its own registry without binding interoperability, and in the absence of a systematic reconciliation mechanism between these registries, a credit neutralized in one registry can remain technically active in another, without any mechanism detecting or correcting this discrepancy. Furthermore, there is nothing to prevent the same emissions reduction from being declared simultaneously in the seller's and the buyer's balance sheets.

Recorded on-chain*, each carbon credit receives a unique cryptographic identifier linked to its entire history: originating project, certification method, issue date, successive transactions, and, crucially, its final withdrawal when used to offset emissions. This neutralization operation is permanently and irreversibly recorded in the distributed ledger, accessible and verifiable by any actor with an internet connection. The problem of double counting does not disappear, however; it simply shifts. Some projects are seeking to combine this traceability with other financial instruments. **EthicHub**¹¹⁴, a decentralized agricultural lending platform operating mainly in Mexico, integrates via the Toucan protocol the generation and tokenization of carbon credits from the agroforestry practices of its borrowers: the repayment of the loan and the sale of on-chain carbon credits* constitute

¹¹³ <https://www.canton.network/>

¹¹⁴ <https://ethichub.com>

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two distinct income streams for the same farmer, directly linking decentralized microfinance and the carbon market.

Tokenization prevents the fraudulent circulation of credit after its on-chain registration*, but it does not resolve the issue of credit quality prior to registration. As established by the study by Probst et al. published in Nature Communications in 2024¹¹⁵ – analyzed in section 1.1.3.2 – less than 16% of the credits issued by the world's leading certifier corresponded to actual emission reductions. Digitizing an overvalued asset is tantamount to freezing it in a degraded state with the same rigor and permanence as any high-quality asset.

On-chain biodiversity credits*: the fungibility problem

While carbon credits present substantial verification challenges, biodiversity credits raise an even more fundamental question: that of their fungibility. A tonne of CO₂ is a uniform physical unit regardless of its origin. Biodiversity, on the other hand, is by nature localized, contextual, and non-substitutable. As The Nature Conservancy explicitly states in its 2024 analysis of biodiversity credit markets, it is “non-fungible – biodiversity that is impacted or lost in one place cannot be replaced by biodiversity improvements elsewhere”¹¹⁶.and there is no single metric or unit of credit that can effectively capture the full range of characteristics and values of biodiversity¹¹⁷.This structural heterogeneity is confirmed in the academic literature, and Wunder et al. note in 2025, in Business Strategy and the Environment, that if the

fungibility of biodiversity credits were allowed without a rigorous ecological equivalence requirement, it would risk “*undermining biodiversity outcomes in compliance markets by facilitating a net loss of the most threatened species and ecosystems*”¹¹⁸.

This constraint significantly limits the scope of tokenization applied to biodiversity. A token representing a tropical forest biodiversity credit cannot be exchanged for a token representing a coral reef or temperate grassland biodiversity credit, or at least should not be if the instrument is to retain its ecological significance. This does not prevent tokenization from providing real added value in terms of traceability, auditability, and financing for conservation projects: several initiatives, including the Verra Biodiversity Standard and the initial experiments conducted within the framework of the Kunming-Montreal Global Biodiversity Framework adopted in 2022, seek to define metrics precise enough to allow verifiable transactions within defined geographical and taxonomic boundaries. However, the voluntary market for biodiversity credits remains, in 2026, structurally fragmented and illiquid.¹¹⁹According to Bloomlabs, cumulative sales since the first documented transactions reached \$6.72 million by mid-2026, including \$2.9 million for 2025 alone, up 38% compared to 2024.¹²⁰.

¹¹⁸ Wunder, S., et al. (2025). Biodiversity credits: An overview of the current state, future opportunities, and potential pitfalls. Business Strategy and the Environment. <https://doi.org/10.1002/bse.70018>

¹¹⁹ Pollination Foundation, cited by BASE – Energy & Finance. (2025). State of the play of biodiversity credits and habitat banks. <https://energy-base.org/news/financing-for-biodiversity-a-state-of-the-play-of-biodiversity-credits-and-habitat-banks/>

¹²⁰ Bloomlabs, The Voluntary Biodiversity Market, KPMG Oslo, May 11, 2026. Bloomlabs is a commercial market intelligence platform specializing in biodiversity credits, whose business consists of aggregating and marketing the data it collects. In the absence of independent academic or institutional publications on voluntary biodiversity market volumes as of this date, these figures are provided for informational purposes only. They should be verified as soon as a non-commercial source confirms or revises them.

¹¹⁵ Probst, B. S., Toetzke, M., Kontoleon, A., Díaz Anadón, L., Minx, J. C., Haya, B. K., Schneider, L., Trotter, P. A., West, T. A. P., Gill-Wiehl, A., & Hoffmann, V. H. (2024). Systematic assessment of the achieved emission reductions of carbon crediting projects. Nature Communications, 15, 9562. <https://doi.org/10.1038/s41467-024-53645-z>

¹¹⁶ The Nature Conservancy. (2024). TNC View: Biodiversity Credits. https://www.nature.org/content/dam/tnc/nature/en/documents/TNCView_BiodiversityCredits_EXTERNAL.pdf

¹¹⁷ Ibid.

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These volumes remain incomparable to those of the voluntary carbon market, whose annual transactions amount to several billion dollars.



Kolektivo¹²¹ is one of the few protocols to have attempted to simultaneously address the two challenges described in this section: on-chain carbon credit traceability* and the tokenization of local, non-substitutable biodiversity assets. Deployed since 2019 on the **Celo** blockchain and selected by the UNICEF Venture Fund, **Kolektivo** operates in Curaçao and Trinidad and Tobago. In Trinidad, the Cashew Token* represents biodiversity credits associated with local food forests. The valuation of these credits is contingent upon ecological metrics verified in the field, including forest area, species diversity, and agroforestry practices, according to the **Kolektivo Impact Measurement and Verification Framework** (dMRV). In Curaçao, the Carbon-Backed Green Coin (CGC) is a stablecoin backed by local carbon assets, designed to anchor the community currency in verifiable natural resources rather than foreign exchange reserves. This device directly illustrates the theoretical tension posed in this section: by assigning a unique and georeferenced identifier to each biodiversity asset (GeoNFT*), **Kolektivo** attempts to preserve the ecological non-substitutability inherent in biodiversity credits while making them financeable by external investors *via* a decentralized market.

The structural limitation remains that described above: the robustness of the tokenized asset remains contingent on the

rigor of the field verification mechanisms, which we will examine in section 2.1¹²².

dMRV as a necessary condition, not as a sufficient solution

Whether dealing with carbon credits or biodiversity credits, the robustness of the tokenized asset remains contingent on the quality of the underlying data. It is precisely to address this challenge that dMRV (digital Measurement, Reporting and Verification) is being developed: the integration of continuous data collection and verification technologies, satellite imagery, sensors, machine learning algorithms, into the certification processes of environmental projects. This mechanism, its technical operation, its real contributions, and its limitations will be discussed in detail in section 2.1. Suffice it to say here that without robust dMRV, tokenization merely shifts the structural problem identified in section 1.1.3: the information asymmetry between the project sponsor and the market persists, even if it is now recorded in an immutable register.

[B] Carbon and biodiversity – two market logics

Carbon credit markets and biodiversity credit markets share a common ambition: to internalize the value of ecosystem services in capital allocation decisions, but they are based on distinct economic assumptions, with direct consequences for their tokenization.

The carbon market is based on fungibility: a ton of CO₂ avoided in the Amazon is worth, within the framework of offsetting mechanisms, the same as a ton avoided in Indonesia or Europe. This property makes

¹²² Regeneration Needs Location Astral's Geospatial Role in the Kolektivo Framework
<https://medium.com/kolektivo-co/regeneration-needs-location-b538cae97ff7>

¹²¹ <https://www.kolektivo.network/>

carbon credits naturally suited to tokenization and trading on global markets. It is also the source of its main problems, insofar as it encourages the production of low-cost credits without regard for the actual quality of the reduction.

Biodiversity markets operate according to the opposite logic: their founding principle, in both regulated ecological compensation markets and academic debates on voluntary markets, is non-substitutability. One hectare of primary forest does not compensate for the destruction of a coral reef, even if both harbor species with equivalent conservation status. This non-fungibility protects the ecological integrity of the instrument but makes its tokenization and circulation on global markets structurally more complex. The International Advisory Panel on Biodiversity Credits (IAPB), an independent initiative co-launched by France and the United Kingdom in June 2023, emphasized that biodiversity credit markets require *"effective, robust, and science-based" measures*¹²³, simultaneously ensuring *"heterogeneity reflecting the diversity of nature"*¹²⁴, two requirements that are difficult to reconcile in a standardized financial instrument with a global focus.

1.2.3 The emergence of Decentralized Microfinance (Micro-DeFi)

Microfinance has been one of the best-documented attempts to direct capital towards populations excluded from the traditional banking system. It has produced real results – millions of borrowers have gained access to credit for the first time – but has also generated serious systemic problems, the structural causes of which were established in the previous section (see 1.1.3.2), namely high operating costs, usurious interest rates, and a shift in focus towards more profitable clienteles.

Decentralized microfinance (Micro-DeFi*) is not the antithesis of traditional microfinance; rather, it is an architectural corrective. By substituting automation through smart contracts* for certain costly functions of institutional intermediation, and by directly connecting local borrowers to global liquidity pools, it seeks to alter the cost structure that mechanically drives high interest rates. This section first examines why this constraint is architectural and not merely regulatory, and then documents concrete applications, access to global liquidity, risk management in unbanked contexts, and the construction of an on-chain credit history*, distinguishing between verifiable promises and what remains, at this stage, an unvalidated ambition.

¹²³ Fawcett, A., & Goulard, S. (2024, January 11). How biodiversity credits can finance nature-positive outcomes. World Economic Forum.

<https://www.weforum.org/stories/2024/01/how-biodiversity-credits-can-finance-nature-positive-outcomes/>

¹²⁴ *Ibid.*

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1.2.3.1 Traditional microfinance in the context of disintermediation

Microfinance was conceived, from its earliest formulations in the 1970s, to offer financial inclusion to populations deemed structurally unprofitable by the traditional banking system. Muhammad Yunus and the Grameen Bank in Bangladesh popularized this model by demonstrating that it was possible to grant unsecured loans to very poor borrowers, relying not on individual guarantees but on collective pressure and responsibility within solidarity groups. This proof of concept was lauded, Yunus received the Nobel Peace Prize in 2006, and the model was replicated in dozens of countries. However, large-scale implementation revealed a structural constraint that the initial vision had not fully anticipated: the cost of proximity.

The *high-touch* model and its consequences for interest rates

Microfinance institutions (MFIs) serve geographically dispersed borrowers with low financing needs, no collateral, and clean credit histories. To assess each application, process loans, monitor repayments, and maintain the trust necessary for unsecured loans, MFIs have developed a high-touch, relationship-intensity model: field agents, regular borrower group meetings, follow-up visits, and manual transaction recording. This model is both the condition of their social effectiveness, direct knowledge of borrowers and peer solidarity make high repayment rates possible, and the source of their structurally high operating costs.

These costs must be recouped through interest margin, but the relationship is arithmetically unfavorable: the costs of managing a microloan, site visits, application processing, and repayment monitoring, are relatively fixed regardless of the amount, so the cost-to-income ratio of a microfinance institution (MFI) mechanically deteriorates as the average loan size decreases. In other words, a €150 loan to a small rural farmer

might require almost as many human resources as a €2,000 loan to an urban entrepreneur, but generate significantly less revenue for the institution.

This arithmetic asymmetry explains why the average interest rate charged by microfinance institutions (MFIs) is around 35%, according to the data¹²⁵ from the Consultative Group to Assist the Poor (CGAP, 2008), with considerable differences depending on the context – from 17% in Sri Lanka to over 80% in Uzbekistan during the same period.

The case of Banco Compartamos in Mexico has become emblematic of this phenomenon: at the time of its initial public offering in April 2007, which crystallized the debate throughout the sector, the institution was applying an effective rate of approximately 86% net of taxes on its loan portfolio – or nearly 100% with applicable VAT¹²⁶ Hudon and Sandberg documented in 2013 that this situation is not isolated and constitutes one dimension of what they call an "*ethical crisis*"¹²⁷ of microfinance, where the pressure towards profitability generates borrowing conditions that the targeted populations can hardly bear.

This dynamic produces what researchers call the "*poverty penalty*": a paradoxical situation where the poorest clients bear the highest borrowing costs, precisely because of the small size of their loans. Ramírez Rocha et al. established in 2018 that there is a significant mediation effect between interest rate levels

¹²⁵ Rosenberg, R., Gaul, S., Ford, W., & Tomilova, O. (2008). Variations in microcredit interest rates. CGAP Brief, July 2008.

<https://www.cgap.org/sites/default/files/CGAP-Brief-Variations-in-Microcredit-Interest-Rates-Jul-2008.pdf>

¹²⁶ Rosenberg, R. (2007). CGAP Reflections on the Compartamos Initial Public Offering: A Case Study on Microfinance Interest Rates and Profits. CGAP Focus Note, June 2007.

<https://www.cgap.org/research/publication/cgap-reflects-on-compartamos-initial-public-offering>

¹²⁷ Hudon, M., & Sandberg, J. (2013). The ethical crisis in microfinance: Issues, findings, and implications. *Business Ethics Quarterly*, 23(4), 561–589. <https://doi.org/10.5840/beq201323440>

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and the financial performance of microfinance institutions (MFIs), confirming that the cost structure of the model mechanically pushes towards high rates for the most vulnerable borrowers.¹²⁸

Mission drift as a structural result

This pressure for profitability has generated a phenomenon long documented in academic literature: mission drift. In 2010, Mersland and Strøm established, using a panel of 379 microfinance institutions (MFIs) in 71 countries over eleven years, that the progressive commercialization of these institutions leads to a shift in the clientele served, from the poorest to the least poor, as profit targets and average operating costs increase¹²⁹. The mechanism is simple: a wealthier client, borrowing a larger amount in an urban area, costs less to educate and generates more revenue; the financial rationale of the institution therefore gradually pushes its agents to target these profiles to the detriment of the most difficult-to-reach populations.

Furthermore, contrary to intuitions stemming from classical economic theory, increased competition between microfinance institutions (MFIs) has not produced a generalized decrease in rates: as long as the cost structure of the high-touch model remains unchanged, operators find themselves in a situation where financial viability constrains rates, independently of competitive pressure.¹³⁰

In its most serious manifestations, this trend has produced documented and severe social

harm. Coercive debt collection practices, coupled with usurious interest rates, have triggered spirals of over-indebtedness in several countries. The 2010 crisis in the Indian state of Andhra Pradesh, marked by a wave of suicides among over-indebted farmers, is the most tragic and well-documented example and was analyzed in section 1.1.3.2 of this report within the context of the systemic drift of impact finance.

The structural promise of disintermediation through Web3

It is precisely this architectural constraint that new decentralized infrastructures offer a solution to. The promise of Micro-DeFi* (decentralized microfinance) is not to replace the human relationship that underpins the microfinance model, but to substitute less expensive automated mechanisms for certain costly functions of institutional intermediation.

The automation of loan origination, disbursement, and repayment functions through smart contracts* can eliminate several layers of administrative intermediation. However, the potential cost reduction stems not only from the self-executing nature of the contract but also more broadly from the decomposition of the microfinance value chain and the decentralized approach that these infrastructures enable. Functions traditionally concentrated within a single institution, fundraising, identity verification, risk assessment, disbursement, and repayment monitoring, can be distributed among different actors or protocols: international lenders, local validators, shared registries, collective guarantee mechanisms, and automated settlement tools. A smart contract* that automatically releases funds according to predefined conditions (borrower identity verification, implementation of a repayment mechanism, and reaching a collective guarantee threshold) therefore does not simply replace a manual operation; it allows for the cost-effective coordination of functions previously integrated into

¹²⁸ Ramírez Rocha, A., Cervantes Zepeda, M., & Bernal Ponce, L. A. (2018). Mediation effect of interest rates on MFIs' financial performance. *Contaduría y Administración*, 64(4). <https://doi.org/10.22201/fca.24488410e.2018.1518>

¹²⁹ Mersland, R., & Strøm, R. Ø. (2010). Microfinance mission drift? *World Development*, 38(1), 28–36. <https://doi.org/10.1016/j.worlddev.2009.05.006>

¹³⁰ Acclassato, D.-H. (2008). Do interest rate caps in microfinance actually serve the poor and small economic actors? *Developing Worlds*, 141(1), 93–109. <https://doi.org/10.3917/med.141.0093>

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cumbersome institutional intermediation. Researchers who conducted semi-structured interviews with microfinance and blockchain experts concluded in 2024 that the technology can *"create credible financial profiles, automate contracting and attract funds at a lower cost"*¹³¹ for unbanked borrowers, while emphasizing that coordination complexities and data protection issues constitute real obstacles to its large-scale deployment.

Protocols like **PACT / ImpactMarket**¹³², with \$1.8 billion in microloans distributed and over one million active borrowers via the **Celo** blockchain, they provide empirical evidence to support this promise. **Jia**, deployed in Kenya and the Philippines since 2022 with over ten million dollars disbursed, offers local SMEs inventory financing, invoice factoring, and working capital with disbursement in less than twenty-four hours, structurally eliminating local banking intermediaries while relying on local validation nodes for loan processing.¹³³

Disintermediation also eliminates the geographical constraints of liquidity. A system based on smart contracts* can directly connect a group of Mexican farmers to capital reserves held by European or Asian investors, bypassing local banks whose operating costs and lack of capital are precisely what generate the high interest rates observed. **Ethichub**, deployed since 2017 on the Ethereum blockchain and now on the **Celo** blockchain, provides such a solution.¹³⁴ This illustrates the architecture: international lenders directly finance Mexican agricultural cooperatives, some of whose members previously bore informal credit rates exceeding 100% per year, and in return receive a return of 8 to 10% – the rate difference that was ultimately captured

by intermediaries is shared between borrowers and lenders.¹³⁵

The second lever is the creation of an on-chain credit history*. One of the structural reasons why conventional banks exclude unbanked populations is the lack of data on their past repayment behavior. Recorded immutably on a distributed ledger, each loan transaction and each repayment constitutes, a priori, a credit file verifiable by any potential lender, without depending on a centralized institution as its sole custodian.

This digital "financial passport" is particularly relevant for populations who have demonstrated a repayment capacity with a local microfinance institution (MFI) but remain invisible to international capital markets.



HiveOnline is a platform that digitizes Village Savings and Loan Associations (VSLAs) in sub-Saharan Africa. These are community-based microfinance structures that operate without bank access, where members contribute collectively and grant each other loans according to internal rules. The application replaces paper passbooks with distributed ledger records: a single smartphone per group is all that is needed to access the shared and immutable record of all the group's transactions.

In December 2025, **HiveOnline** completed the migration of 75,000 users to the Hedera Hashgraph blockchain, building an immutable and portable credit history for each of them¹³⁶. This on-chain ledger* is the operational condition for partner

¹³¹ Hoque, M. M., Kummer, T.-F., & Yigitbasioglu, O. (2024). How can blockchain-based lending platforms support microcredit activities in developing countries? An empirical validation of its opportunities and challenges. *Technological Forecasting and Social Change*, 203, 123400. <https://doi.org/10.1016/j.techfore.2024.123400>

¹³² <https://pactfoundation.com/>

¹³³ <https://www.jia.xyz>

¹³⁴ <https://celo.org/>

¹³⁵ Ethichub. (n.d.). Invest with purpose – How it works.

<https://www.ethichub.com/en/what-is-it-and-how-does-it-work>

¹³⁶ HiveOnline, hiveonline Completes Strategic Migration to Hedera to Scale Financial Inclusion for 75,000 Users, December 16th, 2025.

<https://www.hivenetwork.online/2025/12/hiveonline-completes-strategic-migration-to-hedera-to-scale-financial-inclusion-for-75000-users/>

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banks, including Kingdom Bank Kenya and Microbanco Confiance in Mozambique, to automatically assess the creditworthiness of a rural group without prior physical contact with the institution, opening access to global liquidity for borrowers previously invisible to capital markets.

These promises, however, remain conditional. Borrower selection, project viability assessment, and default management require an understanding of the local context that algorithms cannot unilaterally replace. The most successful concrete applications of Micro-DeFi* – which we will examine in section 1.2.3.2 – have precisely resolved this tension not by eliminating the local actor, but by redefining its role: no longer a collector and redistributor of funds, but a validation and guarantee node within a decentralized liquidity system.

[B] Competition between microfinance institutions without a decrease in interest rates

In classical economic theory, competition among providers of the same service leads to a convergence toward the lowest prices, with the least efficient operators gradually being eliminated from the market. This logic has proven largely ineffective in the microfinance sector, for a structural reason that Del Pilar Miranda documented in 2019 for Latin America: the operational costs associated with the high-touch model are so high and so inflexible, sometimes representing 30 to 40% of outstanding loans, that the room for maneuver on interest rates remains limited regardless of the level of competition¹³⁷. Banco Compartamos illustrates this limitation.

¹³⁷ Del Pilar Miranda, D. (2019, February 20). Disparities in the cost of microcredit in Latin America. Georgetown Public Policy Review. <https://gppreview.com/2019/02/20/disparities-cost-microcredit-latin-america/>

The CGAP analysis published by Rosenberg in 2007 shows that even by reducing its return on equity to a level comparable to other Mexican banks, around 15% instead of over 50%, the institution could have lowered its interest rates to a range of 65% to 70%, not to levels accessible to the poorest borrowers. The source of the problem, therefore, is not solely shareholder profit, but the cost structure of a model that cannot reach its target populations without an incompressible level of relational intensity. It is this architectural constraint, and not just regulation or governance, that disintermediation through smart contracts* seeks to modify.

1.2.3.2 Worldwide liquidity , risk management and on-chain historic.

The disintermediation described in the previous section did not remain at the stage of a theoretical proposal. From 2017 onwards, in the wake of the launch of Ethereum and the first Decentralized Finance (DeFi*) protocols, several initiatives attempted to implement Decentralized Microfinance (Micro-DeFi*) whose analysis reveals three axes: direct access to international liquidity pools, the design of risk management mechanisms adapted to borrowers without collateral, and the progressive creation of an on-chain credit history* for unbanked populations.

Direct access to global liquidity: the EthicHub case



The **EthicHub** platform, founded in Spain in 2017 and operating primarily in Mexico, provides a documented illustration of the transition from theoretical disintermediation to a functional financial architecture. Its model directly connects unbanked smallholder farmers to international investors *via* smart contracts* deployed on the Ethereum blockchain,

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eliminating local intermediaries whose loan rates regularly exceeded 100% per year, according to the platform's own data. Loan security relies on a "crowd-collateral" mechanism: third-party lenders deposit security capital into a smart contract* that absorbs initial defaults, making the transaction acceptable to international lenders without requiring tangible collateral from borrowers. Based on data reported by the platform, it indicates having financed over 600 farming communities for a total volume exceeding six million US dollars (USD), with a reported default rate of approximately 1%.¹³⁸ These figures come from internal institutional sources and have not, at this stage, been subject to independent academic validation, which does not invalidate them but nevertheless requires that they be treated as indicative data.

This model of direct connection between global liquidity and local borrowers, however, requires solving the "last mile" problem: borrower selection, project viability assessment, and support remain the responsibility of local human nodes (Originators), whose role is not eliminated but redefined. **EthicHub** therefore does not disintermediate the entire value chain; it reconfigures its cost structure by replacing a local financial circuit captured by informal lenders with access to global capital pools on more favorable terms for both parties.

Risk management in unbanked contexts: the Colombian pilot

Integrating populations without tangible assets into Decentralized Finance (DeFi) protocols poses a specific risk management

problem that goes beyond traditional DeFi mechanisms, designed for digital assets, not for physical borrowers whose creditworthiness cannot be verified on-chain. A pilot project¹³⁹ led by Mercy Corps Ventures in Colombia in 2024-2025 experimented with an architectural response to this constraint. The hybrid model, developed using the **Anzi Finance** and **Quipu** protocols, connects DeFi liquidity* to a local microcredit institution acting as a trusted interface to end borrowers. A "first-loss" fund is locked in a smart contract*: it absorbs the first defaults and thus attracts institutional or individual lenders who would not have accepted the raw risk profile of this type of portfolio. This blended finance architecture, in which philanthropic or public first-loss capital catalyzes the inflow of private capital, is one of the most studied mechanisms for extending decentralized credit to high-risk contexts. We will examine it in its broader dimensions in section 2.3.1.

On-chain credit history as an inclusion infrastructure

Several platforms are exploring a third way, distinct from direct microcredit: building a credit history recorded on a distributed ledger for populations whose financial invisibility stems precisely from the absence of any trace in centralized systems. Initiatives like Hiveonline, **Jia**, and **Clixpesa** operate on this principle: each loan transaction and each repayment is immutably recorded on-chain*, constituting for the borrower a portable and verifiable informational asset for any future lender, without depending on an intermediary centralized institution. This logic aligns with the conclusions of Hoque, Kummer, and Yigitbasioglu (2024), who establish that blockchains can "create credible financial profiles" likely to reduce the costs of

¹³⁸ EthicHub. (n.d.). How it works.

<https://www.ethichub.com/en/what-is-it-and-how-does-it-work>; and

<https://www.ethichub.com/en/docs/introduction/ethichub> (Internal self-reported data, not verified by an independent academic source at this stage.)

¹³⁹ Mercy Corps Ventures. (2025). Pilot insights: Unlocking DeFi*-powered credit for microentrepreneurs in Colombia. Mercy Corps.

<https://www.mercycorpsventures.com/blog/pilot-insights-unlocking-defi-powered-credit-for-microentrepreneurs-in-colombia>

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accessing capital for borrowers in developing countries, while emphasizing that coordination between actors and data protection issues remain unresolved operational obstacles¹⁴⁰.

Payment infrastructure as a condition of access: HesabPay in Afghanistan

For Micro-DeFi* to operate effectively in constrained environments, it must rely on payment infrastructures accessible to populations without internet-connected phones or bank accounts. The Afghan platform **HesabPay**, launched in Kabul in 2016 and deployed on the **Algorand** public blockchain, exemplifies this. The **Algorand** Foundation presents it as enabling offline transactions via USSD (Unstructured Supplementary Service Data) protocols, which function on basic phones without an internet connection. According to data published by the **Algorand** Foundation – an institutionally linked source for the protocol, whose figures should be considered with the usual caveats – the platform manages the monthly payment of more than 170,000 electricity bills, representing 4 million US dollars (USD) settled in stablecoins (crypto-assets with stable value), and processed more than 4.5 million transactions for 400,000 active users between July 2023 and June 2024¹⁴¹. These data illustrate the potential scope of these devices in contexts of acute banking failure, even if their independent verification remains limited.

Community inclusion currencies as micro-local liquidity

A third category of applications, conceptually distinct from microcredit and payments,

concerns the creation of liquidity at the micro-territorial level via complementary digital currencies. The **Grassroots Economics** Foundation in Kenya enables marginalized communities to issue Community Asset Vouchers (CAVs) registered on the **Celo** blockchain, functioning as a mutual credit system backed by the productive commitments of participants. Clark, Mihailov, and Zargham modeled these Community Inclusion Currencies (CICs) in a study published in *Computational Economics* in 2024, establishing that they can “act as an institutional mechanism for providing local liquidity in poor or isolated economic regions¹⁴²”, while emphasizing that these monetary substitutes are perceived by their users as transitional instruments, inferior to the national currency when it is accessible.

According to data published by **Grassroots Economics** in April 2026, the foundation has 3,540 active users, 141 active reservoirs, and 752 unique asset bonds issued by local individuals and groups, modest adoption figures that reflect both the territorial anchoring of this model and the challenges of scaling it up. This dimension will be explored in greater depth in section 1.3.3.1, dedicated to local inclusion currencies.

[B] The question of scaling up – why use cases remain local

The Micro-DeFi* applications documented to date share a common characteristic: they operate at narrow geographic and demographic scales. **EthicHub** operates in a few hundred Mexican farming communities; **HesabPay**, in the context of a banking crisis specific to Afghanistan; **Grassroots Economics**, in precisely defined rural areas of Kenya.

¹⁴⁰ Hoque, M. M., Kummer, T.-F., & Yigitbasioglu, O. (2024). How can blockchain-based lending platforms support microcredit activities in developing countries? An empirical validation of its opportunities and challenges. *Technological Forecasting and Social Change*, 203, 123400. <https://doi.org/10.1016/j.techfore.2024.123400>

¹⁴¹ AlgorandFoundation. (2023). How HesabPay became the first and only interoperable digital payments platform in Afghanistan.

¹⁴² Clark, A., Mihailov, A., & Zargham, M. (2024). Complex systems modeling of community inclusion currencies. *Computational Economics*, 64(2), 1259–1294. <https://doi.org/10.1007/s10614-023-10445-9>

This confinement is not simply a matter of awareness or resources. It stems from a structural tension between the properties of decentralized protocols, designed for digital transactions between pseudonymous addresses, and the demands of genuine financial inclusion, which requires local knowledge, the management of interpersonal trust, and the ability to handle failures in often fragile legal contexts. The protocols that have managed to move beyond the experimental stage are precisely those that have kept local actors involved, instead of seeking to replace them. Radical disintermediation remains a theoretical promise; the reconfiguration of intermediation, less expensive, more transparent, connected to global liquidity pools, is what documented cases allow us to observe.

These limits will be analyzed in detail in section 2.2.3, which focuses on power asymmetries and the risk of what some researchers refer to as crypto-colonialism.

1.3 Reinventing the governance and allocation of common goods

The two previous sections examined, respectively, the emergence of a regenerative economy and the new financial infrastructures that Web3 makes available to it. But having an infrastructure – a public ledger, tokenized assets, financing protocols – does not answer the most fundamental question of impact finance: who decides the allocation, according to what rules, for whose benefit, and with what control mechanisms?

It is this question, that of governance, that this section examines in its three most documented expressions. First, the algorithmic governance of Decentralized Autonomous Organizations (DAOs*), which aims to replace the board of directors with smart contracts*. Second, the mathematical allocation of quadratic financing*, which seeks to reveal collective preferences where traditional voting structurally amplifies the voice of the largest capitals. And finally, at the most local level, the instruments that create liquidity and infrastructure where neither exists – Community Inclusion Currencies (CICs) and Decentralized Physical Infrastructure Networks (DePINs*).

At each level, the same ambition exists to shift allocation power towards those furthest removed from it. At each level, too, the same open question arises: is this shift real, or does it reproduce, in a new form, the very asymmetries it claims to correct?

1.3.1 Decentralized Autonomous Organizations (DAOs*) with Impact

Every governance institution relies on delegating power to a limited number of agents meant to represent the collective. This delegation structurally creates an asymmetry between those who govern and those who act on behalf of the group, and with it, the risk

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that decisions made in the name of the group ultimately serve particular interests. Decentralized Autonomous Organizations (DAOs) offer an architectural solution to this age-old problem: replacing delegated authority with code. Governance rules are no longer decided by humans, they are encoded in smart contracts, executed automatically, and verifiable by all.

