Understanding and Monitoring our Changing Planet

A Climate Technology White Paper

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Contents

Understanding our changing planet: an introduction

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Introduction

Understanding and monitoring our changing planet

In this paper we show that there are some important and urgent challenges to understanding and monitoring our planet and its role in climate change.

Specifically, we analyze technology innovations, and the early-stage companies developing them, that would contribute significantly to tackling these problems:

1. **Mapping and measuring carbon sinks:** How have humans affected the ability of carbon sinks to absorb CO2, and how much CO2 do carbon sinks absorb? (slides 8-15)
2. **Monitoring and quantifying GHG emissions:** What technologies can provide us with better data to quantify methane and CO2? How can we spot fugitive emissions and incorporate these into calculations? (slides 16-21)
3. **Company-level measurement and reporting:** How can companies track and measure their carbon footprints, assess climate risk, and better plan for their future investments? (slides 22-29)

This paper provides data and context on the challenges, evaluates some of the proposed innovations and suggests ways to overcome potential blockers. We also highlight 64 startups that are leading the charge in these areas. The final section examines cross-cutting technologies that could accelerate innovation and outlines early-stage investment trends for each of the three technology gaps.

BNEF Pioneers: hunting for innovation

This is one of three reports to be published following the 2021 BNEF Pioneers awards.

BloombergNEF's annual Pioneers competition identifies and recognizes innovators developing new technologies to tackle some of the most important challenges in the fight against climate change.

Each year, the Pioneers competition focuses on three innovation challenges.

In 2021 the challenges are:

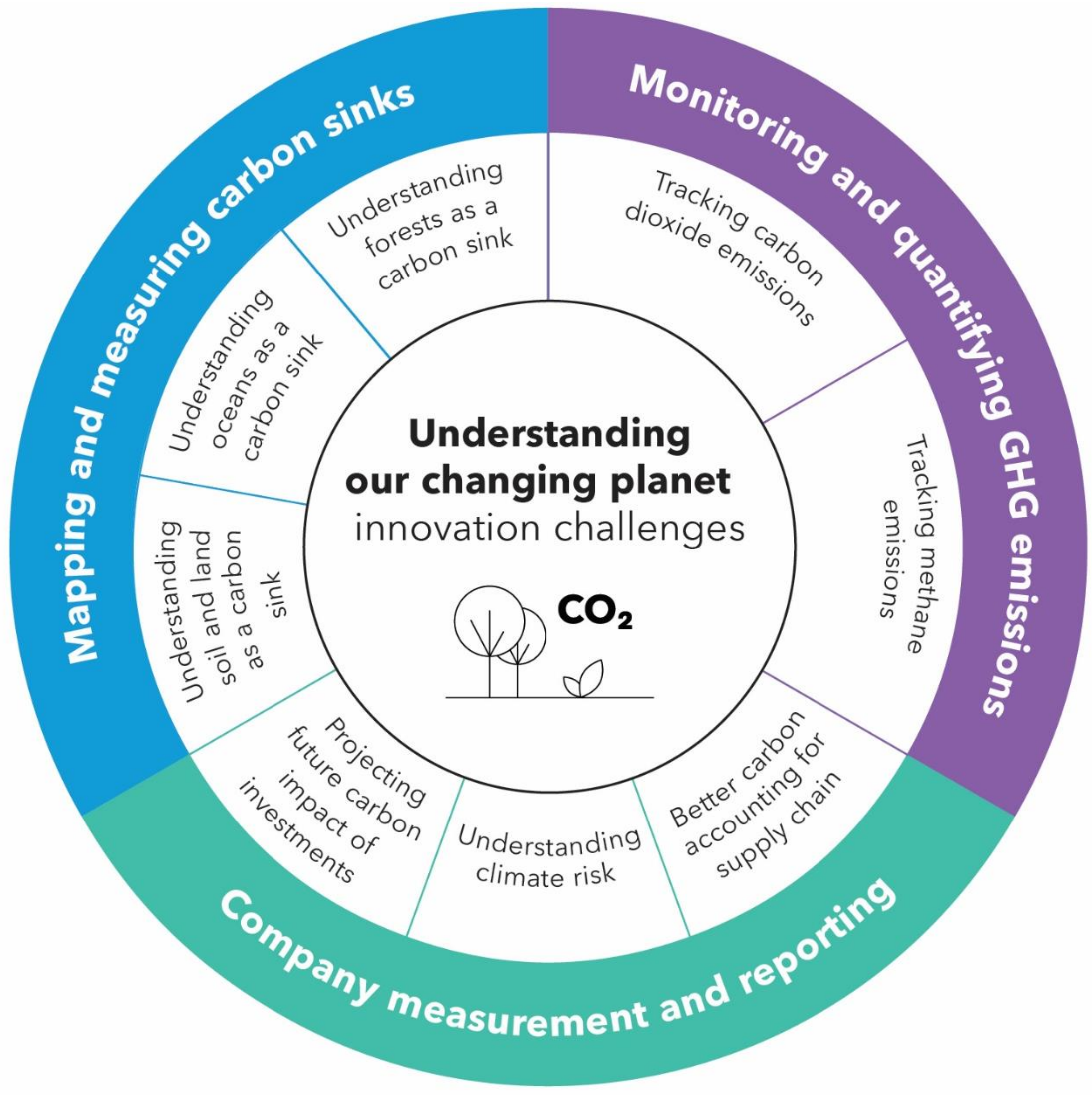
1. Optimizing commercial freight (research note available here)
2. Advancing materials and techniques for sustainable products (research note available here)
3. **Monitoring and understanding our changing planet** (the focus of this research note)

For more information about the Pioneers competition, please visit https://about.bnef.com/bnefpioneers/

Challenges in understanding & monitoring our planet

This report highlights three key challenge areas for understanding and monitoring our planet:

- **Measuring and monitoring carbon sinks:** Most climate-safe scenarios project some need for natural carbon sinks, alongside rapid decarbonization of the global economy. International carbon trading markets will require robust measurement and verification of carbon storage and removal. There is therefore an urgent need to improve measurement technologies to better understand how oceans, trees and soil capture and store carbon dioxide, and how much.
- **Monitoring and quantifying GHG emissions:** The most important greenhouse gases are carbon dioxide and methane. The energy and agriculture sectors are the largest emitters, but it can be difficult to locate the exact sources of emissions, as well as the amount of gas emitted. This is particularly important for fugitive emissions or dispersed sources of emissions that are not properly monitored. A combination of new technologies could help pinpoint and quantify them.
- **Reporting and measuring company-level emissions:** Many of the world's largest corporations are pledging to eliminate or offset all of their emissions, including Scope 3. But very few companies can accurately quantify their carbon footprints, or determine the main sources in their supply chain. Without this information, it is difficult to set realistic carbon reduction goals or credibly meet them. In addition it is urgent that all firms understand, quantify and report on the climate risk to their existing physical assets, and any future projects.



Source: BloombergNEF

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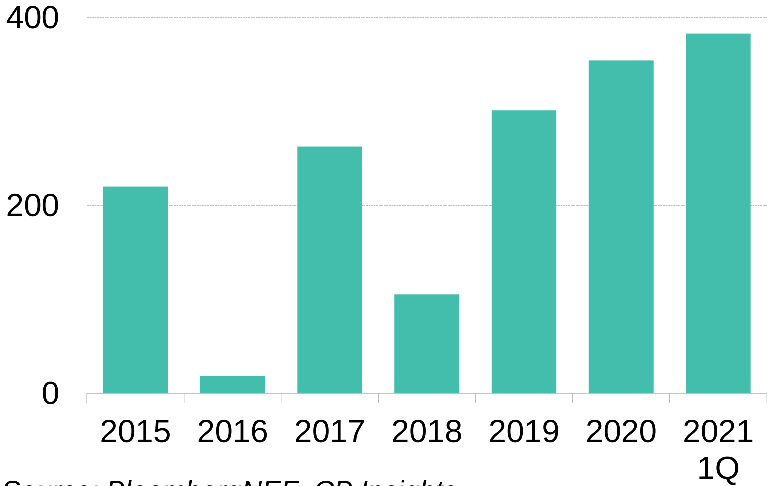
Companies and investment

BNEF tracked 140 start-ups with technologies for understanding and monitoring the planet. They have raised a combined $1.4 billion in early-stage investment from 2015 to 1Q 2021. Funding just in 1Q 2021 exceeded any full year before, showing that VCPE interest in technologies for climate monitoring is growing at pace.

This paper describes 64 of these startups in more detail, under eight innovation areas that contribute to tackling the three overarching challenge areas.

VCPE raised for climate and carbon monitoring technologies

$ million



Source: BloombergNEF, CB Insights

BloombergNEF

BNEF Pioneers 2021 Winners

Challenge 3: Understanding and monitoring the planet

planet.

Tackles the challenges of mapping and measuring carbon sinks and monitoring and quantifying GHG emissions

Planet operates the largest constellation of satellites globally, with more than 200 nanosatellites imaging the Earth daily at a 30-centimeter resolution. It provides spatial data on forests, oceans, carbon dioxide, methane and more, to help understand global and local change, through satellite imagery. Its analytics platform is sold to agriculture, energy, forestry and other sectors.

QLM

Tackles the challenge of monitoring and quantifying GHG emissions

QLM has developed a ground-based sensor that visualizes and quantifies greenhouse gas emissions at source, with a focus on methane. This is particularly useful in the oil and gas industry where there is urgency on this issue. The camera systems use quantum single photon detection technology that works 24/7, without needing in-person operation. Unlike other methane cameras, they can quantify the amount of methane emitted by each leak/flare.

Pachama

Tackles the challenges of mapping and measuring carbon sinks and company-level measuring and reporting

Pachama is a technology company focused on improving the credibility of forest carbon markets. The company uses a combination of AI technology, satellite imagery and lidar to more accurately measure carbon sequestration from forestry projects. The company's goal is to create a more liquid voluntary carbon market for landowners and corporations looking to purchase offsets.

