open climate

Leveraging blockchain for a global, transparent and integrated climate accounting system

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Abstract

The open climate project is an open source initiative exploring the application of distributed ledger technology (DLT) and other emerging technologies, such as IoT (Internet of Things), big data and machine learning, to the challenge of helping the world keep a transparent climate accounting system towards the climate targets set in the 2015 Paris Agreement—i.e. maintaining anthropogenic warming below 1.5^{o}C. Global climate accounting, the process of recording climate actors and their actions in respect to the shared account of the planet's climate state, occurs in diverse set of registry platforms that are individually centralized and collectively dispersed and unlinked. This is often due to lack of trust between actors, resisting to share data that exposes them to scrutiny. This project involves a software 'platform of platforms,' distinguished here as the Open Climate[1] platform, the development of climate communication protocols, and a shared user interface as portal to the system. The platform acts as a common integrator that can reconcile climate records and functions from both legacy and DLT-based climate platforms in the pursuit of helping maintain a decentralized 'ledger of ledgers'. With climate actors and their associated records mapped in a shared network— ranging from countries, to companies to individuals— DLT and other cryptographic tools are primarily used to: provide general transparency alongside individual data privacy, prevention of double counting in the digital certification and trading of climate actions, and a platform for contractual automation of rules and mechanisms with financial nature; from Paris Agreement stocktakes to carbon pricing and rewards for mitigation outcomes.

We present here the architecture for the Open Climate platform as well as describe its full stack prototype. Whilst the platform is currently incubated at the Yale Open Innovation Lab (openlab) it combines multiple other platforms in advanced technological stages; incubated and developed by a growing network of collaborators. For the combined development, the open climate project adopts a multi-stakeholder open innovation framework and consortium to actualize this ambitious endeavor through radical collaboration.

1 We distinguish with capitalized letters the 'Open Climate platform' from the 'open climate project' as a broader initiative involving other networked platforms and protocols.

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A platform of platforms and an open system for global climate accounting and planetary accountability

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We present here the Open Climate platform, an open source software enabling a decentralized and transparent global climate accounting system, operating as 'platform of platform' that acts as the system's routing hub; integrating, via application programming interfaces (APIs), legacy climate data and accounting platforms with emerging blockchain based ones. Using decentralized ledger technology (DLT), the system proposes to harness a radically collaborative network to reconcile aclimate 'ledger of ledgers.' The Open Climate platform includes a user interface as a portal to the system, providing access to the main functions climate actors need to account their climate action progress and participate in compliance, trading and financial schemes. Moreover, it uses the power of smart contracts to automate key articles in the UNFCCC Paris Agreement, linking political actors and their commitments with the physical ecosystem state of the planet, and proposes a mechanism by which subnational and non-state actors can account their actions towards nationally determined contributions and participate in international markets of mitigation outcomes.

The Open Climate platform, portal and integration protocols are in an alpha prototype phase. Platform can be accessed at www.openclimate.earth and source code can be found at www.github.com/YaleOpenLab/openclimate.

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1. Introduction & problem statement

As we move to a stricter management of carbon in our atmospheric commons to prevent global warming from exceeding a dangerous threshold of 1.5/2oC, we must revise the process of transparent carbon and climate accounting. Historically, global accounting has been focused at the county-level, where Parties to the United Nations Framework Convention on Climate Change (UNFCCC)— the primary international climate secretariat— negotiate commitments and submit their greenhouse gas inventories. Ensuring inventories follow the correct guidelines and have robust supporting data has been far from a simple task. Countries are often disincentivized to be fully transparent on their carbon accounting, particularly when economic opportunities are linked, or perceive to be linked, with higher emission practices. This dilemma has eroded trust in the political climate ecosystem.

The 2015 Paris Agreement is a landmark international commitment that introduces guidelines to rebuild climate trust with a strong foundation in transparency and bottom-up action. It is considered a "bottom-up" climate change agreement because it proposes that countries define their own nationally determined contributions (NDCs) towards domestic emissions reductions. Countries are then expected to periodically revise their NDCs and strive to meet more ambitious targets.

Many provisions of the Paris Agreement are obligatory but not legally binding. There are no consequences for failure to achieve one's NDC other than the fact that nations around the world use political pressure to hold one another accountable. Nevertheless, Article 6 of the Paris Agreement opens up avenues for cooperation between nations, for example by allowing international transfers of mitigation outcomes — essential the possibility of transacting climate credits between countries to fulfill NDCs efforts. Article 13 of the Paris Agreement encourages transparency amongst nation-states, as they must submit greenhouse inventories and information on their progress towards implementing their NDCs. This *transparency* drives the need for an innovative approach to

Box 1. Our shared global budget

Planet Earth's atmosphere can hold a limited amount of carbon dioxide equivalent (CO_{2e}) emissions before average global temperatures unleash the most costly and damaging impacts of climate change. The Paris Agreement set a global goal of holding global warming well below 2_{o}C and aiming for a 1.5_{o}C limit of warming, relative to pre-industrial levels.

The limited quantity of emissions relative to this $1.5/2_{o}$C threshold has been termed our global 'carbon budget'. Scientifically, the carbon budget is not a fixed number and never will be — it has an uncertainty range and the data and knowledge used to calculate it is updated every year (Rogelj et al., 2019). However, scientists estimate around 600 GtCO2e remains in the budget, while global annual emissions are around 40 $GtCO_{2e}$. Thus, the key take-away when looking at the carbon budget science is that if present emission pathways are left unchecked, the budget could be consumed in as little as 15 years. After this, we've crossed an irreversible threshold in planetary resilience.

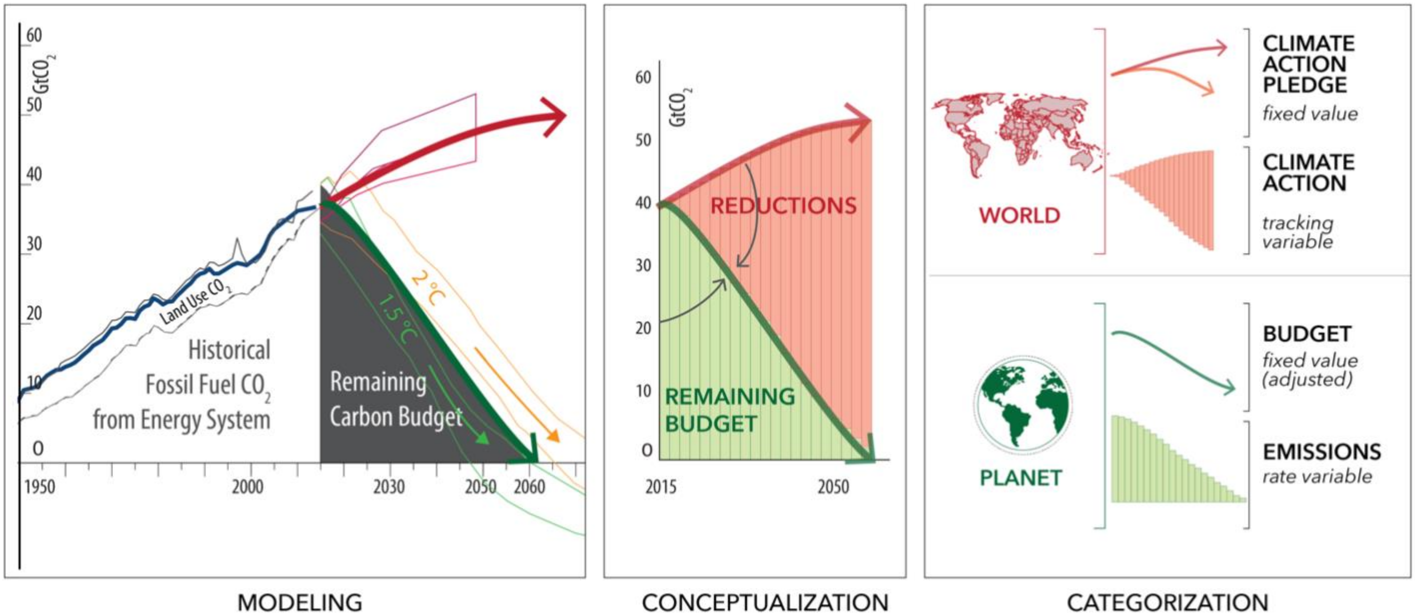


Figure 1. Emission pathways, carbon budgets and the planet vs. world accounting tracks

The figure shows historic anthropogenic greenhouse gas emissions with 'most likely' projected emission trajectory, and those consistent with the 1.5/2oC climate targets set in the Paris Agreement, which define the remaining carbon budget —the total limited amount of CO_{2e} humanity can still introduce into the atmosphere. The diagram is used to conceptualize the two principal carbon and climate accounting track; one relating to the physical planet, and the other involving the political boundaries involved in the human world.

climate accounting. However, the exact mechanisms to deliver this are yet to be fully developed and would still continue to depend on the UNFCCC as the official warehouse tracking national climate actions. Furthermore, nation states are not the sole climate action stakeholders. Cities, provinces and regions (i.e., subnational actors), as well as business, investors and civil society —collectively referred here as non-state actors (NSA)— are increasingly recognized for their ability to catalyze, implement, and innovate climate actions (Hsu et al., 2019). In some cases, these efforts go beyond or are more ambitious than national governments' commitments.

Consolidating a climate accounting system that can combine state and NSA climate actions is essential to the success of the Paris Agreement and the prevention of dangerous global warming. In fact, NSAs and their progress should inform national target-setting, tracking and policy-making that in turn should encourage even more non-state action commitments. Quantitatively assessing and tracking climate pledges and certifying the efforts to achieve them, however, are still fraught with difficulties. Existing measurement, reporting and verification (MRV) systems to track climate action —both from state and NSAs— are labor-intensive and costly, frequently requiring third-party consultants, which discourages resource-constrained actors from participating and recording actions in transnational climate action networks or measuring their climate change impacts at all.

If we were to consolidate and maintain a single record-keeping ledger with global consensus (i.e. where all parties agree) the task would be far from a simple under a trustless and competitive world. Decades of slow climate negotiations among countries attest to the intricacy of this challenge. The rise and maturity of blockchain and its cryptographic science, paired with emerging digital technologies such as internet-connected sensors, big data and artificial intelligence can provide robust opportunities for existing and new climate platforms to streamline and incentivize data collection, climate action certification (i.e. MRV), accounting and trade. These tools could fill a critical gap in the understanding of how bottom-up non-state climate actions are implemented, what they achieve, and how to build a sustainable system that lowers measurement and reporting burdens to be more inclusive globally.

Whilst the initial application of blockchain focused on digital currencies (e.g. Bitcoin), other non-financial applications quickly followed. In fact, its core promise of decentralized consensus eventually caught the attention of the climate world. Eventually, the UNFCCC declared its support for research on blockchain and distributed ledger technologies (UNFCCC, 2018). Following this announcement, initiatives like the Climate Chain Coalition have successfully created a growing network of entrepreneurial actors that are actively exploring the blockchain and climate intersection, each with their own set of technological value propositions.

To date, however, there hasn't been a compelling direct application of the technology, at least not in terms of a global internationally recognized framework for carbon and climate accounting that propose to leverage the power of trustless decentralization and automation to integrate legacy accounting practices with emerging technological ones. There has also been little discussion about how to address questions around the governance of these tools, data sharing between existing climate platforms, development of globally accepted accounting protocols for NSAs, and the dichotomy of maintaining actor data privacy alongside climate transparency.

1.1 Earth's carbon and climate ledger challenge

Most of the ground-work and scientific basis for climate accounting mechanisms have been significantly developed thanks to decades of international scientific and political efforts. We propose that integrated blockchain development efforts, therefore, should focus on complementing existing frameworks; adding a protocol and standards layer for decentralized record-keeping and contractual automation (i.e. smart contracts) to optimize and reduce accounting and transaction costs. In general terms, the application of blockchain technology to provide global climate accountability should consider two distinct accounting tracks, each with both fixed and variable numerical components, whose state can be tracked with distributed ledgers (see figure 1 for a visual breakdown of these components):

1.1.2 The Planet's accounting track—

This track must consider Earth as the physical planet devoid of human created political divisions, and purely based in physical science. In other words, this can be seen as decentralized Earth ledger that encompasses the main aspects covered by working group 1 of the intergovernmental panel on climate change (IPCC). The proposed two fundamental components to develop and track are: 1) A consensus mechanism to determine the remaining **carbon budget** and its unavoidable uncertainty range (see box 1 for more info outlining the importance of tracking the carbon budget). Whilst this number may need to be constantly updated, it can be a fixed value determined by a median range or democratically agreed by, for example, an international scientific committee. 2) The process to track the **aggregate rate** in which this budget is consumed, in real-time or another practical time period. Whilst the aggregate number is the key variable value to monitor, efforts should be placed to track emissions provenance (i.e. their root sources and path).

1.1.2 The World's accounting track —

This accounting track is the one traditionally associated with climate accounting, and described above in section 1, since it must consider the self-defined boundaries in the human civilization: countries, provinces, cities, organizations, individuals, etc. As such, it involves a more intricate political and subjective process.