The promise is considerable. The reality, at this stage, is more limited. According to data from Snapshot Labs, the main voting tool used by DAOs*, the average participation rate of token holders remains below 20%¹⁴³. The State of DeFi* 2025 report, co-published by DL Research and DefiLlama in December 2025, documents a further decline over the past year: across the six largest DAOs* analyzed – Aave, Lido, **Uniswap**, Arbitrum, Balancer, and Frax – the number of proposals submitted fell by at least 60% and up to 90% year-over-year, while median voter participation declined in five of the six protocols.¹⁴⁴

The authors conclude that DAO* governance has evolved from “high-frequency experimentation to professionalized control,” with delegation to a small number of large holders becoming structurally central at the expense of direct participation. This trend led major players in 2025 to abandon their decentralized governance structures: the **Solana** Jupiter exchange cited a “breakdown of trust,” while the CEO of Yuga Labs publicly

described the Apecoin DAO* as “governance theater: slow, noisy, and often unserious.”¹⁴⁵

Examples of truly operational organizations, such as **Big Green DAO**, which has substituted beneficiaries for donors in allocation decisions, or **Octant**, which redistributes the returns from a collective treasury, are documented precisely because they are exceptions. They illustrate what the model can produce when the social, technical, and incentive conditions are right. They say nothing about its average performance.

Automating rules also fails to answer the question of who wrote them, or who holds the tokens that allow participation. This section first examines the formal mechanics of this power transfer, then these two impactful initiatives whose architectures, and limitations, are as instructive as their ambitions.

1.3.1.1 The transfer of power through smart contracts*

The question of governance runs throughout the history of human institutions: how do individuals with divergent interests manage to make collective decisions, allocate common resources, and control their use? Classic institutional answers, the deliberative assembly, the board of directors, the general management, all rely on delegating power to a limited number of agents supposedly representing the group. This delegation inevitably creates an asymmetry between those who govern and those who act on behalf of the group, and with it the risk that decisions made in the name of the collective will ultimately serve particular interests. It is precisely this asymmetry that Decentralized Autonomous Organizations (DAOs) claim to*

¹⁴³ Snapshot Labs, cited in DAOtimes. (2025). Snapshot DAO Tool Report for 2025. <https://daotimes.com/snapshot-dao-tool-report-for-2025/>

¹⁴⁴ DL Research & DefiLlama. (December 2025). State of DeFi* 2025. DL News. <https://www.dlnews.com/research/internal/state-of-defi-2025/>; summary available at <https://www.dlnews.com/articles/defi/daos-grew-quieter-in-2025-per-state-of-defi-report/>

¹⁴⁵ Gilbert, A. (2025, July 9). Is there a future for DAOs? CoinDesk. <https://www.coindesk.com/business/2025/07/09/is-there-a-future-for-daos>

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resolve, not through a reform of governance rules, but through an architectural substitution of their underlying structure.

What the architecture of a DAO* structurally changes

A Decentralized Autonomous Organization (DAO*) is a type of organization whose operating rules and decision-making mechanisms are encoded directly in smart contracts* deployed on a public blockchain. These contracts are accessible, verifiable, and executed automatically without human intervention. Unlike a traditional company or organization, where a small board of directors holds decision-making authority over the organization's finances and strategy, a DAO* transfers this authority to all its members through an on-chain voting system*. Members participate in governance by holding tokens, known as governance tokens, which grant them voting rights proportional to their holdings, or according to alternative models based on reputation or contribution. For example, the **Uniswap** DAO*¹⁴⁶ UNI, a decentralized exchange protocol with a treasury exceeding one billion dollars, submits all decisions regarding fund allocation, fee parameters, or protocol developments to its UNI token holders. Each proposal is thus debated publicly and then submitted to an on-chain recorded vote*, the outcome of which is binding and cannot be overridden by any central authority.

This architectural shift has three distinct consequences. The first is **structural transparency**, since all decisions made, votes cast, and cash flows are permanently recorded and verifiable by any stakeholder on the public ledger. There is no longer any need to trust a manager's statements or an auditor's annual reports – traceability is, a priori, total and

permissionless. The second is the **automation of execution**: decisions approved by vote are executed by smart contracts* without requiring intermediate human validation, eliminating delays, the risk of non-execution, and the possibility of ex post manipulation between the decision and its implementation. The third is **open participation**: anyone with an internet connection and governance tokens can submit a proposal, vote on others' proposals, and audit the collective treasury, regardless of their nationality, institutional status, or geographical proximity to the organization's headquarters.

Esposito, Tse, and Goh, in an analysis published in *Frontiers in Blockchain* in 2025, summarize this reconfiguration by emphasizing that DAOs* "*enable democratic asset management, organizational spending, shared treasury, commons management, without requiring a central governing authority*"¹⁴⁷, the decisions being "*executed automatically*"¹⁴⁸ once approved by the token holder community.

The mechanism of on-chain voting* and its presuppositions

In its most common configuration, the governance of a DAO* operates in three stages. A member submits a proposal, allocating funds to a project, modifying a protocol parameter, hiring a service provider, along with a voting deadline. All governance token holders can then cast their votes during this deadline, with each token conferring one vote.

If the proposal exceeds the approval threshold set a priori in the smart contract code* – for example a simple majority or a minimum

¹⁴⁶ <https://app.uniswap.org/>

¹⁴⁷ Esposito, M., Tse, T., & Goh, D. (2025). Decentralizing governance: exploring the dynamics and challenges of digital commons and DAOs. *Frontiers in Blockchain*, 8, 1538227. <https://doi.org/10.3389/fbloc.2025.1538227>

¹⁴⁸ *Ibid.*

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quorum – it is executed automatically: the funds are transferred, the parameters modified, the rights assigned, without an administrator needing to manually validate the execution.

This architecture rests on an explicit political presupposition, which Jha formulated in 2025 as the principle of *"equal decision-making authority, often mediated by smart contracts"*¹⁴⁹.

This assumption, that decentralizing voting produces fairer governance, has, however, come under increasing criticism in the academic literature. Esposito et al. document that in practice, token-weighted voting tends to produce de facto oligarchic governance, insofar as *"the concentration of governing power creates incentives for collusion and vote buying, with large token holders able to form cartels or delegated governance structures to maintain their control"*¹⁵⁰. Empirical data confirms this trend. For example, in the Decentraland DAO*, the average participation per proposal was 0.79%, with a median participation of 0.16%. Of the 30,000 DAO*s analyzed by the DAO* Index in 2025, 53% were inactive, with no proposals submitted in the previous six months. The apathy of small token holders effectively leaves decisions in the hands of large holders, reproducing a form of shareholder primacy that the DAO* was specifically intended to replace.

¹⁴⁹ Jha, R. (2025). Exploring the governance paradox: An analytical framework for decentralized accountability and impact in climate DAOs. *International Journal of Cryptocurrency Research*, 5(1), 25–43.

https://www.researchgate.net/profile/Rubhesh-Jha/publication/393858174_Exploring_the_Governance_Paradox_An_Analytical_Framework_for_Decentralized_Accountability_and_Impa

ct_in_Climate_DAOs/links/687df0697d202419e84d9b6d/Exploring-the-Governance-Paradox-An-Analytical-Framework-for-Decentralized-Accountability-and-Impact-in-Climate-DAOs.pdf

¹⁵⁰ Ibid.

[B] MakerDAO / Sky - Ten Years of Decentralized Governance

MakerDAO originated from a post on the Reddit forum r/ethereum in 2015 by Rune Christensen, then an entrepreneur in the international recruitment sector, entitled *"Introducing eDollar, the ultimate stablecoin built on Ethereum."* The ambition was simple to state, complex to achieve: to create a stable and decentralized currency, independent of bank reserves.

Technical Construction (2017–2019)

In December 2017, the first formal white paper described the Single-Collateral DAI (Sai) system, in which any user can generate DAI by depositing Ether as collateral *via smart contracts** called Collateralized Debt Positions (CDPs). In November 2019, the protocol reached a significant milestone by accepting multiple collateral assets, opening the architecture to risk diversification. The MKR governance token grants its holders the right to vote on protocol parameters, stability rates, debt caps, and accepted collateral types, on a one-token basis.

Black Thursday: the first systemic test (March 2020)

On March 12, 2020, a sharp drop in the price of Ether caused a congestion on the Ethereum network, preventing price oracles* from updating their feeds in a timely manner. For US\$8.32 million worth of ETH liquidated, no buyers participated in the auction, leaving the protocol with US\$5.67 million in uncovered debt. A class-action lawsuit was filed against the Maker Foundation, representing up to 3,000 investors who suffered losses during this event. The crisis revealed two weaknesses: the reliance on oracles* as a centralized point of failure, and the unsuitability of the auction mechanism for extreme market conditions. **MakerDAO**

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responded with emergency governance action, issuing new MKR tokens to cover the shortfall, and by introducing the centralized stablecoin USDC as an emergency guarantee, marking an initial concession to pragmatism at the expense of decentralization principles.

Real asset integration and ramp-up (2021–2022)

In July 2021, **MakerDAO** became the first Decentralized Finance (DeFi) protocol to extend a \$100 million line of credit to a traditional bank, via SocGen Forge, backed by Real World Assets (RWAs). By 2022, the RWAs, US Treasury bonds, real estate debt, and private debt, were generating over \$100 million in annual revenue for the protocol. This model demonstrates that a DAO can operate at the interface of decentralized finance and the traditional financial system, albeit at the cost of increasing reliance on regulated and centralized assets.

The governance crisis and the “Endgame” (2022–2023)

It is within this context of growth that internal tensions erupt. In October 2022, Rune Christensen submitted a plan for a complete overhaul of the protocol, the “Endgame Plan”, envisaged the creation of autonomous sub-DAOs (MetaDAOs), a restructuring of the tokens, and, ultimately, a decoupling of DAI from the dollar. The proposal deeply divided the community. Analysis of the votes revealed an irreconcilable structural contradiction with the principles of decentralized governance: on the key proposals of the Endgame, approximately 74% of the voting power that approved the measures came from tokens delegated by Christensen himself, leading an internal analyst to summarize the situation as follows:

“If 122 people voted, only one counts, since it represents 63% of the result.” Christensen himself acknowledged that token holder

apathy and very low participation rates constituted the central problem of DAO governance, and that the Endgame was designed precisely to address this.

The **Sky** rebrand and its controversies (2024)

In September 2024, **MakerDAO** rebranded itself as **Sky** Ecosystem and launched two new tokens: USDS, a next-generation stablecoin, and SKY, a governance token replacing MKR at a conversion rate of 1 MKR to 24,000 SKY. The rebranding triggered new tensions. The revelation that the USDS stablecoin would include a freeze function, technically allowing funds to be locked, was perceived by some in the community as a betrayal of the founding principles of DeFi*. During the vote confirming the retention of the name **Sky**, only four entities, out of approximately twenty participants, held nearly 80% of the voting power, each representing roughly 20% of the total. The proclaimed decentralization in the formal architecture contrasted sharply with the de facto concentration of decision-making power.

The current state (2025–2026)

The total value locked in the protocol is approximately US\$6 billion in 2026, of which US\$2.18 billion is backed by US Treasury bonds, the primary reserve asset class, and US\$1.40 billion by Ether. The DAI maintains a market capitalization of approximately US\$5.36 billion with a weekly volatility of around 0.003%. In February 2025, an off-schedule emergency proposal alters the MKR's market parameters by doubling the debt ceiling, sparking a new wave of criticism regarding the actual centralization of governance power and whether **Sky** is still a DAO* or “simply a board with additional steps.”

MakerDAO/Sky remains, to this day, one of the few Decentralized Finance (DeFi*) protocols to have gone through a complete cycle, founding ambition, systemic crisis,

technical reconstruction, governance conflicts, and identity restructuring, over the course of a decade. Its history documents, more than any theoretical demonstration, the gap between the promise of decentralized governance and the real power dynamics that structure it.

The relationship between code and power

This paradox, an architecture designed to distribute power that tends to reconcentrate it, is not contingent but stems from the very nature of token-weighted voting, the initial distribution of which is rarely equal. The protocol's founders, early investors, and technical teams structurally hold dominant positions in governance, even when the formal code of the smart contract* grants them no special rights. As Esposito et al. point out, smart contract* governance introduces a new form of asymmetry, in which real power resides less in the formally encoded rules than in the ability to shape those rules ab initio, that is, in the initial design of the protocol itself.

Initiatives are seeking to shift this design power to communities further removed from the crypto-native ecosystem. **Grassroots Economics'** Cosmo-Local Credit DAO, launched in 2026¹⁵¹ In Kenya, it transfers the management of community credit to a decentralized on-chain* organization in which members, farmers and rural women's groups, collectively decide on allocations via protocols that combine local deliberation and execution by smart contracts*.

In a different vein, the Glo Consortium of **Glo Dollar** illustrates the encoding of a remittance obligation within the protocol itself: organizations adopting the **Glo Dollar** stablecoin* do not have to rely on a promise from the issuer; the smart contract*

mechanically guarantees that seigniorage is remitted to poverty eradication programs, making the code legally and technically enforceable.¹⁵²

This observation does not invalidate the institutional proposal of DAOs*, but rather clarifies the conditions for their effectiveness. Protocols that have developed alternative governance models, quadratic voting*, where the marginal cost of an additional vote increases with the number of votes already cast; reputation voting, based on past contributions rather than token holdings; or bicameral models like that of the **Optimism Collective**, combining a chamber of token holders and a chamber of citizens selected based on their contributions, seek precisely to correct this structural bias. These alternative mechanisms will be examined in detail in section 1.3.2, which focuses on quadratic financing* and its challenges.

[B] The DAO* as heir to the debate on the governance of the commons

The institutional proposal of DAOs* is rooted in an intellectual tradition that predates Web 3: commons governance. Political scientist Elinor Ostrom, winner of the 2009 Nobel Prize in Economics, established in her seminal work that communities could collectively manage shared resources without privatization or state control, provided they met eight structural principles – including a clear definition of members, rules adapted to the local context, mechanisms for collective decision-making, and systems of graduated sanctions.¹⁵³

Esposito, Tse, and Goh explicitly use this framework to evaluate DAOs* in 2025,

¹⁵¹ <https://grassecon.org/about>

¹⁵² <https://www.glodollar.org>

¹⁵³ Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press.

concluding that while smart contracts* provide technical tools to satisfy some of Ostrom's principles, transparency, traceability, and automated execution, they do not guarantee the satisfaction of others, particularly the adaptation of rules to the local context and the equitable resolution of disputes. A DAO* inherits the formal advantages of algorithmic governance, but also its limitations: it can only encode what is quantifiable, and the social, cultural, and political dynamics that underpin the legitimacy of a collective decision exceed the expressive capacity of any smart contract*.

This tension – between the formal robustness of the code and the richness of human deliberation – constitutes the fundamental limit that practical applications of impactful CAD*, which we will examine in section 1.3.1.2, have attempted to resolve with varying degrees of success.

1.3.1.2 Empowering the field: examples of DAO*

The disconnect between capital holders and those with on-the-ground knowledge is one of the structural blind spots of impact finance. In conventional allocation mechanisms, particularly philanthropic foundations, impact investment funds, and public funding programs, it is systematically the former who define the eligibility criteria, deadlines, and reporting requirements; the latter only gain access by translating their real priorities into the language expected by funders, at the cost of a reformulation that often alters their substance. The result replicates the flaws documented in traditional impact finance: a growing friction between stated intention and actual action, and a concentration of normative power in the hands of those who set the rules rather than those who lead the projects. It is precisely this asymmetry that impact-driven Decentralized Autonomous Organizations (DAOs*) seek to reconfigure, by redistributing decision-making authority

through on-chain governance mechanisms*, replacing, at least in principle, the discretionary judgment of funders with codified and collectively deliberated allocation rules. Two initiatives with distinct architectures allow us to assess their concrete scope.

Big Green DAO: when beneficiaries become decision-makers

Big Green is an American non-profit organization founded in 2011 by Kimbal Musk and Hugo Matheson, dedicated to food justice and the development of community agriculture. In November 2021, the organization launched a DAO* whose explicit ambition was to "*dismantle inequitable power structures in philanthropy*" by placing beneficiary organizations in control of fund allocation, according to the terms of its own institutional charter¹⁵⁴. The mechanism is simple in principle but radical in its implications: each participant – donor or beneficiary organization – receives a non-transferable \$GARDEN governance token, granting them one vote in grant allocation decisions. The fundamental rule is absolute equality of votes: regardless of the amount contributed to the common fund, each member has only one vote. Kimbal Musk himself has publicly renounced voting in the DAO*, so as not to influence the decisions of organizations he funds as a donor.¹⁵⁵

This architecture has quantifiable effects on the cost structure. Musk explained this in a 2022 interview with CoinDesk: in a typical philanthropic foundation managing \$100 million annually, approximately 15% is absorbed by staff costs for project selection and reporting, and the beneficiary organizations themselves dedicate about

¹⁵⁴ Big Green. (n.d.). Big Green DAO: Decentralized grantmaking for food justice.

<https://biggreen.org/our-impact/>

¹⁵⁵ Musk, K. (2022, June). Interview with CoinDesk. In Kimbal Musk and his Big Green DAO. CoinDesk.

<https://www.coindesk.com/business/2022/06/02/kimbal-musk-and-his-big-green-dao>

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25% of their resources to fundraising, meaning that only 65% of the capital reaches the fieldwork. The **Big Green DAO** sets an overhead cap of 5%, theoretically bringing the share of funds available for direct action to 95%¹⁵⁶. These figures are self-reported and have not been verified by an independent academic source, but they illustrate the structural logic of disintermediation applied to philanthropy. To date, the foundation reports having distributed over US\$4.4 million directly to community projects through the **Big Green DAO**.¹⁵⁷

The experience nevertheless revealed operational limitations that its designers had not anticipated. Field practitioners, unfamiliar with Web3 digital tools, required significant support to effectively participate in on-chain governance*. The time commitment associated with governance proved substantial for organizations with limited human resources. This gap between the promise of horizontal governance and the technical prerequisites it entails illustrates the tension, analyzed in section 1.3.1.1, between the formal architecture of DAOs* and the social conditions of their actual operation.

Octant: the return on investment in the service of public goods

Octant is an initiative launched by the Golem Foundation that exemplifies a third architecture, distinct from the previous two in its fund generation mechanism. Rather than relying on donations, **Octant** uses the returns generated by staking 100,000 Ether (ETH) tokens held in its treasury to create a continuous funding mechanism for digital public goods. Staking involves locking tokens into a validation protocol on the Ethereum network in exchange for a reward – ultimately,

the network itself generates the distributed funds, without relying on external generosity.

The allocation of these funds does not belong to the Golem Foundation, but to the users who lock GLM tokens on the platform and thus acquire the right to vote during regular funding cycles designated as "epochs".¹⁵⁸ At each stage, participants vote to designate the public interest projects that will receive the available funds, thereby protecting the allocation process from bias or the unilateral will of large institutional funders. This model has the advantage of being structurally independent of philanthropic fundraising cycles, insofar as staking returns* constitute a recurring and predictable source of income – provided that the value of ETH and network yield rates remain stable, which is not a guaranteed assumption in a volatile market environment.

In both cases, these two examples share the same conviction that those directly involved in the action possess on-the-ground knowledge that centralized decision-makers cannot acquire remotely. Other initiatives have sought to export this model beyond a single community: **Gitcoin**, after distributing several hundred million dollars through its quadratic funding mechanism, launched a professional services branch in December 2024 to help other organizations deploy their own decentralized grant programs, exporting its governance model to third-party ecosystems¹⁵⁹ without centralizing control¹⁶⁰. The architecture of impact DAOs seeks precisely to translate this conviction into an operational mechanism, replacing upward delegation of decision-making with downward delegation, facilitated by smart contracts. The two models examined illustrate two

¹⁵⁶ *Ibid.*

¹⁵⁷ Musk, K. (2025, October). A Big Green Bright Future. Medium. <https://medium.com/@kimbal/a-big-green-bright-future-e83567a05351> (Cumulative data reported by the founder; not verified by an independent academic source.)

¹⁵⁸ Bizkova, T., & Simon, D. (2024). Exploring the Octant Ecosystem Part 1: Octant's Innovative Approach to Funding Public Goods Through Community Governance. Crypto Altruists.

<https://www.cryptoaltruists.com/blog/exploring-the-octant-ecosystem-part-1-inside-octant-funding-public-goods-through-innovative-community-governance>

¹⁵⁹ Like ZKsync, Sei, Avalanche.

¹⁶⁰ Gitcoin, 2025, <https://gitcoin.co/blog>

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distinct paths to achieving this objective: formal equality of voting regardless of the amount contributed (**Big Green DAO**) and the community redistribution of returns generated by a collective treasury (**Octant**).



Kolektivo constitutes a fourth model, structurally distinct from the previous three due to its explicit territorial anchoring. Deployed since 2019 on the **Celo** blockchain in Curaçao and Trinidad and Tobago, **Kolektivo** is not a project-based financing DAO: it is an infrastructure enabling Caribbean communities to create and manage circular economies based on their local natural resources, combining community currencies, economic incentive mechanisms, and decentralized governance, what its designers refer to as place-based tokenomics. The project was selected by the UNICEF Venture Fund as one of seven initiatives chosen from four hundred applications.¹⁶¹ **Kolektivo's** governance architecture differs from that of **Big Green DAO**, **Giveth**, and **Octant** on one crucial point: it does not seek to optimize the allocation of external capital to local beneficiaries, but rather to empower communities themselves with the tools to value, certify, and govern their own natural resources, food forests, biodiversity assets, and agroforestry production commitments. Allocation decisions do not concern an external fund; they concern the very definition of what constitutes a valuable local resource and the rules for distributing the benefits of its development. This model directly raises the tension documented in the following box: governance is de facto rooted in the territory, but it presupposes a minimal technical mastery of on-chain tools* on the part of communities for whom this is not necessarily a top priority. The question

of who, in concrete terms, codes the rules and parameters of the smart contract* remains, and with it, the question of the distance between formal governance and real governance.

Each of these architectures has specific advantages and limitations – in terms of accessibility, incentives and resistance to the reconcentration of power – which the following sections and the second part of this report will analyze more precisely, particularly in the examination of the risks of illusion of decentralization in section 2.2.3.

[B] Field governance or crypto-native governance?

The three examples analyzed in this section raise a question that the literature on impact DAOs* is beginning to formulate explicitly: to whom does the de facto power of governance belong in these structures?

In the **Big Green DAO**, the principle of equal voting formally neutralizes the advantage linked to the amount of contributions. However, effective participation in on-chain governance* requires a minimum level of mastery of Web3 digital tools, creating a digital wallet, understanding on-chain voting mechanisms*, and familiarity with governance interfaces, which structurally excludes those on the ground with the least digital capital. The formal architecture of the DAO* can thus reproduce, in a different form, the asymmetry it claims to eliminate: no longer between wealthy donors and impoverished organizations, but between crypto-native participants and practitioners on the ground.

Jha documents this paradox in 2025 by establishing that in climate-impact DAOs*, *"limited access to expertise compromises the quality of decisions"* and that the

¹⁶¹ Kolektivo, 2025, <https://kolektivo.network>

complexity of on-chain governance* creates barriers to entry which tend to concentrate decision-making power in the hands of members most technically familiar with the ecosystem (Jha, 2025).

This observation echoes the broader criticism leveled at token-weighted voting mechanisms, examined in section 1.3.1.1: the shift in power brought about by DAOs* is not always to the benefit of field actors, but sometimes to the benefit of a new technical elite.

1.3.2 The democratic allocation

In any system where influence is proportional to capital invested, collective deliberation structurally drifts towards plutocracy – not through corruption, but by design. A donation of €10,000 from a single contributor invariably trumps one hundred donations of €100, regardless of the community legitimacy reflected in the latter.

Quadratic Funding* is a mathematical proposal to correct this bias. By amplifying the matching contribution not in proportion to the amount of contributions but to the number of contributors, it seeks to reveal what traditional financial markets cannot see – the depth of community support, independent of its financial depth.

The theoretical elegance is well-documented, and large-scale applications attest to its operational feasibility. But the mathematical property that gives the mechanism its distributive power is precisely what makes it vulnerable: if amplifying the number matters more than amplifying the amount, simulating the number becomes the most profitable form of fraud. This section examines both sides of the device, without either obscuring the other.

1.3.2.1 Quadratic Funding*

In any capital allocation system where influence is proportional to the amount invested, actors with significant resources structurally wield decision-making power disproportionate to their representation within the community concerned. This asymmetry is observed both in traditional financial markets, where large institutional investors drive prices and flows, and in crowdfunding mechanisms for public goods, where a single €10,000 contribution from one donor invariably outweighs one hundred €100 contributions, regardless of the actual community support reflected in the latter model. Quadratic Funding (QF) is a market design mechanism specifically designed to correct this asymmetry.

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The theoretical foundations

The mechanism was formalized by Vitalik Buterin, Zoë Hitzig and E. Glen Weyl in an article published in *Management Science* in 2019, entitled *A Flexible Design for Funding Public Goods*¹⁶². The authors begin with a classic problem in economic theory: the underfunding of public goods. A public good, in the economic sense, is a good whose consumption is non-excludable and non-rivalrous, such as open software infrastructure, a shared impact assessment protocol, or an open-access environmental database. Because every actor can benefit from it without contributing to its funding, the private market systematically under-produces it: this is the classic free-rider problem. Conventional mechanisms, majority voting, voluntary donations, centralized public subsidies, only partially resolve this problem, failing to accurately reflect the strength of collective preferences.

Quadratic financing* offers a solution based on the following mathematical structure. Each individual contributes freely to the project(s) of their choice. The total amount received by a project is not simply the sum of individual contributions, but the square of the sum of the square roots of those contributions. The difference between this total and the sum of individual contributions is covered by a matching pool funded by institutional or public investors.¹⁶³ The effect of this formula is counterintuitive but rigorously demonstrated: a project supported by one hundred people each contributing one euro receives a significantly higher contribution than a project receiving one hundred euros from a single contributor, although the gross amounts collected are identical.

¹⁶² Buterin, V., Hitzig, Z., & Weyl, E. G. (2019). A flexible design for funding public goods. *Management Science*, 65(11), 5171–5187.

<https://doi.org/10.1287/mnsc.2018.3279> (Preprint version: Buterin, V., Hitzig, Z., & Weyl, E. G. (2018). Liberal radicalism: A flexible design for philanthropic matching funds. SSRN. <https://doi.org/10.2139/ssrn.3243656>

¹⁶³ *Ibid.*

Formally, one hundred contributors of one euro each generate a sum of the square roots of 100 ($10 \times \sqrt{1} = 10$, resulting in a total funding of $100^2/100 = 100$, to which the matching contribution is added), while a single contributor of 100 euros generates a square root of $\sqrt{100} = 10$, and an identical total funding amount, but without a comparatively higher matching contribution. The mechanism thus amplifies the matching contribution in direct proportion to the number of distinct contributors, and not to the total amount contributed. In economic terms, the matching contribution acts as a signal of collective preference: where many people contribute, even modestly, the matching fund invests more, thus revealing the aggregate social value of a project beyond its mere attractiveness to large capital.

Conditions for application to impact finance

This mechanism is of direct interest to impact finance and Regenerative Finance (ReFi*) for a structural reason: impact projects, community reforestation, water infrastructure in rural areas, development of open ecological verification protocols, often exhibit the characteristics of public goods as defined by Buterin et al.: they generate an impact for a number of actors far exceeding those who directly finance them, and their social value is difficult to reveal through traditional market mechanisms. Quadratic financing* thus offers a mechanism capable of eliciting collective preferences from individual contributions, while incentivizing holders of large capital to contribute to a matching fund rather than exercising direct control over allocation.

The **Gitcoin** platform¹⁶⁴ This constitutes the most documented large-scale implementation of this mechanism. Specializing in funding free software projects and, increasingly, initiatives with environmental and social impact, **Gitcoin** has distributed over US\$67 million to thousands of projects using quadratic funding* as its primary allocation

¹⁶⁴ Fund What Matters <https://gitcoin.co>

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mechanism.¹⁶⁵ The platform organizes funding rounds, called **Bitcoin** Grants Rounds, during which contributors freely allocate small amounts to projects of their choice, while a matching fund, supported by institutional partners, amplifies donations in proportion to the aggregate community support. This structure has allowed projects with little visibility among major institutional investors to receive substantial funding based solely on their strong community roots.

Octant offers a structurally different take on the same mechanism. Rather than raising external donations, the Golem Foundation stakes 100,000 ETH in a staking protocol* and uses only the generated returns, without relying on third-party funders, to build a quadratic fund for digital public goods. Users who stake GLM tokens acquire voting rights during quarterly funding epochs. Since August 2023, eleven epochs have distributed over 2,866 ETH to 120 projects, with V2 introducing thirty-day sliding-window ERC-4626 vaults*, a step towards a continuous and self-sustaining mechanism¹⁶⁶. This model addresses a limitation of the classic mechanism: its structural dependence on the contribution of a counterpart fund by institutional funders, whose preferences can themselves bias the allocations.

Transposing this to impact finance: promises and challenges

Applying quadratic financing* to contexts broader than the financing of digital public goods raises economic and institutional questions that the original authors themselves identify. The first concerns the size of the matching fund: the mechanism only works if external funders agree to contribute to the fund, and the nature of these funders, foundations, states, large institutional investors, can itself introduce biases in the allocation of funds. The second concerns the

geographical and temporal externalities of the impact: a project to restore a marine ecosystem generates benefits for populations that do not necessarily participate in the funding vote, which can lead to the relative underfunding of projects whose benefits are diffuse and long-term.

The extension of quadratic funding* to fields other than digital technology is documented in the field of scientific research. **ValleyDAO**, **AthenaDAO**, and **CryoDAO**, BioDAOs with several thousand active members, apply variations of the mechanism to the allocation of research funds in synthetic biology, longevity medicine, and cryonics, subjecting funding decisions to an on-chain vote* weighted by contributions and reputation within each scientific community.¹⁶⁷

These limitations, which do not call into question the theoretical robustness of the mechanism, call for institutional adaptations which are at the heart of the following section.

[B] Quadratic financing and public goods theory

Quadratic financing* is not an invention ex nihilo of Web3. It is part of a long tradition of economic thought on the problem of public goods, which dates back to the work of Samuelson.¹⁶⁸ In 1954, on the Pareto optimality condition for non-rival goods, and on Groves-Ledyard mechanisms¹⁶⁹ in 1977, on the revelation of preferences regarding public goods.

Buterin, Hitzig, and Weyl's contribution in 2019 was twofold. Theoretically, they demonstrated that, under their basic

¹⁶⁵ Octant, 2025, <https://docs.octant.app>

¹⁶⁶ Ibid.

¹⁶⁷ Molecule, 2025,

<https://www.molecule.to/blog/valleydao-imperial-college-london>

¹⁶⁸ Samuelson, P. A. (1954). The pure theory of public expenditure. *Review of Economics and Statistics*, 36(4), 387–389. <https://doi.org/10.2307/1925895>

¹⁶⁹ Groves, T., & Ledyard, J. (1977). Optimal allocation of public goods: A solution to the "free rider" problem. *Econometrica*, 45(4), 783–809. <https://doi.org/10.2307/1912672>

assumptions, notably that individuals are unaware of their impact on the counterparty fund deficit, quadratic financing* produces an optimal level of funding for public goods, thus resolving the free-rider problem without centralized decision-making. Practically, they emphasized that distributed ledger infrastructures provide, for the first time, a technical substrate enabling the large-scale automation of this mechanism with very low marginal transaction costs: an operational requirement that conventional financial markets could not meet.