Technology challenges

Routes to understanding and monitoring the climate and planet

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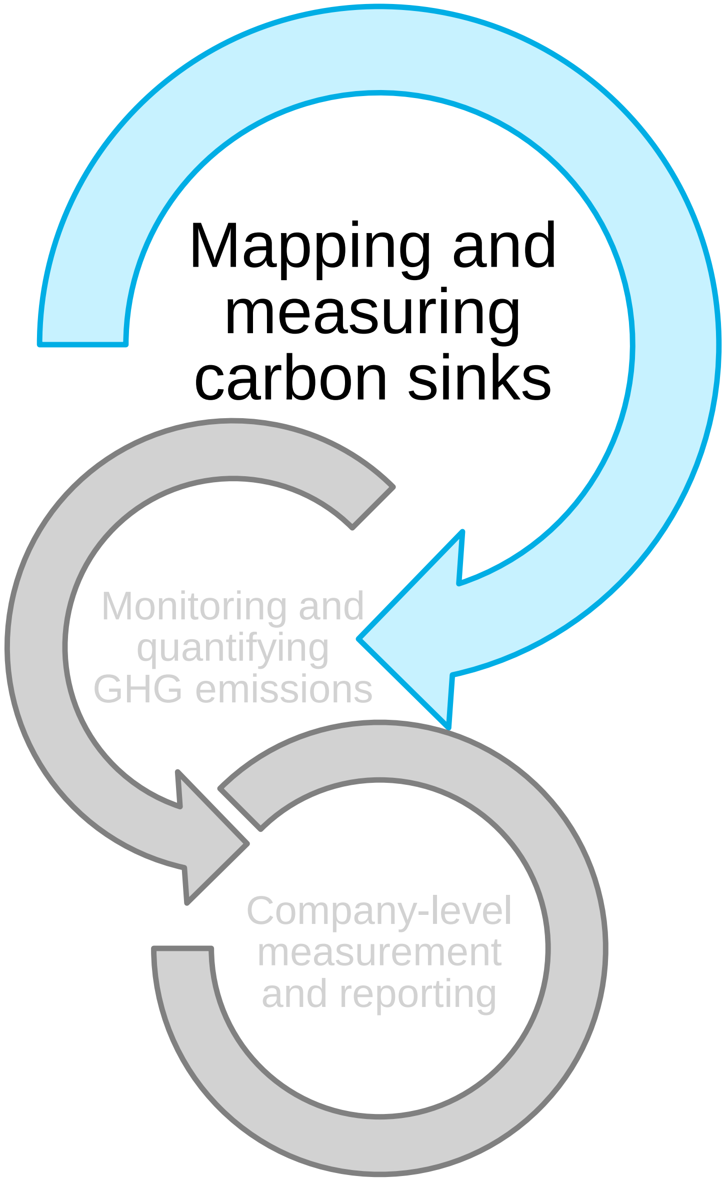
Mapping and measuring carbon sinks
Monitoring and quantifying GHG emissions
Company-level measurement and reporting

The need to map and measure carbon sinks

Most climate-safe scenarios project some need for natural carbon sinks, alongside rapid decarbonization of the global economy. International carbon trading markets will require robust measurement and verification of carbon storage and removal. There is therefore an urgent need to improve measurement technologies to better understand how oceans, trees and soil capture and store carbon dioxide, and how much.

What is a carbon sink?

Oceans, rocks, soil and plants are natural carbon sinks that continuously remove carbon from the atmosphere. These natural environments are crucial to maintaining the planet's carbon concentrations in balance. On the one hand, their preservation and management can help to reduce carbon dioxide concentrations in the atmosphere. On the other hand, anthropogenic activities such as deforestation and human-induced weather changes are decreasing the amount of carbon dioxide absorbed by nature. Both of these effects require better measurement.

How big a problem is it?

Studies show that ocean and land carbon sinks absorb annually over 50% of anthropogenic carbon dioxide emissions. But researchers are unsure as to how climate change is impacting this natural carbon absorption. It does seem that climate change is depleting the size of this carbon store and that certain valuable carbon sinks, such as mangrove forests and kelp forests, are already endangered. Mapping how much carbon land, oceans and forests are absorbing, and their role in the carbon cycle is important in understanding the efficacy of policies used to protect forests or oceans, and enable global carbon markets that rely on natural carbon capture. It will also inform better practices and techniques for managing natural carbon stores.

Why is it difficult to solve?

Until recently, scientists estimated global carbon 'fluxes' from the sum of country reported data. However, unreported events such as deforestation can cause forest carbon to fluctuate massively. Furthermore, voluntary carbon offset schemes are increasingly notorious for over-stating the amount of carbon removed, and few participants are incentivized to spotlight this issue.

Properly quantify carbon sinks requires regular, granular data and analytics that are easy to access and use. While technologies such as nanosatellites, sensors, lidar and artificial intelligence have matured in recent years, they are still expensive and there are remaining technology gaps.

What should we tackle first?

Soil and land: The degradation of soil from unsustainable agriculture and other development has released billions of tons of CO_2 into the atmosphere. Only 3% of North America's tallgrass prairie remains and the world's soils have lost between 50-70% of their original carbon stock.

Oceans: The ocean is a carbon sink for over 9 billion metric tons of CO_2 per year. As the amount of CO_2 in the atmosphere grows, so has the ocean's ability to absorb CO_2. However, it is not certain that it will continue to be a large store. Warmer seawater is less able to absorb CO_2 than colder. And increased storms are destroying kelp forests, one of the most effective carbon sinks.

Forests: Recent research shows that the world's forests absorb 16 billion metric tons of CO_2 per year. However, deforestation, fires and other disturbances cause forests to emit half this absorbed CO_2 – meaning net absorption is around 7 billion tons. Only one major rainforest remains a strong carbon sink (the Congo), with the Amazon and Southeast Asia forests becoming net carbon emitters due to humans.

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Understanding forests as a carbon sink

Forests absorb a net 7 billion metric tons of carbon dioxide annually. But their ability to work as a large carbon sink is shrinking. A large swathe of the word's rainforests are now net emitters. Forests absorb carbon when standing or re-growing, but release it when cleared or degraded. Deforestation, fires and drainage of peat soils all deplete a forest's ability to sequester carbon. New technologies such as satellites, sensors and lidar, plus new analytics methods, can help quantify forest carbon storage and emissions from deforestation. The emergence of robust carbon markets and regulation will both depend on better forest monitoring, and potentially help fund it.

A new method for analyzing forest carbon was used in January 2021, in a study led by NASA. It built on NASA's Landsat-based Global Forest Change product. Landsat imagery for 20,000 sites was combined with 700,000 LiDAR observations to create global maps of forest carbon fluxes.

New approaches and technologies

New remote sensing technologies are creating opportunities to understand forest systems and carbon projects.

Nano-satellites: These are now relatively common and, for forests, can take photos and videos from a height of 200km above the Earth. Companies like Planet can produce images at a 30cm resolution using optical sensors. Such satellites can quantify CO2 emissions by looking at rates of deforestation, the spread of forest fires and spot tree loss.

Sensors and cameras: Sensors, including lidar, infrared spectroscopy and laser can be placed on drones, airplanes, towers or on the ground to capture information on forest fires and trees.

Artificial intelligence: AI and other advanced analytics use data from these sensors and cameras to understand sizes and species of trees. This helps bring transparency to carbon offset projects, with regard to the land that would have been forested.

Limitations

Insufficient political or commercial impetus: Despite emergence of new technologies, there is not much investment in monitoring of forests. Parts of the Amazon or wildfire-prone California are receiving attention, but large areas of woodland will not be monitored with satellites and sensors until regulation kicks in, or carbon markets create a business case.

Technology barriers: The high costs of launching satellites; infrequent images due to low satellite revisit rates; the challenge of capturing data through clouds or smoke, and the effort and time to place ground sensors and cameras all limit our understanding of forests. There is usually low internet connectivity in remote areas where forests are located, making IoT devices difficult to use.

Geographic location of tropical forests: Tropical forests are often located in countries with limited carbon policy or domestic technology.

Potential solutions

Transparent forestry carbon markets: Using digital technologies to accurately track tree growth and reforestation should help boost transparency and confidence in offset markets. These markets in turn should help fund the deployment of technology.

Corporate sustainability initiatives: Growing calls for transparency should help drive corporate investement, either to examine specific forest destruction issues, or to prove provenance of offsets.

Combining technologies: Combining solutions like satellites and lidar will be the most useful for monitoring forests. This requires data standards and open-data sharing initiatives.

New sensors: New nanosatellite sensors (such as Capella Space's radar sensors), can see through forest fire smoke.

Mapping and measuring carbon sinks

Understanding forests as a carbon sink

Satellites and aerial measurements

SINTECSYS

Remote towers and analytics to detect wildfires in Brazil. Aims to have 3,000 towers across Brazil, with partners such as Carbon Pool and Brazilian Federal Persecuttores

NASA

NASA recently updated its forest carbon database by taking new measurements from the Amazon basin. It found that 27% of the world's net forest carbon sinks are in national parks.

Flash Forest

Uses aerial mapping software and satellites to reforest 150 acres of forest in the last year, using drones to drop seeds. Goal is to plant 1+ billion trees by 2028.

Data/AI platforms, carbon offsets

SILVIATERRA

Combination of satellite imagery and field measurements to determine size and species of tree in every forest for carbon markets

Treejer

Pachama

Verifies and monitors forest carbon credits and then uses satellite data to ensure that projects store as much carbon as they claim.

Pachama was named as a BNEF Pioneer in 2021.

overstory

Arbre

Inventory tracking and management system used by 21 corporate customers storing data on trees. 7.9 million inventory items tracked to date.

ecosphere+

Largest portfolio of forest carbon projects globally, with 33 million tons of carbon emissions avoided and 2.2 million hectares of forest protected or restored

Sensors

TREEVIA Forest Technologies

IoT sensors for forest monitoring. The system can identify a 23% difference between areas in terms of growth rate within a single month.

Understanding oceans as a carbon sink

Oceans are the largest single natural carbon sink, absorbing over 9 billion metric tons of carbon dioxide annually (25% of anthropogenic CO2 emissions). CO2 gas dissolves in the water and is consumed by plankton, corals, fish, algae and other photosynthetic bacteria. As human activity impacts the oceans more and more – whether through climate change or activity such as deep sea mining or building offshore wind farms – it is critical that we understand more about it and how its carbon sink works. New technologies such as autonomous underwater vehicles and IoT sensors are collecting data on marine life, temperature, wave pressure, plastic pollution and more. But still over 80% of the ocean remains unmapped.