The two core accounting components distributed ledger should cover are: 1) Open **climate pledges** taken by all the relevant actors. This includes nationally determined contributions (NDCs) in the case of countries, and general climate pledges stated by any NSA, presented as fixed numbers that states an intended positive climate action (eg. emission reduction) in the future relative to a base year. 2)

The process to **affordably track and certify** what indeed was and was not emitted by the respective actor. This, in combination with the other components, is also a strong basis to roll-out global mechanisms to incentivize behavior change (eg. through rewards and penalties).

2. Open Climate System & Platform of Platforms: Solution overview

We propose the Open Climate platform and system based on 6 key pillars. These pillars constitute critical insights derived from a landscape research and analysis of what constitutes success in the blockchain and climate intersection, briefly presented in section 1. These insights have been translated to the main design guidelines and features of the system. From these 6 pillars, we have defined the 5 climate dimensions that the project's scope encompasses, and the 4 integrated layers that the software development effort comprises. This section describes the pillars, dimensions and layers of the project. Figure 2 provides a graphical abstract of this outline

2.1. Six project pillars: guidelines for success in the application of blockchain for global climate accounting

These pillars can be understood as the underlying assumptions of the project based on our accumulated research, as well as their accompanied resulting guidelines that have been considered in the project's scope and architecture. The pillars are therefore presented here as a set of pairs; the insights about what the system should have the capacity to do, and the resulting features that our current prototype development includes. These pillars are:

1. Consensus on the physical state of the planet > Earth ledger

The main insight of this pillar has already been laid out above in section 1.1. There needs to be a clear distinction between the physical planet and the political world. The need for consensus of the Earth's ecosystem state and key 'vital signs' are three-fold. First, a robust and scientific consensus needs to dispel any post-truth or climate skepticism from the general public, it needs to clearly record 'the facts.' Second, this data sets the baseline for all science-based climate targets from state and non-state actors. It also facilitates the evaluation of the aggregate effect of climate actor's collective efforts. Finally, an established immutable value on a distributed ledger can be used for smart contracts to automate certain processes that need to be based on physical metrics. For example, a smart contract can deterministically tie carbon pricing to the remaining planetary carbon budget relative to a 1.5$_o$C target using on-chain records.

This pillar is translated in the concept of an Earth ledger. Section [3.1] describes the architecture and process flow to operate a decentralized carbon budget accounting mechanism, involving global CO_2 internet-connected sensors, multi-source oracles, integrated assessment models, and Earth system governance to manage uncertainty ranges. While we focus here on the carbon modules of the Earth ledger, this is but one of many modules to consider. A natural extension of it could include the tracking of all planetary boundaries (Rockstrom et al., 2009).

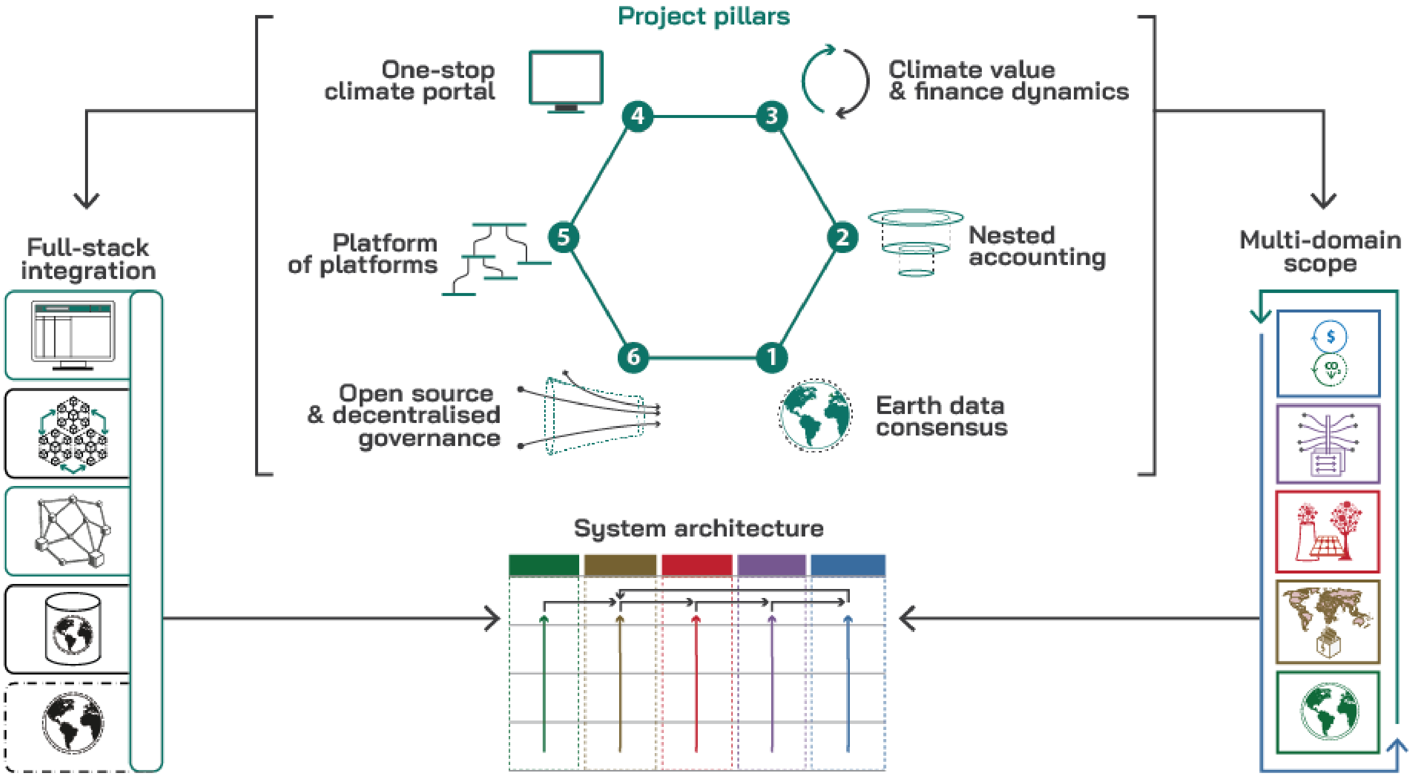


Figure 2. Open Climate solution outline: 6 pillars, 5 climate dimensions and 4 software layers
The Open Climate project is based on these six conceptual pillars, which are both insights from extensive research and analysis on the blockchain and climate intersection and the translation of these insights into core platform design features. These pillars then define the 5 climate domain scopes and their required linked blockchain-based records (see figure 3 for a metadiagram of these domain links) as well the software stack logic (see fIgure 4 for a full-stack description). The cross-section of the software stack with the climate domains defines the proposed meta architecture of the project.

2. Seamless inclusion of state and non-state actions > Nested accounting

Also outlined in section 1 is the importance of the capacity of a global climate accounting system to combine both commitments, actions and politics pertaining to nation-states, as well as those from all NSAs. This feature needs to be achieved without any risk of double counting, which happens to be one of the main values of distributed ledger technologies. This integration should be designed to take advantage of positive feedback loops involved in a win-win dynamic between state and NSA. Namely, accounting the actions of NSAs lessens the climate burden of the national governments, thus fostering federal incentives to support NSAs actions and the capacity building to utilize the same accounting methodologies. With incentives and motivation, NSAs can mobilize the lion share of capital required in finance the climate transition. Conversely, if an elected government from a nation-state loses track of scientific facts and shows minimum signs of planetary stewardship, a mechanism that incorporates NSA accounting can enable a country to maintain a paris-consistent track irrespective of the federal position. A clear example of this dynamic is seen with the Trump administration of the United States of America in regard to the potential pullout of the Paris Agreement, which lead to the immediate NSA backlash in the form of the #WeAreStillIn coalition.

This pillar is translated in a proposed protocol to automate nested accounting of climate actions. This means that, for example, the mitigation certificates generated and retired by a forest conservation project developed by a private actor would automatically be included in the fulfillment of climate commitments of the subnational actor (eg. the province or region in which the project or company is located), and subsequently the nationally determined contribution of the involved country. If the mitigation certificates are sold from the private developer to a company incorporated in a different jurisdiction —and are retired by the buying actor— then, subject to countries approval, the accounting of those actions would fall under the nested scopes involved in the buyer's jurisdiction. A nested accounting mechanism essentially operates the guidelines laid forth in article 6 of the Paris Agreement. Section 3.2.2 describes the architecture and process flow of this proposed features.

3. Linking of all climate related information with financial value mobilization > 5 integrated climate domains

One of our analysis' main insight is that one of the most important values of blockchain and related technologies to climate accounting is the capacity to integrate multiple climate-related records with financial capital. Leveraging the financial technology aspects of blockchains and smart contracts can automate rules for deploying financial capital under positive feedback loop dynamics. In other words, different climate accounting aspects —which includes Earth data records, commitments of actors, the tracking of their progress, the minting of certificates attesting to their tracked action, and the transactions associated to the trading of these certificates— have dynamic influences between them, and the collective supply chain of this climate value information must inform and directly drive climate finance. This allows the application of smart contracts and digital finance to directly link capital with climate value in a low-cost a frictionless way. This can either take the form of tax burdens or pricing associated to negative climate value, and capital financing and rewards for positive climate value creation.

This pillar is translated in a significantly broad scope of the project, involving the proposed direct linking of 5 different climate domains. These domains are: the Climate System (the physical dimension), Climate Agreements and their Actors (the political dimension and required registries), Climate Assets (the certifications of actions), Climate Markets (the networks and rules for transacting those assets) and Climate Finance (the mobilization of capital to finance climate value). Figure 3 shows a metadiagram of this multi-domain integration of climate aspects that can be associated to ledger records. This concept supports the proposition of using a 'ledger of ledgers' and smart contracts to orchestrate a positive system dynamic of finance and information flow. In fact, the metadiagram in figure 3 conveys the scope of the open climate project and the incorporation of pillars 1 to 3.

4. Intuitive and accessible user interface covering all aspects of the system > Open climate portal

Blockchain, distributed ledgers and smart contracts are intricate concepts for the general public. Key climate data and actor's action progress and accountability are scattered in different platforms, making it hard for both key stakeholders and general public to keep track of. As such, this pillar's main insight is the value of a one-stop-shop portal that can connect all meaningful climate accounting records and functions under the same user interface.

A single portal does not necessarily go against the decentralized nature of the project. Front-end software technology through the use of APIs, block explorers and secure credentials, can act as portals to an underlying network with multiple platforms and blockchain ecosystems, and allow logged in users to operate climate functions (eg. accounting, reporting, trading) hosted in different platforms but accessed through the same interface. Having the capacity to do this reduces reporting fatigue from actors that require compliant processes, simplifies user experience through intuitive processes and provide a main function for climate transparency and visibility. As an example, technological improvements in user experience have made the preparation and filing of annual tax returns an accessible process for layman citizens in the United States (eg. with the use of the Turbo Tax software).

This pillar is translated in the creation of an open source front-end platform with special focus on intuitive user experiences in the whole array of climate accounting functionality. Figures 5 and 6 shows examples of the growing number of screens with multiple functionalities in the project's front-end efforts.

5. Capacity to interoperate between legacy and emerging technology climate platforms > Platform of platforms

As mentioned in section 1, blockchain applications in the climate space should not try to replace existing climate accounting frameworks but rather build on top of them to drive higher levels of efficiency. Furthermore, the distributed ledger technology space is characterized by a high levels of entrepreneurial spirit and initiatives. If these are to directly compete against each other with a zero-sum mindset, then the capacity for having a unified climate accounting system is reduced. In other words, the world would not benefit from multiple carbon ledger systems that cannot interoperate with one another. The planet's atmosphere is still a single limited space where all free greenhouse gases reside. Therefore, an open climate system needs the capacity to involve both existing legacy climate registries, platforms and databases, with blockchain based environments that subsequently should interoperate and reconcile records between each other.

This pillar is translated into the effort of generating a platform of platforms (or PoP). Figure 4 shows the role that this PoP has as a middle layer between legacy and blockchain system, integrating them through protocols and APIs, and representing the collective in the user's interface.

6. Open source and radical collaboration > Consortium initiative towards a decentralized autonomous system

Last but certainly not list, the sixth pillar guiding this project posits that the most important innovation the project should focus on is not just *what* needs to be built, but *how*. This points to the social innovation of driving software and solution architecture development through a mindset of radical collaboration, which puts forward a paradigm of unity among all planetary stakeholders, rather than a mindset of competition, which strengthens a paradigm and illusion of separation. This is perhaps the most challenging aspect of the project since modern innovation and technological progress has been driven by the latter mindset and zero-sum dynamics.

The challenge of climate change and its irreversible erosion of planetary resilience is perhaps the ultimate opportunity to mobilize our mental structures. As such, a global climate accounting system needs to have a strong foundation on open data and open source software. A shared platform and its constituent parts need to represent an ecosystem of digital public goods for the global commons. This does not negate, yet indeed challenges, the use of commercial business models. Open source protocol layers can be compatible with proprietary software built on top of it, but innovative business models need to be introduced to allow developers and organizations to have the financial sustainability to operate and maintain such a system.

This pillar translates not only into the open source publication of the Open Climate platform's software, but on the development of a growing network of constituent platforms that can use a consortium model and open innovation framework to govern the initial development process. Part III fully focuses on this aspect and pillar. Furthermore, once an Open Climate PoP and system achieves the technological readiness to operate at a global level, the project has the intention to be released as a decentralized and autonomous organization.