The fundamental tension that the authors themselves acknowledge concerns the robustness of the mechanism against collusion: if actors coordinate their contributions to simulate broad community support without actually possessing it, the mechanism amplifies false information. It is this risk, referred to as a Sybil attack, that we will examine in the following section.

1.3.2.2 The challenges of the model: integrity and vulnerability

The mathematical property that gives quadratic financing* its strength, amplifying the influence of the number of contributors rather than their financial contribution, is precisely what makes it vulnerable to a specific type of attack. If the matching contribution is a function of the square of the number of distinct contributors, any actor capable of simulating a multitude of distinct contributors can fraudulently capture a disproportionate share of the matching fund. This vulnerability is known as the Sybil attack, named after a 1973 psychology book documenting a case of dissociative identity disorder, and constitutes the central technical challenge for any large-scale implementation of quadratic financing*¹⁷⁰.

¹⁷⁰ The term "Sybil attack" was introduced into computer science literature by John R. Douceur in: Douceur, J. R.

The structural nature of Sybil's vulnerability

A Sybil attack occurs when an actor artificially creates a large number of distinct digital identities, in the form of different wallet addresses on a public blockchain, to simulate broad community support for a project they control or benefit from. The barrier to entry for this type of attack is structurally low in Decentralized Finance (DeFi) environments: creating a new on-chain address requires no identification, no delay, and no significant cost. An actor with limited capital can thus multiply their influence vectors at virtually no marginal cost, capturing funding disproportionate to their actual community support. In **Bitcoin** Grants cycles 1 through 15, this vulnerability was systematically exploited: on-chain analyses revealed that flaws could generate returns exceeding 100% on the capital invested by attackers, by directing funding to projects they controlled¹⁷¹.

The Sybil vulnerability is not merely a matter of financial integrity – it threatens the very legitimacy of the mechanism. If legitimate contributors perceive that allocations are systematically captured by coordinated actors rather than reflecting the community's true preferences, trust in the system erodes and genuine participation declines. Quadratic financing* only achieves its optimizing effect if contributions reflect sincere preferences – what economists refer to as preference revelation.

(2002). The Sybil attack. In Proceedings of the First International Workshop on Peer-to-Peer Systems (IPTPS 2002), Lecture Notes in Computer Science, vol. 2429, 251–260. Springer.

https://doi.org/10.1007/3-540-45748-8_24

¹⁷¹ ChainscoreLabs. (n.d.). The hidden cost of quadratic voting: Sybil attacks and the Bitcoin case. <https://www.chainscorelabs.com/en/blog/dao-governance-lessons-from-the-frontlines/governance-post-mortems/the-hidden-cost-of-quadratic-voting-sybil-attacks-and-the-bitcoin-case>

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The technical responses deployed: proof of humanity and aggregation of attestations

The dominant response developed by the ecosystem is proof of personhood: a mechanism allowing a user to demonstrate that they are a unique individual, without multiplying their digital identities, and without revealing their real identity. This technical challenge, proving uniqueness without revealing identity, is one of the most active open problems in applied cryptography.

The **Gitcoin** Passport tool, launched to secure **Gitcoin** funding cycles and renamed Human Passport¹⁷² in December 2024 after its acquisition by the Holonym Foundation, illustrates an approach based on credential aggregation: the user accumulates "stamps" from distinct identity sources – GitHub account, ENS (Ethereum Name Service) name, presence on social networks, attestations of proof of humanity protocols like BrightID or Proof of Humanity – which are weighted to calculate a uniqueness likelihood score.

This score is not binary – it does not certify with certainty that a user is unique – but probabilistic: it increases the economic cost of a Sybil attack by requiring the attacker to create not only multiple on-chain addresses*, but also multiple verifiable presences in heterogeneous identity systems.

Human Passport claims that by 2025 it had secured over US \$430 million in distributed capital through allocation programs and funding rounds, with 2.2 million users and over 120 partners.¹⁷³

This approach doesn't eliminate vulnerability, it shifts the break-even point for attacks. **Gitcoin** explicitly adopts a defense-in-depth approach: the proof-of-humanity score is

combined with on-chain behavioral analysis models, cluster analysis, and analyses of the gap between contributions and typical funding behavior. Despite these measures, the designers acknowledge that Sybil resistance remains an open problem: *"No system simultaneously achieves all three properties, decentralized, privacy-friendly, and resistant to Sybil attacks. **Gitcoin** Passport uses oracles. **Worldcoin** uses biometric hardware. The trilemma persists¹⁷⁴".*

Octant adopts a complementary active governance strategy: beyond the **Gitcoin** Passport score required to participate, a community Grants Council oversees applications, thematic rounds define the categories of eligible projects, and the temporary suspension of the matching fund during Epoch 11, following the V2 migration, illustrates the need for corrective human intervention that automation alone cannot replace¹⁷⁵.

These two cases, **Gitcoin** and **Octant**, illustrate that the operational robustness of quadratic financing* is less a technical property than an active social construct, requiring continuous governance that the code cannot fully delegate.

The trilemma of identity, decentralization, and privacy

This trilemma deserves to be explained, as it reflects a fundamental tension that goes beyond quadratic financing* alone and runs through the entire issue of decentralized governance. Any proof-of-unity system must articulate three mutually constraining properties: resistance to Sybil attacks, which requires some form of anchoring in real identity or in verification processes that are

¹⁷² <https://app.passport.xyz/>

¹⁷³ HumanTech. (2025). Human Passport x Gitcoin Grants: Defending GG23 with model-based Sybil detection. <https://human.tech/blog/human-passport-x-gitcoin-grant-s-defending-gg23-with-model-based-sybil-detection>

¹⁷⁴ ChainscoreLabs. (n.d.). The hidden cost of quadratic voting: Sybil attacks and the Gitcoin case. <https://www.chainscorelabs.com/en/blog/dao-governance-lessons-from-the-frontlines/governance-post-mortems/the-hidden-cost-of-quadratic-voting-sybil-attacks-and-the-gitcoin-case>

¹⁷⁵ Octant, 2025, <https://docs.octant.app/en-FN/quadratic-funding.html>

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difficult to circumvent; privacy protection, which prohibits permanently and publicly linking an on-chain address* to a real identity; and decentralization, which prohibits entrusting verification to a central authority that could arbitrarily exclude participants or constitute a single point of failure.

Biometric approaches, such as the iris scan used by the **Worldcoin** protocol for its World ID, obustly address the uniqueness problem, but at the cost of centralizing biometric data and documented ethical risks, particularly in the context of vulnerable populations. These risks will be analyzed in detail in section 2.2.3, which focuses on power asymmetries and the risk of crypto-colonialism. Social attestation aggregation approaches better preserve privacy but depend on the resistance to collusion of the third-party identity systems they aggregate.

Collusion as an additional limit

The Sybil vulnerability is the most immediately visible, but it is not the only threat to the integrity of quadratic funding*. Collusion between actual contributors, when distinct, authentic individuals coordinate their contributions not out of genuine preference but to manipulate allocations in favor of related projects, constitutes an attack that proof-of-humanity systems cannot, by definition, detect. The seminal article¹⁷⁶ Buterin, Hitzig, and Weyl explicitly identify this risk and propose variants of the basic mechanism, notably Capital-Constrained Liberal Radicalism, that partially limit the possibilities of collusion, without eliminating them entirely. This limitation echoes what Jha emphasized for impact DAOs* in section 1.3.1.1: the formal robustness of an algorithmic

mechanism is not sufficient to guarantee the social robustness of its results.

1.3.3 Local coordination and community inclusion

The mechanisms examined so far – smart contract governance*, quadratic finance*, asset tokenization – all implicitly assume the existence of liquidity to distribute and an infrastructure to which to connect. What happens when these prerequisites are lacking? When there is no national currency available because banking networks do not penetrate the territory, or no infrastructure to use because no operator has deemed deployment profitable?

It is to this space – the one that conventional finance cannot or will not reach – that the two instruments in this section are addressed. While their logic is common, they are distinguished by their architectures and limitations, revealing that they do not constitute a general solution, but operate within a specific set of conditions – beyond which their effects are reversed or disappear.

1.3.3.1 Local Inclusion Currencies (CIC)

The preceding sections examined how Decentralized Autonomous Organizations (DAOs*) are reconfiguring the governance of allocation decisions, and how quadratic financing* amplifies community preferences in the distribution of collective resources. Both mechanisms, however, share a common assumption: the existence of a currency in which contributions can be expressed and funds distributed. It is precisely this assumption that Community Inclusion Currencies (CICs) challenge – complementary monetary instruments that do not seek to improve the distribution of existing liquidity, but rather to create liquidity where none structurally exists.

¹⁷⁶ Buterin, V., Hitzig, Z., & Weyl, E. G. (2019). A flexible design for funding public goods. *Management Science*, 65(11), 5171–5187. <https://doi.org/10.1287/mnsc.2018.3279> (Preprint version: Buterin, V., Hitzig, Z., & Weyl, E. G. (2018). Liberal radicalism: A flexible design for philanthropic matching funds. SSRN. <https://doi.org/10.2139/ssrn.3243656>

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The problem addressed by community inclusion currencies

In many developing regions, rural areas of Kenya, island communities, and the outskirts of major cities, the shortage of national currency does not reflect a lack of real resources. People possess skills, productive capacity, and services they can provide and need. What they lack is a readily available local medium of exchange to circulate this value. National currency is produced by the central bank, distributed by commercial banks, and only enters these areas after the fact, through remittances from the diaspora, salaries of government employees, and revenues from agricultural exports, with erratic liquidity cycles that leave entire sectors of the local economy in a state of forced dormancy.

This configuration is precisely what Clark, Mihailov and Zargham identified in 2024 as the context for the emergence of community inclusion currencies: these instruments seek to *"act as an institutional mechanism for providing local liquidity in poor or isolated economic regions"*, serving *"as a market-based mechanism to alleviate poverty"*¹⁷⁷. The wording is important: the authors do not present community inclusion currencies as a substitute for the national currency, but as a complementary mechanism allowing a local economy to function in parallel with the conventional monetary system, in the intervals where the latter is lacking.

The architecture of the mechanism

A community inclusion currency is a digital voucher issued by an individual or local organization, representing a formal commitment to provide a specified quantity of future goods or services, an hour of farm work, a kilogram of corn, a training session, in exchange for an equivalent amount of vouchers issued by other members of the

network. These vouchers are recorded on a distributed ledger, which gives them the properties already examined in this report: immutability of transaction history, verifiability by any participant, and no risk of double-use.

The **Grassroots Economics** Foundation, operating primarily in Kenya since 2010, is the most documented organization in this field. It is a non-profit foundation that *"seeks to empower marginalized communities to take charge of their own livelihoods and economic future."*¹⁷⁸ The first community inclusion currencies were in printed form before being digitized. After several technical iterations, it migrated to the **Celo** blockchain in 2023 to deploy its Commitment Pooling protocol. The mechanism is as follows: individuals, groups, or cooperatives deposit their productive commitments into common pools (commitment pools), which issue Community Asset Vouchers (CAVs) in proportion to these commitments. These vouchers circulate within the network as a means of exchange, allowing participants to use them to acquire goods and services from other members without needing Kenyan shillings. Transactions are carried out via USSD (Unstructured Supplementary Service Data) protocols, which function on basic phones without an internet connection, making them accessible to populations with limited access to digital equipment.

Data published by **Grassroots Economics** in April 2026 reported 3,540 active users, 141 active pledge pools, and 752 unique asset bonds issued by individuals and local groups. These pools supported agroforestry restoration activities on over 485 hectares, the construction of community infrastructure, and improvements in food security for more than 26,600 individuals.¹⁷⁹— illustrating the ability of these instruments to mobilize local productive capacities that would otherwise

¹⁷⁷ Clark, A., Mihailov, A., & Zargham, M. (2024). Complex systems modeling of community inclusion currencies. *Computational Economics*, 64(2), 1259–1294. <https://doi.org/10.1007/s10614-023-10445-9>

¹⁷⁸ Karibu (Welcome to) Grassroots Economics' Docs <https://docs.grassecon.org>

¹⁷⁹ Grassroots Economics Foundation. (2024). One Year of Impacts 2024. <https://www.grassrootseconomics.org/impacts-2024>

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remain inactive due to a lack of exchange instruments.

Contrasting emission patterns

The **Grassroots Economics** model is based on collective commitment: the cooperative or village community constitutes the reservoir and determines the value of the voucher. Other architectures have made the opposite choice, placing the individual at the heart of the issuance mechanism. **CirclesUBI**, deployed since 2021 on the Gnosis blockchain, illustrates this logic to its logical conclusion: each user issues their own personal currency at a rate of one CRC per hour, and the relational trust between members serves as implicit collateral for the circulation of these vouchers. The value of a CRC is not guaranteed by a tangible asset or a formalized service commitment, but by the reputation of its issuer within their network of acquaintances. To discourage hoarding, a structural flaw of conventional currencies in low-consumption economies, the protocol incorporates a 7% annual depreciation: the value of unused vouchers gradually erodes, creating a structural incentive for circulation rather than accumulation. A recent integration with Gnosis Pay also allows users to spend their CRC *via* a Visa payment terminal, thus raising the still unresolved question of interoperability between community currencies and official monetary circuits.

Comparing these two models is analytically instructive. **Grassroots Economics'** collective model produces liquidity backed by verifiable productive capacities and generates measurable impact data in terms of restored hectares or food beneficiaries. **CirclesUBI's** individual model produces liquidity backed by social trust and generates adoption data that is difficult to aggregate into environmental or economic impact indicators. These two architectures therefore respond to different constraints and call for distinct evaluation methods, which poses an initial challenge for their integration into formalized impact finance frameworks.

The question of scale also deserves consideration. **GoodDollar**, a decentralized universal basic income protocol deployed since 2020, has 618,000 unique users spread across more than 10,000 cities worldwide; its G\$ token is issued by a DeFi* reserve whose returns alone finance distribution, making it independent of any exogenous public or private capital flows[80]. These figures are the largest documented in the category of digital inclusion currencies, and they should be interpreted with caution: widespread adoption does not guarantee integration into real economic circuits, and the exact nature of G\$ usage, speculative savings, daily transactions, simple registration without activity, has not yet been independently documented.

The monetary infrastructure underpinning several of these systems is **Mento Labs**. It operates the protocol that issues the fifteen local currency stablecoins used by **GoodDollar**, **MiniPay**, and Haraka, including cUSD, cEUR, and cREAL, all adopted by over seven million users, more than one million of whom are in sub-Saharan Africa. These local stablecoins are not community currencies in the sense of Clark et al., as they are not issued by the communities themselves, but they fulfill a similar function in contexts of limited access to banking: stable units of account in the face of local devaluations, accessible *via* mobile phone, and usable without a bank account.¹⁸⁰

A case study in public service: EnergyKnip

The preceding examples all stem from initiatives by civil society or the private sector. A case study from a European public service documents another approach: the **MultiKnip** program, developed in the Netherlands with the support of the IOTA Foundation, distributed five million euros to 20,000 households in the city of Emmen in the form of EnergyKnips – a single-use token whose

¹⁸⁰ Mento Labs, 2025, <https://www.mento.org/blog/bringing-stablecoins-to-the-world---one-local-currency-at-a-time>

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rules of use are fully encoded in a smart contract*: a restricted list of partner retailers specializing in energy-efficient renovations, a defined geographical area, and a scheduled expiration date. The token cannot be transferred, resold, or used outside the defined area. This mechanism – described by its designers as a Purpose-Bound Token* – does not, strictly speaking, constitute a community inclusion currency in the sense of Clark et al., as it is not issued by the community and is not linked to local productive commitments. It falls more into an adjacent category, that of public currency with a programmed destination, and participates in the European regulatory sandbox on blockchain¹⁸¹. Its analytical interest for this section lies in the fact that it shares with CICs a fundamental property: the encoding of the conditions of use in the protocol itself, making any misuse technically impossible without requiring ex post administrative control.

The distinctive economic properties of community inclusion currencies

Community inclusion currencies possess two economic properties that structurally distinguish them from national currencies and explain their specific relevance in contexts of liquidity shortage.

The first is their countercyclical nature: because the bonds are backed by local productive capacity and not by external capital flows, their availability is not affected by liquidity crises in the national monetary system. When Kenyan shillings become scarce, due to drought, a fall in agricultural prices, or a currency crisis, community asset bonds remain available as long as the productive capacity of network members has not disappeared. Clark et al. model this dynamic and establish that CICs “can act as a countercyclical stabilization

*mechanism*¹⁸² which allows local economies to maintain a minimum level of activity during phases of contraction of national liquidity.

The second is their territorial anchoring: unlike crypto-assets with a global focus, CICs do not seek to replace national currencies or fuel global exchange markets. Their value is intrinsically local, defined by the trust that network members place in the issuers' commitments. This localization produces documented economic effects: by keeping value flows within a defined territory, CICs reduce economic leakage, the tendency of local income to be immediately reinvested outside the territory, and strengthen the density of intra-community exchanges, what development economists refer to as the local multiplier effect.

The structural limitations of the model

Clark et al. also document a fundamental limitation revealed by their simulations: community inclusion currencies are perceived by their users as transitional instruments, whose value is de facto lower than that of the national currency when the latter is available. In other words, participants prefer to hold Kenyan shillings as soon as they have access to them and only use community vouchers when the official currency is unavailable. This preference rationally reflects the greater liquidity and universality of acceptance of the national currency, which can be used to pay taxes, repay formal debts, and purchase goods outside the local network, something community inclusion currencies do not allow. The authors conclude that community inclusion currencies are inferior goods in the economic sense: their use expands when alternatives become scarce and contracts when they improve.

This limitation does not call into question the usefulness of community-based inclusion

¹⁸¹ European Blockchain Sandbox European blockchain regulatory sandbox for Distributed Ledger Technologies https://blockchain-observatory.ec.europa.eu/european-blockchain-sandbox_en

¹⁸² Clark, A., Mihailov, A., & Zargham, M. (2024). Complex systems modeling of community inclusion currencies. *Computational Economics*, 64(2), 1259–1294. <https://doi.org/10.1007/s10614-023-10445-9>

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currencies in contexts of structural scarcity, but it clarifies their role: not as an alternative to conventional finance, but as a mechanism for local economic resilience activated in areas that conventional finance cannot or will not serve. It is within this specific framework, not as a generalizable model, but as a local stabilization tool in specific contexts, that their relevance to impact finance and Regenerative Finance (ReFi*) must be assessed.

[B] Community inclusion currencies and complementary currencies

Community inclusion currencies are not a Web 3.0 invention. They are part of a tradition of complementary local currencies, the first experiments with which date back to the 1930s, notably the Austrian Wörgl-Schwundgeld – a local currency with programmed depreciation introduced in the town of Wörgl in 1932 to stimulate economic activity during the Great Depression. More recently, Local Exchange Trading Systems (LETS), the English-speaking Local Exchange Trading Systems (LETS), and the Swiss WIR Franc – in circulation since 1934 within networks of small and medium-sized Swiss enterprises – have demonstrated the long-term viability of complementary monetary instruments in constrained economic contexts.

What blockchains bring to this tradition is not the concept itself, but its operational implementation at a low marginal cost. The digital recording of transactions on a distributed ledger replaces paper ledgers, reduces the risks of fraud and duplication of vouchers, and allows for instant verification of balances and histories. Furthermore, USSD technology makes it possible to extend this infrastructure to populations without access to internet-connected phones. The decisive contribution of Web3 is therefore primarily a reduction in the administrative costs of a community monetary mechanism – and not the

invention of a radically new institutional model.

1.3.3.2 Decentralized Physical Infrastructure Networks (DePINs)

The mechanisms examined in previous sections, governance through smart contracts*, quadratic finance*, and community-inclusive currencies, all operate within the space of financial coordination and capital allocation. Decentralized Physical Infrastructure Networks (DePINs) represent an extension of this logic into a different space: the construction and operation of physical infrastructure, wireless networks, energy production infrastructure, and environmental sensor systems, *via* coordinated on-chain cryptographic incentives*. As such, they constitute the most direct point of contact between Web 3 and the physical capital investment needs of real economies, particularly in developing countries where the infrastructure deficit represents one of the main obstacles to inclusive economic growth.

The economic architecture of DePINs*

A decentralized physical infrastructure network (DePIN*) relies on a three-tiered incentive mechanism that emerging literature refers to as the DePIN flywheel: resource providers deploy physical equipment – solar panels, communication antennas, storage servers, environmental sensors – which they connect to a network coordinated by smart contracts* and are paid in native tokens proportionally to their verified contribution to the network; end users access the services produced by this equipment at prices that are in principle lower than those of centralized operators, their use fueling the demand that justifies the issuance of tokens; the governance of the protocol calibrates the issuance and pricing parameters to maintain the balance between the supply of resources and the demand for services. As formalized by the authors of a literature review published in

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Frontiers in Blockchain in 2025, DePINs* tokens fulfill three interdependent functions: utility – they serve as native currency for accessing network services –, governance – they grant voting rights on protocol parameters –, and staking* – they allow providers to deposit collateral attesting to their operational reliability¹⁸³.

This mechanism has a structural property distinct from conventional infrastructure investment models: it allows for the mobilization of distributed physical capital without requiring a centralized investor with sufficient capital to deploy infrastructure on a large scale. Whereas a traditional telecommunications operator must upfront finance its entire network of antennas before generating revenue, a Decentralized Physical Infrastructure Network (DePin*) can grow organically, with each participant financing their own contribution in anticipation of future tokenized revenue. This organic growth property is particularly relevant for infrastructure that is expensive to deploy and whose commercial viability for a centralized operator is uncertain in sparsely populated areas or areas with low purchasing power.

Applications with environmental and social impact

In the telecommunications sector, the Helium Network – founded in 2019 and migrated to the **Solana** blockchain in 2023 – is the most well-documented example. Participants deploy hotspot devices that provide network coverage for connected objects (IoT, Internet of Things) and fifth-generation mobile telephony (5G), and are rewarded with Helium Network Tokens (HNTs) based on the coverage they provide and the data they transmit. By the beginning of 2025, the network had over 335,000 IoT hotspots and 24,800 mobile hotspots in 190 countries, and the volume of data transferred in the fourth

quarter of 2024 had increased by 555% year-over-year.¹⁸⁴ These figures are self-reported and come from the institutional publications of the Helium Foundation – a source structurally linked to the protocol – but they illustrate the order of magnitude of the rapid deployment capacity enabled by this distributed incentive model.

In the energy sector, several protocols seek to apply this logic to the decentralized production and distribution of renewable electricity, with particular relevance in regions suffering from a structural electricity supply deficit. In sub-Saharan Africa, where approximately 600 million people lack access to electricity according to the International Energy Agency (IEA), initiatives such as the **M3tering Protocol** are being developed.¹⁸⁵ In Nigeria, microgrids allow individuals to deploy smart meters connected to solar panels, produce and sell electricity locally to their neighbors, and be compensated with tokens for the kilowatt-hours fed into the microgrid. This model structurally transforms the relationship between energy producers and consumers: an individual who was previously excluded from the centralized electricity distribution system simultaneously becomes a producer, distributor, and investor in their own energy infrastructure, without requiring a financial intermediary to coordinate these functions.¹⁸⁶

In the payments sector, **Blink**, a Bitcoin wallet built on the Lightning Network* in El Salvador, exemplifies a payment DePIN: nodes managed by individuals (Umbrel, Raspibltz) form a global settlement network without a central

¹⁸³ Alshater MM (2026) Decentralized physical infrastructure networks (DePIN) tokenomics. <https://doi.org/10.3389/fbloc.2025.1644115>

¹⁸⁴ Helium Foundation. (2025). Helium Network Q4 2024 Data Report. Helium Foundation.

<https://messari.io/report/state-of-helium-q4-2025>

¹⁸⁵ M3tering is a token-incentivized protocol designed to stimulate capital investment in distributed energy resources (DERs), such as rooftop solar projects. Its goal is to bring clean electricity to underserved communities, particularly in Latin America and sub-Saharan Africa, by encouraging individuals and institutions to become electricity providers through rooftop solar power purchase agreements (PPAs). <https://docs.m3ter.io/>

¹⁸⁶ CARBON Copy. (2024). The Impact DePIN Report 2024. <https://carboncopynews/content/assets/The%20State%20of%20ReFi%20Report%202024.pdf>

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owner, interconnected *via* **Blink** and extended to physical points of sale *via* BTCPay Server and WooCommerce. This model transforms each node operator into a payment infrastructure provider, compensated through routing fees, within a network that already powers some twenty Bitcoin circular economies in South Africa, Honduras, and El Salvador¹⁸⁷. Its articulation with the community currencies examined in section 1.3.3.1 - notably *via* Stablesats (balance in stable dollars within a Lightning wallet*) - represents precisely the combination of monetary stability and decentralized infrastructure that the CICs seek to achieve by other means.

The environmental dimension of these Decentralized Physical Infrastructure Networks (DePin*) for energy has a direct link with the certification mechanisms examined in section 1.2.2. Decentralized renewable energy production infrastructures are, by their very nature, able to generate Renewable Energy Certificates (RECs) in an automated and traceable manner – instruments attesting that a given quantity of energy has been produced from renewable sources, and which constitute a tradable asset on environmental compliance markets.

A smart contract* can be configured to automatically issue a tokenized CER for each megawatt-hour of verified production, creating an additional revenue stream that improves the profitability of solar panel deployment in areas where local demand alone would not be sufficient to justify the investment.

It is precisely this mechanism, the combination of native token remuneration for the provision of energy services and automated generation of green assets, which constitutes the most direct link between the concept of Decentralized Physical Infrastructure Network (DePin*) and

Regenerative Finance (ReFi*) examined in this report.

The structural limitations of the model

Analytical enthusiasm for this model must be tempered by two families of structural limitations that current academic literature is beginning to rigorously document.

The first is **the problem of the economic sustainability of the incentives**. The DePIN* flywheel only works if the demand for services generates sufficient revenue to justify token issuance. In its initial phase, a Decentralized Physical Infrastructure (DePin*) network may attract resource providers with the expectation of future token appreciation, a speculative dynamic that can mask insufficient real demand. The review in *Frontiers in Blockchain* (2025) identifies this risk as the main factor limiting the sustainability of DePin* networks: *"true sustainability depends on converting non-Web3 users into paying customers, thus anchoring the token value in real demand rather than speculation"*¹⁸⁸. This diagnosis applies with particular acuity to impactful decentralized physical infrastructure networks (DePin*) deployed in areas with low purchasing power, where effective demand may be insufficient to support a viable economic model without external subsidies.

The second is **the problem of verification**. The entire incentive mechanism relies on the protocol's ability to verify on-chain* that the declared physical resources have been deployed and are functioning as expected.

This verification, referred to as Proof of Physical Work in the DePIN literature, constitutes a non-trivial technical problem: unlike the Bitcoin protocol's proof of work, which involves a mathematical operation verifiable by the network, proving that a solar panel has produced a kilowatt-hour or that an

¹⁸⁷ Blink, 2025, <https://www.blink.sv>

¹⁸⁸ Alshater MM (2026) Decentralized physical infrastructure networks (DePIN) tokenomics. <https://doi.org/10.3389/fbloc.2025.1644115>

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antenna has provided network coverage in a given geographic area requires oracles*, interfaces between the physical world and the blockchain, whose reliability is itself subject to the risks analyzed in section 2.2.1 of this report. A decentralized physical infrastructure network (DePIN*) whose oracles* can be manipulated is a system whose incentives can be diverted without the protocol being aware of it.

[B] Decentralized physical infrastructure networks (DePIN*)

The question posed by Decentralized Physical Infrastructure Networks (DePIN*) in the context of economic development is that of their positioning in relation to public investment in infrastructure. Two interpretations are possible.

The first point is that Decentralized Physical Infrastructure Networks (DePIN*) fill specific gaps where public investment is lacking and centralized private operators deem the return insufficient: sparsely populated rural areas, cross-border regions, and unstable institutional contexts. In this view, DePIN* networks do not replace public infrastructure policies, but serve as a temporary or complementary deployment

mechanism until the economic environment allows for a more robust institutional response.

The second argument, which the most tech-savvy proponents of the Web3 movement tend to favor, is that Decentralized Physical Infrastructure Networks (DePIN*) represent a superior model to public infrastructures or regulated monopolies, and that they could eventually supplant them. This position clashes with well-documented economic realities: network infrastructures exhibit considerable positive externalities, very high fixed costs, and increasing returns that, in many cases, justify either public provision or the regulation of a natural monopoly. Decentralized Physical Infrastructure Networks (DePIN*) do not fundamentally alter these economic properties but rather modify the ownership structure and coordination mechanisms, not the nature of the underlying economic problem.

It is premature, at the current stage of maturity of documented deployments, to conclude that one model is systemically superior to the other.



PART 2. From the impact statement to its cryptographic proof

The first part of this report established a structural diagnosis and highlighted that the failures of impact finance are not anomalies attributable to actors acting in bad faith, but rather the predictable product of architectures based on self-reporting, discontinuous auditing, and the delegation of trust to intermediaries whose interests do not always align with those of the beneficiaries. It also demonstrated that the new digital infrastructures of Web 3.0, distributed ledgers, smart contracts, and tokenization, offer architectural solutions to these failures, the true value of which depends on the conditions under which they are deployed.

The second part subjects these answers to a rigorous two-stage examination. The first examines the instruments that effectively make it possible to shift the boundary between declaration and proof: continuous digital verification (dMRV*), oracles* that connect the physical world to Distributed Ledger Technologies (DLT*), and new financial instruments, including, as we will see, Impact

Tokens*, **Hypercerts** and **Alpha Bonds** that transform verified proof of impact into a mobilizable financial asset.

The second lists the structural limits and systemic risks of this architecture: the vulnerability of oracles* as a centralized point of failure in a system presented as decentralized, Goodhart's law applied to the tokenization of impact, the risk of hyper-financialization of nature, and the power asymmetries that decentralized protocols tend to reproduce in new forms.

These two times are not sequential: the promises and the limits respond to each other, and it is in their articulation, rather than in their opposition, that the most productive question that this report wishes to bring to light lies.

2.1 Automation, verification and conditional instruments

The first part of this report established the structural diagnosis that systemic greenwashing is not primarily the product of individual bad intentions, but rather of a flawed architecture. When impact is self-reported, verification is sporadic, and the auditor is economically dependent on the certified entity, the information asymmetry is not reduced but becomes institutionalized.

The second part of this report raises a question of a different nature. Is it possible to replace the declaration with proof? Not proof certified after the fact by a third party exposed to the conflicts of interest documented in section 1.1.3, but proof generated continuously, anchored in physical data independent of the project proponent, and immutably recorded in a public register. This shift, from declaration to cryptographic proof, is the central aim of the mechanisms examined in this section.

The fact that this shift is technically possible does not mean, however, that it is without conditions, nor that the new architectures it requires are free from the weaknesses they claim to correct.