New approaches and technologies

New technologies can capture higher-resolution ocean data, from more remote parts of the sea. Other innovations use that data to stimulate CO2 absorption.

Deep sea and seafloor surveys: Autonomous vehicles, both underwater and on the sea's surface, survey the topography and geology of the seafloor, or collect information on melting icecaps, oil spills and ocean acidification.

Advanced analytics: Analytics software can simulate circulation patterns in the ocean to analyze the exchange of CO2 between the ocean and atmosphere. They can also create 3D models of ecosystems to visualize marine life or coral bleaching.

Stimulating carbon uptake: Some startups are encouraging CO2 absorption through mixing cold and warm water, encouraging kelp growth, or building sustainable sea reefs. They collect data to track their performance and sometimes create carbon credits.

Limitations

Only 80% of the ocean is mapped, and seafloors have only begun to be mapped.

A lack of small and sustainable autonomous vehicles: To date, it has been difficult, and expensive, to operate vehicles under the ocean. And they have often caused greenhouse gas emissions and noise pollution. Technology developments, such as solar-powered ocean drones, are helping to address this issue.

Oceans are hard, and expensive, to map: While satellites are useful for ocean weather forecasting, they are less useful for measuring how much CO2 is in seawater. For this we need ships and buoys, which can be costly to deploy and maintain. They also contribute to ocean waste. Most ocean measurements are collected by researchers and collated into the Surface Ocean CO2 Atlas (SOCAT). This work relies on public funding or non-profits because there is no monetized business model.

Potential solutions

More action against ocean pollution and waste: If governments and corporates set goals to reduce ocean waste, this should increase the value of technologies that monitor the oceans. It might stimulate both surface and underwater autonomous vehicles as part of projects with larger companies and startups.

Maritime industry involvement: Decabonization goals set by shipping companies could kick start the funding of ocean mapping projects that will help with more efficient ship routing, and tangentially help increase ocean data and maps.

Recognition of the ocean as a huge, and highly efficient carbon sink: While forestry carbon credits are a thing, ocean carbon credits are not. Yet the ocean absorbs (net) more carbon than trees and can store carbon for longer. Communicating this to corporates might help monetize ocean monitoring technologies.

Mapping and measuring carbon sinks

Understanding oceans as a carbon sink

Stimulating carbon uptake

Ocean-based Climate Solutions, Inc. — Wave-powered technology upwells cold nutrient-rich seawater to trigger phytoplankton growth that absorbs CO2. Confirms amount through real-time data platform led by partner, Woods Hole and CLS.

RunningTide — Attaches kelp to biodegradable buoys in the sea. As kelp grows in weight, the buoys sink to the ocean floor. With help from academics, RunningTide measures the kelp's carbon sink and sells carbon credits to firms including Shopify.

ARC Marine — Makes low-carbon concrete cubes as sea reefs to encourage biodiversity growth as a counter to offshore wind development. Continually monitors sites. In 2020, 100 cubes were deployed in the U.K. funded by British Government. 260 habitats deployed.

Ocean mapping and analytics

bedrock ocean exploration — Ocean floor mapping autonomous vehicle, with the goal of launching a public dataset to garner more accurate climate models, better weather predictions and exploration.

SOFAR — Ocean sensors and data platform for real-time information on wave, wind, temperature, currents and forecasts. Customers include USGS, WMO and IOOS.

TERRADEPTH

SeaDeep — Uses enhanced imaging, hyperspectral data and 3D visualization to spot hazards to marine life, invasive organisms, coral bleaching and harmful effects causing climate change in the ocean. Partners with the New England Aquarium.

OPENOCEAN ROBOTICS — Solar-powered autonomous ocean drone with sensors. Sends data to clients in real-time, who can control the direction of the vehicle. These drones are used to detect oil spills, map the Arctic and replace fuel burning research vessels.

Startup platform for oceans

SeaAhead Bluetech Innovation — Supports ocean-tech startups by providing sensor equipment, dock facilities etc. Focused on ocean sustainability through program with New England Aquarium.

Mapping and measuring carbon sinks

Understanding soil and land as a carbon sink

The Earth's soils hold more carbon than the atmosphere and all living vegetation combined – about 2.5 trillion tons. Regenerative farming practices hold huge potential to build soil health, sequester carbon and reward growers for ecosystem services. But because sequestration rates vary based on geography, soil type and farming practices, accurate and cost-effective soil measurement is needed to better understand what practices are most effective in local contexts. To date, accurate testing has remained expensive, limiting its use. New technologies such as satellites and sensors are solving this problem.

New approaches and technologies

Regenerative agricultural practices can turn back the carbon clock, reducing atmospheric CO2 while boosting soil productivity and increasing resilience to floods and drought. Techniques include planting crops year-round and restoring degraded and eroded lands. Avoiding deforestation and the farming of peatlands is important, which are major reservoirs of carbon and easily decompose upon drainage and cultivation. Carbon markets have typically excluded agricultural projects, until recently.

These all require new technologies that can track crop yields, understand soil carbon through IoT sensors, monitor agricultural land through satellites and lead to precision agriculture methods.

- **Remote sensing satellites:** These provide data on water content and availability of nutrients, enabling farmers to manage inputs to increase crop yields, decrease input costs and reduce soil degradation through targeted fertilizing.
- **Ground sensors:** These can monitor crops, check weather forecasts and calculate elements with free apps. IoT sensors also measure soil moisture and humidity.

Limitations

Soil carbon has been underestimated: While it is a vital route to reducing carbon dioxide in the atmosphere, soil as a carbon sink is taken less seriously than oceans and forests due to a lack of data.

Degraded soil is often in poorer countries: Some of the most degraded soils, inefficient water use and lack of high quality seed are found in sub-Saharan Africa and South America. It is therefore difficult to find funding and incentives to measure soil carbon or innovate with new technologies in these regions, due to a lack of economic resource and prioritization by governments.

No obvious return on investment for farmers storing carbon: To unlock capital for these technologies, investors need to see significant returns on soil carbon investments.

Potential solutions

Financial incentives: Incentives or revenue streams to encourage farmers to monitor and maximize soil carbon, such as carbon offsets. Carbon trading has the potential to bring a new income stream to the agriculture sector.

Stricter government policy on land degradation: For example, Australia suffers from extreme heat and wildfires. Policy-makers are creating programs that build and stabilize soil carbon. 'Regenerate Australia' outlines a strategy to restore up to 740 million acres.

More data sharing is essential, whether incentives for researchers to study soil carbon, or better programs and practices to promote sharing between governments, businesses and policy-makers.

Mapping and measuring carbon sinks

Understanding soil and land as a carbon sink

Creating carbon markets

indigo

A platform where farmers can earn extra income from increasing soil carbon, through selling credits. Maple Leaf Foods and Epiphany Craft Malt recently agreed to purchase verified agricultural carbon credits.

Soil Carbon Co.

Provides carbon offsets and trading incentives for farmers to increase the carbon in their soil

SOIL CAPITAL

The mySoilCapital platform is a data dashboard for farmers, and advises on how to use their land as a carbon sink, and sell credits. A 50 hectare farm could make $1,000/year in credits. Most customers are based in Belgium and France.

Precision agriculture and soil analytics

OneSoil

Precision ag for crop monitoring. Ukraine is OneSoil's largest market. OneSoil currently tracks 71 million hectares of land, mainly for wheat.

regrow

Merger of FluroSat and Dagan to create a digital platform combining agronomy and scenario planning with monitoring, reporting and verification.

cloud agronomics

SMART CLOUD FARMING

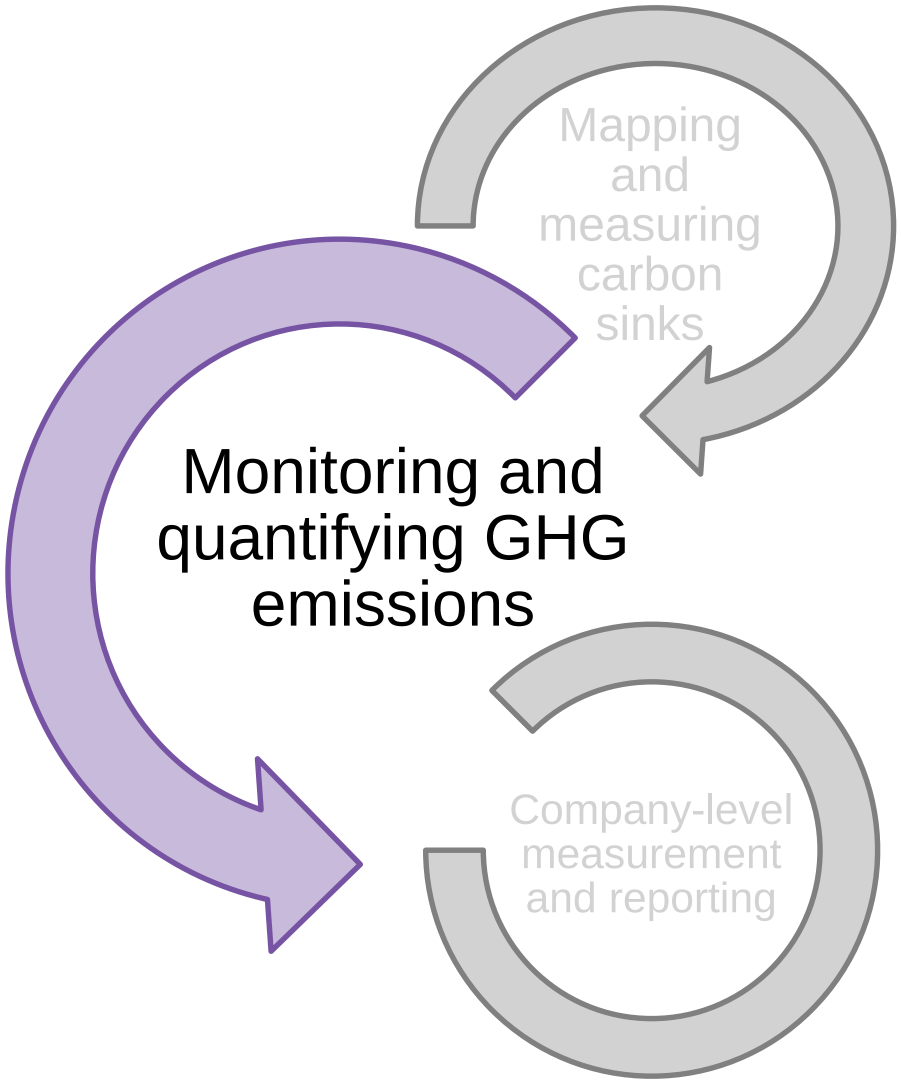
Precision ag startup providing advanced soil analytics and 3D soil maps. Based in Germany.