Perhaps one of the most powerful inventions underpinning the bitcoin network, which catalyzed the blockchain movement, is the fact that what was created was fully emancipated from the hand of the creator (i.e. Satoshi Nakamoto). This motivates the development of truly decentralized systems that require innovative governance schemes. An Open Climate platform and system, should be driven by a mechanism of Earth system governance that can tap into collective intelligence, rather than one centrally managed by a powerful few.

2.2 Multi-domain linking of climate accounting scopes

Building on pillars 1 to 4 mentioned in the previous section, the scope of the project's vision crosses through 5 domains whose climate accounting aspects and records need to be linked to allow for the design of positive system dynamics. These domains are: **1) The Earth system**, including the records with scientific consensus of the *Climate system*'s state as it pertains to (at least) carbon budget tracking; **2) World Actors & Registries**, governed by *Climate Agreement* and including the record of climate actor pledges; **3) Climate Action & MRV**, essentially the methodologies, records and certifications of *Climate Actions* (which in this case includes mitigation, adaptation and emission); **4) Networked Climate Markets,** involving the transaction of these certificated *Climate Assets* under international climate markets, and **5) Climate Finance,** the mobilization of financial capital towards climate action. (see figure 3 for the project's scope and logic).

Such a broad integrated system pertains to a core value proposition that blockchain technology provides. Hosting multiple climate accounting mechanisms connected through shared protocols, allows contractual automation in the link between finance and climate value flow based on agreed physical parameter of the Earth system (eg. 1.5^{o}C warming). As a basis, this can act as a self-enforcing mechanism for the Paris Agreement, as well as enable new Paris-consistent smart contracts with reward & penalty functionalities to ensure accountability.

As previously outlined, while the Paris Agreement pertains directly to countries' roles and responsibilities (i.e. the parties to the UNFCCC), it is now well understood that the most relevant climate action champions are in fact subnational actors, such as cities, and non-state actors such as private corporations and organizations. Furthermore, article 6 of the Paris Agreements introduces the incorporation of bottom-up climate action efforts to parties' accounts, and the cooperation between parties to achieve their respective NDCs using international transfer of mitigation outcomes (ITMOs). The open climate project specifically targets its development to cater for this bottom-up climate action ecosystem, focusing on the mechanisms by which subnational and non-state actor pledges and certified actions can be incorporated into national efforts and international networked climate markets.

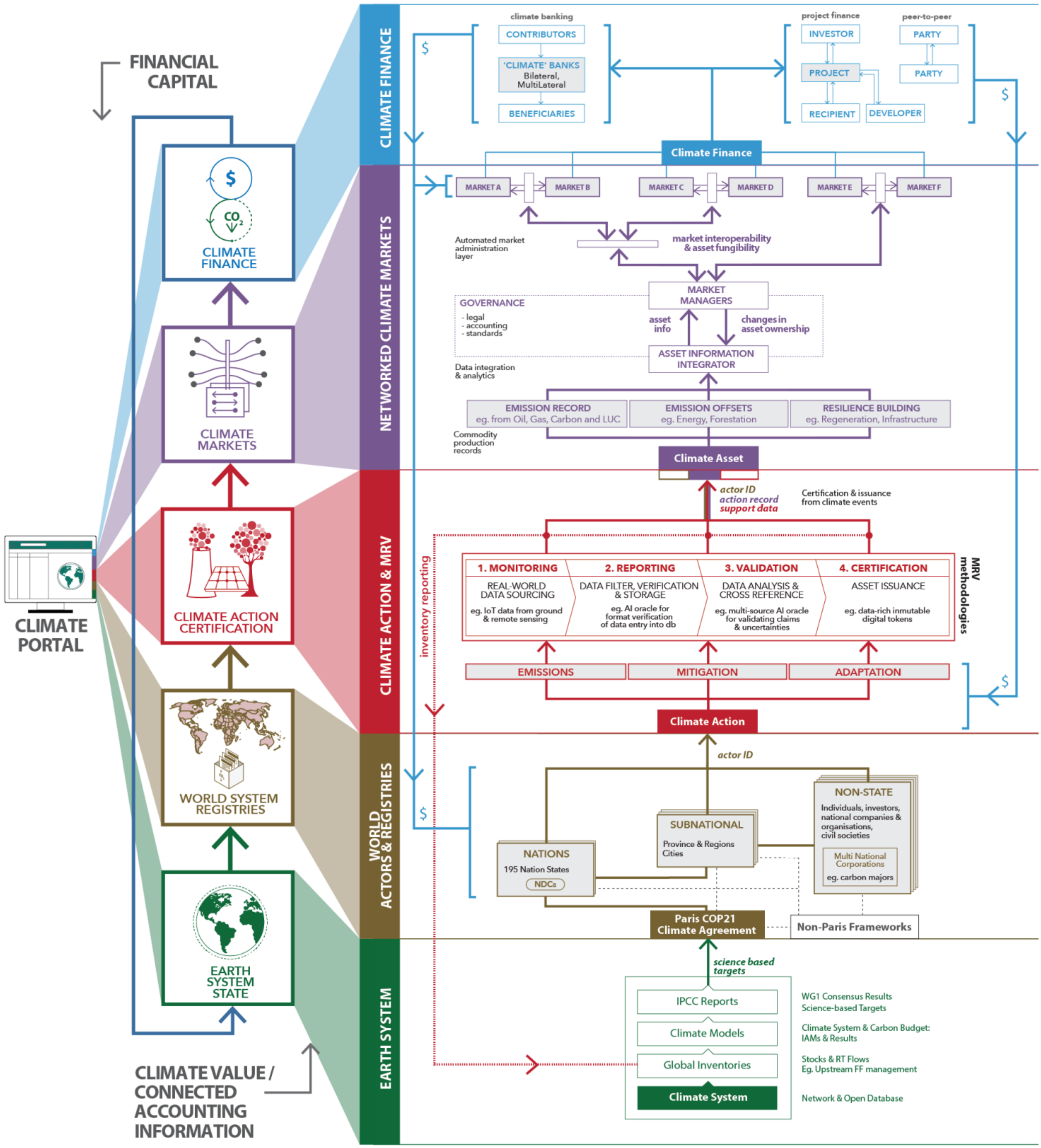


Figure 3. Multi-Domain Integration of Climate Related Ledgers: a metadiagram

This stylized flow diagram provides a visual reference for the potential of applying and integrating blockchain's record keeping system across multiple layers pertaining to global climate accounting and the enforcement of the 2015 UNFCCC Paris Agreement. An integrated system, involving multiple blockchain mechanisms connected through shared protocols, allows contractual automation in the link between finance and climate value flow based on the agreed physical parameter of the Earth system (eg. 1.5ₒC). The climate portal allows users to interface with the global accounting system, as well as digital streamlining the interactive processes for individual actors/agents. The diagram also represents a visual summary of the scope of the project's vision.

*Networked climate market layer adapated from figure 3, World Bank Group "Blockchain and Emerging Digital Technologies for Enhancing Post-2020 Climate Markets," 2018.

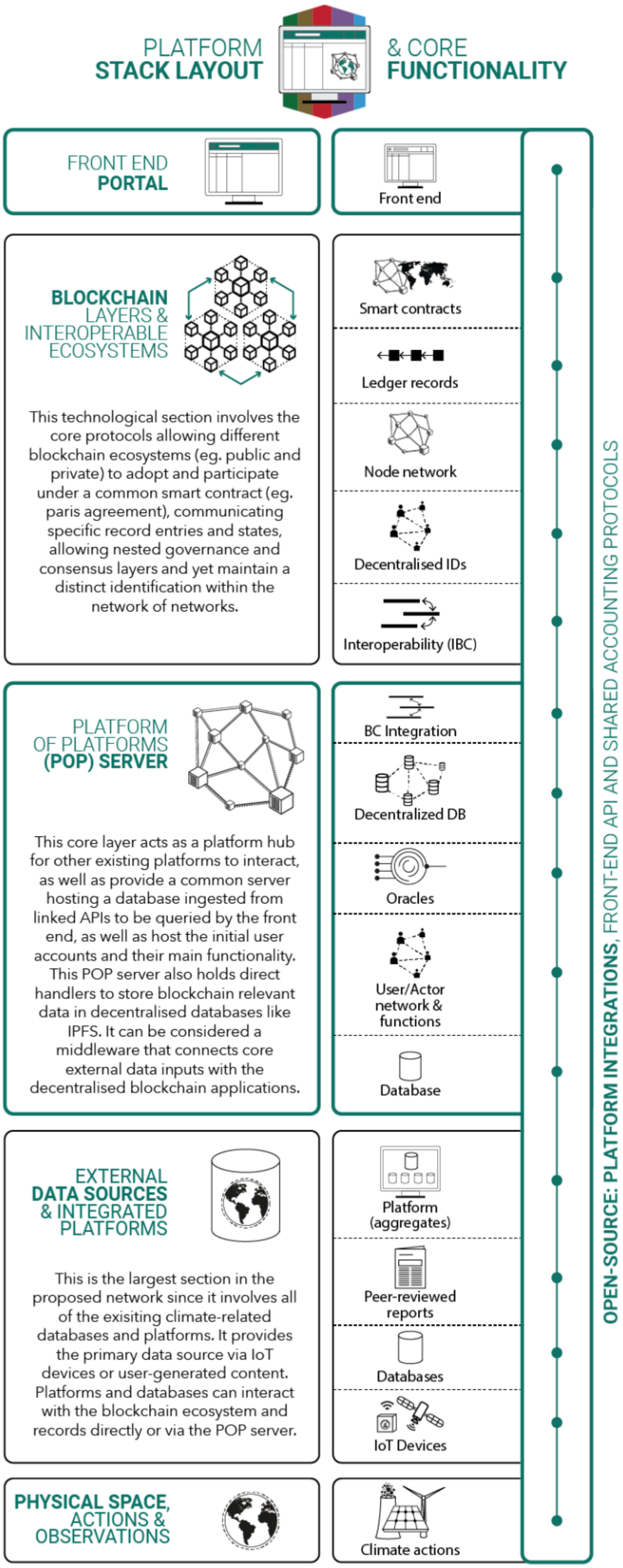


Figure 4. Project stack & three core development components

This stylized software stack diagram provides a visual reference for how the project is currently prototyped. The main development efforts are contoured in green since the external data sources are comprised by existing climate accounting platforms and the blockchain layer includes emerging blockchain-based applications. Prototype developments in the blockchain layer include common smart contracts (eg. the Paris agreement) and handlers to a diverse set of ecosystems (eg. Ethereum, Bitcoin, Cosmos, Stellar etc.).

2.3 Technology stack and platform development

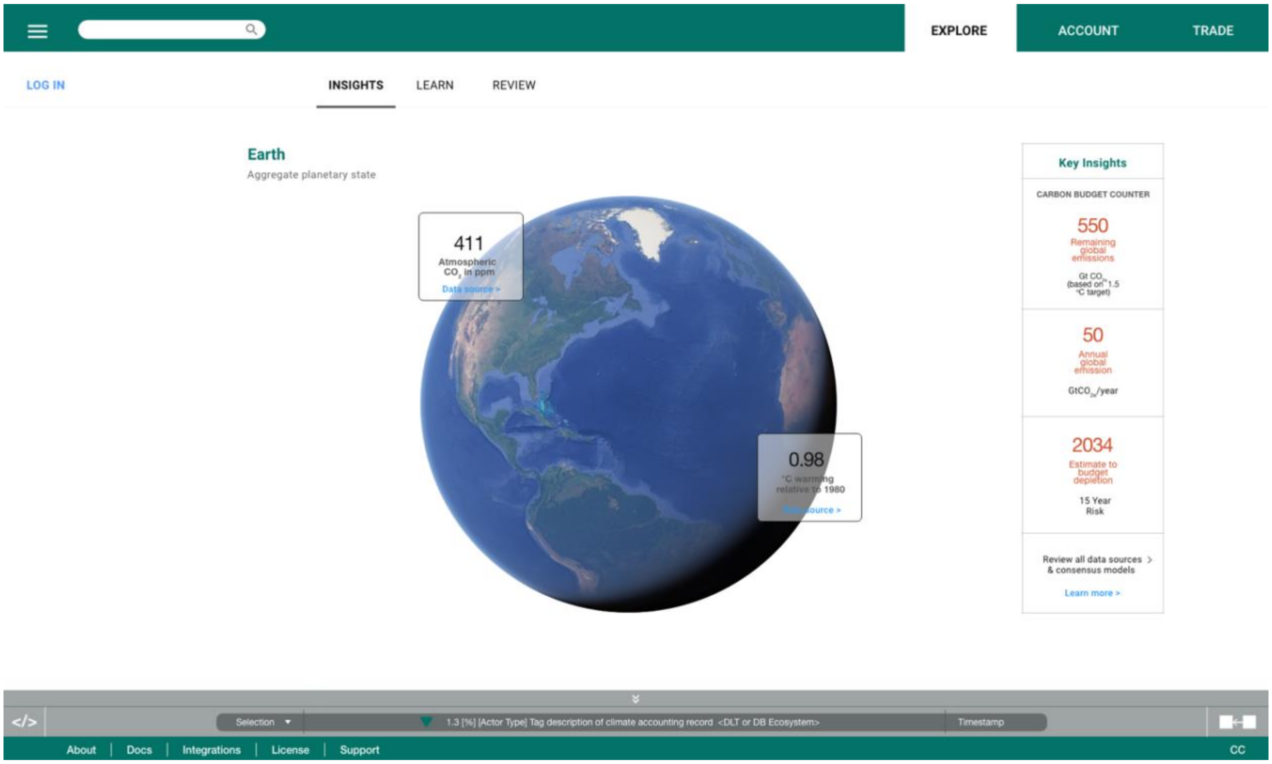
The project seeks to seamlessly integrate the physical world with four general software layer groups. The first layer is the set of existing climate data platforms and databases. The second layer group is the actual platform of platform, acting as a common decentralized server. The third is the range of blockchain ecosystems and their internal layers, from consensus protocols to smart contracts and the actual ledger records. Finally, the top layer is the open front-end portal.