2.1.1 dMRV : digital Measurement, Reporting and Verification

An audit conducted every two or three years, based on data partially compiled by the project developer itself: this is the empirical basis upon which the majority of credits in voluntary carbon markets currently rest. Digital Measurement, Reporting and Verification (dMRV) proposes to break with this discontinuity by replacing periodic audits with continuous, automated verification based on independently collected data – satellite imagery, IoT* (Internet of Things) sensors, and machine learning models.

The documented gains are real. But the disruption introduced by dMRV is not limited to cost reduction: it alters the very nature of the information available to markets, replacing a certificate issued at fixed intervals with a stream of data updated in near real-time. This shift, from a static image to a continuous stream, is precisely what this section examines in its two dimensions: first, the automated collection of physical data, and then the question of its integrity between the time of collection and its use by an investor or regulator. Can physical auditing, a static image certified after the fact, be replaced by a continuous stream of data? And what do public blockchains change, not in terms of data quality, but in terms of data integrity once collected?

2.1.1.1 Automation of ecological monitoring

The first part of this report established why the declarative model of centralized impact finance is structurally exposed to greenwashing, in particular because the opacity of certification chains, discontinuous auditing and information asymmetry between project promoters and capital markets produce credits whose real environmental value remains unverifiable.

The challenge of Digital Measurement, Reporting and Verification (dMRV*) is precisely to close this gap – not through better regulation, but through an architectural transformation of the evidence system.

The structural limitations of traditional MRV

Historically, the environmental impact assessment of climate projects has relied on a Measurement, Reporting, and Verification (MRV) process based on manual field surveys, periodic sampling, and the production of static documentary reports. An accredited Validation and Verification Body (VVB) physically visits the project site at multi-year intervals and conducts measurements according to protocols defined by certification standards – such as the Verified

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Carbon Standard¹⁸⁹ Verra, Gold Standard¹⁹⁰ REDD+ methodologies¹⁹¹, and produces a report on the basis of which carbon credits are issued or rejected.

This model has four structural limitations that are directly detrimental to the liquidity and integrity of climate markets.

- The first is **temporal discontinuity**: between two audits, the actual state of the project – forest cover, biomass, agricultural practices – may have changed significantly without the markets being informed.
- The second limitation is the **high cost structure** inherent in the audit process: field missions to remote areas, fees for accredited Validation and Verification Bodies (VVBs), and documentation production constitute a set of fixed costs that small projects struggle to absorb. The Rocky Mountain Institute estimates that MRV expenses can represent between 20 and 30% of total carbon credit revenue, making initiatives with a high environmental impact but insufficient credit volume to amortize these costs over an extended period economically unviable.¹⁹²
- The third is the **inability to scale up**: the limited number of accredited verification bodies and the sequential nature of the audit process constitute a bottleneck that prevents voluntary carbon markets from reaching the volumes necessary for a systemic climate impact.
- The fourth, finally, is **vulnerability to manipulation**: a process based on documents that the project sponsor

himself helps to create reproduces the information asymmetry identified in section 1.1.3 of this report.

The disruption introduced by the dMRV

To overcome these limitations and meet the scaling requirements of climate markets, the sector is gradually deploying dMRV, a technological approach that replaces episodic monitoring with continuous, automated verification based on data collected independently of the project sponsor.

The dMRV relies on four complementary technology families. High-resolution satellite imagery, provided notably by the European Space Agency's (ESA) Sentinel-1 and Sentinel-2 constellations, NASA's GEDI (Global Ecosystem Dynamics Investigation) satellites, and private operators such as Planet Labs, enables near real-time monitoring of land-use changes, forest biomass growth, and deforestation dynamics over areas of up to several million hectares. LiDAR (Light Detection and Ranging) technologies, deployed on drones or satellites, map forest canopies in three dimensions, enabling precise estimates of aboveground carbon stocks. IoT* (Internet of Things) sensors deployed in situ continuously measure parameters such as soil moisture and carbon, methane fluxes, and air quality. Machine learning models integrate and analyze these heterogeneous data streams to produce continuous estimates of carbon stocks and flows, detecting anomalies and deviations with a sensitivity that periodic human auditing cannot achieve.

The cumulative effect of these technologies is a drastic reduction in verification costs: according to estimates available in the industry literature, the integration of satellite remote sensing tools reduces field sampling requirements by 60 to 70% while maintaining the statistical rigor required by Verra

¹⁸⁹ The Verified Carbon Standard Version

<https://verra.org/programs/verified-carbon-standard/>

¹⁹⁰ Gold Standard certification

<https://www.goldstandard.org>

¹⁹¹ The role of REDD+ in forest protection, March 21, 2023

<https://unfccc.int/fr/news/le-role-de-redd-dans-la-protection-des-forets>

¹⁹² Rocky Mountain Institute. (2023). How to build a trusted voluntary carbon market. RMI.

<https://rmi.org/how-to-build-a-trusted-voluntary-carbon-market/>

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methodologies¹⁹³. And the most advanced dMRV platforms claim measurement costs of less than US\$10 per acre continent-wide, compared to US\$50 to US\$100 for traditional ground sampling.¹⁹⁴ These efficiency gains are not only financial: they structurally broaden the scope of projects eligible for certification, making economically viable small-scale projects or projects in remote areas that previously could not bear the costs of auditing.

The implications for climate finance

The benefits of dMRV for climate finance extend beyond simply reducing verification costs. It changes the timing of information available to markets. Whereas traditional carbon credits are issued based on multi-year audits, producing a static picture of a dynamic reality, dMRV can continuously feed the dashboards of investors, credit buyers, and regulators with up-to-date monitoring data. This informational continuity is the prerequisite for a truly verifiable climate asset class: no longer a certified impact statement at fixed intervals, but a near real-time data stream attesting to the status of a project.

Protocols documented in this report already apply this logic. Since 2026, **Grassroots Economics** has integrated geospatial analysis and real-time AI to transform transactions on the Sarafu network in Kenya into verifiable impact data, making community economic flows, which previously generated no traceable signals for an external investor, visible¹⁹⁵. **Kolektivo** is deploying an automated MRV framework for food forests in the Caribbean, where field data directly triggers token rewards for local ecological

regeneration actors.¹⁹⁶ In the field of blue carbon, **Pleno** uses remote sensing and machine learning to continuously map carbon stocks in Indonesian mangroves, making certification projects economically viable that traditional audit costs would have rendered prohibitive at this scale.¹⁹⁷

The Bank for International Settlements (BIS) and the Hong Kong Monetary Authority (HKMA) were among the first leading financial institutions to operationally explore this convergence within the framework of Project Genesis (2021-2022). This experimental program developed prototypes of tokenized green bond issuance platforms combining blockchain, smart contracts, and IoT to enable real-time tracking of the environmental outputs of funded projects. Genesis 2.0, conducted in 2022 with Goldman Sachs and the UN Climate Change Global Innovation Hub, furthered the experimentation by introducing Mitigation Outcome Interests (MOIs), financial instruments directly backed by tokenized emission reduction units tracked via IoT sensors, allowing investors to receive a return linked to the verified environmental performance of the underlying project.¹⁹⁸

This experiment illustrates the central ambition of dMRV in the context of climate finance: to shift the boundary between declaration and proof, and in doing so, to transform the very nature of the climate asset – from a certificate issued ex post on the basis of a documentary assessment, to an asset whose value is anchored in a continuously verified stream of data.

¹⁹³ Perennial/Verra, VM0042 v2.2 Methodology, approved by the ICVCM in November 2024. Data reported by Sustainability Atlas (2026). <https://sustainableatlas.org>

¹⁹⁴ Sustainability Atlas. (2026). Trend analysis: Soil carbon MRV & incentives. <https://sustainableatlas.org>

¹⁹⁵ Grassroots Economics, 2026, <https://grassecon.org/about>

¹⁹⁶ Kolektivo, 2025, <https://medium.com/kolektivo-co/regeneration-needs-location-b538cae97ff7>

¹⁹⁷ Pleno, 2025, <https://eblockchainconvention.com/pleno-refi/>

¹⁹⁸ BIS Innovation Hub & HKMA. (2021). Project Genesis: prototype digital platforms for green bond tokenization. BIS. <https://www.bis.org/publ/othp43.htm>; BIS Innovation Hub, HKMA & UN Climate Change Global Innovation Hub. (2022). Project Genesis 2.0. BIS. https://www.bis.org/about/bisih/topics/green_finance/green_bonds.htm

[B] What input data? The fundamental limitation of dMRV

Automating environmental monitoring does not fully solve the problem of the integrity of climate markets. It shifts the issue from the reliability of the human auditor to the reliability of the data input to the system.

Two problems remain. The first concerns the quality of the satellite data itself: cloud cover, resolution limitations in certain types of ecosystems, and the assumptions of the allometric models used to convert vegetation indices into carbon stocks introduce margins of uncertainty that must be quantified and communicated to the markets. The scientific community has shown that systematic biases in these models can lead to significant overestimations of sequestered carbon stocks, a problem that blockchain tokenization does not solve, since it merely freezes potentially false data in an immutable ledger.

The second problem concerns oracles*: for data from IoT sensors* or satellite imagery to feed a smart contract* that will automatically trigger the issuance of a loan or the payment of a return, this data must pass through an interface between the physical world and the blockchain. This interface, the oracle*, constitutes a centralized point of failure in a system that presents itself as decentralized. If the oracle* is compromised, manipulated, or simply fails, the entire value chain of the tokenized credit is affected. This risk, which is structural and unresolved at this stage, will be analyzed in section 2.2.1.

2.1.1.2 Reliability and immutability of reports

The automation of physical data collection represents a decisive step forward in resolving the temporal discontinuity of traditional MRV.

However, it only addresses half the problem, since data collected continuously and in near real-time is only valuable if its integrity can be guaranteed between the time of collection and the time of its use by a market, regulator, or investor. It is on this second front, that of the immutability and traceability of reports, that Distributed Ledger Technologies (DLT*) make a structural contribution distinct from dMRV understood as a simple measurement tool.

The problem of data integrity after collection

In the traditional MRV system, the data integrity problem is largely resolved by delegating to a trusted third party: the accredited validation and verification body (VVB) produces a signed report whose probative value rests on its institutional reputation and accreditation. This solution is costly, discontinuous, and, as shown in section 1.1.3.2, susceptible to documented conflicts of interest.

In a dMRV system, this problem shifts. If data is collected automatically by IoT sensors* or satellite imagery, it passes through processing layers, aggregation, transformation, modeling, before being presented as an impact report. Each of these layers represents a potential point of alteration, whether intentional or not. Therefore, the issue of report integrity does not disappear with the digitization of data collection but is reconfigured as a question of data architecture.

The structural contribution of blockchain: immutability as proof

It is precisely this architecture that Distributed Ledger Technologies (DLT*) modify. By recording each collection, processing, and notification event on a public ledger with a cryptographic timestamp, the public blockchain used transforms a simple digital declaration into a verifiable and irreversible trace. Data recorded on a public blockchain cannot be retroactively altered without the break in the cryptographic fingerprint chain

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being immediately detectable by all nodes in the network. As a literature review published in Discover Environment in 2025 established, *"distributed ledgers create immutable records of the origin, tracking, and ownership of carbon allowances, support more efficient transactions, and reduce opportunities for fraudulent activity"*¹⁹⁹.

This immutability property has three direct effects on the architecture of climate finance. The first is the complete **traceability of an ecological asset's lifecycle**: from the on-the-ground event that generates it, such as a measured forest area or a verified hectare of soil carbon, to its final withdrawal from the market, each step is recorded in a ledger accessible to any actor with an internet connection, without prior authorization. The second effect is the **elimination of double counting**: a credit recorded on-chain* with a unique cryptographic identifier cannot be simultaneously recorded in two separate balance sheets, a property directly linked to the immutability of the ledger²⁰⁰. The third effect is **the reduction of information asymmetry between project promoters and investors**: the latter no longer have to rely on discontinuous audit reports whose accuracy they can only verify by trusting the auditor, since they have direct access to the primary source of monitoring data.

Let us take another example in the global agricultural sector, whose value chains involve thousands of stakeholders spread across several continents and whose opacity is structural, which in this respect constitutes a particularly revealing field of application.

¹⁹⁹ Merlo, A.L.C., Mendonça, D.S., Santos, J. et al. Blockchain for the carbon market: a literature review. Discov Environ 3, 68 (2025).
<https://doi.org/10.1007/s44274-025-00260-4>

²⁰⁰ European Commission – Technopolis Group. (2023, December). Study on the potential of blockchain technology and distributed ledger technology for EU climate policies. European Commission.
<https://technopolis-group.com/wp-content/uploads/2024/06/study-on-the-potential-of-blockchain-technology-and-ML0224255ENN.pdf>



Justoken²⁰¹, a Latin American platform for tokenizing real assets based on geospatial data and blockchain infrastructure, offers this service through its T&S Explorer module.²⁰² An auditable supply chain in which a producer's harvest is no longer declared by them, but certified by sensors and georeferenced data. This reversal of the flow of evidence, from declarative to instrumental, effectively eliminates the evaluator's dependence on information provided by the evaluated party. This system has notably been deployed in partnership with the trader Bunge.²⁰³ to ensure the traceability of deforestation-free soy, and at the date of writing this report, made it possible to certify more than one million tonnes of raw materials spread across eleven product categories and eight certification standards.



AgriDex²⁰⁴ a digital marketplace founded in the UK in 2020 and built on the **Solana** infrastructure, it records provenance data and environmental, social, and governance (ESG) credentials directly on the blockchain, making them enforceable against any global buyer without a centralized verification intermediary. The platform claims to cover the majority of the 1,100 data points required by the European regulation on sustainability disclosure in the financial services sector, the Sustainable Finance Disclosure Regulation (SFDR) of 2023, with each transaction resulting in the creation of a non-fungible token (NFT*) containing the complete metadata of the exchange: product specifications, quality certificates, provenance data, and settlement confirmation.

²⁰¹ <https://www.justoken.com/>

²⁰² <https://www.justoken.com/#solution-tse>

²⁰³ <https://www.bunge.com/>

²⁰⁴ <https://agridex.com/>

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These two cases illustrate how automated proof can structurally reduce the cost of verification for agricultural assets. However, it is important to clarify their context: Justoken and **AgriDex** are private commercial entities whose claims regarding the elimination of information asymmetry are based, in part, on their own corporate communications, as no independent academic evaluation has yet been published. The question of the governance of the repositories to which these systems are linked, which bodies accredit sensor protocols, according to what criteria ESG credentials are selected from among the 1,100 available points, and with what legitimacy these choices are made, remains entirely open. As will be examined in section 2.2.3, this constitutes a systemic challenge inherent to any decentralized verification architecture: automated proof does not, in itself, resolve the question of who defines what deserves to be proven.

In the field of carbon and social certification, **Change Code** adopts a complementary approach based on the Ethereum Attestation Service (EAS)²⁰⁵ as an immutable attestation layer: each impact certification produced by its technology stack (GoodGenerator, Hypercert, EAS, ImpactReserve ERC-6551) is recorded on-chain* as a Change Credit (ERC-721 - NFT), representing a verified result, such as a carbon reduction or a social impact certified *via* BCarbon. Since an EAS attestation cannot be modified retroactively, this system directly meets the auditability requirements of institutional ESG standards by producing an unalterable end-to-end trace, from field data to the transferable financial asset.²⁰⁶

Smart contracts* as an engine for reporting automation

Beyond the immutable preservation of data, smart contracts* enable the encoding of rules for calculating environmental benefits and the

automatic generation of disclosure reports when predefined thresholds are reached. As part of the Project Genesis 2.0 experiments conducted by the Bank for International Settlements (BIS) and the Hong Kong Monetary Authority (HKMA) with Goldman Sachs in 2022, this mechanism was applied to tokenized green bonds: IoT* sensors measuring the renewable energy production of the underlying projects transmitted their data to smart contracts*, which automatically calculated the corresponding CO₂ emission reductions and reflected them in real time in the value of the Mitigation Outcome Interests (MOIs) attached to the bonds²⁰⁷.

This automated reporting model is particularly relevant for regulated finance, where disclosure requirements, such as the European Union's Taxonomy of Green and Economies Regulation (TAX), the Taskforce on Nature-related Financial Disclosures (TNFD), and the Corporate Sustainability Reporting Directive (CSRD), demand increasingly accurate, auditable, and continuous environmental data. A smart contract* can be configured to automatically generate compliance reports in standardized formats as soon as the monitoring data reaches a sufficient level of statistical confidence, thereby reducing the time and costs associated with manual document production.

Persistent limitations: the oracle problem* and the input data

These properties do not constitute a complete and unconditional solution. A public blockchain guarantees the integrity of data after it is recorded on the ledger; it does not guarantee the quality of the data before this recording. In other words, an inaccurate or deliberately manipulated measurement will, once recorded on-chain*, benefit from the same guarantee of immutability as a high-quality measurement.

²⁰⁵ Ethereum Attestation Service (EAS) <https://attest.org>

²⁰⁶ Change Code, 2025, <https://docs.changecode.io/data-schemas/hypercerts/>

²⁰⁷ BIS Innovation Hub, HKMA & UN Climate Change Global Innovation Hub. (2022). Project Genesis 2.0. BIS. https://www.bis.org/about/bisih/topics/green_finance/green_bonds.html

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This is what practitioners refer to as "*garbage in, garbage out*": the distributed ledger seals true and false data with the same cryptographic rigor.

This problem of input data quality is directly linked to the issue of oracles* – the interfaces between the physical world and the blockchain through which data from sensors, satellite imagery, or algorithmic models pass. An oracle* represents a centralized point of failure within a system that otherwise presents itself as decentralized: if it is compromised, malfunctions, or is simply inaccurate, the entire value chain of tokenized credit is affected, without the ledger itself reporting any anomaly. This structural risk, which remains unresolved at this stage of development of digital climate markets, will be examined in detail in section 2.2.1 of this report.

[B] What public blockchains actually bring to environmental auditing

Hashing, timestamping, and cryptographic proof. The value of a public blockchain in the context of MRV rests on two fundamental cryptographic properties, the scope of which should be clarified for a non-technical reader.

The first is hashing*: every piece of data recorded on a blockchain is transformed by a deterministic mathematical function into a fixed-length digital fingerprint – the hash* – which is unique to that piece of data. Modifying a single bit of the original data produces a completely different hash*, making any alteration immediately detectable. This property guarantees the integrity of each individual record. (Try it²⁰⁸ by yourself).

The second is block chaining: each new block of transactions incorporates the hash

of the previous block into its hash*, creating a continuous chain where any retroactive modification of a block invalidates all subsequent blocks. It is this property that makes falsifying an on-chain data history* computationally impossible in systems using robust consensus mechanisms.

When applied to MRV data, these properties enable the creation of an immutable audit trail: any actor, regulator, investor, or non-governmental organization (NGO), can independently verify that a tracking data point has not been altered since its recording, without needing to trust a central institution. This ability to transfer trust from an intermediary to a mathematical protocol is the specific contribution of blockchain to the reliability of climate finance reports.

2.1.2 The bridge to the physical world: Oracle, IoT, AI and humans

A smart contract* is, by design, blind to the physical world. It can only perform operations on data already present in the ledger; it is structurally impossible for it to observe the ground, read a sensor, or interpret a satellite image. For programmable environmental finance to function, that is, for example, for a payment to be automatically triggered by the measurement of a carbon stock or a biodiversity index, a bridge between physical reality and the blockchain is necessary. This bridge has a technical name: the oracle*.

This is precisely where the promise of decentralization encounters its most fundamental constraint. Satellites, Internet of Things (IoT) sensors, and Artificial Intelligence (AI) models constitute the three families of sources that feed these oracles, each with its own documented performance, blind spots, and points of failure. This section examines their architecture and complementarity. Their systemic vulnerabilities will be addressed in section 2.2.

²⁰⁸ SHA256
<https://emn178.github.io/online-tools/sha256.html>

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2.1.2.1 The critical role of Oracles and the Internet of Things (IoT)

Smart contracts* operating on a blockchain are, by design, technically isolated from their physical environment. This isolation is inherent to their architecture: to guarantee deterministic operation verifiable by all nodes in the network, a smart contract* can only execute operations on data already present in the ledger. It is structurally incapable of natively accessing external information, market prices, weather data, sensor measurements, satellite imagery. Caldarelli summarized this constraint in a 2020 literature review published in the journal *Information*: data from the real world must be provided by *"a single, unambiguous third-party source whose reliability is beyond question for all nodes"*²⁰⁹. This interface is referred to as an oracle*.

The nature and role of oracles* in environmental finance

An oracle* is not a single program or a specific device, but an architectural concept. Any entity capable of providing a smart contract* with data external to the ledger can be considered an oracle* – whether it is a physical sensor, an API (Application Programming Interface) aggregating market data streams, a satellite image processed by a machine learning algorithm, or, in the case of non-automatable data, a human operator directly entering a value²¹⁰. In the field of environmental finance, oracles* constitute the link between physical field data – biomass measurements, methane flows, renewable energy production, forest cover – and the tokenized assets derived from them: carbon credits, green bonds with programmable impact, biodiversity tokens.

The practical value of this device is considerable.

²⁰⁹ Caldarelli, G. (2020). Understanding the blockchain oracle problem: A call for action. *Information*, 11(11), 509. <https://doi.org/10.3390/info11110509>

²¹⁰ Ibid.

Without an oracle*, a smart contract* for conditional financing can only release funds to a reforestation project once a human operator has manually entered measurement data into the system – effectively reproducing the information asymmetry and risks of manipulation that blockchain was supposed to eliminate. With a robust oracle* connected to IoT* sensors and satellite imagery feeds, triggering can be fully automatic, verifiable in near real-time, and resistant to unilateral manipulation by a single actor.

The technical ecosystem: IoT sensors, satellite imagery and field data

The Internet of Things (IoT*) is the most direct primary source for environmental finance oracles*. Sensors deployed in situ, soil carbon content probes, hygrometers, methane flow sensors, and electricity production meters for solar installations, continuously and automatically measure ecological variables with a temporal granularity impossible to achieve through periodic human auditing. These data streams are aggregated, filtered, and transmitted via secure protocols to oracles*, which record them in the ledger after validation.



IXO Protocol²¹¹ demonstrates the direct connection between a physical object and an on-chain conditional payment*. In Zambia's SupaMoto project, cookstoves are equipped with IoT sensors* that transmit their usage data to AI-powered oracles* integrated with Agentic Networks developed by IXO. When usage thresholds are reached, a conditional payment is automatically triggered on-chain* via a smart contract*, without human intervention in the validation chain. The business model is two-pronged, based on a subscription paid by the household, with a deposit of \$6.80 for the cookstove and \$7.30 per

²¹¹ <https://www.ixoworld.io/ixo-protocol>

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month for 30 kg of pellets, approximately half the cost of their previous charcoal expenditure. The pellets are made from sawmill waste sourced from sustainable Zambian forest plantations, transforming waste into a local value chain. SupaMoto retains ownership and maintenance of the cooking stoves and uses mobile money for payments, eliminating any banking friction. In February 2025, the PIDG (Private Infrastructure Development Group) and EDFI Management Company jointly invested €4 million to accelerate the deployment of the model in Zambia²¹². This investment will fund 14,800 new connected homes, ultimately benefiting 74,000 people. The Modern Cooking Facility for Africa (MCFA) has also allocated €0.6 million in fixed grants and €1.4 million in performance-based funding, ensuring minimal access costs for low-income households. Revenue from the sale of verified carbon credits, generated by measured IoT* usage in homes and certified under Article 6.2 of the Paris Agreement in partnership with the Zambian government, is explicitly earmarked to sustainably subsidize service accessibility as carbon markets develop.

Satellite imagery constitutes a second complementary source, particularly well-suited to large-scale space projects. Constellations such as Sentinel-1 and Sentinel-2 (European Space Agency, ESE) or GEDI (Global Ecosystem Dynamics Investigation, NASA) provide multispectral and LiDAR (Light Detection and Ranging) data that can be used to estimate aboveground biomass, detect changes in forest cover, and monitor agricultural practices.

Combined with machine learning models, this data feeds oracles* capable of producing continuous estimates of sequestered carbon stocks, which can be directly transmitted to smart certification contracts*.

The systematic review published in the Journal of Integrative Agriculture on blockchain systems integrating IoT* for carbon finance in the agricultural sector establishes that *"designing an event-based data authenticity system"* involves three successive phases: evaluating the responsiveness and reliability of IoT* sensors, collecting geolocated data per event, and analyzing probabilistic correlations between these events to assess their reliability, a multi-layered validation process that reduces the risk of erroneous or manipulated data reaching the ledger²¹³.

²¹² PIDG / ElectriFI, "Scaling access to clean cooking solutions in Zambia", 24 February 24, 2025 pidg.org/scaling-access-to-clean-cooking-solutions-in-zambia

²¹³ Chaudhari, A., Karde, P., Randad, V., Limbhore, D., & Lonikar, R. (2025). A Blockchain-based Carbon Credit Ecosystem. International Journal for Research in Applied Science & Engineering Technology (IJRASET), 13(11), 2450-2456. <https://doi.org/10.22214/ijraset.2025.75904>

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The benchmark institutional experiments

The most documented institutional applications of this oracle*-IoT* scheme in environmental finance come from Project Genesis 2.0, conducted in 2022 by the Bank for International Settlements (BIS), the Hong Kong Monetary Authority (HKMA) and the UN Climate Change Global Innovation Hub with Goldman Sachs²¹⁴. This program experimented with the direct connection between IoT sensors* measuring the renewable energy production of underlying projects and smart contracts* managing tokenized green bonds, with sensor data automatically feeding into the calculation of Mitigation Outcome Interests (MOIs), financial instruments backed by verified emission reductions, without human intervention in the transmission chain²¹⁵.

These experiments remain essentially at a pilot or development stage, but they document the technical feasibility of the oracle-IoT*-blockchain architecture for automated environmental certification.



At the commercial level, the **Arbol** platform illustrates the transition from experimentation to operational deployment. Oracles* powered by climate data from **dClimate**²¹⁶ and secured by the **Chainlink** network²¹⁷ automatically trigger parametric agricultural and reinsurance compensation as soon as a predefined meteorological threshold is reached, without human intervention in the

validation chain²¹⁸. Since its launch in 2020, **Arbol** has transacted over \$1 billion in notional risk, with \$100 million in premiums in the first half of 2022 alone and more than 700 institutional clients. The operational robustness of the system was tested in real-world conditions during Hurricane Milton in October 2024: \$20 million in parametric claims were paid to reinsurers in less than 30 days after the disaster, without any conflicting expert assessments²¹⁹. In April 2024, **Arbol** raised \$60 million in Series B funding to accelerate its international expansion.

The problem of the oracle* as a structural limit

These contributions should not obscure the fundamental limitation that Caldarelli formulated as early as 2020 and which academic literature has since amply confirmed: oracles* reintroduce, into a system designed to be decentralized and trustless, a dependence on external data sources whose reliability cannot be guaranteed by the blockchain itself. Caldarelli describes this dependence as *"two steps back from decentralization"*: by delegating to an oracle* the responsibility of providing data to the smart contract*, the system re-establishes a single point of failure in an architecture that claims to be free of them²²⁰.

This vulnerability takes many forms. Centralized oracles, a single data provider

²¹⁴ BIS Innovation Hub, HKMA & UN Climate Change Global Innovation Hub. (2022). Project Genesis 2.0. https://www.bis.org/about/bisih/topics/green_finance/green_bonds.htm

²¹⁵ *Ibid.*

²¹⁶ dClimate <https://www.dclimate.net>; Jha, S. dClimate: Smart contracts* for the warming world. Nasdaq. October 11, 2022

<https://www.nasdaq.com/articles/dclimate-smart-contracts-for-the-warming-world>

²¹⁷ <https://chainlink/>

²¹⁸ Arbol & Chainlink. (2021). Businesses and farmers can now hedge weather risk through the Arbol platform and Chainlink data. <https://www.arbol.io/post/businesses-and-farmers-can-now-hedge-weather-risk-through-the-arbol-platform-and-chainlink-data>

²¹⁹ ReinsuranceNews. Arbol parametric insurance pays out \$20m in under 30 days after Milton's landfall. December 5, 2024.

<https://www.reinsurancene.ws/arbol-parametric-insurance-pays-out-20m-in-under-30-days-after-miltons-landfall>

²²⁰ Caldarelli, G. (2020). Understanding the blockchain oracle problem: A call for action. Information, 11(11), 509. <https://doi.org/10.3390/info11110509>

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aggregating satellite or sensor measurements, can be compromised by a technical failure, deliberate manipulation, or calibration error that will automatically propagate throughout the value chain without the ledger itself detecting the anomaly. Decentralized oracles, aggregating data from multiple sources using a consensus mechanism, reduce this risk but do not eliminate it, and introduce additional technical and governance complexities. A review published in *Frontiers in Blockchain* in 2025 concluded that *"despite significant technological advances, the conceptual challenges of oracles persist, making them a critical but often overlooked issue in blockchain research and practice"*²²¹.



The **Etherisc** protocol²²² precisely illustrates the point of tension surrounding the reliability of oracles*, but also what the oracle-blockchain combination can change for the most vulnerable populations. The Lemonade Crypto Climate Coalition (LCCC), launched in March 2022 by the Lemonade Foundation²²³. With **Etherisc**, **Chainlink**, Avalanche, Hannover Re, and Pula, it offers Kenyan smallholder farmers parametric crop insurance at minimal cost, automatically triggered by weather oracles* without the need for filing a claim or human expert assessment²²⁴. During the short rainy season from October 2022 to January 2023, nearly 7,000 Kenyan farmers purchased crop protection insurance. The first farmer to benefit from the program, Eunice

Jesang, in Makeuni County, Kenya, insured her entire maize harvest for \$0.83 for the whole season.²²⁵

Farmers subscribe from a basic phone and pay less than a dollar to insure their entire crop against drought and flooding. At the end of the season, fund transfers are automatically triggered from zone yield data, triangulated with weather data, and transmitted to smart contracts* via standard **Chainlink** oracles*.²²⁶ In 2021, **Etherisc** had already integrated over 17,000 smallholder farmers across 17 regions of Kenya during its first season in partnership with ACRE Africa, **Chainlink**, Mercy Corps Ventures, and the Ethereum Foundation. In total, **Etherisc** has deployed parametric agricultural and climate insurance in over 15 countries, with more than 10,000 policies issued since 2021²²⁷. The economic model relies entirely on the reliability of climate oracles*: **Etherisc's** Generic Insurance Framework (GIF) is designed to be source-agnostic, meaning that the entire value of the protocol, and the full extent of the protection granted to farmers whose insurance coverage in Kenya does not exceed 3% of the population, depends on the quality of this data. A faulty or manipulated oracle* does not simply produce an error in the ledger; it deprives vulnerable farmers of compensation to which they are legitimately entitled, or triggers unjustified payments that jeopardize the fund's viability. This case illustrates why the oracle* issue is not merely a matter of technical

²²¹ Caldarelli G (2025) Can artificial intelligence solve the blockchain oracle problem? Unpacking the challenges and possibilities. <https://doi.org/10.3389/fbloc.2025.1682623>
²²² <https://etherisc.com/>

²²³ Etherisc. (2022, March 26). Etherisc becomes founding member of Lemonade Crypto Climate Coalition. Etherisc Blog. <https://blog.etherisc.com/etherisc-becomes-founding-member-of-lemonade-crypto-climate-coalition-b48da7bd5d9c>

²²⁴ Lemonade Foundation. (2022). Fighting world hunger with blockchain. Lemonade Blog. <https://www.lemonade.com/blog/lccc-world-hunger/>

²²⁵ Etherisc. (2023, March 29). Etherisc protects another 7,000 Kenyan farmers as part of the Lemonade Crypto Climate Coalition. Etherisc Blog. <https://blog.etherisc.com/etherisc-protects-another-7-000-kenyan-farmers-as-part-of-the-lemonade-crypto-climate-coalition-e169eca3d6bc>

²²⁶ *Ibid.*

²²⁷ CoinLaw. (2026, March 16). Decentralized insurance statistics 2025: Big numbers, bold moves. <https://coinlaw.io/decentralized-insurance-statistics/>

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architecture, but a matter of distributive justice in impact finance²²⁸.