TRACE GENOMICS

Soil insights and genomics to determine soil health. Soil microbiome data has been used by agronomists such as Schweigert, Nutrien Ag Solutions and Anez Consulting

REGEN FARMER

AI platform, RegenWorks, uses analytics for agroforestry planning, making landscape more resilient to environmental extremes.


Mapping and measuring carbon sinks
Monitoring and quantifying GHG emissions
Company-level measurement and reporting

The need to monitor and quantify GHG emissions

The most important greenhouse gases (comprising 90% of all GHGs) are carbon dioxide and methane. The energy and agriculture sectors are the largest emitters, but it can be difficult to locate the exact sources of emissions, as well as the amount of gas emitted. This is particularly important for fugitive emissions or dispersed sources of emissions that are not properly monitored. A combination of new technologies could help pinpoint and properly quantify emissions.

How big a problem is it?

Our 2020 New Energy Outlook report estimated that total global greenhouse gas emissions were 52.5GtCO2e in 2019, a 47% increase from 1990. The IEA reported that global methane and CO2 emissions reached 570Mt and 33Gt respectively in 2019 (from the energy sector, excluding land use).

Atmospheric levels of methane in 2017 were 150% higher than pre-industrial levels, largely driven by the oil & gas and livestock sector. However, poor tracking of distributed emissions sources, such as methane flaring and venting, landfills, rice paddies and livestock mean that emissions are quite likely under-reported. And importantly, without good data, the operators of these activities have no incentive to take action.

Why is it difficult to solve?

There has historically been a lack of accurate emissions monitoring data, due to a lack of means to measure and quantify emissions. Today, there are more technological tools available to understand emissions, such as software and hardware advances in satellites, sensors and artificial intelligence.

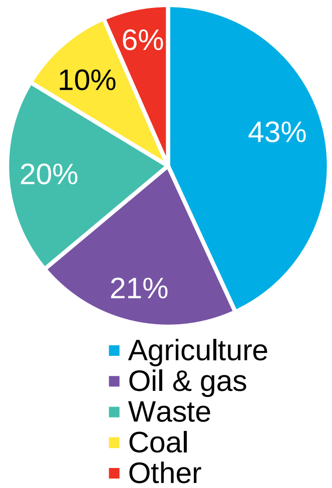
Emissions estimates are usually based on paper-based calculations that are inaccurate for methane specifically due to unexpected leaks. Policy and regulation for both gases is also lagging, which reduces incentives for companies to take action.

Technologies to measure CO2 and methane are similar, but as these gases absorb light at different spectral signatures, different types of sensors are required. CO2 is more difficult to measure.

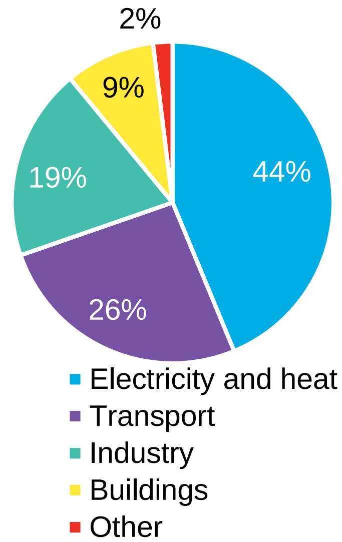
Where is this problem greatest?

Energy-related emissions from electricity and heat generation, industry and transport have been growing the fastest and are the largest emitters of carbon. Measuring carbon dioxide emissions in cities is particularly difficult without air-based technologies, while methane emissions from the oil and gas value chain are difficult to track without ground-based sensors.

Methane emission sources, 2021



Carbon dioxide emission sources, 2018



Source: BloombergNEF, GMI, IEA

Tracking carbon dioxide emissions

Technologies to track, understand and quantify CO2 emissions include optical and hyperspectral satellites, carbon dioxide sensors and aggregated data platforms. Most CO2 emissions data are currently estimated, and new technologies can help strengthen these estimates and provide more accurate data. They can also make measurements of emissions sources that were previously difficult to estimate, such as land-related emissions.

New approaches and technologies

Satellite technologies: New technologies are better able to monitor CO2 emissions. ESA's Sentinel-2 and China's TanSat were the first, using optical imaging satellites to cover large areas but at lower resolution. New, smaller and cheaper, satellites are emerging with specialized gas or optical sensors that can make more accurate daily measurements above cities or industrial facilities. For example, Planet's optical satellites recognized 23% higher CO2 emissions from deforestation in Peru.

Analytics platforms make sense of the data: The data coming from satellites can be hard to interpret or not useful on its own. Startups are having success pulling in public and private satellite data, combined with weather, economic data and buildings data. These platforms can calculate emissions factors for whole industries.

Ground-based IoT sensors: For capturing accurate CO2 data in cities, or air pollution levels, new forms of more accurate sensors are being developed.

Limitations

Greenhouse gas sensors are still nascent: It was not until 2019 that the ESA launched Sentinel-5P and startups began launching nanosatellites with gas sensors. The miniaturization of satellites allowed this, as well as instruments that can be flown on satellites resisting extreme conditions.

High accuracy measurements and high temporal frequency are expensive: It is possible to get highly accurate measurements that revisit a certain spot once a week, but this is expensive. Miniaturization of sensors and satellites, and the falling launch costs for satellites, are bringing down costs.

Inaccurate measurements: There are still uncertainties with space-based measurements. CO2 bands are contaminated when very thin layers of clouds are present and other aerosols lie in the sensor's path.

Potential solutions

Joint projects with larger firms: Collaboration to tackle the problem would encourage CO2 tracking, eg, NASA working with smaller startups to combine their innovations with manufacturing capacity and operations knowledge.

Reducing costs by using smaller satellites: This, alongside sourcing hardware in bulk, are now being done by many startups such as GHGSat.

Public platforms with open-source datasets: These allow governments and non-profits to use the data to track their emissions and enforce regulations. Examples of this include ClimateTrace, which plans to offer emissions data for free.

Use spectral sensors: Instead of using data from satellites such as Japan's GOSAT and NASA's Orbiting Carbon Observatory, governments should increase use of spectral sensors such as GHGSat and ESA's. Better software that can remove cloud cover will also help.

Tracking carbon dioxide emissions

Cross-industry

Planet

Emissions can be calculated using optical nanosatellite data. Planet found that carbon emissions caused by deforestation in Peru were 24% higher than those reported by annual assessments.

Planet was named as a BNEF Pioneer in 2021.

Forests and agriculture focus

Blue Sky Analytics

Analytics platform using satellite data, with datasets on forest fires and CO2 emissions. Used by companies to monitor their ESG data and by third-party providers.

Corporates and cities focus

Aclima

Measures air pollution and carbon dioxide emissions in cities through IoT sensors and its AI software platform.

Carbon Mapper

Non-profit that outsources satellite operation to Planet and other companies, using the data to measure carbon emissions across forests and industry.

SCARBO – Space Carbon Observatory

Project run by 8 EU organizations to monitor emissions. Led by Airbus Defence and Space, project aims to overcome cost barriers of satellites while creating an accurate carbon dioxide and methane sensor.

Satellite Vu

Thermal imaging satellites that can calculate the CO2 emissions of buildings and cities through creating digital twins.

Climate TRACE

This coalition of organizations aims to combine satellite imagery of smoke from power plants and factories with infrared heat imaging and nitrogen oxide sensor data, to produce carbon emissions data for individual power plants.

Tracking methane emissions

Methane emissions are a growing problem, and are more difficult to track and quantify than carbon dioxide due to the small size of leaks or unregulated releases from oil and gas equipment, landfill and cattle farming. Companies are trialing technologies including satellites, drones, aircraft-based sensing and optical gas imaging, against a backdrop of increasing pressure and commitments to solve the problem.

New approaches and technologies

Satellites and software platforms: Two types of satellite are used for methane tracking: optical satellites to spot large plumes over regions, or sensitive hyperspectral satellites that can spot methane locations down to the facility level. Satellites can either be tasked to one specific area, usually provided by a private firm such as Satellogic, or data can be ingested from larger organizations or companies that use monitoring satellites, such as Planet. Data can be bought from providers such as Kayrros, which aggregates data from multiple providers, ranging from daily revisit rates to annual.

Aircraft and drone-mounted sensors: These are used to find facility and regional data at higher resolution than satellites, but can be more expensive.

Ground-based measurements: Sensors are used to pinpoint exact leak locations. These include optical and laser-based imaging and/or lidar. Usually these are hand-held and therefore only used periodically, eg, quarterly.

Limitations

High costs: Using these technologies regularly is difficult for oil and gas companies to justify. Satellites are expensive, costing up to $100,000/year per asset for high resolution monitoring of the facility. Drones and aircraft are cheaper at around $1,000/year, however without enough of a push from policy and regulation, companies are unwilling to spend this amount on measuring methane.

Scaling is difficult: Many of these new technologies are developed by startups, and being hardware-based are expensive and slow to scale. Startups may struggle to get their technology to suit large oil firms without joining forces or attracting significant new funding.

Underestimating the significance of methane emissions has been a problem: Kayrros found that 120Mt more methane was leaking from the Permian than expected, from combining satellite data with other factors such as weather.

Potential solutions

Industry initiatives and partnerships to set methane reduction goals: Industry initiatives are running ahead of national regulations. Oil & gas firms should build on their commitments to accelerate technology deployment for methane mitigation.

Expanding methane detection technologies to other industries: Spreading to sectors besides oil & gas (such as agriculture and waste management) will help grow revenue streams.

Reducing the cost of satellites and manufacturing: Launch costs can be reduced by sharing rides and miniaturizing satellites.