Our main open source software development efforts are focused on three main components. First, the decentralized server hosting the cross-platform web application that can integrate multiple existing climate related platforms, so that they can interoperate with common functions and reconciled records. Second, the consolidation of protocols and standards to enable such an interoperable and multi-layers climate accounting ecosystem, and the required governance mechanism to achieve and maintain it. This includes protocols for metadata schemas (eg. for the nested accounting function), as well as shared API functions. And third, a climate portal that allows multi-stakeholder users to interface and interacts with the global accounting system, either directly via the web application or via their integrated platforms.

2.4 User experience and climate portal interface

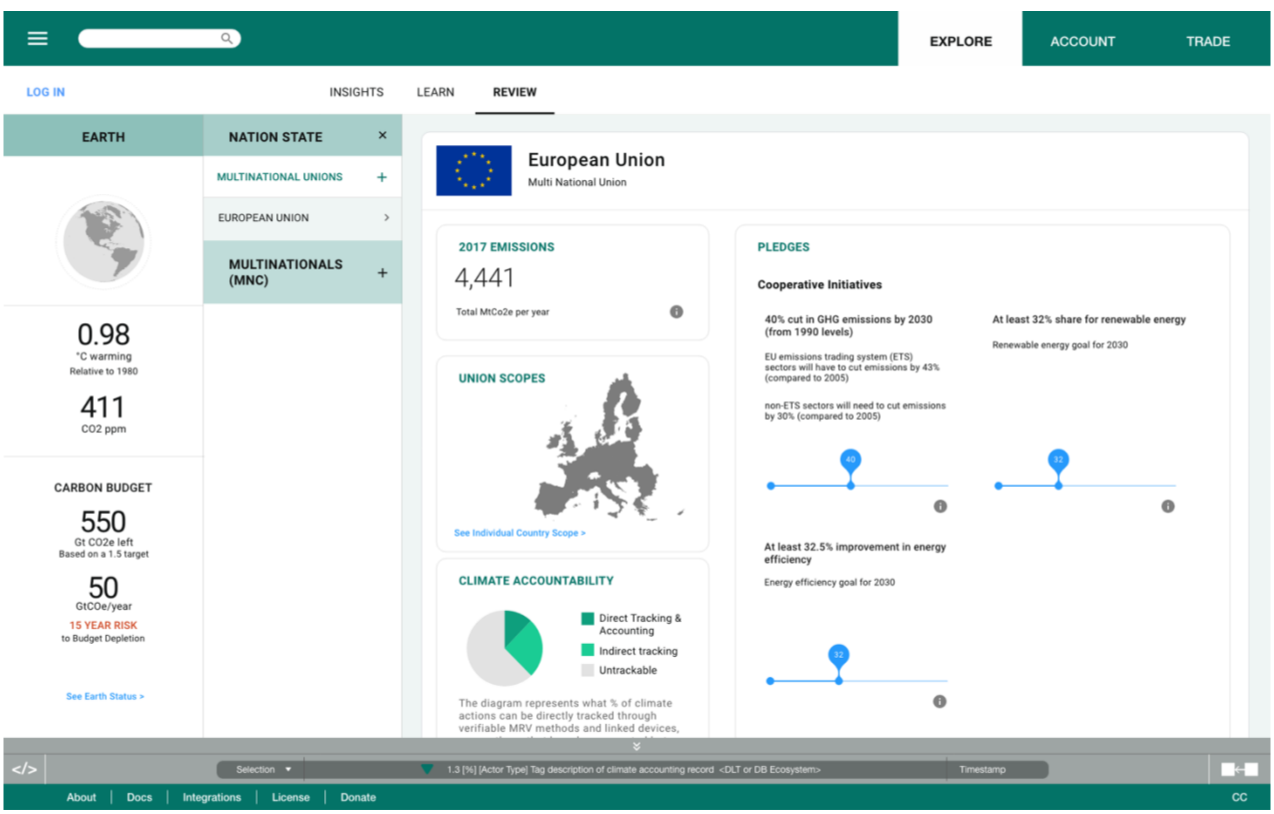
Special development efforts have been placed in the design of the platform's user interface and front-end environment. Over 100 screens have been designed and coded. Considering the role of a 'platform of platforms,' the user interface is one of the most important pieces because it represents the core visual language that all climate actors and their respective users engage with. It is the window to the digital climate space and the underlying blockchain data layer.

The current site structure is divided into three main sections representing distinct user stories— Explore, Account and Trade. Explore shows the publicly available data, both at the aggregate planetary level as well as the individual actor level (i.e. its pledges and action progress). Account serves as the main interface for climate actors to integrate their accounting ecosystems (i.e. database or blockchain based) and manage all records and assets. Only Explore and Account have been prototyped, since Trade depends highly on the architecture of a networked climate market system.



Interface A. UX/UI: Explore / Earth Data

This screenshot shows the initial version of the landing site with the main insights of the planet's carbon state. Atmospheric CO2 data is read from a block explorer that has already compiled data from IoT sensors and CO2 assessment platforms. Anthropogenic warming is integrated using APIs to integrated assessment models. The key insights of the carbon budget module follow a process outlined in section 3.1. All records displayed in this screen would follow the data flow of Figure 5.



Interface B. UX/UI: Explore / Pledges / European Union

This screenshot shows the function of the Review tab in Explore, which provides the publicly available commitments and progress of each climate actor. Climate actors are divided between those associated to Nation States —including domestic companies, subnational actors and multinational unions (such as the EU)— and Multi-National Companies, which include the group of Carbon Majors (coal, oil, gas and cement companies who exceed >8 million tons of carbon per year (MtC/yr) of fossil fuel production records). This interface shows the EU climate commitment under the Paris Agreement. Climate accountability traction relates to the extent of climate action tracking done through direct verifiability (eg. with IoT devices), indirect (eg. using third party auditors), or untrackable climate action reports.

The main distinction of the front-end design is that it considers the user requirements of both state and non-state actors. This is particularly relevant because one of the core value propositions of this open climate accounting system, is the possibility for all non-state and subnational actors to account their individual (certified) actions in a nested way within the national efforts, thus participating with the corresponding NDC as well as the eventual ITMOs. Figure 10 shows an example of this nested accounting relationship from the perspective of a renewable energy company.

2.4.1 Explore / A window into the global climate accounting system

The explore tab is the landing section of the tool displays public information about both the aggregate state of the planet and its carbon budget (reading from the underlying blockchain records), as well as the whole set of climate actors (i.e. State and NSAs) whose accounts register publicly made climate commitments.

Interface A and B show examples of the key functions provided by the Explore tab. Their captions explain the main distribution of information architecture and source data.

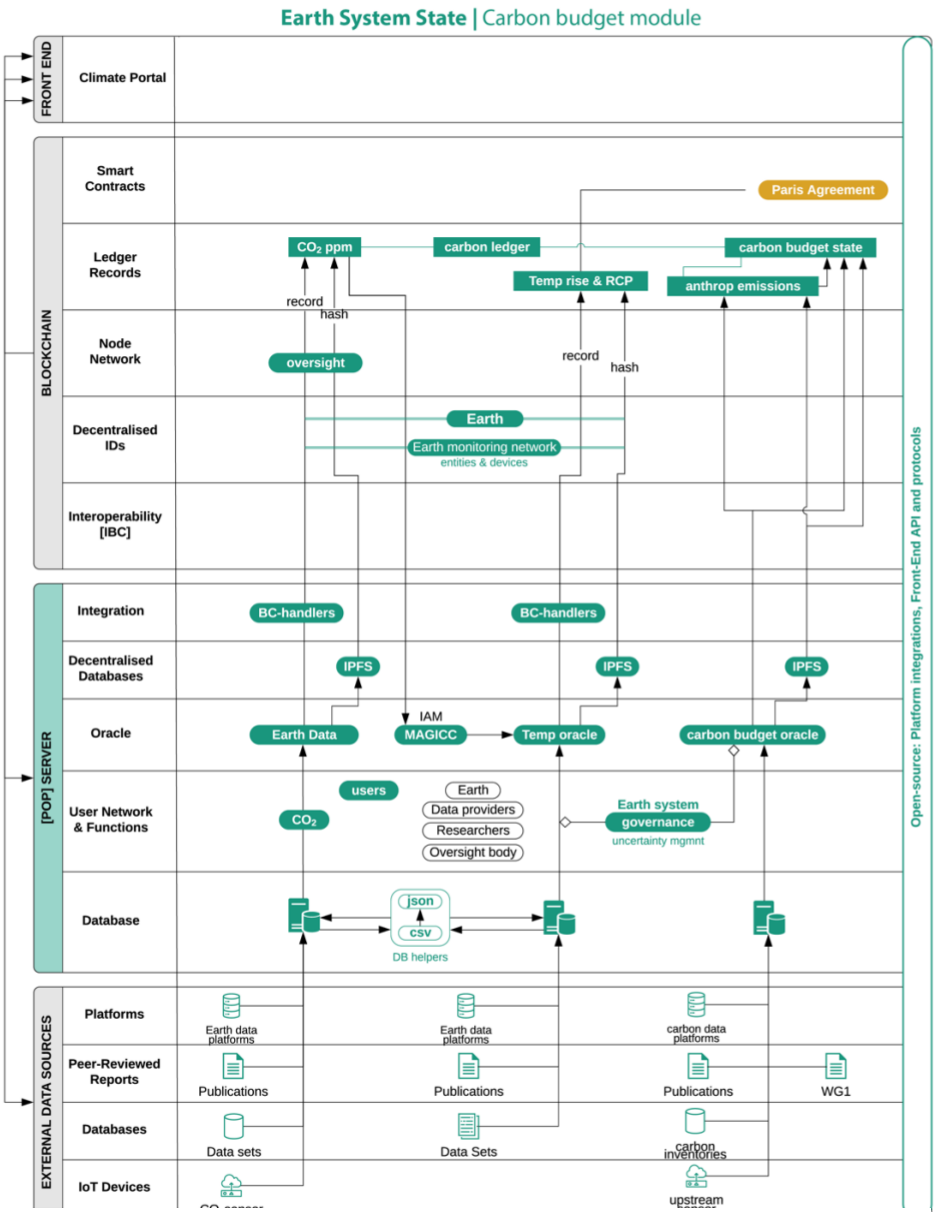


Figure 5. Earth System domain and carbon module's process architecture.
The carbon module begins with direct physical measurements (i.e. multiple CO_2 sensors around the world), cross referenced by a multi-source oracle, and recorded on a blockchain record (currently using Ethereum). This on-chain record is used to run a light version of an integrated assessment model (IAM) that assesses the radiative forcing of the CO_2 content into a temperature value, which acts as a direct input to article 2 of the Paris Agreement (i.e. stating efforts below 2_oC). Carbon budget assessments have higher degrees of uncertainty and are therefore ingested

3. Meta Architecture: Highlighted Blockchain Functions & Process Flows

Introduction

The platform's architecture of data and process flows is the result of directly combining the 5 domains outlined in section 2.2, with the 4 software layer groups outlined in section 2.3. All of this is informed by the project's 6 pillars. Figure 2 shows how the system architecture is literally derived from visually combining the structures of Figure 3 and 4. This section provides some highlights of this architecture, key functions provided by the platform, and the specific uses of blockchain in the climate accounting scheme.

Figures 5 onwards show the process flows of the first three domains as they cross different software layers. The information here represents the result of an extensive analysis and integrated design of how these processes should be mapped in the climate accounting system. Some of these processes have been prototyped and tested in the backend, while others have been mapped and are yet to be tested in proof-of-concepts.

3.1 Earth data oracles & scientific consensus: *towards a decentralized science-based accounting of the planet's carbon budget*

A foundational part of the system architecture relates to the accounting of the planet's physical state, as outlined in pillar 1 and the first climate domain in figure 2 (i.e. the Climate System). The underlying science of this domain is covered by working group 1 of the IPCC. The role this

segment has in the Open Climate architecture is to digitize, make visible and apply decentralized consensus to some of the key Earth metrics and variables that are to be considered by other functions and applications of the platform. In this instance, we have focused on the level of CO_2 in the atmosphere, the anthropogenic warming relative to pre-industrial level, and the tracking of the remaining carbon budget relative to $1.5_{o}C$.