This problem of information veracity and computer code security is not merely theoretical in the context of climate finance, since if an oracle* provides inaccurate deforestation data, due to insufficient calibration of a satellite model or manipulation of a sensor stream, for example, overestimated carbon credits will be issued and immutably recorded in the ledger, reproducing on-chain* the same information asymmetry that the dMRV* was supposed to correct. This limitation will be analyzed in section 2.2.1, which focuses on the systemic risk of garbage in, garbage out in the Web3 Regenerative Finance architecture.

2.1.2.2 Artificial Intelligence in the service of certification

The Internet of Things (IoT*) provides the raw data; a public blockchain guarantees its integrity after registration on the decentralized ledger; but between these two layers lies a problem of increasing complexity. The data collected by sensors and satellites is heterogeneous, voluminous, noisy, and multimodal: multispectral imaging, LiDAR (Light Detection and Ranging) data, environmental DNA (eDNA) sequences, acoustic recordings, and gas flow measurements. No human listener, and no simple algorithm, is capable of simultaneously processing these flows at the scale of contemporary environmental projects to extract a reliable estimate of carbon stock or biodiversity index. It is in this space, between raw data and certifiable proof, that Artificial Intelligence (AI) emerges as the third functional pillar of dMRV.

The challenge of certification at scale: the multi-modality of ecological data

The rigorous certification of an ecological impact, carbon sequestration, biodiversity conservation, soil restoration, requires triangulating fundamentally heterogeneous data sources. A reforestation project in the Amazon, for example, uses at a minimum multispectral satellite imagery to detect changes in vegetation cover, LiDAR or Synthetic Aperture Radar (SAR) data to estimate aboveground biomass in three dimensions, IoT sensor measurements for methane flux and soil carbon content, and potentially eDNA data to assess soil microbial health or the species richness of fauna and flora. Each of these sources has its own spatial resolution, update frequency, and specific margins of uncertainty.

In this respect, DNA is a particularly significant development for biodiversity certification in carbon markets. This technology makes it possible to identify the specific composition of an ecosystem, microbes, invertebrates, vertebrates, from genetic traces present in water, soil, or air, without physically capturing any organisms and without requiring the specialized taxonomic expertise needed for conventional survey methods. A systematic review published in *Communications Earth & Environment* in 2024, covering 129 forest carbon projects and 396 academic studies, established that DNA-based methods offer *"broad taxonomic scope, simplified field sampling, and efficiency gains at scale"*²²⁹ particularly well-suited to the certification requirements of carbon markets – where traditional biodiversity monitoring methods are too expensive, too slow, and too variable to be systematically integrated into verification protocols. This ability to obtain holistic biodiversity information from a single field sample, combined with the algorithmic

²²⁸ Etherisc. (2023, March 29). Etherisc protects another 7,000 Kenyan farmers as part of the Lemonade Crypto Climate Coalition. Etherisc Blog. <https://blog.etherisc.com/etherisc-protects-another-7-000-kenyan-farmers-as-part-of-the-lemonade-crypto-climate-coalition-e169eca3d6bc>

²²⁹ Allen, M.C., Lockwood, J.L., Ibanez, R. et al. eDNA offers opportunities for improved biodiversity monitoring within forest carbon markets. *Common Earth Environ* 5, 801 (2024). <https://doi.org/10.1038/s43247-024-01970-y>

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processing of satellite remote sensing data to extrapolate these point measurements to large areas, is precisely what makes AI indispensable for large-scale ecological certification in the context of impact finance.

Machine learning architectures for verification

Machine learning models, particularly deep learning networks, random forests, and Gaussian regression models, are now being deployed in several critical functions of dMRV. The first is the detection of land-use change and deforestation: convolutional neural networks (CNNs) trained on time series of satellite imagery can detect forest cover anomalies with an accuracy and speed unmatched by human visual analysis, even under partial cloud cover, using SAR data that penetrate clouds. The second is the estimation of biomass and carbon stock: allometric models calibrated on LiDAR data and field measurements enable the derivation of continuous estimates of carbon sequestration over millions of hectares. The third is the validation of consistency between sources: machine learning models are used to identify inconsistencies between field IoT* data and satellite imagery – an anomaly detection technique that limits the risks of manipulation of a single source.

Wu et al. emphasize in 2026 in *Ecology and Evolution* that "*the integration of eDNA with image recognition-assisted machine learning, remote sensing and automated sampling systems*" constitutes an active research frontier for improving the accuracy and cost-effectiveness of monitoring aquatic ecosystem conditions²³⁰.

In terrestrial environments, a pilot study published in PLOS ONE in 2024 by researchers from the USDA (United States Department of Agriculture) demonstrated the

operational feasibility of a monitoring system coupling remote sensing and eDNA to annually quantify the environmental benefits of sustainable agriculture projects in the Brazilian Amazon, by calculating indicators of change in forest cover and species richness directly usable for investment funds.²³¹

From raw data to certifiable proof: the role of AI in the dMRV architecture

In the dMRV architecture, AI occupies a pivotal position between raw sensor data collection and registration on the distributed ledger. Its role is not simply to process data: it is to transform it into standardized metrics, along with their confidence intervals, in formats compatible with approved certification methodologies – Verra VCS, Gold Standard, **Regen Network** – and directly usable by smart contracts* that trigger the issuance of credits or payments. It is in this translation function that AI's distinctive value for climate finance lies: **it not only automates data collection, but also automates the conversion of physical data into verifiable financial assets.**

The Shamba Network²³² illustrates this architecture in the African field: it acts as a specialized oracle* that collects terrestrial observation data from space agencies, processes it *via* machine learning algorithms to derive indicators of soil health and vegetation cover, then cryptographically records these metrics on the distributed ledger to trigger the execution of smart contracts* for payment to farmers

²³⁰ Wu, Y., et al. (2026). Environmental DNA (eDNA) technology in biodiversity and ecosystem health research: Advances and prospects. *Ecology and Evolution*, 16, e72891. <https://doi.org/10.1002/ece3.72891>

²³¹ Dyson, K., Nicolau, A. P., Tenneson, K., Francesconi, W., Daniels, A., Andrich, G., Caldas, B., Castaño, S., de Campos, N., Dilger, J., Guidotti, V., Jaques, I., McCullough, I. M., McDevitt, A. D., Molina, L., Nekorchuk, D. M., Newberry, T., Pereira, C. L., Perez, J., Richards-Dimitrie, T., ... Saah, D. (2024). Coupling remote sensing and eDNA to monitor environmental impact: A pilot to quantify the environmental benefits of sustainable agriculture in the Brazilian Amazon. *PloS one*, 19(2), e0289437. <https://doi.org/10.1371/journal.pone.0289437>

²³² Verifiable Earth Data for a Regenerative Economy <https://www.shamba.network>

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participating in regenerative agriculture projects.

Two protocols explore a specific variation of this architecture, combining AI and zero-knowledge proof to resolve a particular challenge: producing certifications auditable by institutional third parties without revealing the raw data of the beneficiaries. **IXO Protocol** deploys, *via* its WISP agent, a verification mechanism based on Zero-Knowledge Machine Learning (ZKML): AI certifies a climate impact without exposing the underlying field data, allowing foundations and regulators to audit the proof without accessing sensitive information about project stakeholders²³³. **PACT Foundation / ImpactMarket** applies the same architecture to social impact assessment: ZKML analyses produce transparent and auditable certifications of microcredit programs while preserving the confidentiality of individual borrower data.²³⁴

The limitations of AI in environmental certification

These analytical capabilities are not without limitations. The first is the risk of model bias: an algorithm trained on data from one type of ecosystem or geographic region can produce highly biased estimates when applied to different contexts. Allometric biomass models developed for tropical rainforests are not directly transferable to savannas or boreal forests, and their application without recalibration can lead to systematic overestimations of sequestered carbon, reproducing a modeling error on-chain* and with the blockchain's guarantee of immutability.

The second limitation is that of explainability: the most effective deep learning models are "black boxes" whose internal decision-making processes are difficult for non-specialists to

audit and understand. However, environmental certification requires that methods be documented, reproducible, and verifiable by accredited third parties. A neural network model that produces a carbon estimate without providing auditable reasoning creates algorithmic opacity, reproducing, in a different form, the trust problem that dMRV was supposed to solve. Standardization bodies, including the ICVCM (Integrity Council for the Voluntary Carbon Market) and Gold Standard, are working on developing audit frameworks for AI models used in certification processes, but these frameworks are still under development as of 2026.

These limitations are not unique to green certification. **Penomo**, which deploys AI agents to analyze data rooms and automate transaction structuring in private infrastructure lending, documents a similar problem: if the documents submitted to AI analysis are falsified or incomplete, the system can automate an erroneous financing decision. The point of trust is not eliminated; it shifts from human judgment to the quality of the input documentary data, which researchers refer to as a "*documentary oracle*" subject to the same structural vulnerabilities as physical data oracles.²³⁵

[B] Eco-acoustics – an emerging frontier in biodiversity certification

Among the multimodal data sources used in dMRV, ecoacoustics represents one of the most recent and least documented advances in the financial literature. It is based on the principle that the "soundscape" of an ecosystem, the composition of sounds produced by animal species, insects, wind, and water, is an indicator of its health and biological richness. Microphones deployed in forests and connected *via* IoT* to central analysis platforms continuously record these

²³³ IXO, 2025, <https://docs.ixoworld.com/guides/digital-mrv>

²³⁴ ImpactMarket, 2025, <https://docs.impactmarket.com/impactmarket-apps/master/the-concept>

²³⁵ Penomo, 2025, <https://penomo.com>

soundscapes, which machine learning models then analyze to identify the species present, detect disturbances (illegal logging, unauthorized human activity), or measure indices of acoustic biodiversity. This technology offers a significant operational advantage over satellite imagery or field surveys: it can operate under dense vegetation cover, continuously, and at a low marginal cost. However, it has important methodological limitations, sensitivity to climatic conditions, the lack of universal reference databases for tropical species, and difficulties in calibrating between sites, which means that its integration into recognized certification protocols is still in the experimental stage. Nevertheless, it illustrates the direction in which biodiversity certification is heading: towards continuous, multi-source, and automated monitoring, where AI is the central processing infrastructure.

The architectures described in this section position Artificial Intelligence as a measurement tool: a passive, albeit powerful, tool that transforms raw data into metrics usable by smart contracts*. An emerging frontier pushes this logic a step further: that of autonomous AI agents capable of acting on-chain* not on living organisms but on behalf of natural entities. The **terraO** project²³⁶, initiated in 2016 by Paul Seidler, Paul Kolling and Max Hampshire at the Universität der Künste in Berlin, posed the question in its most radical form: can a forest own itself? The envisaged mechanism combined a smart contract* holding the title to a forest plot, satellite data feeding an oracle* and a management algorithm automating the sale of exploitation licenses, so that the forest accumulates capital and gradually buys back its own land value.²³⁷

²³⁶ <https://terra0.org/>

²³⁷ Seidler, P., Kolling, P. & Hampshire, M. (2016). terraO – Can an augmented forest own and utilize itself? White paper, Universität der Künste Berlin.

This concept, which for a long time remained an artistic provocation, took an operational step in 2024: **terraO** acquired two forest plots in Reesdorf (Beelitz, Germany), administered by a Verein under German law - an association form comparable to the 1901 law association in France - whose governance is delegated to a Decentralized Autonomous Organization* (DAO), (the first German forest managed by a DAO)²³⁸. But this implementation also reveals the gap between the concept and its realization: Reesdorf's governance is exercised by human NFT* holders, not by an autonomous algorithmic agent. The architecture remains that of a digital commons, not a natural entity with its own agency.²³⁹ The transition from the first to the second would require solving a problem that neither cryptography nor machine learning can adequately address: that of the legitimate representation of an ecosystem whose interests are neither expressible nor reducible to a single objective function.

This problem is not only technical, it is legal and political. The so-called "rights of nature" frameworks adopted by Ecuador (2008 constitution, recognizing the rights of Pachamama), New Zealand (2017 law granting legal personhood to the Whanganui River, represented by two human guardians) and Spain (legal personhood of the Mar Menor lagoon in 2022) establish the principle that an

https://terra0.org/assets/pdf/terra0_white_paper_2016.pdf

²³⁸ LAS Art Foundation & terraO (2024). Autonomous Forest.

<https://www.las-art.foundation/programme/terra0-autonomous-forest>. See also: "terraO's Self-Governing Forests", Frieze, 2023.

<https://www.frieze.com/article/terra0-profile-2023>

²³⁹ Agency (from the English word): the capacity of a system to initiate actions autonomously based on its own understanding of its objectives, rather than simply responding to explicit instructions. In the philosophy of action, the concept traditionally implies intentionality and the capacity to pursue goals. Applied to non-human systems, ecosystems, legal entities, algorithmic agents, etc., it refers, by extension, to a system's ability to act on its own behalf, that is, to produce effects in the world based on its own interests, not those delegated by a human principal. It is precisely this attribution of agency to a forest that the terraO project seeks to operationalize, and which Reesdorf's implementation demonstrates remains, at this stage, a legal and technical fiction rather than a functional reality.

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ecosystem can hold rights and be represented by a representative.

The rise of on-chain AI agents* in 2025–2026, equipped with their own cryptographic wallets and capable of autonomously participating in governance votes, makes the convergence between these legal frameworks and decentralized architectures technically feasible. An agent continuously fed with the satellite, acoustic, and biodiversity data streams documented in this section could, in theory, exercise a veto right in a DAO* when a management decision threatens a critical ecological threshold. But the question remains: who configures the agent? If the algorithm optimizes carbon sequestration at the expense of biodiversity, or if it is trained on geographically biased datasets, the oracle problem* documented in section 2.2.1 is transposed into an alignment problem where the agent no longer represents nature as it is, but as its designers have modeled it, reproducing in algorithmic form the information asymmetry that decentralization promised precisely to correct.

These experiments are part of a broader conceptual horizon: that of a "Digital Earth" in which non-human entities (ecosystems, species, watersheds) would be incorporated into global governance *via* AI agents embedded in crypto-institutions. As early as 1991, the philosopher Bruno Latour formulated the idea of a "Parliament of Things" in which natural entities would be represented on the same footing as humans in deliberative processes; Isabelle Stengers, in her "cosmopolitan proposal" (2005), argued for the inclusion of what she calls the "unrepresented" (living beings and ecological systems) in the assemblies that decide their fate.²⁴⁰

²⁴⁰Latour, B. (1991). We have never been modern. La Découverte. Stengers, I. (2005). "The cosmopolitan proposition". In: Lolive, J. & Soubeyran, O. (eds.), The emergence of cosmopolitics, La Découverte, 45–68.

What was once a matter of political philosophy now falls, at least partially, under the purview of engineering. Researcher Austin Wade Smith has formalized the concept of an "autonomous ecological institution": a DAO* anchored to an ecological element by legal means, which ingests data from environmental oracles* and executes a finite set of actions when predefined biophysical conditions are met or violated.²⁴¹The underlying infrastructure already exists in a fragmented state: the Earth Species Project uses AI to decode inter-species communications, the CETI (Cetacean Translation Initiative) consortium aims for two-way communication with cetaceans, and eco-jurisprudence frameworks are documenting an increasing number of cases where non-human entities exercise governance powers ranging from board representation to contractual capacity.²⁴²The question that these developments pose to Regenerative Finance (ReFi) is not whether these institutions are technically possible (they are), but whether the societies that deploy them will be able to resist the temptation to parameterize their objectives according to the logic of markets rather than according to that of the living systems they are supposed to represent.

2.1.3 New instruments of proof

Continuously measuring impact and immutably recording this measurement on a distributed ledger represent real progress in verification architecture. But they only address half the problem. The other half is financial: how does a verified on-chain* result become an asset that capital markets can recognize, value, and leverage? And above all, how can funding be structured not around the promise

²⁴¹Wade Smith, A. (2025). "Ecological Institutions: Protocols to Grow Autonomous and Convivial Ecological Actors". Paragraph, Regen Foundation. Cited in: Rawson, P. & Borreani, L. (2026). The Green Crypto Handbook: Blockchain for Sustainability Professionals, CRC Press, chapter 4.

²⁴²Eco-Jurisprudence Monitor (n.d.). <https://ecojurisprudence.org/?map-style=political> - Armstrong, K. (2024). "Towards Interspecies Communication". In: Interspecies Future: A Primer, LAS Art Foundation, 89. Salguero (2024), *ibid.*, 93.

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of a future impact, but around proof of an impact already achieved?

This temporal reversal – from prospective to retrospective – is the central issue of this section. It examines the instruments that attempt to make it operational (Impact Tokens*, **Hypercerts**, **Alpha Bonds**), the first experiments that document its feasibility, and the structural limitations that condition its recognition, particularly by the regulatory frameworks of sustainable finance.

2.1.3.1 Impact Tokens*: Tokenization of the result

Impact finance has, from its inception, grappled with a structural contradiction: it seeks to direct capital toward positive social and environmental outcomes, but these outcomes are precisely what conventional financial markets struggle to measure, value, and reward. An investor who puts funds into a reforestation project in the Amazon or an education program in Mozambique has no standardized financial instrument at their disposal to track the impact produced, to demonstrate its reality to third parties, or to transfer it to another actor wishing to claim the benefits. The impact remains a positive externality, real, but invisible in accounting terms and financially illiquid.

The preceding sections demonstrated how dMRV and blockchain address the first part of this problem: the measurement and immutability of the proof. This section examines the conversion of this proof into a transferable, programmable financial asset that can be integrated into conditional financing structures. This is the purpose of Impact Tokens* – a class of digital assets whose value is directly anchored in a verified and documented on-chain* outcome.

An Impact Token* is the digital representation of a unit of social or environmental impact that has been formally quantified, measured, and verified by an independent third party, then immutably recorded on a distributed

ledger. By cryptographically recording this proof, blockchain technology transforms what was once a statement, always contestable, into a digital asset that is liquid, programmable, and tradable on open and decentralized markets. This transformation is the prerequisite for truly results-based financing, in which the triggering of a payment or reimbursement is no longer subject to the judgment of a human auditor but to the automatic execution of a smart contract* reading verified data.

On the IXO protocol – one of the leading protocols in this space, developed in South Africa and operational on its own Cosmos blockchain since 2019 – an “Impact Credit” can represent any formally verified social, environmental, economic, or climate outcome for which stakeholders are willing to pay or invest²⁴³It is precisely this versatility that distinguishes the Impact Token* from carbon credits, whose scope is limited to a single class of outcome.

[B] Clean cooking and cryptographic impact proof

Among the most documented applications of the dMRV-blockchain architecture in a large-scale public policy context, the platform designated within the IXO ecosystem as the Emerging Cooking Platform constitutes an interesting case study. Its field of application is the global market for carbon credits linked to clean cooking – a sector with considerable health and climate implications, since the combustion of traditional biomass (wood, charcoal) is “responsible for nearly 2.9 million premature deaths in 2021” according to the World Health Organization, “including more than 309,000 children under the age of five,” and represents a significant source

²⁴³ IXO Foundation. (2024). Impact Credits.

<https://www.ixoworld.com/impact-tokens>; Center for a Digital Future. (2024). IXO Protocol.

<https://www.centerfordigitalfuture.org>

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of deforestation and methane and black carbon emissions in developing countries.

The architecture deployed by the IXO protocol on a dedicated blockchain (Impact Hub, built on the Cosmos network) treats each clean cooking device, electric cooker, improved biomass stove, biogas or ethanol installation, as an individually identifiable digital impact asset. Unlike conventional clean cooking carbon credit certification methods, which rely on annual field surveys and statistical models of estimated usage, this system uses IoT (Internet of Things) sensors or mobile applications to continuously record the actual usage data of each device. These data streams feed impact oracles, machine learning algorithms, which calculate the corresponding CO₂ equivalent emission reductions according to agreed-upon methodologies and trigger the automatic issuance of certified Impact Tokens.

In May 2024, at the International Energy Agency's Summit on Clean Cooking in Africa, IXO launched Mission Control for Clean Cooking²⁴⁴. A decentralized digital registry dedicated to this segment allows for near real-time monitoring of deployed devices, generated carbon credits, and associated funding flows, operating as a digital public goods infrastructure. The relevance of this mechanism to the shortcomings documented in section 1.1.3.2 is straightforward. The voluntary market for clean cooking carbon credits suffered from the same structural flaws as the forestry carbon market: baseline scenarios built on questionable usage assumptions, costly periodic verification, and opaque financial flows that frequently deprived local communities of the revenues they were entitled to. Cryptographic certification based on real-world usage data replaces these

statistical estimates with continuous proof, and smart contracts* enable the automatic and traceable redistribution of a portion of carbon credit revenues to project developers and, depending on the architectures deployed, to end beneficiaries – effectively reducing intermediation costs, estimated at 30 to 40% in conventional supply chains.

This model reached a significant institutional milestone in 2026. On February 18, 2026, at the International Energy Agency (IEA) Ministerial Meeting, an alliance called the Clean Cooking Accelerator was officially launched, bringing together the Rockefeller Foundation, the Clean Cooking Alliance (CCA), the Global Energy Alliance for People and Planet (GEAPP), and Energy Corps²⁴⁵. This initiative is part of the Mission 300 objective²⁴⁶. This initiative, jointly led by the World Bank Group and the African Development Bank since 2024, aims to connect 300 million people to electricity in sub-Saharan Africa by 2030, making clean electric cooking a strategic priority. The alliance's overall objective is to reach one billion beneficiaries by 2030, requiring an estimated investment of over \$2 billion per year.²⁴⁷ The same period saw the Global Carbon Council publish, in January 2026, a dMRV methodology specifically dedicated to clean cooking, validating de jure the use of

²⁴⁵ The Rockefeller Foundation, Global Energy Alliance for People and Planet, Clean Cooking Alliance & Energy Corps. (2026, February 18). Rockefeller Foundation, Global Energy Alliance, Clean Cooking Alliance, Energy Corps to Scale Modern Cooking Technologies in Africa. Press release, PR Newswire. <https://www.prnewswire.com/news-releases/rockefeller-foundation-global-energy-alliance-clean-cooking-alliance-energy-corps-to-scale-modern-cooking-technologies-in-africa-302691490.html>

²⁴⁶ World Bank & African Development Bank. (2024). Mission 300: Connecting 300 million people to electricity in sub-Saharan Africa by 2030. <https://www.worldbank.org/en/programs/energizing-africa/overview>; <https://www.afdb.org/en/topics-and-sectors/initiatives-and-partnerships/mission-300>. The initiative was launched at the 2024 Spring Meetings of both institutions.

²⁴⁷ The Rockefeller Foundation. (February 18, 2026). <https://www.rockefellerfoundation.org/news/rockefeller-foundation-global-energy-alliance-clean-cooking-alliance-energy-corps-scale-modern-cooking-technologies-in-africa/>

²⁴⁴ IXO World. (2024, May). Mission Control: Launching a Decentralized Digital Registry for Clean Cooking. Impacts Network – IXO Chronicle. <https://chronicle.impacts.network/mission-control/>

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digital tracking protocols – including that of IXO – for carbon certification in this segment.

The analytical value of this case goes beyond mere technical demonstration. It illustrates the mechanism by which leading institutional investors, philanthropic foundations, multilateral development banks, now condition their commitment on a high level of carbon credit integrity that conventional reporting systems can no longer meet. In this context, the IXO protocol is not a field operator; it provides the software and financial layer, the trust layer, that makes massive investment flows auditable in real time by the institutions that finance them. This positioning illustrates one of the central hypotheses of this report: new digital architectures do not replace institutional actors in impact finance, but rather modify the structure of evidence upon which these actors base their allocation decisions.

This case, however, raises the same analytical concerns as those expressed in sections 2.1.1.1 and 2.2.1. Ultimately, the robustness of the mechanism relies on the reliability of the IoT sensors* and the emission reduction estimation algorithms – two layers whose calibration limitations and risks of manipulation have been documented. The impact figures put forward by the project proponents currently come from sources institutionally linked to the protocol and have not yet been subjected to independent and published academic evaluation. Their illustrative value is real; their probative value remains to be established.

The Amply project: proof by use

The **Amply** project, launched in South Africa in 2017 in partnership with the United Nations Children's Fund (UNICEF), represents the first large-scale deployment of this mechanism within a public policy context. Its focus is the South African government's early childhood education program, with an annual budget of US\$200 million and covering approximately 700,000 children aged two to five in

thousands of small educational centers across the country. The program's management relied on the transmission of paper attendance records, which centers submitted monthly to the Department of Social Development, before a manual administrative verification process determined the amount of the subsidy to be disbursed. This system was slow, costly, and susceptible to fraud, particularly the registration of fictitious children ("ghost children") to artificially inflate the subsidy entitlement.

Amply replaced this process with a mobile application that allowed educators to record each child's attendance daily. Each validated attendance generated a verifiable claim, securely and immutably recorded on the Ethereum blockchain. At the end of the month, the system aggregated these claims to issue an Impact Token* accurately certifying the amount of educational services provided. The school then transferred this token to the government as irrefutable proof of its activity, triggering the precise disbursement of the corresponding subsidy²⁴⁸.

This mechanism – attendance attested via mobile application, verifiable declarations recorded on distributed ledger, monthly aggregation into an impact token, transfer to the funder triggering the payment of the grant – illustrates the fundamental logic of the Impact Token* in its purest form: impact is no longer declared, it is proven; and this proof is the title that entitles the holder to funding.

The **Amply** project illustrates the fundamental logic of the mechanism, but it is not an isolated case. The underlying protocol-token-smart contract architecture* can be generalized to any class of measurable outcome. This is precisely what the IXO Foundation formalizes with its base-layer protocol dedicated to impact finance, now

²⁴⁸ Fernando, A. (2017, October 10). Blockchain for schoolteachers and international development. Medium. <https://medium.com/@00AaronFernando/blockchain-for-schoolteachers-and-international-development-46ce29df-f8a0>

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operational on its own Cosmos blockchain. Each project deployed on the IXO protocol generates verifiable claims for each action within its impact scope, use of a clean cookstove, delivery of a health consultation, planting and survival of a tree, which are aggregated and converted into tokenized Impact Credits according to a predefined methodology. In May 2024, IXO launched Mission Control for Clean Cooking, a decentralized digital public goods registry that tracks clean cookstove projects, deployed devices, generated carbon credits, and associated funding flows in real time.²⁴⁹ For each connected device, sensors transmit real-time usage data, which is automatically correlated with fuel purchase declarations to calculate emission reductions according to the Gold Standard methodology and issue the corresponding Impact Tokens*.

South Pole also implemented this approach in partnership with the IXO Foundation and Gold Standard for a solar photovoltaic pilot project in Thailand, in which the IXO protocol facilitated the submission of verified production data and the automatic issuance of certified carbon credits – reducing the time and costs associated with the conventional audit process.²⁵⁰

Hypercerts: an open standardization of the impact certificate

In parallel with the IXO approach, geared towards development projects and carbon markets, Protocol Labs – the Web3 infrastructure behind the IPFS protocol and the Filecoin blockchain – developed a more general impact standard starting in 2022:

Hypercerts (Hyper Certificates of Impact). A Hypercert is a semi-fungible token (compliant with Ethereum's ERC-1155 standard) representing a statement of impact structured according to five formally defined dimensions: the scope of the work carried out, the extent of the impact produced, the time period of this work, the time period of this impact, and the identity of the contributors²⁵¹.

The structural distinction between **Hypercerts** and conventional carbon credits lies in the timing of the financing they enable. The conventional model is prospective: funds are disbursed before the impact is realized, based on a promise, exposing the funder to the risk of non-delivery and incentivizing the project developer to present an optimistic view of their ability to produce results. The **Hypercerts** model is retrospective: the impact is first generated and documented, then the Hypercert is issued and sold to funders who pay for a result they have been able to verify before committing. This temporal reversal fundamentally alters the incentive structure and rewards what has worked rather than what promised to work, creating a secondary market for verified impact evidence. Protocol Labs describes **Hypercerts** as "an interoperable data layer for impact financing mechanisms," agnostic to the financing method, quadratic financing*, weighted voting, retroactive public goods funding, and compatible with any platform wishing to integrate it²⁵².

In the environmental field, **GainForest**, a partner of the **Hypercerts** Foundation, uses this standard to document and fund forest conservation projects in developing countries,

²⁴⁹ Center for a Digital Future. (2024). IXO Protocol. <https://www.centerfordigitalfuture.org/blog/60kqfdqb4f8kljgy1j4ujvaqr1bx5y-364pg-bskhw-58qfs-c9t7w-cr3mn-Y6Fse-i9krz>; IXO Foundation. (2024). Impact Credits. <https://www.ixoworld.com/impact-tokens>

²⁵⁰ South Pole, IXO Foundation & Gold Standard. (2018). South Pole, ixo Foundation, Gold Standard develop blockchain app for carbon credits. <https://www.southpole.com/news/southpole-ixo-goldstandard-blockchain-application-for-carbon-credit-tokenization>

²⁵¹ Protocol Labs & Hypercerts Foundation. (2022). Hypercerts: A new primitive for public goods funding. <https://www.protocol.ai/blog/hypercert-new-primitive/>; Gitcoin. (2023). Hypercerts for public goods funding. <https://www.gitcoin.co/blog/hypercerts-for-public-goods-funding>

²⁵² Uzsoki, D., & Guerdat, P. (2019). Impact tokens: A blockchain-based solution for impact investing. International Institute for Sustainable Development (IISD). <https://www.iisd.org/publications/report/impact-tokens-blockchain-based-solution-impact-investing>

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issuing **Hypercerts** that attest to preserved areas verified by satellite imagery. Optimism, an Ethereum scaling solution (Layer 2), has distributed over US\$100 million in Retroactive Public Goods Funding (RetroPGF) to 501 contributors, partly using **Hypercerts** as a standard for tracking the impact of contributions²⁵³.

Octant embodies a complementary variation of this principle in its V2: ERC-4626 vaults with a thirty-day sliding window lock ETH in staking, and only the generated returns reach the beneficiaries of the selected projects. The initial capital remains intact, permanent, and unconsumed. In its mechanics, this is the purest form of programmable finance: no human decision is made on a transaction-by-transaction basis, and the allocation rule is entirely encoded in the protocol²⁵⁴.