Technology options for methane tracking

	Region	Facility	Leaks
Optical satellites	Onshore	Onshore	
GHG satellites	Onshore	Onshore	Onshore
Aircraft	Onshore	Onshore	
Drones		Onshore & offshore	Onshore & offshore
On-site sensors			Onshore & offshore

Source: BloombergNEF

Tracking methane emissions

Drone-mounted sensors

Drone-mounted sensors used in oil and gas facilities to locate leak locations. The technology can locate exact leak sources.

SeekOps

Aircraft-mounted sensors

KAIROS AEROSPACE

Aircraft-mounted sensors measure the absorption of reflected sunlight by methane molecules. Can survey 100 square miles per plane per day.. Reduced two kilotons of methane in 2019 from locating and stopping leaks.

Ball

Lidar-based methane remote sensors that can be mounted to planes or satellites. High-resolution data offers significant cost savings for mapping leaks from oil and gas pipelines.

Ground sensors

QLM
Enabling Net Zero

QLM has built a ground-based optical and laser spectroscopy technique to detect the location of methane leaks and quantify the amount leaking, without the need for a handheld device.

QLM was named as a BNEF Pioneer in 2021.

PROJECT CANARY

Satellites and analytics platforms

KAYRROS

Kayrros' 'Methane Watch Platform' pulls in satellite imagery from public providers such as the ESA, as well as private satellite operators for facility/regional emissions.

GHGSat
GLOBAL EMISSIONS MONITORING

GHGSat's miniaturized methane sensor has measured the smallest methane emission from space at 205kg/h, with a constellation of two nanosatellites monitoring industrial emissions.

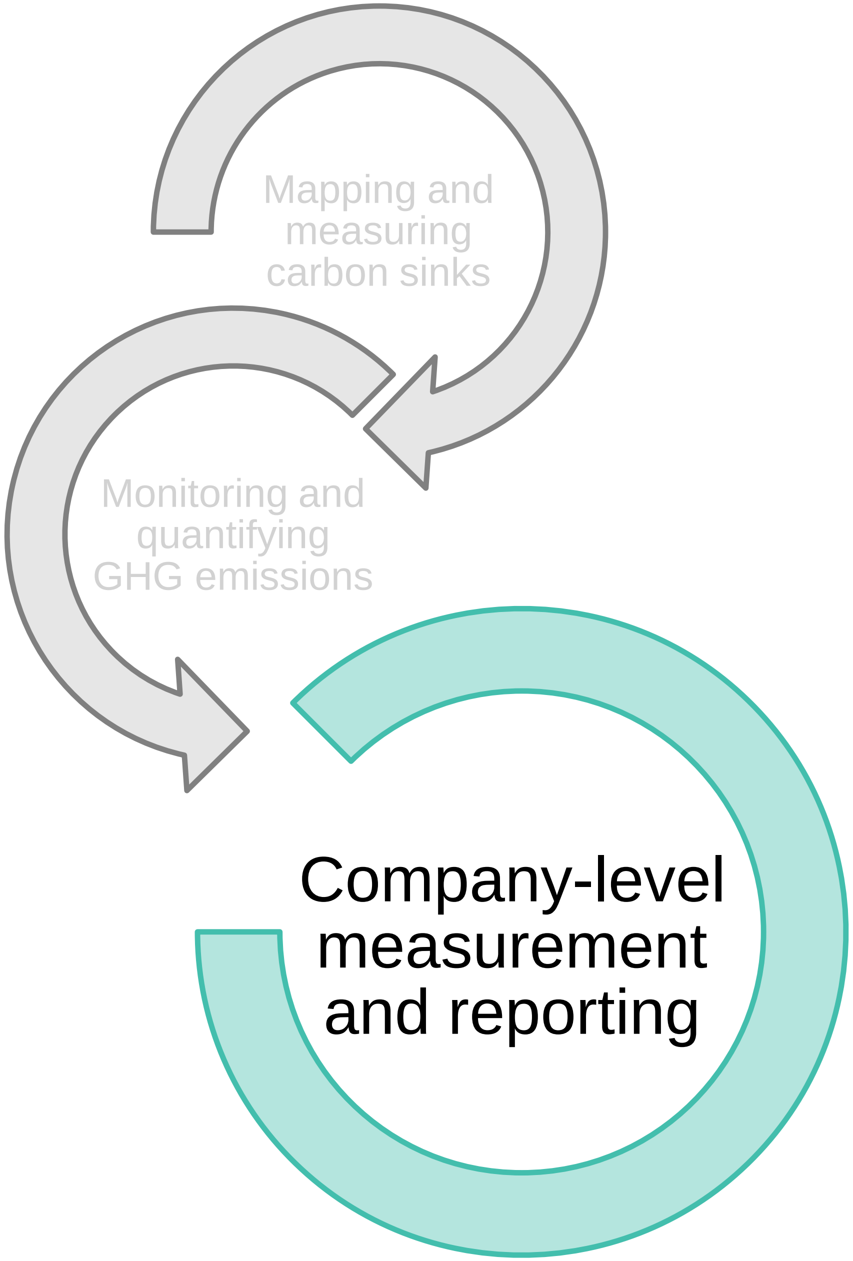
GHGSat was named as a BNEF Pioneer in 2020.

SA
SPHERICAL ANALYTICS

Spherical Analytics has the Climate Action Engine (CAE) methane emissions platform with Rocky Mountain Institute, that ingests different data sources to measure methane in oil and gas facilities.

Bluefield

Uses data from 23 satellites, ground sensors, government records and weather, to deduce methane emissions globally from 120,000 companies.


Mapping and measuring carbon sinks
Monitoring and quantifying GHG emissions
Company-level measurement and reporting

Company-level measurement and reporting

Many of the world's largest corporations are pledging to eliminate or offset all of their emissions, including Scope 3, but very few companies can accurately quantify their carbon footprints, or determine the main sources in their supply chain. Without this information, it is difficult to set realistic carbon reduction goals or credibly meet them. In addition, financial institutions will need to begin calculating the carbon impact of their portfolios, and any future investments they make. All corporations and financial institutions will also need to understand, quantify and report on the climate risk to their existing physical assets, and any future projects.

How big a problem is it?

Corporates and financial institutions are busy setting carbon reduction targets. To meet any robust CO2 goal, firms must improve their quantification of emissions, particularly Scope 3. While Scope 1 and 2 are relatively easy to keep track of, the inclusion of Scope 3 (emissions from supply chain and customers) is what makes a high quality net-zero target. Of the 150 companies with net-zero targets that BNEF tracks, only 66 address some, or all, of their Scope 3. These firms score an average of 4.75/10 in BNEFs net-zero index (see chart), compared to 1.78/10 for those without a Scope 3 goal.

The climate risk to physical assets globally is immense. At least 60% of S&P 500 companies own assets at a high risk of climate-change physical risk, yet very few corporates understand the extent of the risk or how to mitigate it.

Why is it difficult to solve?

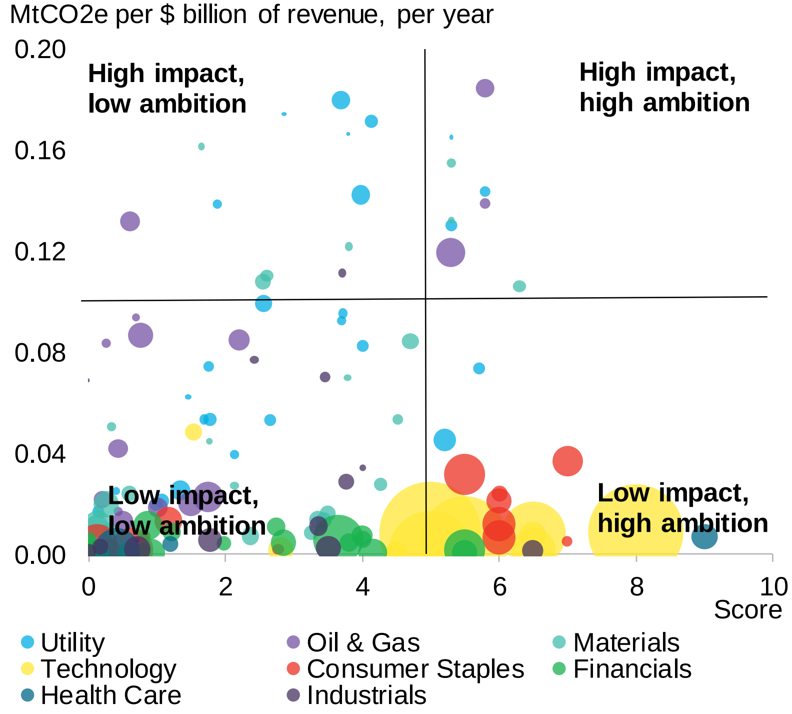
Scope 3 emissions come from a company's suppliers and customers. Collecting this data involves third-party compliance, data standardization and potential double counting. It is a complex problem that only a few percent of corporates tackle. Where they do calculate it, it's often a one-off carbon footprint calculation done infrequently.

Quantifying climate risk is an even more nascent area, with very little data and few models available off-the-shelf.

Where is this problem greatest?

The least amount of information exists for Scope 3 emissions in the supply chain. While tech companies have ambitious goals, their emissions are not significant compared to energy companies (who often have weaker goals excluding Scope 3). For assessing climate risk, often physical assets at most risk are those in poorer countries without access to expensive climate change models.

The CO2 impact, and level of ambition of select net-zero corporate emission targets



Source: BloombergNEF. Corporate Net-Zero State of Play (web| terminal).

Better carbon accounting for supply chains

Carbon accounting is the process by which organizations quantify their GHG emissions, so that they may understand their climate impact and set goals to limit their emissions. Innovations are required for accurately tracking supply chain, and customer, emissions. Startups are innovating by aggregating fragmented supply chain data and integrating with APIs, and using satellites and sensors to capture new data. These tools can show clients their emissions weak spots and even model how best to reach corporate carbon goals.