Information on these key values of Earth's state is to be updated in near-real time based on data sourced from various organizations. For example, to obtain an accurate measure of the amount of atmospheric CO_2, we take the most recent readings of sensors from NASA, NOAA, and ESA and use statistical analytics to determine the most accurate and globally average record. This data processing is done by a multi-source oracle prior to committing the record on a blockchain.

Oracle machines are abstract computers that can solve decision problems by executing complex mathematical formulas and act as an impartial untampered third-party agent. In their blockchain use, the oracle's role is to filter, verify and harmonize real-world data so that it can safely integrate into the blockchain and be used, for example, in the execution of smart contracts. When equipped with machine-learning functionality, oracles can help rapidly resolve contradicting inputs or data anomalies prior to their entry on the blockchain. The blockchain does not store the raw environmental data from IoT sensors, but it can store its hashes, and the single record with agreed consensus.

Oracles act as the middle agent ensuring these steps are following a protocol, particularly in cases where multiple sensors are attesting to the same event and an impartial resolution is needed. Figure 5 shows the proposed information chain linking physical measurements of atmospheric CO_2, the assessment of anthropogenic temperature increase and the eventual carbon budget tracking submodule. On-chain records such as temperature increase are then linked to the Paris Agreement smart contract, which queries the state of the planet in the progress to preventing warming below $1.5_{o}C$.

3.2 World System Registries: National & non-state accounting in the Paris agreement

This climate domain's architecture has three main components: the incumbent Climate Agreement, the inventory and commitment registries of Nation States, and those from all subnational and NSAa.

The incumbent global climate agreement is the Paris Agreement (PA), which we have translated into a blockchain-based smart contract (current prototypes are in solidity language and deployed in the Ethereum blockchain). This (PA)

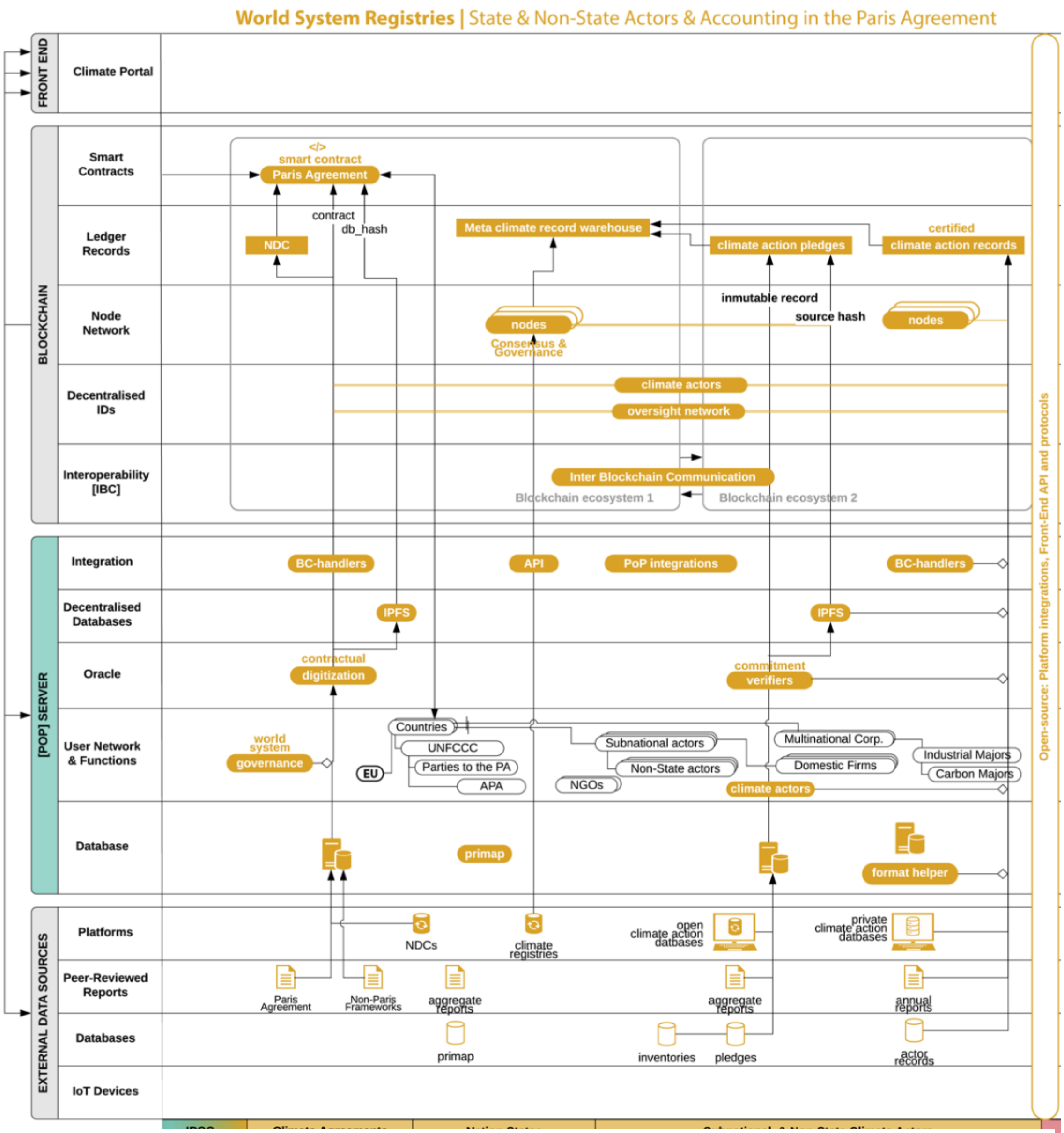


Figure 6. Architecture and process flows in world system registries

This climate domain is composed by the Paris Agreement in smart contract form, the National registries and NDCs, and the set of all subnational and non-state actor's commitments and inventories. Blockchain applications here include the provision of decentralized identifications (DID) to all actors, immutable records for accountability over their pledges and progress, and automation processes from the Paris smart contract, as well as other smart contract functionalities that can be developed in parallel to it.

smart contract acts as the primary action hub for all climate actors, their registries and their commitment to transparency, science-based targets and accountability. The preliminary process to translate the Paris agreement into a smart contract is briefly described in section 3.2.1.

The second component involves the inventories or registries of all nation states, including the record of their NDCs; components managed both by the individual countries and the UNFCCC database system. Many countries, particularly developing ones in the now lapsed Annex II list of the Kyoto protocol, do not yet have the full capacity to keep an active carbon inventory and registry. However, this module includes aggregate information from existing country registries as well as recognized scientific databases that have compiled and maintained country emissions data (eg. the primap database maintained by the Potsdam Institute). The World Bank Group (WBG) has placed specific architectural focus in the conception of a meta registry —or warehouse— using blockchain for managing countries inventories and progress (WBG, 2018). This project places direct consideration and collaboration in its conceived architecture for compatibility with the WBG guidelines and prototyping efforts.

The third component or submodule, which is the largest in terms of data records, includes climate pledges and progress tracking of all NSAs—including subnational actors such as cities, to multinational corporations. One example of a relevant repository holding information about NSAs pledges is UNFCCC's Global Climate Action (Nazca) portal. The Global Climate Action Portal sources data from third parties such as CDP (formerly Carbon Disclosure Project), itself one of the largest repositories of corporate climate data. To provide accountability and linking of certified assets from these NSAs commitments and progress, we consider blockchain integrations of data from climate action platforms that have both fully open data policy, as well as those that that hold private data. Platforms that have publicly available data can utilize the 'platform of platform' (PoP) server hub, for database and web services functions to integrate onto the open climate system. For platforms with private climate action data with high restrictions on data sharing (eg. CDP's private company data), the system would provide routing and blockchain helper tools without that need of data ingestion or API into the PoP server. This data can be masked to safely provide aggregate information without disclosing individual data points. These considerations essentially point to the fact that the management and sharing of NSA data, being heterogenous and sensitive, requires careful governance and sharing protocols in order to be properly assessed and incorporated into an open climate accounting system and analyzed for their aggregate climate value effects (Hsu et al., 2019).

Data-Driven Lab has to date compiled the largest database of subnational and non-state climate actions, aggregating more than 20 voluntary reporting platforms for cities and companies, including the Global Covenant of Mayors for Climate & Energy, Compact of States and Regions, ICLEI Local Leaders for Sustainability Carbonn Climate Registry, C40 Cities for Climate Leadership, and CDP, among others. In total, it includes more than 10,000 subnational actors and 4,000 corporate actors, with detailed emissions and climate commitments for just over half of these actors. This third component will leverage this database and networks and translate these commitments to Climate Action Blocks (CABs) – immutable, transparent records stored within the BCAT system that will serve as a foundational element for tracking.

Beyond data sharing between legacy platforms and a global network, the most relevant function relating to NSA climate action tracking is that of nested accounting, which accounts for various overlaps between actors' emissions and commitments. For example, to ensure against double counting of emission reductions, it is critical to design accounting capability that would factor in overlaps between actors' baseline emissions or overlaps in target emission reductions. This feature, allows NSA actions to be included into NDCs. It would also simplify the burden of climate action tracking and pledge accountability of governmental actors. Section 3.2.2 describes this process and preliminary proof-of-concepts.

3.2.1 The Paris Agreement: developing a digital smart climate contract

As mentioned in the introduction, many provisions of the Paris Agreement (PA) are obligatory but not legally binding. This is primarily defined by the legal language used in each article. Use of the word 'shall,' for example is considered legally binding, whereas 'should' or 'may' are less so. The underlying concept of the PA is that countries should present their Nationally Determined Contributions (NDCs) to the aggregate climate action efforts (preventing warming below 2_oC with efforts below 1.5_oC). In general, there is no recourse for failing to achieve ones NDC other than the fact that nations around the world use political pressure to hold each another accountable.

Our work has focused on translating the legal language into a 'thoughtware' document that provides the guidelines for a 'software' translation into a digital smart contract. The most relevant PA articles identified in our work are: article 2, which sets the overall climate target goal; article 4, which presents the mechanism for NDCs and 5 year stocktake periods to evaluate and increase ambitions of these NDCs; article 6, which opens up avenues for cooperation and managing trading of international transfer of mitigation outcomes (ITMOs); and article 13, which encourages transparency amongst nation-states, as they must submit greenhouse gas inventories and information on their progress towards implementing their NDCs.

Considering these digitizable aspects, the current PA smart contract puts forth the main temperature goal —whose progress can be tracked by the on-chain record described in the previous section, the mapping and public address assignment to the involved actors (i.e. countries parties to the UNFCCC COP that ratified the PA), their presented commitments (i.e. article 4, NDCs) as well as the stocktake process and other key articles that are compatible with contractual digitization (eg. article 6, ITMOs, and 13, transparency).

The basic function of the PA smart contract requests and receives the countries NDCs. Figure 7 shows a snippet of the NDC structure written in solidity. Countries have an assigned decentralized identity in the network and readable public address, eg. "country_name.opencimate.eth." Their accounts give them the capacity to hold digital wallets, where they can allocate funds to stake a position, or have a specifically assigned voting right with specific weight.

Perhaps the most valuable aspect of smart contracting the PA, is that its basic functions can be used to add multiple other digital functions that countries may want to engage with, which could automatically execute with little operational effort. For example, some of our first tests of this includes application of tokenomics. A specific test implementation has been to issue tokens equal to the GHG reduction goals set by parties in their NDC, where 1 token = 1 ton of CO_2. These tokens are locked on the PA smart contract address (i.e. escrow) and hold a specific high value, currently set at $1000/ton but with the option to be subject to how ambitious the NDCs are and the aggregate temperature effects. The value can be linked to locked funds on a contract or equitable in credit lines from international development banks or other international funds. Parties can redeem these tokens at each stocktake year upon presentation of NDC progress in the form of digital certificates of mitigation outcomes. Parties hold a function to allow or reject the incorporation of certified mitigation outcomes from non-state actors as part of the NDC progress, and the capacity for these to automatically redeems the escrow held tokens and/or receive other fiscal compensations from the corresponding country.

We expect smart contract innovation proposals can be highly valuable for implementation of both for unofficial and voluntary schemes, as well as those developed and presented by the governing bodies of the Paris Agrement (eg. the APA).

3.2.2 Nested accounting: metadata for incorporating non-state actor's climate actions

Performing a nested geographical accounting on the retired climate credits of non-state actors is one the main pillars of the project and key function of the climate actors and registries domain. It allows parties to the PA to include official actions from cities and companies, lessening the burden of the federal state, and the capacity to incentivize the private sector to mobilize climate action capital, rewarding by conventional economic returns, as well as digital credits eligible for global trading (eg. ITMOs).

Figure 8 shows how nested accounting is proposed and tested in the Open Climate platform. In this case, it shows the interface of a logged in non-state actor —spanish renewable energy company Iberdrola— viewing one of their major solar projects in the region of Extremadura, Spain. This solar project, Nuñez de Balboa, will be fully functional in 2020 but in this case already started to produce renewable energy certificates (equal to 1 MWh). Once the Iberdrola company retires these certificates (meaning they are no longer eligible for trading in a market) these can be accounted as mitigation outcomes belongingto the company and act as proof of progress to their climate pledge, but are also immediately accounted to the corresponding subnational actors (i.e. the province of Cáceres and the region of Extremadura) who also have a respective climate pledge. Furthermore, the same credits hold a protocol metadata schema that allows them to be tagged directly to Spain's NDC. Prior to retirement, these credits could have participated under the trade of an ITMO.