The common limitations of Impact Tokens* and Hypercerts

These two approaches share structural limitations that the report must identify precisely, at the risk of presenting as solved problems that remain open.

The first is the problem of defining and comparing impact. *An Impact Token** certifying a reduction of 340 kilograms of CO₂ calculated using the Gold Standard methodology and a Hypercert attesting to the protection of ten hectares of forest using a proprietary methodology are not directly comparable, even if both are recorded on-chain* with the same cryptographic guarantees. The lack of a standardized impact ontology, that is, a formal classification system allowing for the comparison of results of different kinds, constitutes the main

limitation to the liquidity and fungibility of impact asset markets. Protocol Labs has explicitly identified this problem, undertaking work to map impact token categories aimed at building “a fundamental framework and layer on which actors can create standards”²⁵⁵.

Some projects seek to address this comparability issue through specific designs. **Kolektivo's** GeoNFT represents a georeferenced physical territory (GeoJSON polygon) with an associated ecological index calculated from verified field data, thus preserving the location and non-substitutability of each biodiversity asset²⁵⁶. **Carbonds**²⁵⁷ issues tokens designed as cryptographic proof of real, additional, and permanent CO₂ reduction or sequestration, positioning on-chain immutability* as a guarantee of additionality that declarative ledgers cannot produce. **EcoBridge** adopts a complementary approach: impact certificate NFTs are issued only upon the final withdrawal of carbon credits, producing an immutable record of their irreversible consumption and thus neutralizing the risk of double counting²⁵⁸.

The second risk is the potential for discrepancies between the on-chain declaration* and the actual impact. A Hypercert recorded on the blockchain guarantees the immutability and traceability of the impact declaration; however, it does not guarantee that the declared impact corresponds to a physical or social reality verifiable by an independent third party. This limitation is not unique to **Hypercerts**, it is inherent to any impact declaration system, but it is exacerbated by the tendency to interpret cryptographic immutability as a form of verification, whereas the blockchain merely

²⁵³ Protocol Labs & Hypercerts Foundation. (2022). Hypercerts: A new primitive for public goods funding. <https://www.protocol.ai/blog/hypercert-new-primitive/>; Bitcoin. (2023). Hypercerts for public goods funding. <https://www.bitcoin.co/blog/hypercerts-for-public-goods-funding>

²⁵⁴ Octant, 2025, <https://docs.octant.app>

²⁵⁵ Protocol Labs. (2022). Incentivizing impact beyond carbon. <https://www.protocol.ai/blog/transcription-impact-tokenization-beyond-carbon/>

²⁵⁶ Kolektivo, 2025, <https://medium.com/kolektivo-co/regeneration-at-institutional-scale-591cfa972d8>

²⁵⁷ <https://carbonds.io/>

²⁵⁸ EcoBridge, 2025, <https://www.ecotoken.live>

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seals a claim whose basis it has not assessed. For this reason, **Hypercerts** include a layer of third-party evaluators, organizations that, like rating agencies in traditional finance, would certify the value of impact declarations, but this evaluation infrastructure was still under construction in 2026.

2.1.3.2 Programmable and retrospective (ex-post) financing

The previous section established that an Impact Token* transforms a verified outcome into a financial asset. This section examines the direct consequence of this transformation on the temporal structure of financing: if impact can be tokenized and certified on-chain*, then the disbursement of capital can be conditional upon proof of this outcome rather than on the promise of its future realization. This reversal of the financing temporality, from prospective to conditional-progressive or retrospective, is the most substantial financial governance innovation brought about by these new instruments.

Prospective financing and its structural limitations

The dominant model of public and private impact finance relies on ex-ante allocation: funds are committed before impact is achieved, based on an assessment of the project promoter's capacity, the robustness of their action plan, and the credibility of their performance indicators. This model generates two structural problems well-documented in the development finance literature. The first is the risk of non-delivery: once funds are disbursed, the project promoter's incentives to actually maximize results rather than simply meet formal reporting requirements are weakened. The second is selection bias: the projects most easily financed are those whose promoters are most adept at writing compelling proposals, which does not necessarily correlate with their actual capacity to generate impact.

Milestone financing: AGUA as a case study

One initial response to these limitations is not to finance an entire project upfront, but to make successive disbursements contingent upon the validation of intermediate milestones. The **AGUA** (Advancing Global Unified Accountability) platform, developed by the Argentinian company Atix Labs – winner of the first UNICEF Venture Fund blockchain cohort in 2018 – operationalizes this mechanism on the blockchain²⁵⁹. **AGUA** structures each project into a series of milestones and activities, each with a defined budget, formalized acceptance criteria, and a designated auditor. Funds are held in a smart contract* and are only disbursed to the beneficiary after an external auditor has uploaded the evidence of milestone completion into the system, automatically triggering the release of the corresponding tranche. All financial transactions and associated evidence are recorded in the distributed ledger, creating an audit trail that is verifiable by all donors and cannot be altered.

This conditional/progressive financing model improves incentive alignment compared to fully prospective financing, but it remains fundamentally ex-ante in its logic: the project sponsor gains access to capital before producing impact, in exchange for a promise of results formalized in milestones. The innovation lies in the automation and immutability of the control mechanism, not in the timing of the financing itself.



Rahat (a Nepali word meaning "help" or "relief") is an open-source humanitarian aid distribution platform developed by eSatya and deployed in

²⁵⁹UNICEF Venture Fund. (n.d.). AGUA: Revolutionizing global collaboration for funding transparency. <https://www.unicefventurefund.org/story/agua-revolutionizing-global-collaboration-funding-transparency-growth-graduate-atix-labs>

Nepal since 2020 in partnership with UNICEF and several local NGOs. It exemplifies the mechanism of conditional financing in its most directly life-saving form: the distribution of cash to disaster-stricken populations without bank accounts or smartphones. Its Anticipatory Action module directly encodes the conditions for triggering aid into a smart contract*: if an official rainfall threshold (derived from government meteorological data) is reached, the cash transfer is automatically triggered before the disaster, allowing households to purchase emergency supplies before access routes are cut off. The conditions are coded, the payment is automatic, with no human decision-making in the validation loop. The identities of the beneficiaries, stored off-chain to protect personally identifiable information (PII), are linked to printable QR codes that can be read by basic smartphones, making the system operational for populations without personal digital infrastructure²⁶⁰. The activation conditions are entirely objective and verifiable, the triggering is automatic, and the beneficiary receives aid without having to prove their claim, file a claim, or depend on the availability of a field agent. This model nevertheless raises the same structural question as all conditional instruments: the reliability of the trigger (here, government weather data) is the only guarantee that aid reaches the right people at the right time.

Hypercerts: Retrospective financing as a paradigm shift

The **Hypercerts** model, introduced by Protocol Labs in 2022 and now deployed on the Optimism blockchain²⁶¹ and several other Ethereum networks, take a further step by completely reversing this timeline. The impact is first generated, then documented in a tokenized Hypercert, then evaluated by independent third parties, and finally retrospectively funded by actors who pay to claim the benefit of a result whose reality is already established. This mechanism, referred to in Web3 literature as retroactive public goods funding, fundamentally alters the incentive structure: a project proponent knows they will be compensated in proportion to the actual impact generated, not the quality of their initial proposal. **Hypercerts** thus create an ex-post impact market where value is allocated after verification of the result rather than before its realization.²⁶²

Protocol Labs describes **Hypercerts** as "*an interoperable data layer for impact financing mechanisms*"²⁶³. The Hypercert is agnostic regarding the chosen financing method – quadratic financing*, open auction, token-weighted voting, or institutional grant. The architecture comprises three sequential phases. In the first phase, the project owner completes their work and issues a Hypercert documenting what has been accomplished, such as the scope of work, the timeframe, the identity of contributors, and the extent of the claimed impact. In the second phase, independent evaluators examine these claims and assign them credibility – their role is structurally analogous to that of rating agencies in conventional finance, with the difference that their evaluations are themselves recorded on-chain* and therefore traceable. In the third phase, retrospective funders – impact funds, companies seeking to

²⁶⁰ Rahat, 2025, <https://rahat.esatya.io/blogs/rahat-an-open-source-block-chain-based-humanitarian-aid-distribution-management-system/>

²⁶¹ <https://www.optimism.io/>

²⁶² Protocol Labs & Hypercerts Foundation. (2022). Hypercerts: A new primitive for public goods funding. <https://www.protocol.ai/blog/hypercert-new-primitive/>

²⁶³ *Ibid.*

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attribute positive externalities to their balance sheets, and public institutions – purchase fractions of these **Hypercerts** to appropriate the corresponding verified impact²⁶⁴.

In practice, Optimism has distributed over US\$100 million in retroactive public goods funding to 501 contributors through its Retroactive Public Goods Funding (RetroPGF) program, relying in part on **Hypercerts** as a standard for tracing contributions.²⁶⁵

Alpha Bonds: Dynamic and Cybernetic Financing

Alpha Bonds, developed by the IXO Foundation in collaboration with the research firm BlockScience and the Interchain Foundation, represent a third, more complex and ambitious architecture in which the pricing of financing is itself a dynamic variable, adjusted in real time based on risk signals from the field. Formally, **Alpha Bonds** implement Risk-Adjusted Bonding Curves (RABCs), continuous market mechanisms in which the price of tokens for participation in an impact bond is algorithmically determined by a mathematical function that incorporates estimates of the probability of achieving the project's outcomes²⁶⁶.

The mechanism relies on four interdependent components: two standard bond-to-mint functions, bond-to-mint (buying tokens creates liquidity for the project) and burn-to-withdraw (buying tokens removes this liquidity), and two prediction mechanisms, attest-positive (attestations of progress increase the alpha parameter, reflecting a

growing probability of success) and attest-negative (adverse signals decrease it). The alpha parameter, ranging from 0 to 1, represents the estimated probability that the project will achieve its objectives: when it approaches 1, the price of participation tokens increases, rewarding investors who bet on the project early; when it approaches 0, the price decreases, incentivizing all stakeholders to correct failing trajectories. This architecture transforms the funding contract of a static event into a continuous feedback loop: field data, academic outcomes, device usage levels, ecological health metrics, feeds alpha oracles that calculate the probability of success and update the alpha parameter, modifying the cost and terms of funding in real time. IXO tested this mechanism in an adaptive learning funding pilot in India, in partnership with Chimple (a Global XPRIZE in Education winner) and the UBS Optimus Foundation, in which children's interaction data with a learning tablet directly fed the funding contract's alpha oracles.²⁶⁷

The common boundaries

These three approaches, milestone-based financing (**AGUA**), retrospective financing (**Hypercerts**), and dynamic risk-adjusted financing (**Alpha Bonds**), share two structural limitations, which Section 2.2 will address in detail. The first is their dependence on the quality of the input impact data: a milestone validated on the basis of manipulated evidence, a Hypercert issued on the basis of an unverified declaration, or an alpha parameter fed by a faulty oracle* will produce real financial effects while reflecting no real impact, **the garbage-in, garbage-out problem applies here with particular acuity, since the automation of disbursements mechanically amplifies input errors.** Parametric insurance applied to wildfires illustrates the same mechanism in another form. The product launched by **Arbol** in California in September

²⁶⁴ Gitcoin. (2023). Hypercerts for public goods funding. <https://www.gitcoin.co/blog/hypercerts-for-public-goods-funding>

²⁶⁵ Gitcoin. (2023). Hypercerts for public goods funding. <https://www.protocol.ai/blog/hypercert-new-primitive/>

²⁶⁶ BlockScience & IXO Foundation. (2022). Alpha bonds: Risk-adjusted bonding curves for financing impact. <https://blog.block.science/alpha-bonds-risk-adjusted-bonding-curves-for-financing-impact/> (Simulation results from a formalized research collaboration; to be completed by the publication of the DAO model on GitHub: <https://github.com/BlockScience/Risk-Adjusted-Bonding-Curves>)

²⁶⁷ IXO Foundation / Chimple. (2022). The journey to build a new tokenized education economy. https://impacts.ixoworld/refi_education/

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2025 automatically triggers a payment if satellite data crosses a predefined fire proximity threshold, without any conflicting expertise or human intervention in the validation chain. Payment is based on physical evidence, not the claimant's declaration. This architecture makes the commercial viability of the model contingent on the absolute accuracy of the triggering data, illustrating once again that the value of automation depends entirely on the integrity of the source data²⁶⁸.

The second is the question of standardization and institutional recognition: none of these instruments are currently recognized in the regulatory frameworks of sustainable finance – European green taxonomy, TNFD or CSRD reporting frameworks – and their integration into the portfolios of institutional investors requires legal and accounting clarifications that have yet to be developed.

²⁶⁸Arbol, 2025, <https://www.artemis.bm/news/arb-automates-parametric-reinsurance-triggers-using-a-blockchain/>

2.2 The pitfalls and systemic risks of Web3 Regenerative Finance

The preceding sections documented the real benefits of the new verification architectures: the continuity of monitoring enabled by dMRV, the immutability of reports guaranteed by distributed ledgers, and the temporal reversal of financing made possible by **Hypercerts** and **Alpha Bonds**. These benefits are genuine. They represent a structural break from the model of periodic auditing and self-declaration.

But every architecture also produces its own inherent flaws. The automation of payments mechanically amplifies errors in input data. The tokenization of life can reproduce, under the guise of innovation, the extractive logics it claims to transcend. And the governance of decentralized protocols tends to recentralize power in the hands of those who hold the most tokens, reproducing a form of shareholder primacy that formal decentralization alone cannot neutralize.

This section examines these three risk categories in their empirical reality and their systemic implications. It does not aim to invalidate the instruments analyzed previously, but rather to clarify the conditions under which their deployment risks displacing the problems of impact finance rather than solving them.

2.2.1 Dependence on oracles and distortions of tokenized measurement

The first systemic risk of Regenerative Finance (ReFi) is infrastructural. It stems directly from a fundamental technical constraint of smart contracts: their inherent inability to observe the physical world. For a smart contract to automatically trigger a payment in response to a measurement of sequestered carbon or a restored biodiversity index, this data must be

transmitted to it *via* an interface external to the ledger, the oracle. However, this oracle is precisely the centralized point of failure that the decentralized architecture was supposed to eliminate.

The vulnerability of oracles, technical failure, deliberate manipulation, calibration bias, is the visible face of the problem. The less immediately perceptible face is incentive-based: as soon as a measurable indicator automatically triggers a financial reward, project sponsors are structurally incentivized to optimize that specific indicator, regardless of its relevance to the systemic objective. This is what the principle formulated by economist Charles Goodhart in 1975, reformulated by sociologist Marilyn Strathern as *"once a measure becomes a target, it ceases to be a good measure"*, allows us to anticipate accurately in the context of ReFi*.

These two dimensions – the vulnerability of oracles* and the incentive distortion by tokenized measurement – are examined successively in this section, the conclusions of which directly feed into the analyses of the risks of hyper-financialisation (2.2.2) and of power asymmetries (2.2.3).

2.2.1.1 The vulnerability of Oracles

Smart contracts* are, by design, blind to what happens outside their own computer network. To interact with the real economy, receiving data on weather conditions, soil quality, the deforestation rate of a plot of land, or the price of a raw material, they rely on software intermediaries called oracles*, which translate events from the physical world into digital data usable by the smart contract*²⁶⁹.

This dependency creates a structural paradox. The architecture of distributed ledgers is designed to eliminate the need for trusted third parties; the integration of oracles*

²⁶⁹ Caldarelli, G. (2020). Understanding the Blockchain Oracle Problem: A Call for Action. *Information*, 11(11), 509. <https://doi.org/10.3390/info11110509>

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reintroduces precisely this type of intermediary at the heart of the system. An oracle* constitutes a single point of failure: if the physical sensor that feeds it fails, if the entity managing this oracle* is compromised, or if the transmitted data is deliberately falsified, the smart contract* will execute on false premises, automatically and without the possibility of manual interruption. Researchers at the Bank for International Settlements (BIS) emphasize that this dependence on external data sources leaves considerable room for manipulation, making decentralized systems particularly vulnerable to targeted attacks²⁷⁰.

Mitigation attempts exist. Decentralized oracle networks* – such as **Chainlink**²⁷¹. Created in 2017, these systems aggregate data from multiple independent nodes to reduce the risk of a single provider falsifying transmitted information. While this approach does mitigate the risk of individual manipulation, it doesn't eliminate it entirely: if the data collected upstream of the nodes, satellite readings, field reports, IoT sensors, is itself flawed or biased, decentralized aggregation merely amplifies these errors. Trust is shifted, not eliminated; it migrates from the manager of a centralized oracle to the network node operators, whose incentives and reliability remain to be verified on a case-by-case basis.

The cases documented in this report illustrate this limitation concretely. At **IXO Protocol**, whose Agentic Networks connect IoT cooktops to conditional payments (see section 2.1.2.1), the structural risk is explicitly documented by the team: if the AI oracles* are biased or if a sensor is manipulated, the entire funding chain relies on corrupted evidence without a manual interruption mechanism. **Arbol**, whose operational robustness was validated during Hurricane Milton in October 2024, remains entirely dependent on the integrity of its **dClimate** and **Chainlink** oracles*: manipulation of the

input weather data can trigger large-scale, unjustified payments, jeopardizing the viability of a fund whose solvency is the sole guarantee for hundreds of insured farmers. These two cases illustrate why Caldarelli describes this dependence as "*two steps backwards towards centralisation*": the point of trust does not disappear, it migrates to the oracle* operator.

It is therefore necessary to qualify the postulate of technological infallibility frequently associated with Web3: if the registry technology is robust in its internal execution, the point of collection and insertion of physical data remains a structurally centralized vulnerability.

2.2.1.2 The data Trap and Goodhart's Law

The vulnerability of oracles* leads to the second, more fundamental pitfall: the computer science principle of garbage in, garbage out – erroneous input data necessarily results in an erroneous output. A distributed ledger guarantees that information cannot be modified once recorded, but it has no intrinsic ability to verify the accuracy of that information before it is written.²⁷² Digitizing a flawed or fraudulent rating system on a public blockchain does not correct these flaws but rather freezes them. As researchers at the Bank for International Settlements (BIS) point out, once validated, false data cannot be corrected, and the financial contracts that refer to it will execute permanently on erroneous premises – making errors far more costly and difficult to rectify than in traditional finance.²⁷³

In addition to this risk to data integrity, there is a structural incentive distortion, first described by economist Charles Goodhart in 1975 and since known as Goodhart's Law.

²⁷⁰ Duley, C., Gambacorta, L., Garratt, R., & Koo Wilkens, P. (2023). The oracle problem and the future of DeFi*. BIS Bulletin, 76. <https://www.bis.org/publ/bisbull76.htm>
²⁷¹ <https://chainlink/>

²⁷² Caldarelli, G. (2020). Understanding the Blockchain Oracle* Problem: A Call for Action. Information, 11(11), 509. <https://doi.org/10.3390/info1110509>

²⁷³ Duley, C., Gambacorta, L., Garratt, R., & Koo Wilkens, P. (2023). The oracle problem and the future of DeFi*. BIS Bulletin, 76. <https://www.bis.org/publ/bisbull76.htm>

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Goodhart observes that any statistical regularity tends to break down when subjected to control pressure²⁷⁴. This intuition was reformulated in a way that is more directly applicable to incentive systems by sociologist Marilyn Strathern, who explains that *"as soon as a measure becomes a target, it ceases to be a good measure"*²⁷⁵.

In the context of regenerative finance (ReFi*), this principle takes on particular significance. When a specific ecological or social indicator automatically triggers a financial reward – in the form of an impact token or a retrospective (ex post) payment – project promoters are structurally incentivized to optimize this specific indicator, regardless of its relevance to the systemic objective sought.

Actors are then driven to maximize easily quantifiable and tokenizable metrics, the number of trees planted to trigger a carbon credit, for example, at the expense of more complex and less directly monetizable objectives, such as the preservation of endemic biodiversity, long-term soil quality, or respect for the rights of local communities. **KlimaDAO** provides the most well-documented empirical illustration of this distortion in the ReFi ecosystem. By becoming, at its peak in 2021–2022, a dominant player in the voluntary market for tokenized carbon credits, the protocol exerted upward pressure on the price of the KLIMA token, which gradually became disconnected from the ecological quality of the underlying credits. The pressure to increase the token's price incentivized market participants to maximize the quantity of aggregated credits rather than their integrity, reproducing on-chain* and with unprecedented liquidity the same quality degradation dynamics as

traditional voluntary markets. The migration of the protocol to Base and the publication of a whitepaper 2.0 demonstrate an attempt at recalibration, but the case remains in academic literature the benchmark example of the application of Goodhart's law to tokenized carbon markets²⁷⁶.

This dynamic does not stem from a technological failure in the strict sense, but from a tension inherent in any attempt to monetize or monetize proof of systemic impact through discrete indicators. It constitutes a limitation that the design of Decentralized Impact Finance (ReFi) protocols cannot ignore, lest the pursuit of a financially profitable indicator replace the real transformation that the technology initially sought to certify.

2.2.2 The hyper-financialization of nature

The second systemic risk is of a different nature. It is not technical, but conceptual: it is the risk that ReFi*, in seeking to mobilize financial markets in the service of life, will produce the opposite effect – by transforming life into a new class of speculative assets responding to the logic of markets rather than that of ecosystems.

This risk manifests itself in two complementary ways. The first is the commodity frontier, a process by which components of life, previously excluded from the logic of market exchange, are progressively securitized, pledged as collateral, and traded on highly liquid markets, with a speed and scope that the infrastructure of distributed ledgers makes technically possible on an unprecedented scale. The second is the intrinsic limit of ecological quantification: certain dimensions of life, biodiversity, interactions between species, the evolutionary memory of an ecosystem, are

²⁷⁴ Goodhart, C. (1975). Problems of monetary management: The U.K. experience. In *Papers in Monetary Economics* (Vol. 1). Reserve Bank of Australia.

²⁷⁵ Strathern, M. (1997). 'Improving ratings': Audit in the British University System. *European Review*, 5(3), 305–321.

<https://www.cambridge.org/core/journals/european-review/article/abs/improving-ratings-audit-in-the-british-university-system/FC2FE640C0C44E3DB87C29FB666F9AAB>

²⁷⁶ Ballesteros-Rodríguez A, De-Lucio J and Sicilia M-Á (2024) Tokenized carbon credits in voluntary carbon markets: the case of KlimaDAO. *Forehead. Blockchain* 7:1474540. doi: 10.3389/fbloc.2024.1474540

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structurally non-fungible, non-substitutable, and, strictly speaking, incommensurable. Reducing them to standardized metrics compatible with financial instruments traded on global markets carries the risk of producing financially coherent but ecologically empty assets.

This section distinguishes these two dimensions and examines the academic and empirical arguments that allow us to assess their relevance in the current context of ReFi*.

2.2.2.1 The transformation of living organisms into speculative assets

One of the systemic risks of Regenerative Finance (ReFi*) lies in its propensity to reproduce, under the guise of technological innovation, some of the very extractive logics it aims to transcend. This phenomenon manifests itself in the increasing commodification of global commons: new environmental markets assign a price to components of life in order to exchange them as optimizable financial instruments²⁷⁷.

The infrastructure of distributed ledgers tends to accelerate this dynamic by allowing an unprecedented number of natural assets to be securitized, pledged as collateral and traded on highly liquid primary and secondary markets (Bennett, 2025)²⁷⁸. By applying these mechanisms to global commons, technology risks turning them into a new commodity frontier – a term coined by environmental historian Jason W. Moore to describe the process of appropriation, exploitation, and ecological fragmentation generated by the

continued expansion of extractive economies^{279 280}.

The inherent danger in this dynamic is that it disconnects financial activity from real physical impact. Digital tokens representing carbon emission reductions can theoretically finance genuine carbon sequestration projects; they can just as easily circulate on secondary markets for purely speculative purposes, generating *"transactions without tangible environmental benefits on the ground"*²⁸¹. This risk becomes concrete as soon as tokenized natural assets enter highly liquid secondary markets. **Pleno**, a blue carbon certification protocol for Indonesian mangroves, will have to navigate an inherent tension in its model: once a mangrove credit becomes an on-chain tradable asset*, its value fluctuates according to the supply and demand for carbon in financial markets, and not according to the actual ecological health of the underlying ecosystem, the degradation of which can occur simultaneously with a rise in the credit price.²⁸²

Therefore, if technological tools merely increase the efficiency of existing markets without altering the incentive structure that directs capital toward short-term returns, the monetization of nature risks accelerating its degradation rather than guaranteeing its preservation, an observation also made by environmental economists outside the Web 3.0 field, such as the work of the Dasgupta report on the economics of biodiversity, which highlights the structural inability of markets to capture the complex physical reality of living things: *"Some aspects of nature are mobile;*

²⁷⁷Bennett, K. (2025). An evaluation of the regenerative claims of Web3's ReFi movement. *Frontiers in Blockchain*, 8, 1564083. <https://doi.org/10.3389/fbloc.2025.1564083>
²⁷⁸Ibid.

²⁷⁹Moore, J.W. (2000). Sugar and the expansion of the early modern world economy: Commodity frontiers, ecological transformation, and industrialization. Review (Fernand Braudel Center). <https://jasonwmoore.com/wp-content/uploads/2017/08/Moore-Sugar-and-the-Expansion-of-the-Early-Modern-World-Economy-REVIEW-2000.pdf>

²⁸⁰Moore, J.W. (2015). *Capitalism in the Web of Life: Ecology and the Accumulation of Capital*. Back.

²⁸¹Bennett, K. (2025). An evaluation of the regenerative claims of Web3's ReFi movement. *Frontiers in Blockchain*, 8, 1564083. <https://doi.org/10.3389/fbloc.2025.1564083>

²⁸²Pleno, 2025, <https://eblockchainconvention.com/pleno-refi/>

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others are invisible, as in soils; and many are silent. These characteristics mean that the effects of many of our actions on ourselves and others, including our descendants, are difficult to trace and go unaccounted for, resulting in widespread 'externalities' and hindering the proper functioning of markets²⁸³.



KlimaDAO represents the most documented empirical case of the tension between financialization and integrity in on-chain carbon markets*. Launched in 2021, the protocol aimed to create a reserve of tokenized carbon credits on the Polygon blockchain and to mechanically drive up their market price via a link curve model, with the stated ambition of "behaving like a central carbon bank." At its peak in late 2021, the price of the KLIMA token reached several thousand dollars per ton of CO₂ equivalent.

Two independent analyses – that of CarbonPlan in 2022²⁸⁴ and that of researcher Kate Bennett in 2025²⁸⁵ establish that this mechanism produced effects contradicting its stated intentions. On the one hand, the credits aggregated by **KlimaDAO** came primarily from low-quality reduction/avoidance methodologies (notably HFC-23 and REDD+ forest credits), without any filtering for ecological integrity. On the other hand, the speculative liquidity generated by the value of the KLIMA token created incentives to maximize the quantity of

aggregated credits rather than their quality, structurally exacerbating the problem documented in section 1.1.3.2. The protocol represented less than 1% of the total voluntary carbon market at its peak, illustrating both the current quantitative marginality of carbon ReFi and the ability of small on-chain volumes* to distort pricing mechanisms in emerging markets. The migration to the Base blockchain in 2025 and the redesign of the model in a whitepaper 2.0 constitute an attempt to correct this distortion, but the case remains in the academic literature the reference illustration of the risk of hyper financialization of carbon in the Web3 ecosystem.

2.2.2.2 The limitations of ecological quantification

In addition to the speculative risk, there are the intrinsic limitations of any attempt to quantify living things for financial purposes.

An analytical distinction is necessary here, which Bennett (2025a) explicitly formulates: that between quantification and commodification²⁸⁶. If the first refers to the ability to measure aspects of the natural world for stewardship and monitoring purposes, the second is "the process by which these measurements are converted into negotiable financial instruments"²⁸⁷ or the transformation of these same measures into negotiable financial instruments. Bennett emphasizes in this regard that distributed ledger technology makes possible environmental accounting that does not necessarily require commodification; a ledger can track ecological health indicators without converting them into financial assets, but that ReFi* must remain attentive to the

²⁸³ Dasgupta, P. (2021). The Economics of Biodiversity: The Dasgupta Review. HM Treasury.

<https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review>

²⁸⁴ CarbonPlan, 2022,

<https://carbonplan.org/blog/klimadao-bct-response>

²⁸⁵ Bennett, K. (2025). The ReFi movement in Web3: Implications for the Global Commons. *Frontiers in Blockchain*, 8, 1564073.

<https://doi.org/10.3389/fbloc.2025.1564073>

²⁸⁶ Bennett, K. (2025). The ReFi movement in Web3: implications for the Global Commons. *Forehead. Blockchain*, 8, 1564073.

<https://doi.org/10.3389/fbloc.2025.1564073>

²⁸⁷ *Ibid.*

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purpose it assigns to quantification: does it fall under stewardship, or does it open new markets that deepen the financialization of life?

This confusion is particularly problematic when applied to natural assets whose very nature is that of being fundamentally non-fungible. Carbon markets are based on an equivalence assumption: a tonne of carbon dioxide (CO₂) avoided or captured constitutes, as a first approximation, a comparable physical unit regardless of its geographical origin – although this assumption is itself challenged when one distinguishes between avoided carbon, removed carbon, and sequestered carbon, or when one incorporates the issues of permanence and additionality. Biodiversity, on the other hand, obeys a radically different logic, since it is by its very nature localized, contextual, and non-substitutable²⁸⁸. The ecological richness of a specific site – the interactions between species, the dynamics specific to a habitat, the evolutionary memory of an ecosystem – cannot be compensated for by improvements made in another region of the world.²⁸⁹

No single metric can capture all the characteristics, interactions, and values of a complex living system²⁹⁰.²⁹¹ A hectare of restored temperate forest in Europe does not exhibit the same ecological dynamics as a coral reef in Indonesia, and the financial equivalence between the two, if institutionalized by a biodiversity market, would not correspond to any biological reality.

²⁸⁸ Dasgupta, P. (2021). The Economics of Biodiversity: The Dasgupta Review. HM Treasury.

<https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review>

²⁸⁹ Mace, G. M., Meyers, B., Alkemade, R., Biggs, R., Chapin, F. S., Cornell, S. E., ... Woodward, G. (2014). Approaches to defining a planetary boundary for biodiversity. *Global Environmental Change*, 28, 289–297.

<https://doi.org/10.1016/j.gloenvcha.2014.07.009>

²⁹⁰ The Nature Conservancy. (2024). One future, many voices: 2024 annual report.

<https://www.nature.org/en-us/about-us/who-we-are/accountability/annual-report/2024-annual-report/>

²⁹¹ Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., ... Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, 486(7401), 59–67. <https://doi.org/10.1038/nature11148>

Treating complex ecosystems as interchangeable tokens, without requiring a strictly defined ecological equivalence, risks facilitating a net loss of the most threatened species and habitats, thus undermining the very conservation goals that these markets are supposed to fund²⁹².

Some players are seeking to address this risk through "high integrity" verification architectures. **EcoBridge**, in partnership with **Regen Network** since November 2024, is developing a real-time verification platform, scan.ecotoken.earth²⁹³ aiming to maintain differentiated ecological quality criteria as credits circulate between more than seventy chains via the CCEP protocol. The stated challenge is precisely that identified in this section: to prevent cross-chain liquidity from leveling ecological quality downwards by treating as fungible credits originating from ecosystems whose biological value is fundamentally irreplaceable²⁹⁴.