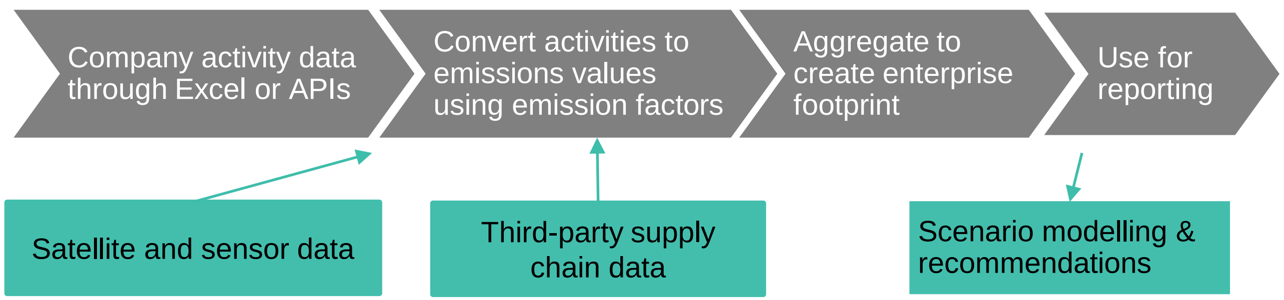
New approaches and technologies

New satellite and sensor data: This will help customers track emissions from location-specific assets (for their Scope 1 and 2) and from emissions hot spots in their supply chain (such as upstream mines or pipelines). Using satellites and sensors means the emissions data is accurate (and includes fugitives), rather than being calculated by using proxies.

New ways of data aggregation and integration: APIs, blockchain and the cloud have all made it easier to safely share data between companies. To track Scope 3 will always involve receiving data from third parties. For instance, blockchain is used to create an accurate digital record of a material or product through it's lifetime, including full carbon footprint.

AI for scenarios and recommendations: Newer carbon footprinting companies are offering not just static results but models that show how corporates could improve their emissions most easily.

Carbon accounting software process, including innovation areas



Source: BloombergNEF

Limitations

Connecting with suppliers is hard: Many carbon accounting tools use outdated information because it is difficult to get real-time data from third-party suppliers.

There are many standards: A variety of standards, and complex methodologies, makes calculating carbon footprints difficult. Carbon footprinting technology providers may have to design a product that adheres to all standards.

Only a few companies host large volumes of supply chain data: SAP and Oracle sell most supply-chain software and it is not easy to do real-time calculations with them, or pull data from these systems into third-party software.

Potential solutions

Cheaper IoT sensors: Lower-cost sensors would make it more affordable to track information about goods in real time.

Better analytics to model the impact on carbon footprints: Advanced computing (or quantum computers) could model the complex impact of theoretical changes to supply chain carbon footprints.

Global standards and rankings: Ultimately convergence of standards and scores may be needed to facilitate large-scale uptake of carbon accounting platforms.

Developing better carbon accounting methods

Satellite and inventory data

Consolidates GHG and financial data from teams, facilities and supply chain, in transport, materials, utilities, buildings and consumer goods industries.

SINAI

Combines satellite, sensor and inventory data to measure emissions from companies in agriculture, food, timber, pulp and paper. Satellite data comes from GOSAT, ESA's Sentinel-5P and OCO-2 satellites.

CarbonSpace

Carbon offsets

Calculates emissions from business activities such as flights and vehicle operations, by integrating with existing enterprise systems. Purchases offsets to match the client's emissions.

cloverly

Recently released a database of 87,000 carbon emission factors for clothing, travel, housing, food in over 260 countries. Customers including the UN, Baidu, JD and Vanke use these factors.

碳阻迹 Carbonstop

Digital twins and blockchain

Uses blockchain to capture supply chain data and builds digital twins of materials as they go through their lifetime. Clients and partners include Volvo, Oracle, Mercedes, Boeing. Focuses on ethics as well as carbon emissions.

Circulor

KOOLING

Data from satellites, sensors, traffic, buildings and other IoT devices. Customers include the European Commission, Manchester City Council, GSMA and FI-Ware.

Everimpact

Measure carbon footprint for cities. 81% less time spent on city-wide climate action planning and reduced customer costs by 50%.

Dynamhex

Emitwise assess corporate carbon footprints using supply chain and operations data. Can help clients pinpoint where to make the biggest impact on emissions, using machine learning.

Emitwise

Understanding climate (physical) risk

Climate (physical) risk is the expected impact of climate change-related hazards, such as fire, drought, sea-level rise or extreme weather, on a company's physical assets. Over the past decade wildfires, hurricanes and extreme temperatures have caused almost $3 trillion in losses. Physical risk data platforms help investors, companies and communities to understand their risks due to the changing climate. (This is separate to climate transition risk, which is the risk to a business from a rapid transition to a low-carbon economy.) Scenarios and models can detail the impact of flooding, wildfires, extreme heat, drought, wind, and precipitation and offer spatial resolutions from tens of kilometers down to the street level. They cover future time horizons from one hour to 80 years.

New approaches and technologies

Climate model projections: All startups modelling climate risk use climate model projections as a baseline for the results. Ultimately, this projection data is merged with customer asset data and then processed with econometric impact/hazard functions to model vulnerabilities. Software providers can then deliver graphs and data on the severity, location and timing of climate-related risks.

AI for climate forecasts: AI advances are enabling more accurate weather forecasts using more historical data to plug into ML models. This enhances climate models.

Predictive analytics and IoT sensors: While companies have been including climate change in scenarios, their projections are not site-specific. Predictive analytics, combined with global sensor data can provide real-time information on a specific city or facility. Companies like Jupiter aim to provide customers with detailed maps of how climate change will impact a region up to 50 years in advance.

Limitations

No commonly accepted methodology for assessing and prioritizing climate risk: This is a very new area, with no set methodology or criteria that identifies key thresholds in these risks. Neither are there practices for what are important criteria for managing these risks.

Limited number of companies: Due to the complexity and cost of modeling climate risk, there are very few companies in the space. A few companies dominate the field and as climate risk is so new, with most startups only funded in the last three years, data can be difficult to source for startups.

Weather is still extremely unpredictable: If companies are paying a software provider to model the impacts of a flood that may happen in two years, they want this information to be accurate. However, there is a limit to how accurate climate risk data can be, and results are inherently probabilistic.

Potential solutions

Government and public entities can help: If these groups disclosed historical climate-related physical risk data, in one easy to access place, with predetermined units this could be invaluable for machine learning models. These models could use the data to forecast predictions and calculate future climate risk for assets.

Agreeing upon climate scenarios: The World Meteorological Organization, IPCC and other bodies could agree upon globally recognized climate scenarios. This would provide some broad view on the risk of temperatures increasing by certain percentages, and resultant climate disasters.

Understanding climate (physical) risk

Climate risk for companies

TCS

Multiple climate scenarios to the year 2100 to enable decision-making for companies. Backed by 4 IPCC Nobel Prize winning scientists and IBM.

JUPITER – Predicting risk in a changing climate

Serving multiple industries, including companies such as BP, ConEdison, NASA, Terna and Liberty Mutual Insurance. Models uncertainty and scenarios to 2100.

Large-scale impacts on sectors

RIVERSIDE global science solutions

Provides climate risk assessments and recommends management strategies. Worked for General Services Administration (GSA) to evaluate the climate change impact on the telecom and data center sectors. Also worked with NOAA on a public climate risk data tool.

Climate risk for particular sectors

one concern

Offers multi-hazard risk assessment, disaster management and evacuation protocols for cities. Aimed at cities, governments, businesses and insurance.

CLIMATE AI

2-week weather forecasts, 1-year climate forecasts and 50-year long-term forecasts aimed at businesses' supply chains. Strong presence in agriculture and ag-tech.

GEOSPIZA

kettle

Specializes in wildfire prediction, and resultant built infrastructure risk, for the reinsurance sector. Uses ML and computer vision. It's model is 89% accurate in pinpointing wildfire breakout.

ClimateView®

Currently, over 26 million citizens' emissions managed and measured through the ClimateOS platform, aimed at cities and governments.

Cloud to Street

Official satellite flood map provider for the United Nations. Tracks floods in real-time for businesses and governments.

Company-level measurement and reporting

Projecting future carbon impact of investments

Corporations and investors also need to be able to project the sustainability impact of future choices and investments. For asset owners this might mean modelling the carbon impact of future building portfolios. For venture capitalists this might mean using tools to ensure their startup investments provide an environmental return as well as financial. To project the future carbon impact of an asset, or early-stage company, investors are turning to new analytical tools. Today there is only a small demand for these complex tools but this should grow as more investors sign up to climate pledges and disclosure mechanisms.

New approaches and technologies

Online projection models: New web tools will take corporate data on assets under management, or a VC portfolio, and personalize carbon emission projections. Users can refine their projections by inputting values about the target market.

Develop a view on the scaling potential of early-stage technologies: These tools can take data from startups to calculate the emissions reduction potential for climate-tech startups, when they scale. This could be used by impact investors (see graphic).

Limitations

Usually only carbon dioxide emissions: Most projection software is CO2-focused, forgetting the other greenhouse gases.

Many of the tools are reliant upon data input by the user: Currently, most popular tools are reliant on data input by the user, with no external verification. This raises questions as to how accurate these tools are.

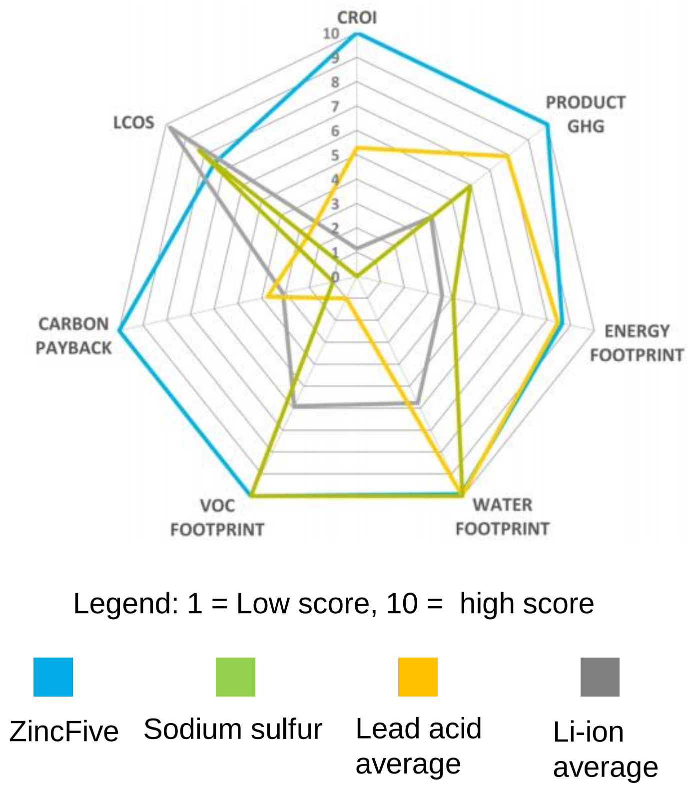
Lack of data makes projection difficult: There is a lack of data for early-stage companies and technologies specifically, which makes it difficult to create accurate projected emissions reduction profiles.