This Spanish example emulates an ongoing pilot being developed with Iberdrola and their US subsidiary Avangrid in the state of Connecticut, USA. The application of this mechanism in this pilot is particularly relevant if the USA pulls out of the PA, since it would allow the WeAreStillIn coalition

```
Katowice Climate define following guidelines for reporting:
 - national inventory report on anthropogenic emissions by sources
    1. 2006 IPCC guidelines
    2. 100 year gwp CO2e
    3. seven gases (CO2, CH4, N2O, HFCs, PFCs, SF6 and NF3);
*/
struct country_NDC {
    bytes32 country_name;
    // GHG mitigation goals
    int CO2; // (required) in metric tonnes
    int CH4; // (required) in metric tonnes
    int N2O; // (required) in metric tonnes
    int HFCs; // in metric tonnes
    int PFCs; // in metric tonnes
    int SF6; // in metric tonnes
    int NF3; // in metric tonnes
    int AltEnergy; // alternative/renewable energy usage in MWh
    // Adaptation goals
    // Capacity building
    // Finance
    int Mobilization; // (required) in billions USD.
    int ContribGreenFund; // (required) Contribution to Green Clim
    int BilateralLoan; //  Bilateral loan to developing country Pa
    // Technology transfer
    // Transparency
    // util variables
    uint timeTarget; // set a time target
    uint index;
}
```

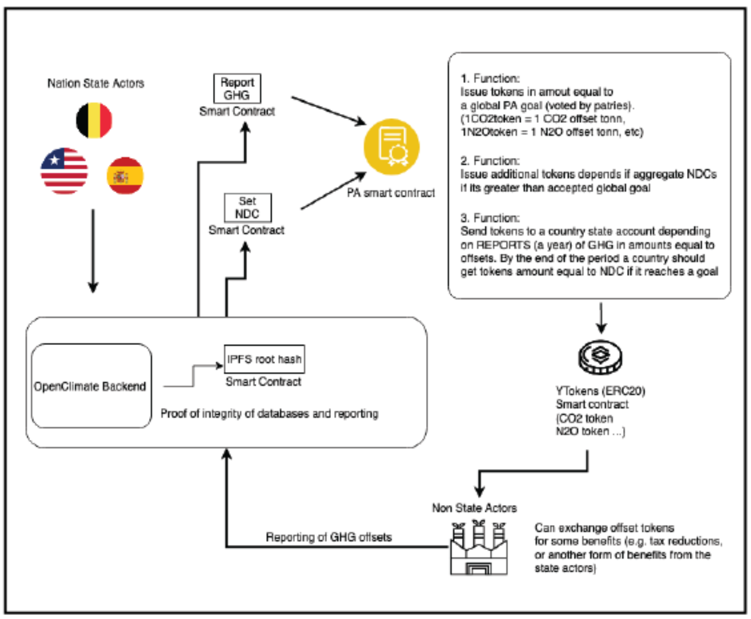


Figure 7. The Paris agreement smart contract.
The left side shows a snippet of the structure of an NDCs as seen in the Paris agreement contract on the Open Climate platform, written in solidity language (Ethereum based). Contract functions include the request of these NDC from countries (with specific addresses and accounts), and the capacity for adding subsequent self-executed actions thereafter. The right side show a basic process outline of both the capacity of extending deterministic functions to the contract, such as with tokenomics, as well as the incorporation of NSAs within the contract given a nested accounting practice.

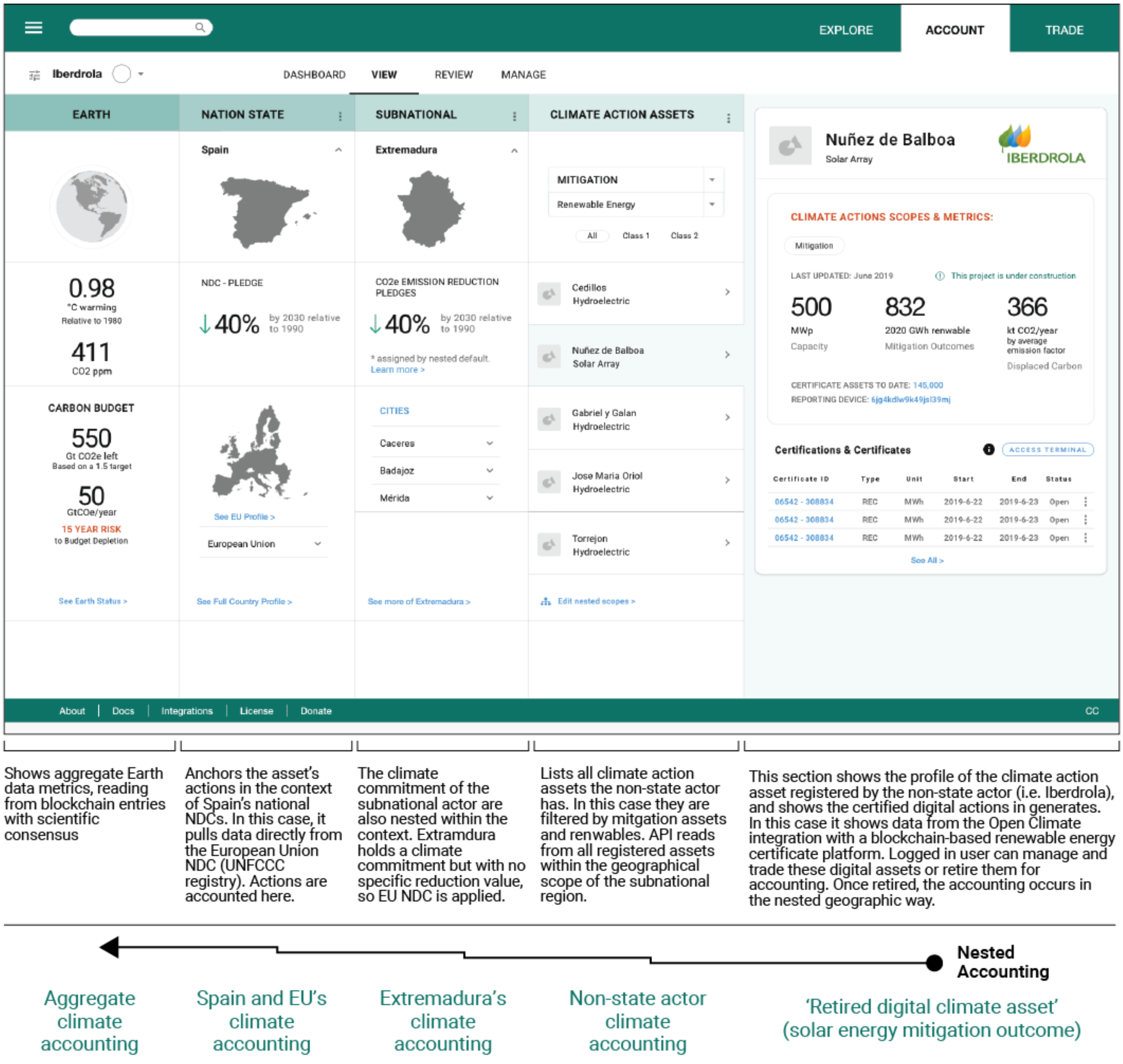


Figure 8. User interface: Account / Solar action from Cáceres to the EU

The top section of the figure shows a screenshot of the Open Climate portal with a non-state actor as logged in user (i.e. Iberdrola) and in the 'Account' section. The user views here information of a specific solar array as a mitigation asset. Actor's assets are seen in the platform in the context of their nested geographical scope and includes the information from the subnational and national NDC to remind the NSA that a retired climate asset (meaning no longer available for trading and assigned to a specific actor) will be accounted within the nested hierarchy. The bottom section of the figure describes the different segments of the interface and the nested accounting logic. This screenshot is a Spanish example based on a real Open Climate pilot being deployed with Iberdrola's USA subsidiary (Avangrid) in the state of Connecticut, for non-state actor accounting under the USA's NDC.

to have a mechanism to actually remain accounted in the PA. In order to operationalize this at a global level, an open innovation process can be used to determine shared protocols for the metadata schemas these digital climate assets should have.

3.3 Climate Actor Accounts & Asset Registration process

The Open Climate platform, in its current prototype, creates and issues accounts, belonging to climate actors (eg. countries and companies), as well as users who operate these accounts. Information that can be obtained publicly is pre-loaded onto the platform and used to create pre-existing unclaimed accounts. Private data belonging to non-state actors can either be obtained by special permissions from the platforms that hold it, or directly from these actors if they so choose when they are onboarded to the platform. This section describes the users experience through the platforms registration process to both claim or created these accounts, as well as link assets involved in a specific climate action (eg. a solar plant).

3.3.1 User & account registration

The current user onboarding process requires a secure authentication procedure for verifying corporate or governmental identities. If a company wants to register an account on the platform, then an authorized user from that company (e.g. the CEO, CFO, CGO, etc.) can visit the platform's website and navigate to the registration page. At this stage, the user can enter the name of the company, city, state, or country the user wants to claim or register, and search if the organization already has a pre-loaded official title in the platform's database. The user can then verify that this is the correct company name, correct it, or create a new account if it has not been pre-loaded.

In order to authenticate a user and the account they wish to register, documentation needs to be submitted by the user to prove that the entity engaging with the Open Climate platform on behalf of the company is actually authorized to create the company's account. Such documentation might include the company's certificate of formation, articles of incorporation, recent utility bill, or tax returns, as well as government issued identification of the user attempting to make the account and proof of the user's employment with the relevant account's organization. Upon receipt of these documents, the platform issues the company secure administrator login credentials, which allows the administrator to access the company's account on the platform and subsequently grant access to specific members of the company.

When a user registers a new account, a unique ID number is generated that identifies that account. Currently these IDs are made using Golang's database library, but eventually the platform will be extended to support a distributed ID (or DID) system. In collaboration with researchers at Yale University's School of Engineering & Applied Science, we are designing this platform to operate in the absence of a centralized authority. DIDs would enable ID assignment in a decentralized manner.

Once the user identity and affiliations are verified, the user is guided through a series of setup questions to help both validate the information pre-loaded on record for that account (using integrations with climate action platforms) as well as add additional information to make the account more comprehensive. These questions are tailored to the type of account being registered (namely, state versus non-state actor).

3.3.2 Asset Registration

Users can register assets to their account. Assets are considered physical projects engaged in climate action (i.e. emissions, mitigation, adaptation) and often than not involve a hardware asset (eg. a power plant, wind turbines etc.). If following the appropriate MRV methodology, these assets create the digital assets that attest to the climate action generated (eg. a carbon offset). Assets can be added individual or integrated in bulk using the API of the pre-existing mechanism for asset management or climate accounting (eg. an ERP or a climate credit generating platform).

Upon registering a new asset under a user's account, the user must enter the unique name of the asset and proof of ownership of that asset. This is to ensure that an asset (and its emissions or mitigations contribution) are not claimed by more than one user, nor claimed multiple times by the same user. While pending verification, the user is prompted to enter the latitude and longitude coordinates of the asset. This enables the platform to determine the geographical location of the asset which simplifies nested data aggregation across state and non-state actor accounts. Once uniqueness and ownership of the asset is verified, the asset will be entered into the platform's record with a unique identity number and metadata detailing its location, owner, and emissions/mitigations history. An API integration with the asset management platform can allow all the digital credits to also be visible in the Open Climate system. This is specifically the case in the example of Figure 8, where the Iberdrola account holds the solar asset Nuñez de Balboa whose credits could be managed by a blockchain based renewable energy certification system, such as Swytch.io.

3.3.3 Privacy Settings

Prior to onboarding, data on the Open Climate platform consists only of public data. However, when an entity claims a user account and registers additional assets with that account, the entity (or entities) are able to specify what information is to remain public or private on the platform. This is done on a *per asset* basis. However, users can also specify "groups" of assets (e.g. categorized by geographical location, asset type, or any other specified grouping) so that access control can be managed in a coarser-grained fashion. Information that is marked as private by the asset manager is hidden from public view on the platform and can only be seen by members with authorized access to the account owning the private asset.

Although information that is deemed private by the asset owner is not viewable to the public, that information can still be used to compute aggregate data while maintaining user privacy. This functionality is achieved using differential privacy. For example, suppose that Company X enters Assets 1 through 10 onto the platform and wants to keep specific emissions data from Asset 1, Asset 4, and Asset 9 private. Then Company X can declare these three assets as "Viewable only by Company X." This will prompt the platform to sample a random value from the normal distribution with mean zero and pre-specified variance (tuned according to a privacy parameter) and when Open Climate ingests data for these assets, it will add a freshly sampled random value to each data value. This means that the aggregate data will maintain the same average with high probability, but that each individual piece of data stored in the database for these private assets will vary from the true value.