What environmental economists refer to as the incommensurability of living things, that is, the impossibility of reducing values of a heterogeneous nature to a single scale of comparison²⁹⁵. This constitutes a limitation that technological sophistication alone cannot overcome. Digitizing an ecological indicator does not resolve the question of its representativeness, but it amplifies its effects, both positive and negative.

Faced with this tension between financial fungibility and ecological non-substitutability, a design approach is emerging in the Web 3 ecosystem under the term "*conditional fungibility*."

²⁹² Wunder, S., et al. (2025). Biodiversity credits: An overview of the current state, future opportunities, and potential pitfalls. *Business Strategy and the Environment*.

<https://doi.org/10.1002/bse.70018>

²⁹³ <https://scan.ecotoken.earth/>

²⁹⁴ EcoBridge / EcoToken, 2025,

<https://medium.com/regen-network/ecotoken-partners-with-regen-network-to-bring-ecocredits-to-all-web3-ecosystems-8fea8b28f82b>

²⁹⁵ Martinez-Alier, J., Munda, G., & O'Neill, J. (1998). Weak comparability of values as a foundation for ecological economics. *Ecological Economics*, 26(3), 277–286. [https://doi.org/10.1016/S0921-8009\(97\)00120-1](https://doi.org/10.1016/S0921-8009(97)00120-1)

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This refers to the ability of a digital asset to be exchangeable within a defined class, but not interchangeable with assets of another class. The conditions for switching between classes are themselves configurable and adjustable by the protocol's governance. The concept extends a fundamental analytical distinction in the design of digital assets: that between so-called fungible tokens, i.e., interchangeable, and non-fungible tokens, also called NFTs (Non-Fungible Tokens), which are unique by definition. Conditional fungibility introduces an intermediate state: semi-fungible assets, exchangeable with each other only when they satisfy a set of shared ecological criteria.

The redesign of the **KlimaDAO** protocol under the name Klima 2.0, documented in this section, illustrates this approach: carbon credits are organized into "carbon classes" whose internal interchangeability can be dynamically adjusted according to methodological and geographical criteria²⁹⁶.

This architecture does not resolve the problem of the incommensurability of living organisms posed by environmental economists (a hectare of mangrove does not become a substitute for a hectare of boreal forest simply because a protocol classifies them differently), but it represents an attempt at a design that acknowledges non-fungibility rather than ignoring it, by imposing quality constraints within the exchange infrastructure itself. Its actual effectiveness will depend, as with the verification mechanisms analyzed in section 2.1, on the rigor of the classification criteria and the independence of the governance that defines them.

2.2.3 Power asymmetries

The integration of Web3 technologies into the sustainable finance sector raises a question that decentralizing rhetoric tends to obscure: that of the power relations that these systems reproduce, or even amplify. Two distinct dimensions deserve to be distinguished. The first is internal to the protocols themselves: the governance mechanisms of decentralized ecosystems structurally concentrate influence in the hands of those who hold the most capital or the most tokens. The second is geopolitical: when applied to countries of the Global South, regenerative finance (ReFi*) solutions risk reproducing patterns of extraction and dependency that technological innovation does not automatically neutralize.

2.2.3.1 The illusion of genuine decentralization

The fundamental promise of Web 3 rests on the advent of horizontal and democratic governance. Empirical analysis of decentralized ecosystems leads to a substantial qualification of this promise, to the point that some researchers speak of an "illusion of decentralization."²⁹⁷ In practice, efficiency constraints and consensus mechanisms tend to concentrate power. The proof-of-stake consensus mechanism*, although less energy-intensive than proof-of-work*, inherently favors the concentration of influence in favor of those who already hold the most capital, since the probability of a node being selected to validate a block is indeed proportional to the amount of tokens staked, which tends to consolidate existing positions.²⁹⁸

This asymmetry is also found within Decentralized Autonomous Organizations (DAOs*).

²⁹⁶ Klima Protocol (2026). Klima 2.0 Whitepaper. <https://whitepaper.klimaprotocol.com/>; See also: Rawson, P. & Borreani, L. (2026). The Green Crypto Handbook, CRC Press, chapter 5, for an analysis of fungibility transformations in digital green assets.

²⁹⁷ Abid, A., & Farooq, O. (2026). The illusion of the Web3 decentralization <https://doi.org/10.2139/ssrn.5008910>

²⁹⁸ Bank for International Settlements. (2021). Annual Economic Report 2021, Chapter III: CBDCs: an opportunity for the monetary system. BIS. <https://www.bis.org/publ/arpdf/ar2021e3.htm>

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Their governance models are most often based on token-weighted voting, an architecture that fosters the emergence of a plutocracy where decision-making influence is strictly proportional to the capital held.²⁹⁹ Large holders – often referred to in ecosystem jargon as whales, a term that designates actors whose holdings are large enough to influence markets – or the technical founders who allocated themselves a significant fraction of the tokens at the launch of the protocol thus have a decision-making weight that small holders cannot counterbalance, even if they participate massively in the votes.

To this first imbalance is added a second, of a sociological nature: voter turnout rarely exceeds 10% in the documented DAOs, effectively leaving structuring decisions in the hands of a minority of large, active shareholders³⁰⁰. These two phenomena, plutocratic concentration by design and the apathy of minority participants, are cumulative and do not simply resolve one another: addressing the latter would not be enough to correct the former. Far from redistributing power equitably, technology risks generating a new technocratic and financial elite in this context, whose interests do not necessarily align with the stated objectives of impact.

This dynamic of reconcentration is not specific to any particular failing implementation; it stems from structural properties of the consensus mechanisms themselves. Academic research has developed several instruments to quantify the degree of decentralization of a system. The Nakamoto Coefficient expresses the minimum number of actors who would need to collude to compromise the security or governance of a given protocol; Gini coefficients applied to the distribution of governance tokens map inequalities in decision-making power with a

precision comparable to that of income inequality analysis. These approaches coexist with other indicators used in the literature, notably Shannon entropy, the number of active nodes, and the Herfindahl-Hirschman index, to analyze the degree of decentralization in the crypto ecosystem. These instruments reveal a constant: networks exhibiting technical decentralization at the infrastructure level (distributed nodes, permissioned participation) maintain political centralization at the governance level.

The distinction is analytically crucial. As stated in the report *Balancing Code and Law* produced by the Stanford Cyber Policy Center³⁰¹ “Blockchain systems do not eliminate trust or power; they redistribute them.” This redistribution, in practice, tends to consolidate the positions of early adopters, major validators, and founding teams with disproportionate initial allocations. The most direct assessment of this phenomenon remains what researchers call the Bahamas test: would a protocol survive the sudden disappearance of its founders, like Satoshi Nakamoto? In almost all documented ReFi ecosystems, the answer is no, revealing less a design flaw than an inherent limitation of distributed governance when the human and financial resources that make it work remain concentrated in the hands of a few³⁰².

These diagnostic observations (plutocratic concentration, apathy among minority groups, dependence on founders) nevertheless call for a design-based response, not just a descriptive one. Recent literature on crypto-institutions with an ecological focus identifies four structural tensions that any designer of decentralized governance must arbitrate, and whose arbitration determines whether the protocol will reproduce or correct

²⁹⁹ Esposito, M., Tse, T., & Goh, D. (2025). Decentralizing governance: exploring the dynamics and challenges of digital commons and DAOs*. *Frontiers in Blockchain*, 8, 1538227. <https://doi.org/10.3389/fbloc.2025.1538227>

³⁰⁰ *Ibid.*

³⁰¹ Sell, F.G. (2026). *Balancing Code and Law: Governance and Policy Challenges of Blockchain*. Stanford Cyber Policy Center, Program on Governance of Emerging Technologies. Stanford University. <https://fsi.stanford.edu/publication/balancing-code-and-law-governance-and-policy-challenges-blockchain>

³⁰² *Ibid.*

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the asymmetries documented above³⁰³. The first contrasts decentralization and coordination: a more distributed governance is more resistant to capture, but slows down decisions, whereas a conservation project facing a fire or an invasive species requires a rapid response capacity, which argues for emergency authority mechanisms coexisting with a broad distribution of power in ordinary times.

The second contrasts transparency and confidentiality: open registries strengthen trust, but locating land guardians, endangered species sites, or community financial data can expose vulnerable populations, a tension that zero-knowledge proofs, documented in section 2.1.2.2, are beginning to address at the technical level. The third contrasts financial incentives and genuine participation: token rewards attract liquidity but also extractive actors, while reputation-based systems filter out genuine engagement but limit growth. The fourth, perhaps the most decisive, contrasts territorial rootedness and digital detachment: Will Ruddick, designer of the **Grassroots Economics** community currency network documented in section 1.3.3.1, proposes mapping institutions along two axes: proximity (sharing daily life, embodied presence) and accountability (peer oversight, open registries). and shows that the institutions that are close and accountable are those that maintain a sustainable participation beyond speculative cycles³⁰⁴. This framework suggests that the problem documented in this section (the reconcentration of power in DAOs*) is less an inherent flaw in the technology than a predictable consequence of the territorial uprooting of protocols designed for global markets rather than for situated communities.

³⁰³Rawson, P. & Borreani, L. (2026). The Green Crypto Handbook: Blockchain for Sustainability Professionals, CRC Press, chapter 4.

³⁰⁴Ruddick, W. (2025). Community of Practice Framework. Grassroots Economics. Quoted in Rawson & Borreani (2026), ibid.

2.2.3.2 The risk of crypto-colonialism and green grabbing

The application of Regenerative Finance (ReFi) solutions in the Global South also raises ethical, social, and territorial questions that academic literature documents under two complementary concepts. The first is that of crypto-colonialism, referring to the process by which distributed ledger technology reproduces historical patterns of exploitation and economic dependence in the Global South under the guise of benevolent innovation.*³⁰⁵ The second is that of green grabbing (or virtual land grabs), which refers to the process by which the rights of local communities to their natural resources are erased in favor of green investments and speculation on ecological assets³⁰⁶.

One example illustrates the convergence of these two risks in the field of digital identities: the **Worldcoin** project.³⁰⁷ organized the collection of biometric data, via iris scans, from populations in developing countries in exchange for a distribution of crypto-assets, raising major controversies regarding informed consent and privacy protection³⁰⁸. This approach carries a risk of converting sensitive identity data of displaced or marginalized people into transactional digital fingerprints that can be exploited by private entities³⁰⁹. Within the framework of partnerships involving international agencies enjoying legal immunity, this dynamic

³⁰⁵Colón Cruz, M.D.L.M. (2022). Blockchain Island A critical discourse analysis of the colonial construction of a Puerto Rican crypto utopia. No. 264 Media@LSE, London School of Economics and Political Science. <https://www.lse.ac.uk/media-and-communications/assets/documents/research/msc-dissertations/2021/Colo%CC%81n.pdf>

³⁰⁶Howson, P., Rosales, A., Jutel, O., Gloerich, I., Llorens, M. G., de Vries, A., et al. (2024). Crypto/space: computational parasitism, virtual land grabs, and the production of Web3 'exit zones'. Political Geography, 115, 1–11. <https://doi.org/10.1016/j.polgeo.2024.103210>

³⁰⁷<https://world.org/>

³⁰⁸Nothias, T. (2025). An intellectual history of digital colonialism. Journal of Communication. <https://doi.org/10.1093/joc/jqaf003>

³⁰⁹Lemberg-Pedersen, M., and Haioty, E. (2020). Re-assembling the monitorable refugee body in the era of data-craving. Citizenship Studies, 24(5), 607–624. <https://doi.org/10.1080/13621025.2020.1784641>

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generates what Lemberg-Pedersen and Haioty (2020) describe as outsourcing loopholes where *"private technology companies can thus test new digital tools on populations in the Global South without assuming direct legal responsibility in the event of rights violations"*³¹⁰. Researchers have shown that these identifiers, imposed from the outside rather than developed with the communities concerned, risk strengthening bureaucratic and commercial control over the most vulnerable populations rather than empowering them³¹¹.

This asymmetry is not limited to biometric identity systems. In the area of on-chain* SME lending, **Untangled Finance**, which structures the financing of African trade receivables via tokenized pools on **Celo**, restricts access to its pools to only accredited (US regime) and sophisticated (EEA/UK regime) investors. Sub-Saharan African SMEs, whose receivables form the underlying asset of these instruments, have no say in the governance of the pool that finances them: the value generated by their economic activity is captured by global institutional investors, according to a logic structurally analogous to that documented in traditional emerging market credit markets³¹².

In terms of land and the environment, the large-scale acquisition of carbon rights illustrates the territorial tensions generated by the financialization of life. According to the Rights and Resources Initiative coalition (2024)³¹³ The Dubai-based company Blue Carbon Inc. has signed memoranda of understanding covering carbon credit trading rights for approximately 20% of Zimbabwe, 10% of Zambia, 10% of Liberia, and 8% of Tanzania, areas of exceptional size. These agreements were reportedly concluded without public consultation or the free,

informed consent of the people living in these territories.³¹⁴ Documented cases show that this logic can lead to forced displacement of populations under the guise of carbon offset projects, as illustrated by the situation of the Ogiek people in Kenya³¹⁵.

2.3 Conditions for scaling up: financing, identity and regulation

The two preceding sections mapped the systemic risks inherent in the current architecture of Regenerative Finance: dependence on oracles*, the incentive distortions of tokenized measurement, the risk of hyper-financialization of life, and the power asymmetries that decentralized protocols tend to reproduce in new forms. These risks are real and documented. They do not condemn the ReFi* project, they clarify the conditions for its realization.

The question is not whether new digital architectures can, in the abstract, improve the verifiability of impact and direct capital towards regeneration. The experiments documented in this report show that they can, under specific conditions. The question is under what conditions these local experiments can become a fully-fledged financial system, capable of attracting institutional capital, operating within recognized legal frameworks, and functioning for populations whose access to digital technology is not guaranteed.

This section examines three categories of conditions. The first is economic: how to overcome the financing trilemma that confines most ReFi* projects between

³¹⁰ *Ibid.*

³¹¹ Cheesman, M. (2020). Self-sovereignty for refugees? The contested horizons of digital identity. *Geopolitics*, 27(1), 134–159.

<https://doi.org/10.1080/14650045.2020.1823836>

³¹² Untangled Finance, 2025, <https://untangled.finance>

³¹³ <https://rightsandresources.org/>

³¹⁴ Rights and Resources Initiative. (2024). State of Carbon Rights of Indigenous Peoples, Local Communities, and Afro-descendant Peoples in Tropical and Subtropical Lands and Forests (Information Note). Rights and Resources Initiative (RRI).

<https://rightsandresources.org/fr/publication/etat-des-droits-sur-le-carbone-2024/>

³¹⁵ Marshall, C. (2023, November 9). Kenya's Ogiek People Being Evicted for Carbon Credits – Lawyers. BBC News. <https://www.bbc.com/news/world-africa-67352067>

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profitability criteria incompatible with venture capital logic and insufficient philanthropic resources. The second is infrastructural: how to build decentralized identity systems that truly serve populations excluded from centralized systems, without reproducing the data and governance asymmetries that these systems generated. The third is regulatory and institutional: how can Regenerative Finance integrate with the normative frameworks of traditional finance, CSRD, MiCA, TNFD, without being absorbed by them, and without creating an additional area of opacity for institutional investors?

2.3.1 The economic challenge: overcoming the financing and adoption trilemma

Among the obstacles to scaling up Regenerative Finance, the economic obstacle is structurally the most immediate. ReFi* encounters a paradoxical situation that the sector refers to, without yet having a stable academic formulation, as a financing trilemma: projects aiming for a systemic transformation of the relationship between the economy and ecosystems inherently have long maturity horizons, uncertain short-term financial returns, and a dependence on verification mechanisms whose costs remain high. These three characteristics make them structurally ineligible for the criteria of venture capital funds and too complex for traditional philanthropic calls for projects.

This section first examines ways in which this trilemma can be mitigated, in particular by formalizing an “economic proof” of the value of regeneration for institutional investors, and by using blended finance mechanisms that leverage first-loss public or philanthropic capital to catalyze private capital inflows. It then examines the complementary challenge of market adoption, which involves building products accessible to investors who are not specialists in decentralized protocols, and thus masking the technical complexity without masking the risks.

2.3.1.1 Overcoming the trilemma of financing through “economic proof”

The transition from an experimental phase to scaling up confronts ReFi* projects with what the sector refers to, without yet having a stable academic formulation, as a “*financing trilemma*.” This trilemma describes the difficulty of simultaneously reconciling access to sufficient capital, the scale of financing needed to generate a systemic impact, and the commercial viability of the underlying business models³¹⁶. Because they prioritize the long-term restoration of ecosystems and the inclusivity of beneficiaries rather than the extraction of short-term returns, many ReFi* projects struggle to meet the exponential growth criteria demanded by venture capital funds. Unable to attract these investors, they find themselves confined to a highly competitive grant ecosystem, where available resources remain structurally insufficient to ensure large-scale development³¹⁷.

To break free from this dependence on philanthropic funding and capture the attention of institutional investors, the sector is led to formalize what Dumont (2026) calls “economic proof” – establishing that investment in the capabilities of living systems is not a cost or a compliance measure, but that companies that “*anchor their model in living systems*” *reduce their exposure to shocks (climate, regulatory, social) and secure their territorial anchoring*³¹⁸, thus generating a structurally more resilient cash flow profile.

Without the accounting and financial formalization of this economic proof, institutional capital will continue to view the impact as a constraint accepted despite the

³¹⁶ CARBON Copy. (2024). The State of ReFi Report 2024. <https://carboncopy.news/reports/The%20State%20of%20ReFi%20Report%202024.pdf>

³¹⁷ *Ibid.*

³¹⁸ Dumont, J. (2026). White Paper – What the regeneration of living organisms changes for business decisions. We Are Alive. <https://noussoinmesvivants.co/livre-blanc-ce-que-regeneration-veut-dire-pour-une-entreprise/>

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risk, and not as a structuring factor of long-term return.



AAVE and **Sky** have shown that DeFi protocols can generate sustainable revenue comparable to that of traditional financial institutions, without state-backed deposits or a banking license. With a Total Value Locked (TVL) between \$34 billion and \$44 billion in 2025 and estimated annualized revenue between \$100 million and \$120 million, **AAVE** generates cash flow comparable to that of a mid-sized regional bank, but without regulatory capital, a branch network, or a sovereign guarantee.³¹⁹ The closure without penalty of the investigation by the US Securities and Exchange Commission (SEC) in December 2024 and the institutional partnerships with Circle, Franklin Templeton and VanEck (via **AAVE** Horizon, deployed for the tokenization of money market funds) are regulatory validation signals that institutional investors have begun to integrate into their risk analyses.

Sky (formerly **MakerDAO**), whose protocol issues the USDS stablecoin via decentralized collateral vaults*, projects gross revenue of \$611.5 million for 2026, an 81% year-over-year increase, with net income of \$157.8 million, profitability ratios exceeding those of many comparable-sized commercial banks.³²⁰ These two examples do not invalidate criticisms of DeFi's systemic impact limitations, but they demonstrate that the economic sustainability of a bank-scale decentralized protocol is now a verifiable reality, not a prospective hypothesis. This reality constitutes the first credible argument to institutional investors skeptical of ReFi's economic viability.

³¹⁹ DefiLlama, 2025, <https://defillama.com/protocol/aave>

³²⁰ BlockEden, 2026, <https://blockeden.xyz/blog/2026/04/03/dai-usds-migration-makerdao-sky-protocol-stablecoin-rebrand/>

To address this challenge, practitioners and observers in the sector are proposing new approaches to capital allocation. One of these is known as ergodic ecosystem investing³²¹. (Ergodic Ecosystem Investing, or EEI) is inspired by the theoretical framework developed by economist Ole Peters on ergodicity in economics³²². This framework shows that under the dynamics of compound returns, the average growth observed across a group of investors diverges from the growth experienced by each individual investor over time – exposing the latter, in the isolated case, to a risk of ruin.³²³ Irreversible even when the aggregate average is positive. Ergodic ecosystem investing (EEI) therefore posits that investing in an ecosystem of interconnected and collaborative projects produces more stable returns and reduces this risk of individual ruin, while also allowing for the pooling of resources during periods of crisis³²⁴.

2.3.1.2 Towards ecosystem investments and blended finance

The second challenge of scaling up is market adoption. A significant number of ReFi protocols initially targeted a highly speculative audience, native to the crypto ecosystem and known in industry jargon as "degens," attracted by maximizing short-term returns.

³²¹ Ergodic: That which allows the statistical determination of all realizations of a random process from a single realization of that process. CNRTL

<https://www.cnrtl.fr/definition/ergodique>

³²² Peters, O. (2019). The ergodicity problem in economics. *Nature Physics*, 15(12), 1216–1221.

<https://doi.org/10.1038/s41567-019-0732-0>

³²³ In this context, an isolated ReFi* project, even one with a generally sound business model, is exposed to the risk that its specific time trajectory, a liquidity shock, a downturn, oracle failure, will lead it to a point of no return before it has had a chance to capitalize on its long-term prospects. Investing in an interconnected ecosystem of projects aims to make the collective system more ergodic: by sharing resources and pooling risks among related entities, the probability of a specific shock permanently exhausting a given project is reduced, and the individual trajectory of each component is brought closer to the collective average.

³²⁴ CARBON Copy. (2025). The State of ReFi Report 2025. <https://carboncopy.news/reports/The%20State%20of%20ReFi%20Report%202025.pdf>

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This approach proved to be a dead end: this segment, while possessing capital, generally does not prioritize environmental sustainability in its investment criteria.³²⁵

[B] The great transfer of wealth: a structural recomposition of demand

The adoption challenge facing regenerative finance (ReFi*) is not solely due to technical complexity or the profitability of protocols. It also lies in the composition of institutional capital, which is undergoing a transformation driven by a documented demographic phenomenon: the intergenerational transfer of wealth. Cerulli Associates estimates that \$124 trillion of wealth will change hands by 2048³²⁶.

However, available surveys document significantly different allocation preferences among the heirs of this capital. According to the Morgan Stanley Institute for Sustainable Investing's Sustainable Signals 2025, a survey of 1,765 active investors with over \$100,000 in investable assets across three geographic regions, 97% of millennials and 99% of Generation Z members report being interested in sustainable investing, compared to significantly lower proportions among baby boomers.³²⁷

Capgemini's World Wealth Report 2025 confirms that 88% of wealth managers are observing an increased appetite for alternative assets among their younger clients and a tendency to combine

profitability with extra-financial criteria³²⁸. Specific sector surveys also document that this appetite for alternative assets increasingly includes digital assets: among wealthy investors aged 21 to 43, 49% reported holding crypto-assets and 14% of their portfolios were allocated to them, compared to 1% among their elders³²⁹.

These figures, however, warrant careful interpretation. An annual survey of 2,072 American investors conducted by David Larcker, Amit Seru, and Brian Tayan for Stanford Graduate School of Business, the Hoover Institution, and the Rock Center for Corporate Governance shows that in 2024, only 11% of young investors considered it "extremely important" for investment firms to exert their influence in favor of environmental priorities, compared to 44% in 2022 and 27% in 2023, a decline the authors attribute to inflationary pressures during this period.³³⁰ The stated preference for impact investing does not automatically translate into actual allocation and remains sensitive to macroeconomic conditions; these figures indicate a demand variable in formation, not a market guarantee.

Scaling up would require building products accessible to traditional finance investors and non-specialist end users, which implies masking the inherent technical complexity of Web3, particularly the management of crypto

³²⁵ *Ibid.*

³²⁶ Cerulli Associates. (2024). Cerulli anticipates \$124 trillion in wealth will transfer through 2048. <https://www.cerulli.com/press-releases/cerulli-anticipates-124-trillion-in-wealth-will-transfer-through-2048>

³²⁷ Morgan Stanley Institute for Sustainable Investing. (2025). Sustainable signals: Individual investors 2025. https://www.morganstanley.com/content/dam/msdotcom/en/assets/pdfs/2025_Sustainable_Signals_Individual_Investors_2025_report.pdf

³²⁸ Capgemini Research Institute. (2025). World wealth report 2025: Sail the great wealth transfer. <https://www.capgemini.com/insights/research-library/world-wealth-report/>

³²⁹ Bank of America Private Bank. (2024, June). 2024 Bank of America Private Bank study of wealthy Americans: As wealth transfer continues, outlooks and emotions influence financial decisions. Bank of America Corporation. <https://newsroom.bankofamerica.com/content/newsroom/press-releases/2024/06/bofa-private-bank-study-of-wealthy-americans-finds-generational.html>

³³⁰ Larcker, D., Seru, A., & Tayan, B. (2024). 2024 survey: Investors, retirement savings & ESG. Stanford Graduate School of Business; Hoover Institution Working Group on Corporate Governance; Rock Center for Corporate Governance. <https://gsb.stanford.edu/faculty-research/publications/2024-survey-investors-retirement-savings-esg>

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wallets and the execution of smart contracts*. Industry players suggest that integrating conversational interfaces based on Large Language Models (LLMs) could help reduce this technical friction, enabling smoother allocation to instruments that link financial returns with environmental impact.³³¹ This hypothesis remains prospective at this stage and is not supported by large-scale usage data.

In terms of financing structures, mixed finance³³² (Blended finance) is a lever identified by academic and institutional literature³³³. Long before the emergence of Web 3.0, this mechanism mobilizes public or private capital to create a first loss tranche, absorbing the first potential defaults and thus reducing the risk profile of projects for private institutional investors. In a ReFi context, this architecture can be implemented through smart contracts that automate the activation of this protection, making the triggering conditions transparent and verifiable for all parties.

Projects documented in this report implement these architectures at varying stages of development. **Empowa**, deployed in Mozambique and now in discussions with the Nairobi Securities Exchange (NSE) for a Kenyan deployment, combines African institutional capital (NSE), crypto capital (EMP token on Cardano), and Project Catalyst grants to finance affordable housing: each component absorbs a different level of risk, allowing the institutional tranche to enter into a risk profile compatible with its mandates³³⁴. **MiniPay**, with its 8 million wallets activated via the Opera mobile browser, illustrates the logic

of ecosystemic investment on another scale: Opera finances mobile rail infrastructure and third-party projects (Haraka)³³⁵ (**GoodDollar**, **ImpactMarket**) are deploying on this platform without replicating their own user acquisition costs, pooling the infrastructure as a digital common good³³⁶. In the field of financing European private impact markets, **Dowgo** seeks to connect project promoters and professional investors in a segment structurally neglected by traditional institutional channels, with more than 300 million euros of identified projects awaiting distribution.

Finally, investment vehicles specifically designed for the real economy are emerging to try to operationalize regenerative finance at the local level. Impact Search Funds (ISFs), by adapting the acquisition-based entrepreneurship model, allow entrepreneurs to acquire small and medium-sized enterprises (SMEs) essential to a local community, in sectors such as agriculture, health, or education, in order to transform them sustainably, prioritizing the long-term viability of the asset within the community and the resilience of stakeholders rather than a short-term financial exit³³⁷. This model, still in the experimental and formalization phase, illustrates how new instruments can attempt to link institutional capital to the vitality of territories – provided that their economic and social performance is rigorously and independently documented.

A structural obstacle to scaling up, which previous developments only indirectly

³³¹ CARBON Copy. (2025). The State of ReFi* Report 2025. <https://carboncopy.news/reports/The%20State%20of%20ReFi%20Report%202025.pdf>

³³² OECD (2018), Making Blended Finance Work for the Sustainable Development Goals. OECD Publishing, Paris, <https://doi.org/10.1787/9789264288768-en>.

³³³ Convergence. (2023). The State of Blended Finance 2023. <https://www.convergence.finance/resource/state-of-blended-finance-2023/view>

³³⁴ Empowa, 2025, <https://bitcoinke.io/2024/08/empowa-proposes-tokenization-solution-for-kenya-housing-market/>

³³⁵ Today we are shutting down the Bondy app and winding Haraka down, may, 2026 https://www.linkedin.com/posts/haraka-xyz_today-we-are-shutting-down-the-bondy-app-activity-7455981055758749696-SWA5

³³⁶ MiniPay, 2025, <https://minipay.to/blog/minipay-2-years-stablecoins-ever-yday-payments>

³³⁷ Reyazat, F. (2025). The Impact Search Fund: A Regenerative Finance Approach to Transforming Community-Rooted Entrepreneurship. Reyazat Institute Papers. <https://www.reyazat.com/2025/11/14/the-impact-search-fund-a-regenerative-finance-approach-to-transforming-community-rooted-entrepreneurship/>

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address, is the operational isolation of Regenerative Finance (ReFi*) protocols from one another. Each project documented in this report (from **GainForest** to **EthicHub**, from **Kolektivo** to **Regen Network**) operates according to its own governance architecture, its own ledgers, and its own financing mechanisms, without systematic institutional interoperability. However, the environmental problems that these protocols seek to solve do not respect the boundaries of each project: a watershed crosses several jurisdictions, a migratory species does not know the limits of a geolocated carbon credit. Inter-DAO (DAO-to-DAO, D2D) coordination mechanisms are beginning to emerge to address this fragmentation. Among those documented in recent literature are co-collateralized liquidity pools, in which two crypto-institutions pool assets to stabilize their exchanges; co-insurance, joint funds released under certain ecological or climatic conditions for the benefit of participants in both networks; and data pooling, whereby institutions collaborate to aggregate, share and license environmental data whose value increases with the scale of aggregation.³³⁸

The Sarafu network in Kenya concretely illustrates this logic at the community level: two distinct local currencies have established an inter-community liquidity pool allowing cross-exchanges between their respective economies, with documented empirical results.³³⁹ The transposition of these D2D mechanisms to the bioregional scale (between, for example, a forest carbon credit protocol and an agricultural micro-insurance protocol operating on the same territory) constitutes one of the conditions for the transition of Regenerative Finance from the stage of local experimentation to that of an integrated financial infrastructure.