Potential solutions

Standardizing early-stage technology carbon abatement benefits: A public database of carbon abatement values for a range of the most common early-stage technologies would help companies standardize their models. As would agreement on set units of abatement for a variety of different technologies.

Align with TCFD and other standards: Institutions that subscribe to TCFD should find carbon projection tools especially useful if their data outputs are in line with the disclosure guidelines.

Example sustainability metrics for a battery startup, evaluating key criteria against industry standards



Source: ZincFive. Notes: Assessment done by Boundless. CROP is 'carbon return on customer purchase' and VOC is 'volatile compound'

Projecting carbon impact of future investments

Evaluates emissions reduction potential of early-stage companies

CRANE

Non-profit that was developed by Prime Coalition to assess emissions reduction potential of early-stage companies in the U.S. It is publicly available data since April 2020 and is for impact-focused investors to find startups.

PERSEFONI

Carbon accounting software used by organizations such as Y Analytics to identify carbon reduction initiatives. Use software to analyze companies before they enter a VC portfolio.

Y ANALYTICS

Launched by TPG VC firm, to ensure that capital is directed at addressing the UN SDGs and impact investing. Will translate research to help decision makers evaluate impact at the front end of the capital allocation process.

Evaluating carbon impact of investment portfolios

BOUNDLESS IMPACT RESEARCH & ANALYTICS

Provides research and data on a company's supply chain to investors and funds. Uses company footprint to create 100-year and 200-year global warming scenarios.

PACTA Paris Agreement Capital Transition Assessment

Paris Agreement Capital Transition Assessment is a freely accessible tool developed by 2 Degrees Investing Initiative for investors to measure alignment of portfolios with climate scenarios. Aimed at many sectors including oil, gas, coal, power, steel, cement, aviation etc.

Evaluating future carbon impact of planned projects

One Click LCA

Software to evaluate carbon impact of products, buildings and real estate portfolios. Customers include the Norwegian government and Grosvenor. Has over 10 million square feet of new construction projects added to its platform every week.

Early-stage investment trends

For understanding and monitoring our planet

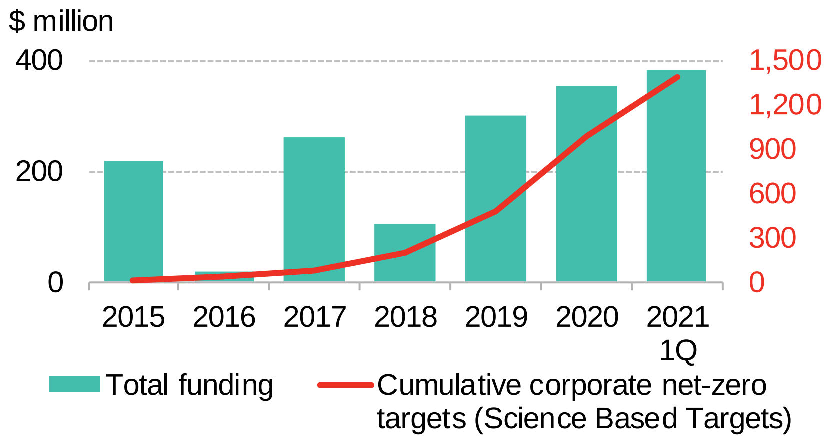
Early-stage investment trends

Investments for monitoring and understanding our planet

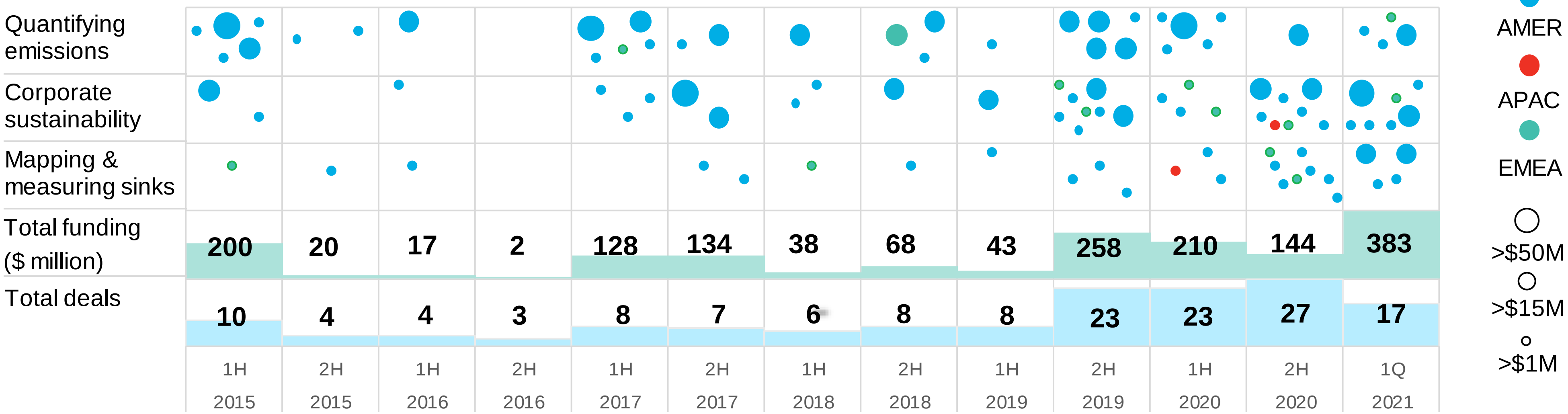
Corporate and government emission reduction targets have spurred early-stage investments into technologies that monitor our planet (see chart to the right and BNEF tool here). 1Q 2021 funding has been more than all of 2020.

- From 2015 to 1Q 2021 VCPE investment totaled $1.4 billion. This amount is roughly ten times more than was invested in the prior five years. The investment was driven initially by a few large deals for private satellite and geospatial analytics companies. Recent investments have diversified into other categories, such as carbon accounting software and mapping carbon sinks.
- Heavily-emitting corporations looking to monitor emissions, and corporates looking to reach net-zero carbon emissions, have led VC investment in this space. Technology-focused venture capital firms like DCVC and Space Angels have also been involved.

VCPE raised for climate and carbon monitoring technologies



Largest VCPE deals for climate and carbon monitoring technology startups



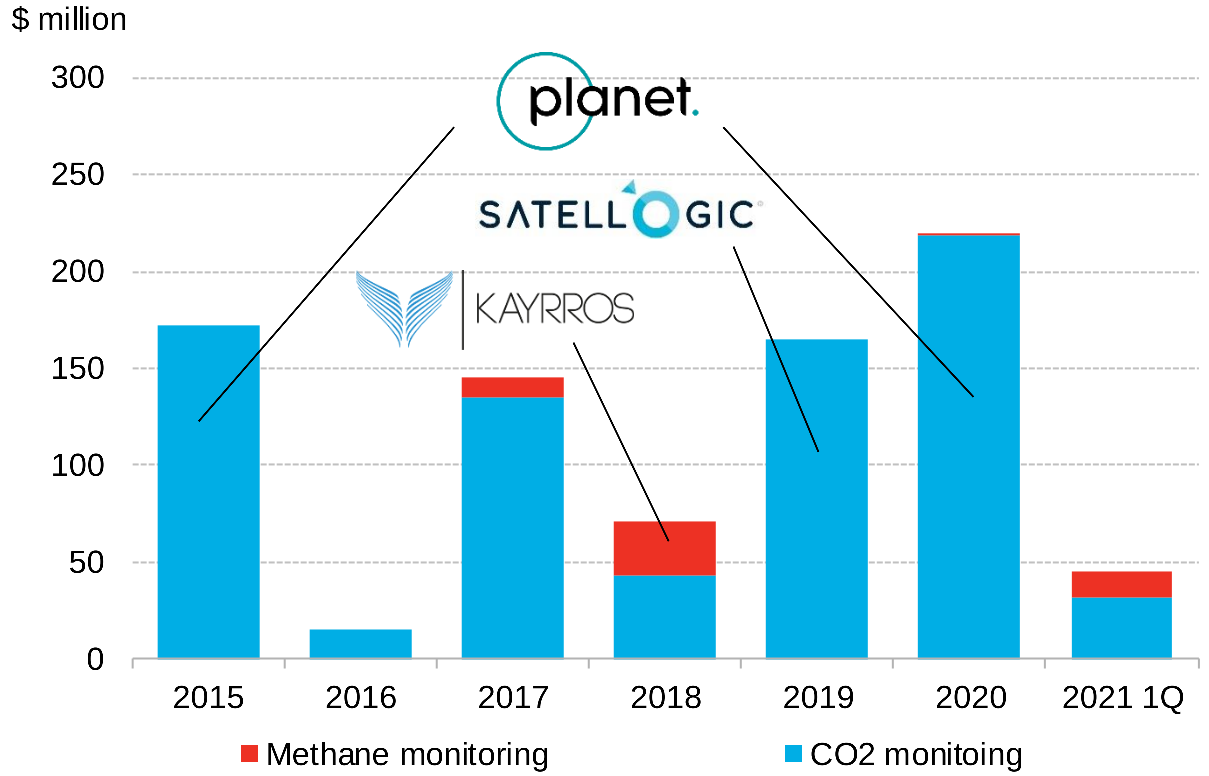
Source: BloombergNEF, CB Insights. Note: bubbles represent deals over $5 million in each quarter.

VCPE investment trends for GHG monitoring

The most funded startups for GHG monitoring are nanosatellite firms, some of which have been raising VC funding for a decade. Roughly two-thirds of this category's capital was raised by three companies: **Planet Labs** ($367 million), **Orbital Insights** ($125 million) and **Satellogic** ($121 million).