3.4 Climate Action Monitoring Reporting and Verification

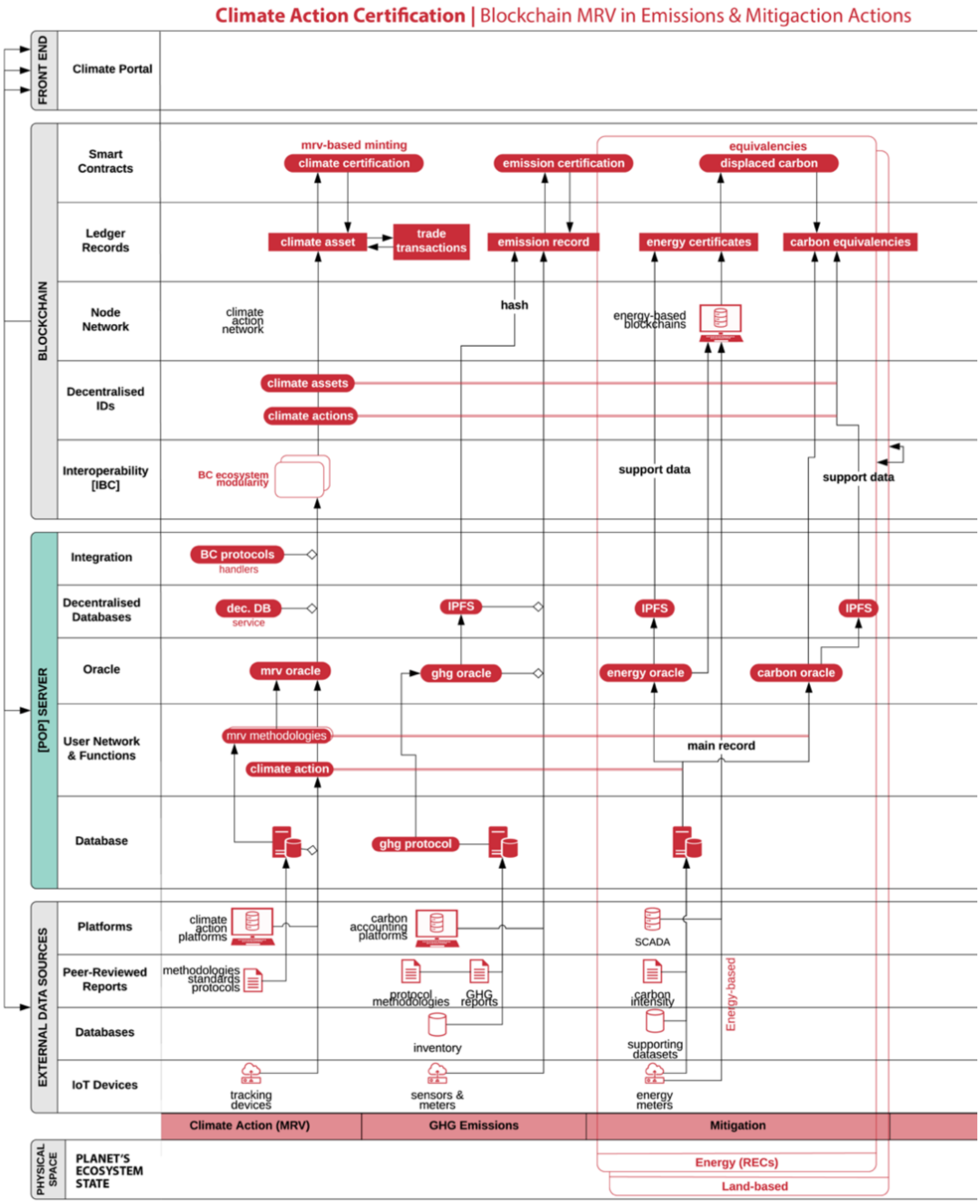
One of the most prominent values in the application of blockchain and complementary technologies —such as internet of things— to climate accounting, is the streamlining of monitoring, reporting and verification (MRV) of climate actions for the subsequent minting of a certification of the action. While these processes are often costly and methodologically cumbersome, excluding actors and project without the capacity to afront them, these technologies can reduce marginal costs and bring about higher level of inclusivity in the space.

Figure 9 below shows the general paradigm of how these technologies are leveraged in a certification process. Sensors provide direct attestation of observations, from CO_2 emissions to MWh generated, the data is hashed and timestamped on a blockchain, a machine learning oracle can review application of the appropriate standards and methodologies, and a smart contract can mint a digital token with metadata attesting to the climate action and it associated value, which differs if this is an emission, mitigation or adaptation record. The action holder can then trade or retire that digital asset for accounting. The platform's architecture organizes these processes on the three main modules (emission, mitigation and adaptation), with submodules depending on, for example, what type of mitigation is being attested to (eg. renewable energy vs. forestation projects).

The integration of platforms that provide MRV services are crucial to the success of the project. The Open Climate as a platform of platform depends on these to provide the core services, but also supplies the protocol functions in order for the records created and maintained in these platforms to participate in global accounting and eventually trade. Our first end-to-end pilots covering the process flow in figure 9 have been done using the renewable energy certification (REC) process, with an API into blockchain-based REC platform Swytch. Our next pilot will focus on land-based mitigation, coastal adaptation projects, and direct tracking of emissions from upstream carbon major's productions.

Figure 9. Climate action domain with digital Monitoring, Reporting and Verification (MRV)

This domain's architecture fully bridges the value of IoT sensors with blockchain records, and considers distinct modules for emission, mitigation and adaptation processes, and their submodules based on the methodological requirements (eg. with land-based vs. energy-based mitigation. Most blockchain and climate applications provide a form of digital MRV to mint a DLT-based token. The architecture of the Open Climate system considers the integration of these platform services via APIs, and the link to the unique actor accounts and common protocols.



3.5 Climate Finance

As presented in pillar 3 of the project, one of the most important values a blockchain-based climate accounting system can provide is the contractual automation between verifiable climate value with financial capital.

The climate transition requires over $1 trillion/year in financial capital to achieve the established climate goals. Part of these funds will come from international climate funds, multinational development banks, and countries. However, the lion share of climate finance needs to be mobilized by private capital. Whilst we have explored the role of linking capital from governmental funds and shared climate funds with climate action data using smart contracts (see related mentions in section 3.2.1), a focus of the Open Climate project has been the development and function integrations around project finance of climate actions. This has been primarily developed and tested with one of the integrated platforms in the Open Climate system, OpenX.

OpenX is a platform developed in a collaboration between the Digital Currency Initiative at the MIT Media Lab and the Yale Open Innovation Lab. It is a partner project of Open Climate and is, in itself, another platform of platforms but with a specific purpose on climate finance.

This section describes the main functions of OpenX with a focus on one of its platform instances —OpenSolar— in the context of a pilot project involving international climate financing between investors in the European Union, United States and Rwanda.

3.5.1 OpenX / OpenSolar: Contractual automation for p2p project finance of climate actions

The OpenSolar platform uses the Stellar blockchain and IoT-based smart contracts for disintermediation and contractual automation in financial processes to drive community-owned solar projects and microgrids. OpenX is its underlying platform framework extendable to climate finance as whole and integrated with the Open Climate platform.

The platform is designed with a project marketplace where multiple investors can be pooled to finance a single project (i.e. crowd investment) even if these have different return expectations. This includes the blending of mainstream investors that expect market rates returns on investment, with impact investors that allow concessionary or first-loss capital as long as there are certifiable social and environmental returns.

Receivers of the project's assets (eg. renewable energy infrastructure or other climate asset), are often the end-users of these services and local community actors. Although initially debtors, receivers pay for the services provided by the project (eg. solar kWh) through regular utility-like payments with no down payment and gain full ownership of the assets once payments accrue to cover capital costs and investors. All financial transactions and rules are automated through the project's smart contract, hosted in the OpenSolar platform as an escrow account with capability to hold and transact stable digital currency.

Payments from receivers to the contract are driven by IoT data (eg. power meter data), which is also used by another key function of the project contract; the minting of a digital climate asset (i.e. token) as attestation of the underlying climate value. In the case of solar energy, this is a Renewable Energy Certificate (1MWh) and displaced carbon equivalencies.

The OpenX platform is designed with full integration to the Open Climate platform so that the same smart contract mechanism can be used for other climate mitigation projects, such as forest conservation initiatives The OpenX and OpenSolar platform has been tested in real-world projects for the financing of solar energy in schools in Puerto Rico. Since 2019, the project expanded its scope to include platform considerations to allow cross-border investments for financing distributed solar infrastructure in rural Africa. Specifically, thanks to a collaboration between Yale University and the Rwandan government, the platform is currently being tailored to deploy its first international climate finance pilot.

The pilot project seeks to show an operational proof-of-concepts of: the use of decentralized ledger technologies (DLT) for cross-border crowd investment using a Climate Bond as its security, the use of a cross-border bank network using DLT for expedited clearing and settlement processes, the use of smart contracts to perform

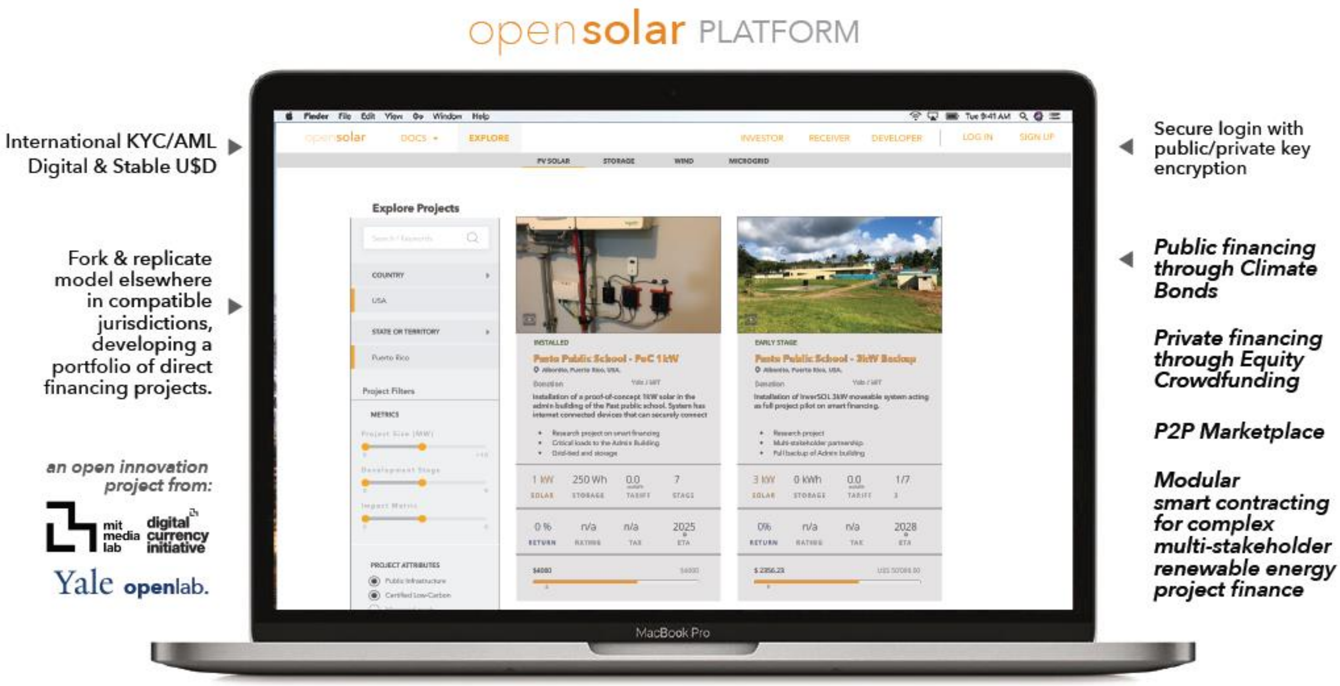


Figure 10. The OpenSolar platform for crowd-investment of solar projects.
The platform (www.openx.solar) provides financial smart contracts that disintermediate and automate payment rules in the project finance of distributed solar infrastructure. Its project marketplace allows crowd-investment and blended capital to fund projects, that provide certified climate assets as part of the project's return and allow community end-users to have no down-payment but acquire full ownership of the project through regular utility-like payments.