2.3.2 The digital identity infrastructure

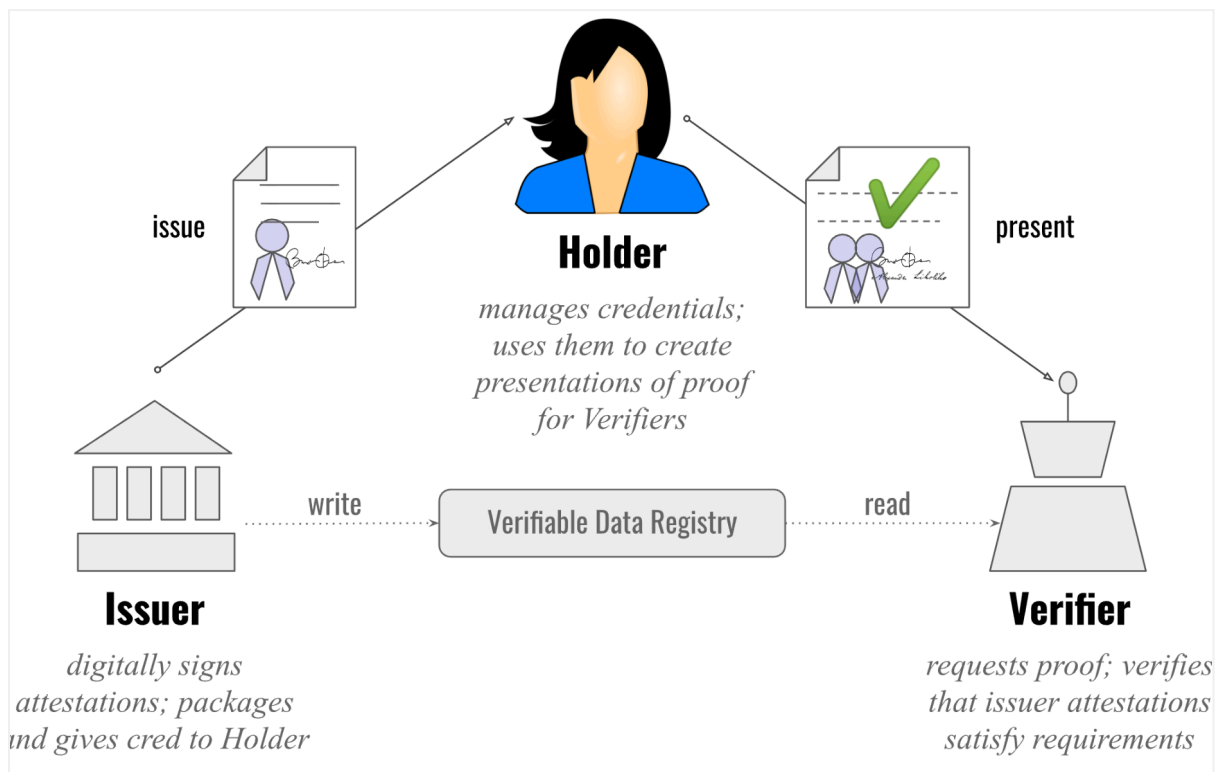
The second structural condition for scaling up is less frequently discussed than financing, but it is the unspoken prerequisite: without the ability to reliably, portably, and sovereignly identify borrowers, project initiators, and local intermediaries, none of the ReFi instruments examined in this report, Micro-DeFi*, community inclusion currencies, and impact verification systems, can operate at scale. The reason is structural: the populations these instruments seek to reach are precisely those that centralized identity systems have historically served the worst, unbanked, without a credit history, and invisible to formal capital markets.

Decentralized Identifiers (DIDs) and Verifiable Credentials (AVs) offer an architectural response to this constraint: enabling an individual or organization to prove their eligibility for funding, build a portable credit history, or demonstrate the reality of an impact, without relying on a centralized database or an intermediary with exclusive control. This is less a question of technology than a question of identity data governance, and it is in this capacity that it shapes all the mechanisms examined in this report.

This section examines the first operational deployments of this model in impact investing contexts, and then the obstacles hindering its widespread adoption: fragmentation of standards among stakeholders, institutional resistance to interoperability, and the risk that identity decentralization will reproduce, in a new form, the very power asymmetries it purports to correct.

³³⁸Rawson, P. & Borreani, L. (2026). *The Green Crypto Handbook: Blockchain for Sustainability Professionals*, CRC Press, chapter 5 – Table 5.4: “DAO-to-DAO Collaborative Policies”.

³³⁹Ruddick, W. (2023). “Commitment Pooling”. *International Journal of Community Currency Research*, 27. Grassroots Economics (2025). Sarafu Network. <https://sarafu.network/>



[F] Decentralized identity and verifiable attestations

Source³⁴⁰

2.3.2.1 Decentralized Identifiers (DID) and Impact Financing

Access to credit, investment, and Regenerative Finance instruments rests on a rarely stated assumption: that the actors involved, borrowers, project developers, local organizations, can be reliably, verifiably, and accessibly identified by financial counterparties. This assumption is structurally flawed for a considerable portion of the populations that ReFi aims to serve. According to the World Bank's Identification for Development (ID4D) initiative, nearly one billion people worldwide remain without legally recognized identity, effectively excluding them from formal financial

channels.³⁴¹ An unbanked farmer in Kenya, a rural cooperative in Zambia, a small civil society organization in Senegal do not exist in the databases of formal capital markets. They are solvent, active, and carrying out projects with real impact – and yet financially invisible, lacking an identifier recognizable by institutions outside their territory.

It is precisely this invisibility that the Self-Sovereign Identity (SSI) model seeks to resolve through an architectural break. The SSI paradigm rests on two complementary technical components whose specifications have been ratified as open standards by the World Wide Web Consortium (W3C). Decentralized Identifiers (DIDs)³⁴², adopted as an official W3C recommendation on July 19, 2022, allow an individual or organization to create and control their own digital identity without depending on a central authority, bank, state, or platform.

³⁴¹ World Bank - ID4D Initiative. (2021). Identification for Development (ID4D) Global Dataset.

<https://id4d.worldbank.org/global-dataset>

³⁴² DID, Decentralized Identifiers

<https://www.w3.org/TR/did-core>

³⁴⁰ Hardman, D. Triangle of Trust, 5 November 2019, <https://commons.wikimedia.org/>

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Verifiable credentials*, standardized by the same consortium³⁴³. These are cryptographically signed digital certificates issued by trusted third parties, financial institutions, certifying organizations, local governments, and stored by their holders in a digital identity wallet. Unlike centralized systems that merge the identifier, personal data, and database within a single entity controlled by a third party, this paradigm separates these three elements: the distributed ledger serves only as a public infrastructure to verify the authenticity of signatures, without storing the personal data itself.

In the context of impact finance, the implications are direct. A borrower who has repaid several on-chain microcredit cycles* via a platform like **EthicHub** can build, transaction after transaction, a portable credit history in the form of verifiable attestations* – presentable to any future lender, without depending on a centralized institution as its sole custodian. A local organization that has received a verifiable attestation of its capacity to execute can present it to an impact fund or a blended finance mechanism without submitting a new, complete application to each donor. A project leader can demonstrate the reality of their local roots and partnerships without transmitting all of their operational data to a centralized platform.

These applications remain largely experimental at this stage. Scaling up the SSI model in impact finance contexts faces non-trivial infrastructure requirements, connectivity, equipment, support, and a more fundamental governance question: who issues verifiable attestations*, according to what criteria, and with what liability in case of dispute? The value of a digital identity document (DID) in a financial circuit depends entirely on the trust that counterparties place in its issuers, which merely shifts the issue of trust, without eliminating it. Nevertheless, a few operational

deployments document real-world use cases. In India, **Algorand** connected its custody wallet infrastructure to the DigiLocker national digital identity registry, enabling thousands of rural women borrowers to access formal financing for the first time through an on-chain credit history* built from their verified identity documents.³⁴⁴ **Jia**, active in Kenya and the Philippines, builds an on-chain financial identity* for local SMEs based on total transparency of fund use and repayment rates, substituting verifiable reputation for physical collateral as a guarantee of access to credit – concretely translating the promise of DID in highly informal contexts.³⁴⁵

2.3.2.2 The challenge of global standardization and interoperability

While the architectural promise of decentralized identifiers is real, their usefulness in financial systems depends on a condition that technology alone cannot fulfill: standardization. A DID issued by a protocol is only recognized by a funder if the latter has previously agreed to assign it a value, which presupposes agreement on formats, verification methodologies, and levels of trust among all actors in a given ecosystem. In the absence of such agreements, the proliferation of incompatible decentralized identity systems reproduces, in a technologically sophisticated form, the fragmentation of centralized registries that it claims to correct.

The Decentralized Identity Foundation³⁴⁶(DIF) is working to prevent this pitfall by developing open source libraries³⁴⁷and universal identity

³⁴³ World Wide Web Consortium. (2022). Verifiable Credentials Data Model v1.1. W3C Recommendation. <https://www.w3.org/TR/vc-data-model/>

³⁴⁴ Algorand Foundation, 2025, <https://www.prnewswire.com/news-releases/thousands-of-first-time-women-borrowers-in-india-gain-access-to-formal-finance-through-blockchain-based-credit-scoring-302441299.html>

³⁴⁵ Jia, 2025, <https://www.thisdaylive.com/2025/01/01/blockchain-based-microcredit-promises-to-transform-financial-inclusion-in-africa/>

³⁴⁶ <https://identity.foundation/>

³⁴⁷ Universal Resolver implementation and drivers <https://github.com/decentralized-identity/universal-resolver/>

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resolvers³⁴⁸ allowing heterogeneous systems to interpret each other, thus laying the technical foundations for global interoperability.

At the level of legal entities, the verifiable Legal Entity Identifier (vLEI) standard, managed by the Global Legal Entity Identifier Foundation (GLEIF)³⁴⁹ vLEI represents the most advanced standardization effort to date. It cryptographically combines three sources of identity, the entity's identity represented by its LEI code, an individual's personal identity, and that individual's official role within the organization, enabling instant and automated verification in any type of digital interaction, from signing regulatory reports to authorizing payments and conducting due diligence in supply chains. In the context of impact finance, this infrastructure is particularly relevant for small, local organizations that currently have to repeat the same due diligence processes with each donor, absorbing a significant portion of their operational resources in audit and reporting costs. The potential of vLEI to reduce these frictions in financing small and medium-sized enterprises was documented at the first global vLEI hackathon organized by GLEIF in 2025, where winning teams demonstrated direct applications to agricultural access to credit in Africa and Asia.³⁵⁰

In the field of impact evidence, a similar evolution is observed. **Hypercerts** V2 adopts the off-chain ATProtocol combined with the Ethereum Attestation Service (EAS) as its attestation infrastructure, with cross-app credentials allowing any impact registry (carbon, education, health, science) to

connect to the same certification layer without conversion or recertification³⁵¹. For biodiversity and carbon credits, **Regen Network** faces an architectural decision whose key issue is global interoperability: remaining on the Cosmos SDK or migrating to an EVM environment will determine whether ecocredits certified on **Regen Network** are directly usable by buyers operating on Ethereum, Polygon, or **Celo**, or whether they will require costly gateways that weaken the chain of proof³⁵². **Mento Labs** addressed a version of this issue for its stablecoins by explicitly adopting the **Chainlink** Data Standard in May 2025 to secure its automated market maker (vAMM), and by deploying Squid Router integration to ensure cross-chain transferability of cUSD without compromising the integrity of the reserve mechanism.³⁵³

The **Tadamon** platform concretely illustrates this dynamic surrounding digital identity within the context of civil society. Bringing together some 5,200 organizations in 57 member countries of the Organisation of Islamic Cooperation (OIC), the platform has partnered with the Cardano Foundation to integrate a decentralized identity wallet – the “**Tadamon ID**.” Each local organization creates its own decentralized identifier and receives a cryptographically signed, verifiable attestation, which it can instantly present to various donors – including the United Nations Development Programme (UNDP) and the Islamic Development Bank (IsDB) – without having to submit a new verification file each time.³⁵⁴

This case illustrates both the potential of the model and the conditions for its success. Interoperability cannot be decreed technically:

³⁴⁸ The Universal Resolver resolves Decentralized Identifiers (DIDs) using many different DID methods, based on the W3C DID Core 1.0 and DID Resolution specifications. It is a work item of the DIF (Decentralized Identity Foundation) Identifiers & Discovery working group <https://resolver.identity.foundation/>

³⁴⁹ Global Legal Entity Identifier Foundation (GLEIF). (2020–2026). The Verifiable LEI (vLEI). <https://www.gleif.org/en/organizational-identity/lei-vlei/the-verifiable-lei-vlei>; full technical documentation:

³⁵⁰ The verifiable LEI (vLEI) <https://www.gleif.org/en/organizational-identity/lei-vlei/the-verifiable-lei-vlei>

³⁵¹ Hypercerts, 2025, <https://docs.hypercerts.org/core-concepts/what-is-hypercerts>

³⁵² Regen Network, 2025, <https://docs.regen.network/modules/ecocredit/>

³⁵³ Mento Labs, 2025, <https://www.mento.org>

³⁵⁴ Cardano Foundation. (2023). UNDP Tadamon - Case Study. <https://cardanofoundation.org/case-studies?search=UNDP>

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it requires prior agreement between competing institutions on the standards to be adopted, a willingness to share the verification infrastructure rather than retaining it as a competitive advantage, and system governance that does not, under the guise of decentralization, recentralize accreditation power in the hands of the most technically advanced actors. Without these political and institutional conditions, the standardization of decentralized identifiers will remain a technical undertaking with no real financial impact.

2.3.3 Hybridization and the double regulatory constraint

The third constraint on scaling up is the one that ReFi players tend to mention last in their roadmaps, yet it proves to be one of the most crucial for attracting institutional capital: the clarity of the regulatory framework. Regenerative Finance operates at the intersection of two regulatory universes whose legal frameworks are evolving rapidly but in an uncoordinated manner – sustainable finance, structured by the Corporate Sustainability Reporting Directive (CSRD), the Financial Services Sustainability Disclosure Regulation (SFDR), and the EU Green Taxonomy on the one hand; and the crypto-asset economy, governed by the Markets in Crypto-Asset (MiCA) Regulation on the other.

To these two normative constraints is added a third, more fundamental one, which legal practice is only now beginning to formalize: the question of the responsibility of human actors within systems designed to operate without them. The thesis of alegality (the idea that decentralized protocols establish themselves in a lawless space, governed solely by their code) is proving, in light of recent case law, to be far less robust than its proponents assume. Several developments illustrate this evolution. In the United States, the Fifth Circuit recognized, in the **Tornado Cash** case, that immutable smart contracts do not constitute "property" subject to seizure under economic sanctions law, insofar as no human actor controls them, thus partially validating the alegatist thesis for autonomous code. But this same decision confirmed that the founders of the protocol remain fully subject to criminal law: alegality protects the code, not the individuals who designed it. In the realm of Decentralized Autonomous Organizations (DAOs*), US jurisdictions have progressively reclassified unincorporated DAOs as general partnerships, exposing governance token holders to joint and several unlimited liability, the exact opposite of the

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promise of decentralized anonymity. These developments converge on a diagnosis precisely formulated by the Stanford Cyber Policy Center³⁵⁵. Existing legal frameworks are systematically reaffirmed at the points of contact between the protocol and identifiable human actors. The dual regulatory constraint weighing on ReFi is therefore not only that of coordination between MiCA and the green taxonomy: it is also that of individual legal responsibility that inevitably follows project sponsors, smart contract developers* and active governance members, regardless of the formally decentralized architecture of the protocol they operate.

Instruments situated at the intersection of these two worlds, tokenized natural assets, on-chain green bonds*, and hybrid finance structures activated by smart contracts*, do not yet have a unified legal status in any jurisdiction. This uncertainty is not merely a formal obstacle; it determines the ability of institutional managers, subject to specific fiduciary obligations, to invest in vehicles whose legal and accounting nature remains ambiguous. This section examines existing and emerging regulatory frameworks, the risks of regen-washing that insufficient regulation allows to flourish, and the conditions for a productive rather than merely additive convergence between traditional finance and Web3.

[B] What civil liability exists in terms of extra-financial commitments?

Corporate liability law rests on a fundamental distinction that public debates on sustainability rarely mention explicitly. The obligation of means compels the debtor to make reasonable and diligent efforts toward an objective, without the

failure to achieve that objective necessarily giving rise to liability, provided that the means have been effectively implemented. The obligation of result, on the other hand, directly links the debtor's liability to the achievement of a specific and verifiable result: if this result is not produced, failure is presumed, regardless of the efforts made.

Companies' environmental and social commitments, such as carbon neutrality, greenhouse gas emission reductions, and respect for human rights in supply chains, are, for the most part, obligations of means. A company that "aims" for carbon neutrality by 2050 or that "commits to" reducing its carbon intensity by 30% is not automatically subject to legal sanctions if the target is not met, provided it can demonstrate that it has deployed proportionate measures. The Corporate Sustainability Reporting Directive (CSRD) strengthens the requirements for transparency and external verification, but it does not yet fundamentally alter the legal nature of these commitments, especially at a time of widespread distrust.

It is precisely here that the instruments examined in section 2.1 introduce a potentially far-reaching disruption. A smart contract* for conditional financing that automatically triggers the payment of a grant when a verified on-chain* carbon sequestration threshold is reached, or that blocks this payment otherwise, is not a means-tracking mechanism: it is a results certification mechanism, executed without human deliberation and immutably recorded in a decentralized public register.

If such a mechanism were to be recognized by a judge or regulator as constituting a commitment of result, for example in the context of a tokenized green bond contract or an Alpha Bond type instrument, the issuer's liability in the event of a discrepancy between the on-chain metric*

³⁵⁵ Sell, F.G. (2026). Balancing Code and Law: Governance and Policy Challenges of Blockchain. Stanford Cyber Policy Center, Program on Governance of Emerging Technologies. Stanford University.
<https://fsi.stanford.edu/publication/balancing-code-and-law-governance-and-policy-challenges-blockchain>

and the actual impact would be of a legally distinct nature from that which arises from a declarative sustainability report.

This development remains hypothetical, as no jurisdiction currently explicitly recognizes the outcome of a smart contract* as constituting an obligation of result under civil or commercial law. However, as on-chain* data becomes recognized as admissible evidence in court, the line between a declaration and a legally binding commitment could shift. If this trend materializes, it would fundamentally redefine corporate civil liability with respect to non-financial commitments and give cryptographic evidence tools a legal scope that far exceeds their purely technical utility.

2.3.3.1 From CSRD to regenerative standards (AFNOR, TNFD)

To scale up, ReFi projects must navigate within a dual regulatory constraint that combines the requirements of sustainable finance and those of the digital economy.

On the one hand, financial actors must align themselves with the evolution of European non-financial reporting. The Corporate Sustainability Reporting Directive (CSRD, Directive 2022/2464/EU) and the Sustainable Finance Disclosure Regulation (SFDR, Regulation 2019/2088/EU) impose rigorous transparency based on the principle of dual materiality: companies are required to report not only on how sustainability issues affect their profitability, but also on the environmental and social impacts that their own activities have on the world³⁵⁶. On the other hand, the underlying technological infrastructure must comply with the European regulation on markets in crypto-assets (MiCA,

Regulation 2023/1114/EU)³⁵⁷, which came into phased implementation between June and December 2024, regulates crypto-asset service providers, mandates the publication of certified white papers, and guarantees investor protection³⁵⁸.

Beyond regulatory compliance, the sector is exposed to the risk of regen-washing – a phenomenon whereby an actor adopts a narrative or communication focused on regeneration without transforming the extractive logic of its underlying business model, thus reproducing the greenwashing dynamics already documented in traditional sustainable finance.

To mitigate this risk and anchor practices in verifiable standards, two frameworks are emerging. At the international level, the recommendations of the Taskforce on Nature-related Financial Disclosures (TNFD), published in September 2023, provide a strategic framework enabling organizations to identify, assess, and disclose their dependencies on and impacts on natural ecosystems, thereby directing financial flows toward measurable outcomes for nature³⁵⁹. At the French national level, AFNOR SPEC 2315 "Regenerative Economy", published in December 2024, offers a unique normative framework that structures practices around a triple value creation: ecological restoration, social improvement, and the creation of economic value rooted in local areas³⁶⁰.

At a more experimental stage, **MultiKnip** / **PBTokn** has been participating in the European Blockchain Regulatory Sandbox since 2024, testing the regulatory compliance of

³⁵⁶ European Commission. (2023). European Sustainability Information Standards (ESRS) – Delegated Regulation (EU) 2023/2772. Official Journal of the European Union. <https://eur-lex.europa.eu/legal-content/FR/TXT/?uri=OJ:L.202302772>

³⁵⁷ European Parliament and Council of the European Union. (2023). Regulation 2023/1114/EU on crypto-asset markets (MiCA). Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/FR/TXT/?uri=CEL_EX:32023R1114

³⁵⁸ *Ibid.*

³⁵⁹ TNFD – Taskforce on Nature-related Financial Disclosures. (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. <https://tnfd.global/recommendations-of-the-tnfd/>

³⁶⁰ AFNOR SPEC 2315 <https://www.boutique.afnor.org/fr-fr/norme/afnor-spec-2315/aspec-economie-regenerative/fa209119/426267>

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tokenized public aid (Physical Backed Tokens) within the framework of the European energy renovation program – foreshadowing a possible standard for the tokenization of impact public subsidies³⁶¹. In the field of the regulated carbon market, **Initiativ/InEx** is explicitly positioning itself on ETS2, which is scheduled to come into force in 2027 for buildings and transport, building now a digital infrastructure for access to carbon compliance for sectors which until now had no direct interface with quota markets.

2.3.3.2 The necessary convergence of TradFi and DeFi

The analysis conducted in this section identifies several structural conditions upon which the convergence between traditional finance (TradFi*) and Web3 innovations within a regenerative framework depends. These conditions are distinct in nature – technical, institutional, temporal, and governance-related – and their simultaneous fulfillment constitutes the central challenge of scaling up.

The first condition is the standardization of data exchange protocols between on-chain* and off-chain* systems. The coexistence of multiple distributed registries, heterogeneous data formats, and unharmonized impact assessment frameworks currently prevents cross-referencing of instruments. The standards being deployed, decentralized identifiers, verifiable attestations*, vLEI for legal entities, and ESRS standards for non-financial reporting, constitute common infrastructure building blocks without which capital flows between the two systems remain fragmented and costly to manage.

Some protocols have already crossed this threshold of technical convergence. **Celo** completed its migration to Layer 2 Ethereum in 2025, combining a DAO governance structure including Opera, cLabs, and traditional financial institutions with the

cryptographic security of the Ethereum ecosystem: the convergence here is architectural, not merely declarative³⁶². **Morpho**, a DeFi lending protocol deploying \$960 million in secured loans in partnership with Coinbase, integrating Société Générale Forge for MiCA-compliant stablecoins, and with a stake acquired by Apollo Global Management (right to purchase 9% of the MORPHO offering), represents the most documented case of simultaneous use of a DeFi infrastructure by some of the world's most regulated financial institutions³⁶³.

The second condition is the clarity of the regulatory framework applicable to hybrid instruments. If MiCA³⁶⁴. While the CSRD now regulates crypto-assets in Europe and mandates sustainability reporting from companies, instruments at the intersection, tokenized real assets, on-chain green bonds*, and hybrid finance structures activated by smart contracts*, do not yet benefit from unified legal treatment. Regulatory uncertainty directly hinders the engagement of institutional investors, whose mandates require legal certainty that decentralized protocols alone cannot guarantee. The 2025 transformation of NovaBay Pharmaceuticals into a Stablecoin Development Corporation (SDEV), a listed entity raising \$134 million to acquire 9% of SKY tokens, illustrates the opposite dynamic: a regulated TradFi entity is restructuring to hold governance in a Web3 protocol, signaling that convergence can occur from both directions³⁶⁵.

The third condition is the alignment of time horizons. Ecological restoration and social impact projects operate on cycles of ten to twenty years; decentralized finance protocols have thus far operated on much shorter liquidity cycles, often less than a year.

³⁶² Celo, 2025, <https://www.notboring.co/p/celo-building-a-regenerative-economy>

³⁶³ Morpho, 2025, <https://morpho.org/blog/morpho-institutional-grade-lending-infrastructure/>

³⁶⁴ See above.

³⁶⁵ Sky, 2025, <https://makerdao.com/da/whitepaper/>

³⁶¹ PBTokn, 2025, <https://www.pbtokn.com/multiknip-ebs.html>

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This structural asymmetry discourages the commitment of patient capital. The investment vehicles documented in this report, impact research funds, first-loss tranche hybrid finance structures, outline some responses to this tension, but their widespread adoption requires that Web3 protocols develop liquidity lock-up and long-term governance mechanisms compatible with the fiduciary requirements of institutional managers.

The fourth condition, perhaps the most demanding, is that of the quality and integrity of impact data. As established in section 2.2.1, the credibility of any financial instrument linking return and impact depends on the reliability of the data at the source, regardless of the robustness of the registry that records it.

Before institutional capital can commit based on evidence of on-chain impact*, validated data flows, decentralized oracles* subject to independent audit and standardized verification methodologies must be deployed on a sufficient scale so that the data produced can be used against third parties – regulators, auditors, shareholders.

The fifth condition, finally, concerns the governance of the hybrid systems themselves. The convergence of Traditional Financial Services (TradFi*) and Web3 is not simply a matter of technical integration: it requires defining who controls the protocol parameters, according to which decision rules, and with what responsibilities in case of failure. The governance asymmetries documented in 2.2.3 – concentration of voting power, apathy of small holders, risk of founder capture – must be addressed by hybrid governance architectures that reproduce neither the plutocratic flaws of current protocols nor the bureaucratic rigidity of traditional institutions.

These five conditions are not sequential but rather interdependent.

Data standardization is only valuable if the regulatory framework recognizes its legal scope; temporal alignment is only achieved if governance protects long-term commitments against short-term opportunistic behavior.

It is their joint treatment, and not the isolated advance of each, that will determine whether the convergence between the two universes produces a more robust financial system for the regenerative economy, or simply a new layer of complexity on top of unchanged asymmetries.

Conclusion

This report started from a question posed for more than half a century by responsible finance, which new digital architectures have reformulated as follows: can we replace the impact statement with cryptographic proof? No longer a certification granted after the fact by a third party exposed to the same conflicts of interest as the one being evaluated, but a trace generated continuously, anchored in physical data independent of the project sponsor, and immutably recorded in a public and immutable register because it is decentralized.

The answer that this report provides is nuanced, but it is not indeterminate.

Yes, Distributed Ledger Technologies (DLTs) structurally shift the boundary between declaration and proof. The combination of continuous digital monitoring (dMRV), oracles connected to physical sensors, and machine learning algorithms produces a data stream whose granularity, continuity, and unit cost represent a true breakthrough compared to periodic auditing.

Recording this data on a public blockchain transforms a measurement into an immutable trace, verifiable by any actor without prior authorization. Impact Tokens, **Hypercerts**, and **Alpha Bonds** outline a class of financial instruments whose value is anchored in a verified result rather than a promise, reversing the temporality of financing and modifying the incentive structure for project developers.

No, this architecture is not without its own conditions and vulnerabilities. The quality of the proof depends on the quality of the source data, which a blockchain cannot guarantee on its own. Oracles* reintroduce into the heart of the decentralized system a dependence on external interfaces whose

reliability remains the central problem of digital environmental finance.

Goodhart's law applies to impact markets as to all others, and as soon as a measurable indicator automatically triggers a financial reward, project promoters optimize that indicator, and not necessarily the living system it was supposed to represent.

The hyper-financialization of life, the risks of land grabbing, green grabbing, and the power asymmetries that decentralized protocols tend to reproduce in new forms complete this picture.

What this report will hopefully have helped to establish is that the relevant debate is not between Web3 and traditional finance, technology and politics, or markets and life itself. The relevant debate is about the architecture of incentives, about whether the tools we deploy are designed so that transparency is structural rather than declarative, that allocation power is distributed rather than concentrated, and that the value assigned to ecosystems reflects their physical reality and not simply their financial liquidity.

It would, however, be inaccurate to interpret these tensions as transient frictions destined to disappear as regulatory frameworks mature or protocols gain technical maturity.

A comparative analysis of the regulatory strategies adopted to date (observational approaches, enforcement-based regulation, proactive MiCA-type frameworks, prohibitions) leads to a conclusion that the Stanford Cyber Policy Center states unambiguously: *"No jurisdiction has succeeded in resolving the fundamental tension between decentralized, permissioned systems and legal frameworks built around identifiable intermediaries and centralized controls"*³⁶⁶. Regulation inevitably gravitates

³⁶⁶Sell, F.G. (2026). Balancing Code and Law: Governance and Policy Challenges of Blockchain. Stanford Cyber Policy Center, Program on Governance of Emerging

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towards accessible access points (exchanges, service providers, stablecoin issuers*), leaving fully decentralized protocols in a legal uncertainty that is not temporary.

This is not a lack of regulatory ambition but a structural mismatch between digital architectures designed to operate without identifiable central actors and rights built around the opposite assumption.

For impact finance, this inadequacy has a direct practical consequence, as the most innovative instruments (Impact Tokens, **Hypercerts**, **Alpha Bonds** activated by smart contracts*) operate precisely in the zone of uncertainty that existing legal frameworks do not yet cover stably. The transition from impact declaration to cryptographic proof therefore depends not only on the technical maturity of dMRV protocols, nor on the availability of institutional capital: it requires adaptive legal governance, developed within a framework of international coordination, *"which seeks neither to impose the paradigms of traditional finance on decentralized architectures, nor to allow the latter to self-govern through the logic of code alone"*³⁶⁷.

Regenerative finance is not an invention of Web3. It has been championed for decades by economists, biologists, accountants, agronomists and development practitioners who, before public blockchains existed, built the theoretical frameworks and measurement tools whose application digital architectures now seek to automate and democratize.

What Web3 brings to this movement is not a "new paradigm" or a "revolution", but a set of tools, powerful because decentralized and open source, imperfect of course, but whose real value will depend less on their cryptographic properties than on the rigor with which the companies that deploy them choose to define their purpose.

Technologies. Stanford University.
<https://fsi.stanford.edu/publication/balancing-code-and-law-governance-and-policy-challenges-blockchain>
³⁶⁷*Ibid.*

IAgraphie

For the purpose of publishing this report, we used Google's NotebookLM (NB) and Anthropic's Claude (CL). NotebookLM is a web-based research and note-taking application developed by Google Labs. It uses artificial intelligence (AI), specifically Google Gemini, to help interact with a selection of documents, in this case, the bibliography (excluding books) and paywalled materials. Claude and NotebookLM were used as follows:

	YES	NO	MIXED* Hybridization
Ideation		X	
Information gathering and synthesis of the state of the art. (NB, CL)			X
Editorial (CL)			X
Reformulation (CL)			X
Spelling and/or grammar correction (CL)	X		
Summary and/or keyword generation (CL)	X		

*Mixed refers to a hybrid process involving more or less numerous interactions between the artificial intelligence (AI) tool and the authors, and whose final version has systematically been edited, reviewed and validated by the latter.

A public version of the NotebookLM "Responsible Finance and Web 3 - 2026 Report, The Blockchain for Good", based on the sources listed in the bibliography, is available at this link (in French):
<https://notebooklm.google.com/notebook/71e038f3-b61e-4dd8-b01d-a4497d87792b>

This mention of AI is inspired by "How to indicate the use of AI in a scientific publication? Guide 'Citing AI' (Version 1, October 2024) Working document prepared by: Ioana Galleron within the framework of the work of Axis No. 3 of the ARIANE Consortium-HN
https://shs.hal.science/halshs-04756419v1/file/Guide_citation_IA.pdf

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Responsible Finance and Web3

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In 2023, \$7.3 trillion was invested in activities harmful to nature, against \$200 billion in solutions that preserve it. After half a century of reforms, the imbalance remains intact.

Is this a risk problem, one that better models would solve, or a trust problem, one that evidence could restore?

What distinguishes an impact declaration from a proof recorded on a public blockchain, verifiable by anyone? Has decentralised finance already taken ownership of the issue? Does tokenising a natural ecosystem make it a better-protected common good, or a speculative asset all the more exposed to market pressures?

These are some of the questions this report sets out to raise, and, wherever possible, to document.



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