These companies have built up high barriers to entry with a combination of complex intellectual property and expensive satellite constellations, and it seems that investors are content following on their investments in the market leaders. In recent years there has also been funding into ground-based sensors, drones and airplane startups, also tracking emissions.

VCPE investments into technologies monitoring emissions



Source: BloombergNEF, CB Insights. Note: Logos indicate most funded companies each year.

Investor spotlight: Data Collective VC

Venture capital investment into monitoring emissions has been led by a combination of corporations in the oil & gas sector and venture capital firms focused on data and technology. Data Collective VC, a technology-focused venture capital firm, has helped spur some of the investment in the early years.

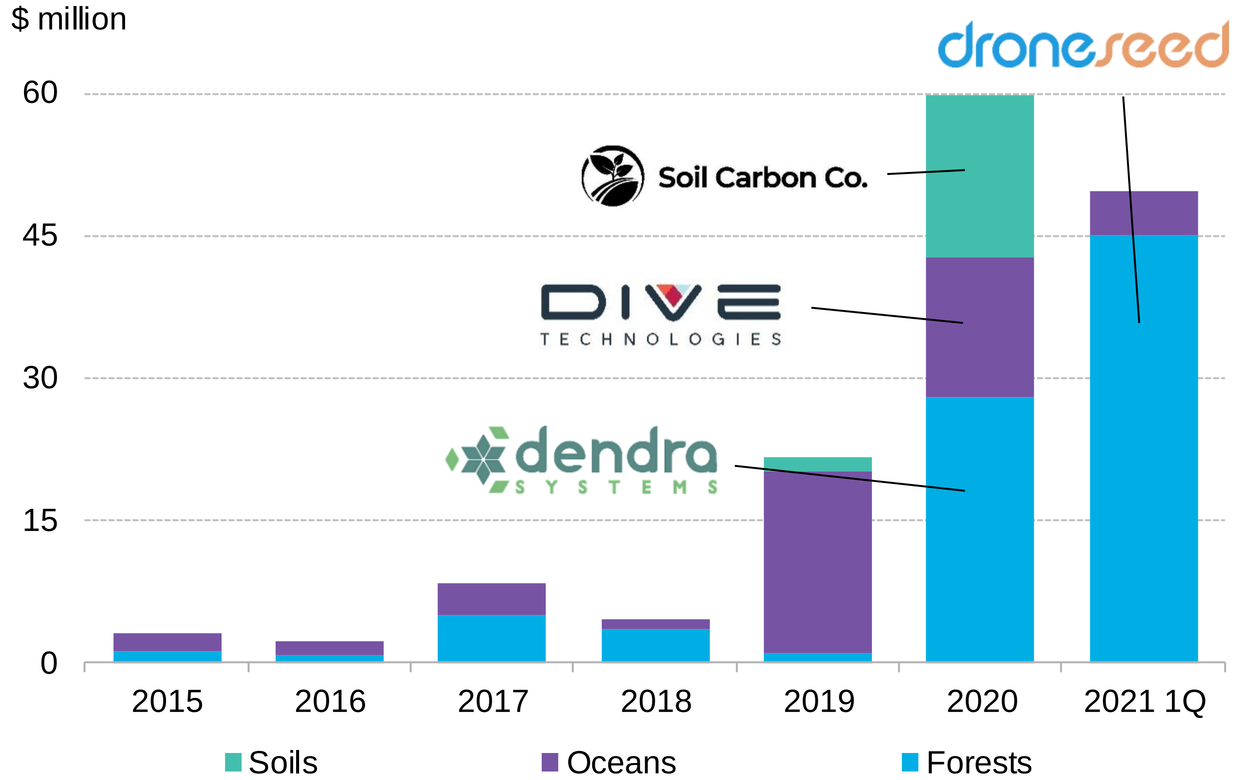
- Founded in 2011, the firm has invested over $7.5 billion in companies using big data to change various industries. Data Collective has a geospatial division, through which it invests in companies that monitor emissions.
- The firm has invested in multiple companies in the space:
  - Planet Labs' series A, B and C rounds from 2013 to 2015
  - Capella Space's seed, series A and B rounds from 2016 to 2018.
  - Descartes Labs's series A round in 2015

VCPE investment trends for carbon sink mapping

Interest in, and funding for, startups trying to understand carbon sinks has grown in the last two years, albeit from a very small base. VCs have spent $150 million on early-stage companies monitoring oceans, land and forests since 2014. While forest-based carbon markets are not new, investors are interested in technologies that automate the process and reduce costs.

Pachama, a U.S. company focused on quantifying forest carbon, and **DroneSeed**, a U.S. company focused on drone based reforestation, have raised the most capital ($24 million and $37 million respectively). There are also a group of companies working on similar pursuits for soil carbon and ocean carbon. The startups with most funding there are **Dive Technologies** ($14 million) and **Soil Carbon Co.** ($7 million).

VCPE investments into technologies mapping carbon sinks



Source: BloombergNEF, CB Insights. Note: Logos indicate most funded companies each year.

Investor spotlight: Lowercarbon capital

Storing carbon in natural sinks could dramatically slow climate change, and climate-focused venture capitalists have started to invest in technologies that could enable the practice.

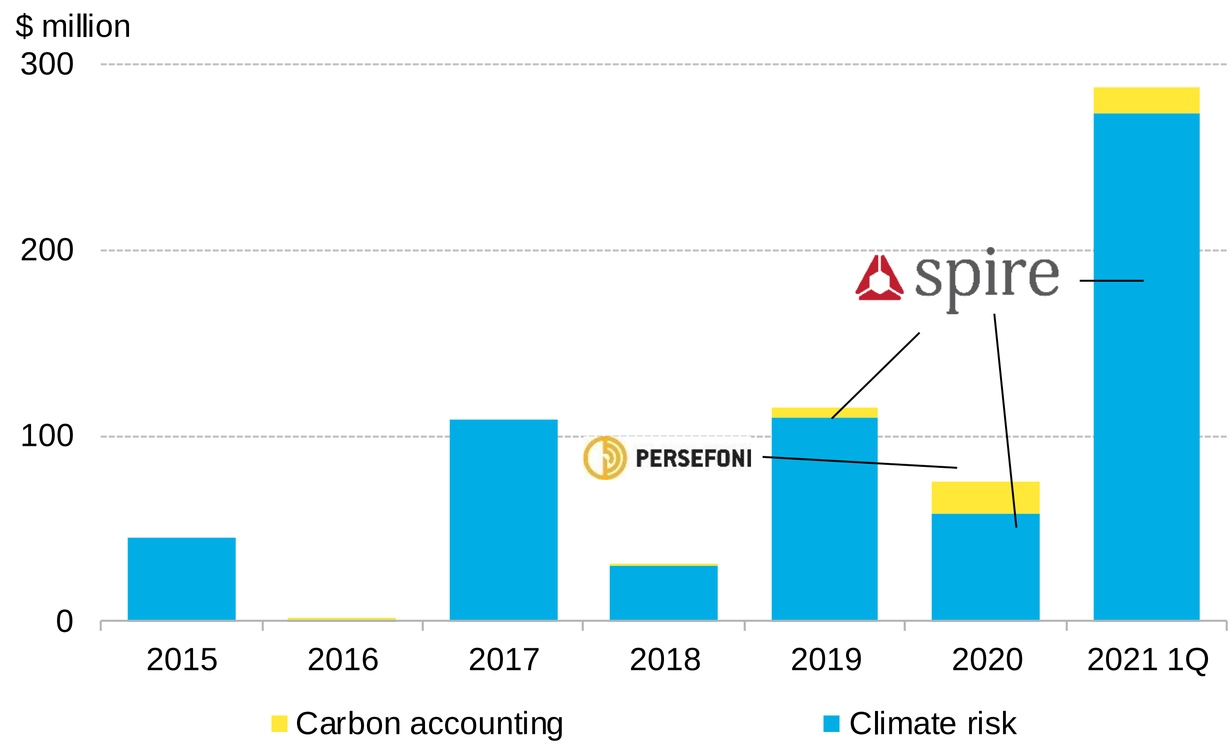
- Lowercarbon Capital, founded by the successful investment team of Lowercase Capital, has set out to work on climate-related issues. The firm is investing in climate-positive businesses that it believes will make money by lowering the carbon intensity of various industries.
- The firm has identified carbon sink measurement as a key investment strategy. Since its founding, the company has made several investments in the space:
  - Pachama's series C round in 2021
  - Dendra Systems's series A round in 2020
  - Soil Carbon Co's seed round in 2020

VCPE investment trends for serving corporate climate concerns

Climate risk is becoming more of a concern in board rooms around the world, and entrepreneurs have started to respond. It is still early for this group of technologies, with only two companies raising over $50 million dollars in the past five years (**Spire** and **One Concern**). With that said, we believe that a combination of corporate interest and new data streams will drive more investment into this space. 1Q 2021 funding was so large because of a $245 million investment in climate satellite and analytics company **Spire**, as the PIPE part of its SPAC. Investors include BlackRock Advisors and Tiger Global Management.

Carbon accounting is perhaps a more popular topic than climate risk, yet the VC funding here is very small. While 14 carbon accounting startups have raised money since early 2020, they are very early stage (mostly seed and series A). The most funded startup here is **Persefoni**.

VCPE investments in corporate sustainability technology startups



Source: BloombergNEF, CB Insights. Note: Logos indicate most funded companies each year.

Investor spotlight: Liberty Mutual Strategic Ventures & MS&AD Ventures

As corporations start to raise concerns about climate change, the financial system that supports them needs to better understand the associated risks. Some companies within the insurance and accounting industries have turned to startups to help them better understand climate risk and carbon accounting.

Liberty Mutual Strategic Ventures and MS&AD Ventures are the strategic venture arms of global insurance firms, Liberty Mutual and MS&AD. In 2020, both venture firms invested in climate risk analytics startup **Jupiter Intelligence.**

- MS&AD is currently partnering with Jupiter Intelligence to offer climate risk services in Japan, and will look to expand its partnership.
- Liberty Mutual will use this new investment to start to build new insurance products to help mitigate and manage the risk of climate change.

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