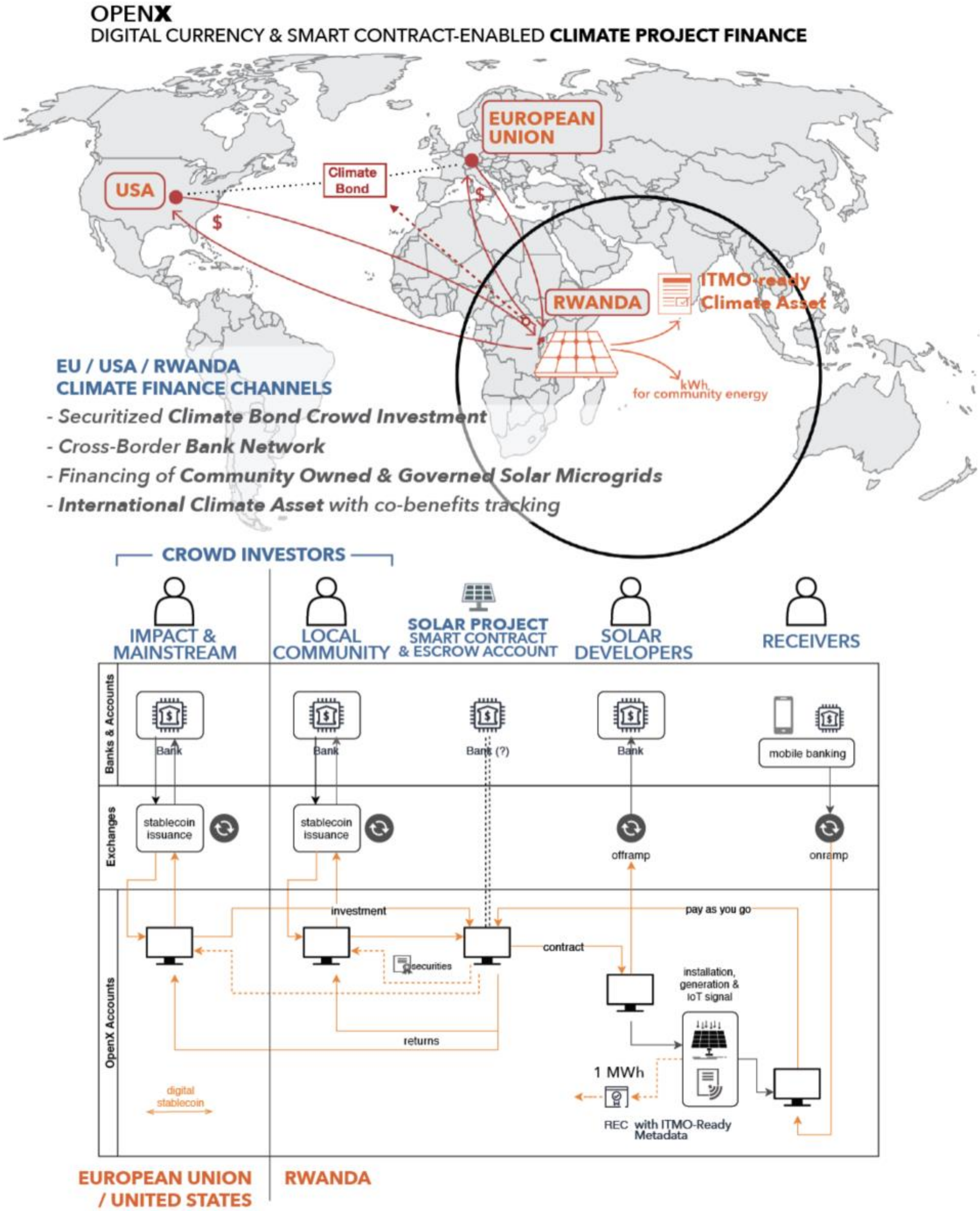


Figure 11. OpenX climate finance pilot in Rwanda

The pilot will use smart contracts and stable currency to facilitate international crowd-investments from USA and the European Union using a climate bond to finance distributed solar infrastructure in rural Africa. The platform's integration with Open Climate will allow the generation of a certified climate asset (i.e. MWh) with attestation of social co-benefits, which can be either used in the accounting of the host country, or transferred internationally back to investors as a mitigation outcomes.

automation in the acquisition of financed public infrastructure by a local community, and the use of an international digital climate asset, integrated with the Open Climate platform to be included as climate accounting compatible with UNFCCC's Paris Agreement.

4.Current Open Climate's state and next steps

After over a year of architecting and several months of incubation, the project is in an advanced prototype phase and is currently deploying its first real-world pilots. U

The blueprint of the project's meta architecture is in its first full draft, and maps how data and process flows cross multiple layers of the technology stack, spanning from IoT-based datasets, to platform functions, blockchain ledger records, smart contracts and user interface displays. The architecture is tested by different proof-of-concept of these data flows but will require a higher level of testing by directly integrating of the platform ecosystems of the initial collaborating partner. Our real-world pilots are focused on the certification and minting of digital climate assets from the generation of renewable energy by non-state actors (eg. private companies). We are primarily focusing on the compatibility of these assets (eg. mitigation outcomes) with subnational and national climate records in order to enable the automated nested accounting system once those assets are retired. Other next steps are outlined in Part III of this document.

4. Integrated platforms and working groups under an open innovation framework

4.1. Introduction

The open climate project and its underlying global climate accounting system and platform cannot be developed in silo, and certainly not under legal layers of protected proprietary software. It requires a higher level of participation, collaboration and interoperability among climate stakeholders and technological providers; from established government and private actors, to new climate action innovators and, ultimately, individual citizens. Innovation needs to not only occur in blockchain for climate accounting and related software systems but in decentralized institutional models that can steer and maintain global projects and their associated business models. Blurring organizations' IP boundaries in the innovation process allows a rich ecosystem for such solutions to emerge. Here we present the open innovation framework adopted by the project and its initial participants.

As a platform of *platforms*, Open Climate would lack significant value without the integration of its constituent platforms via application programming interfaces (APIs) and shared protocols. This section introduces the first group of integrated platforms with their respective technological capabilities, how they participate in the project as part of working groups to deliver robust real-world pilots, and their intention to form part of a growing network and consortium to develop and govern the underlying climate accounting system. Furthermore, it presents the overall project development timeline until the release of the operational Open Climate platform, proposed here to be governed by a decentralized autonomous and self-sovereign organization.

4.2. Integrated Platforms

4.2.1 Integration process and stages

In order for participating platforms to functionally integrate in the Open Climate platform, we have laid out three key development stages. These are 1) Workshops and system mapping, 2) Sandbox for API testing and 3) Pilot testing. These stages engage both the Open Climate and constituent platform development teams.

The first stage involves identifying the whole chain of data records and processes across the system architecture (see Fig 4 for stack reference and sample architectures in figures 5,6 and 9). This is done through workshop exercises and review of technical documentation. This stage also identifies technological compatibilities, in terms of platform coding languages, existing APIs and used metadata schemas. The second stage translates the mapping of stage 1 into common code and performs testing of APIs calls. Additionally, in stage 2 the groups develop any front-end and user interface adjustments required in the Open Climate portal for functions and APIs to be called directly from the interface. At the end of stage 2, the development teams are testing all functionalities in the lab and sandbox environment.

By stage 3 the group has identified a strategic real-world pilot to deploy a test the full functionalities of the integration. This often has a first phase with low-risk proof-of-concept phase, and a second phase testing the pilot with external stakeholders that expect full operational capacity. Pilots ideally combine the technological capabilities of more than one integrated platform.

4.2.2 Platform summaries and status

The following list outlines the participating platforms and clarifies their technological readiness level (TRL) as per EU H2020 definitions, and the integrate stage they hold with the Open Climate platform.

These are integrated groups and part of ongoing working group as of September 2019. However, this section is subject to constant change as more platforms and partners are added to the project.

DataDrivenLab's Climate Action DB: TRL7 | Integration stage 2
Democracy Earth: TRL8 | Integration stage 1
Swytch: TRL7 | Integration stage 3
OpenX/OpenSolar: TRL7 | Integration stage 3
VERSES: TRL7 | Integration stage 1
Pachama: TRL5 | Integration stage 1
Commit.Me: TRL 4 | Integration stage 2
Adaptation Ledger: TRL4 | Integration stage 1
Sensorica: TRL8 | Integration stage 1

4.3. Working groups and pilots

We have identified 5 initial strategic working groups (WG) to guide the collective work of the open climate project and open innovation consortium. These have a specific theme centered around an essential aspect of the Open Climate architecture, a lead organization that acts as WG task and budget manager, and an identified pilot where the shared work will be deployed and tests. These five working groups are:

WG. A) Non-state climate action data with nested accounting

This WG focuses on the mechanisms by which non-state actors (NSA) can integrate climate action tracking data as progress to their pre-established commitments into the Open Climate platform and subsequently to NDCs. This includes understanding the technical, privacy and political constraints of the existing legacy platforms that hold NSA climate action data, and how these platforms can engage integrate with the open climate system and vice versa. This WG also places specific focus on developing the proposed protocols for metadata schemas used in nested accounting, which enables NSA accounting into Subnational and National Leveld.

WG members: Data Driven EnviroPolicy Lab (lead), Commit Me, Swytch, Verses

Pilot: Nested accounting of NSA renewable energy certificates in the USA under the WeAreStillInCoalition.

WG. B) Decentralized IDs (DID) & distributed Earth data consensus and governance

This working group focuses on the key aspects of the open climate decentralized nature. The first entails the technological development of climate DIDs, for assigning them to different accounts and elements in the platform and the interoperability of these DIDs with different blockchain ecosystems. The second is the method for decentralized governance from the scientific community to arrive at consensus of Earth system data, both from objective measures from multiple disperse IoT devices, as well as data that requires subjective decisions, for example with respect to climate budget metrics. The third aspect of this WG entails the technological requirements and mechanisms for the decentralized management and decision-making of the open climate project itself. This includes processed relevant to the open innovation network and consortium management.

WG members: Verses (lead), Democracy Earth, Sensorica.

Pilot: Open Climate DID implementation and decentralised governance of the open climate consortium as a DAO-style project.

WG. C) Climate bonds for international climate finance

This working group focuses on the financial technology aspects of blockchain under the Open Climate platform to streamline the use securitized instruments (eg. Climate bonds) for climate finance, and the role of certified MRV actions (eg. certified MWh) as another instrument to both leverage the capital and participate in international networked climate markets. The WG particularly focuses on financing distributed energy infrastructure and it needs to leverage the work developed by the WG involved in nested accounting.

WG members: OpenSolar (lead), Swytch, Commit.Me

Pilot: Climate bonds and cross-border investments for solar rural electrification in Africa.

WG. D) Land-based mitigation MRV

This WG focuses on land-based mitigation, in contrast with WG C that has a specific focus on energy-based mitigation. Its role is to map out the different methodologies and standards that apply to land-based mitigation strategies and identify processes for digitization and automation. This WG will particularly focus on forest-based mitigation and the use of remote sensing for monitoring changes in above-ground biomass.

WG members: Pachama (lead), Verses, OpenX

Pilot: Reduced emissions from forest conservation in the Amazon region

WG. E) Climate adaptation financing and certification

This WG focuses on the incorporation of certified adaptation actions into the global climate accounting system with specifics on Paris agreement compatibility. It places special considerations of the use of smart contract for financing adaptation, linking it with methodologied to certify resilience building / vulnerability reductions.

WG members: Adaptation Ledger (lead), OpenX, DataDriven Lab

Pilot: Financing coastal infrastructure and measurements for adaptation to sea-level rise. Florida State and AOSIS countries are potential pilot targets.

4.4 Open innovation framework in a consortium effort

The development of the open climate project adopts an open innovation framework to manage the multi-stakeholder collaborative effort to develop the Open Climate platform the set of protocols and standards of the underlying global accounting system.

Highlights from this framework include:

Mission statement: To develop and disseminate an open-source, integrated system and platform for helping the world transparently account and track its climate pledges and actions to prevent anthropogenic warming above 1.5$_o$C.

Shared attribution, not IP: The proposed framework is of *shared attribution* while placing any IP generated by the collective development into an open-source license compatible with proprietary developments. This does not mean that all the IP that participants already have is relinquished. Participants are encouraged to share *only* what they are willing to share openly, thus maintaining agency about their proprietary content. Contributors are also encouraged to manage their own IP throughout the process.

5. Project notes

A note on project name, ownership and decentralized institutional strategy

We have been using ‘Open Climate’ to identify the platform and ‘open climate’ to identify the project, but not as a brand name but as a placeholder description for the project’s intention. Other ‘Open Climate’ projects already exist. These include the Open Climate Network, spearheaded by the World Resource Institute, the Open Climate Data repository developed by the Potsdam Institute for Climate Impact Research, and the Open Climate Workbench hosted by the Apache Foundation, to name a few.

Far from competing with these initiatives, this project proposes to leverage these and a myriad of other similar climate efforts, including multiple initiatives and projects that already leverage blockchain technologies for climate accounting (eg. the set of members of the Climate Chain Coalition) that are not yet included as participating platforms. In fact, one of the most important design challenges the project faces are in its institutional strategy. Two dichotomies are presented; on one hand the development of an ownerless and decentralized system, yet democratically owned and governed by everyone, and on the other hand an institutional ego-detached strategy that can prevent clashes of organizational egos and competition from roadblocking scalable collaboration, and yet also have a distinct and unified image so that all stakeholders can recognize and engage with.

Acknowledgements

About the Yale Openlab

The Yale Open Innovation Lab (openlab) produces, incubates and collaborates with multiple stakeholders on bold open source projects that sit in the intersection of emerging technologies and global challenges. Its current target challenge is the climate & energy transition, with an ongoing focus on blockchain for climate action tracking and financing. The openlab was launched at the Tsai Center for Innovative Thinking at Yale (CITY) as a partnership with the Center for Business and the Environment at Yale (CBEY), and the Center for Collaborative Arts & Media.

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Openlab’s climate development team: Talley Amir, Kristine Ericson, Varunram Ganesh, Pavel Krolevets, Jamie Lee Ying, Brian Li, Amanda Patterson, Franz Hochstrasser, Steve Ettinger, Martin E. Wainstein.

See more at: www.openlab.yale.edu

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