A Geofinancial Engineering Initiative: Using Real-Time Environmental Data from Satellites to Move Financial Markets and Improve Climate Outcomes

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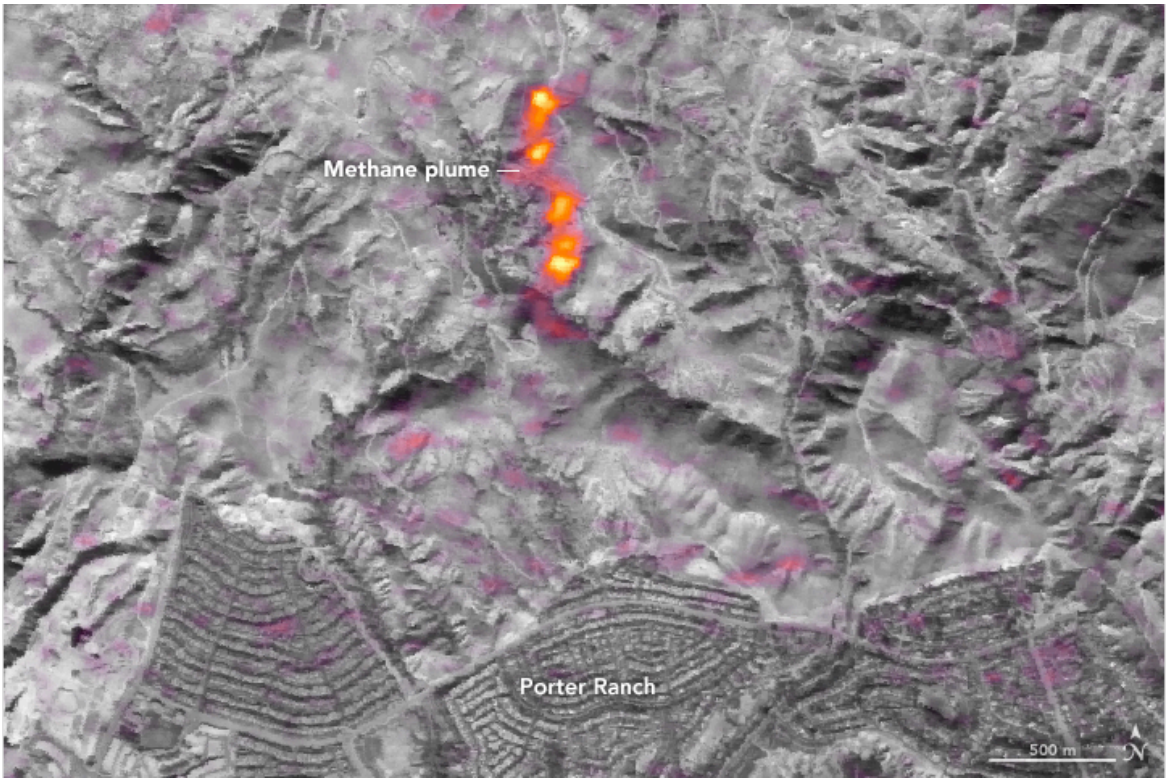
Abstract

Geofinancial engineering is the use of both financial tools and scientific knowledge to leverage the capital markets to alter human impact on the physical world and thus improve the odds of averting catastrophic climate change. While many long-term institutional investors are integrating climate change considerations into their investment decisions, hedge funds and quantitative (or algorithmic) trading systems – which often buy and sell in a matter of milliseconds – are, with few exceptions, inherently climate-agnostic. Although these now-pervasive strategies focus more on signals than fundamentals of underlying securities, they typically do not take real-time signals linked to the environment into account. Such signals are either not systematically accessible in a standardized manner or simply not connected to the datasets and applications available to the trading community. Making relevant, real-time environmental risk data readily available to climate-agnostic traders and investors – both automated and human – could shift financial market sentiment against behavior deleterious to climate stability. At the same time, such transparency could enable those traders and investors who proactively use such new datasets to avoid climate-related market risks and seize opportunities. We describe how and why such *geofinancial engineering* could be effective and explore one promising example: satellite data on methane emissions by publicly traded fossil fuel producers and utilities (Figure 1). A suite of information aggregated from existing and planned public satellites has the potential to detail methane flaring and venting activity at a fine enough spatial and temporal scale to allow for a nearly real-time assessment of methane emissions. By assigning this emission data to the spatial location of specific company assets, changes in both long-term behavior and short-term anomalous emission activity can be acted upon by traders and investors. This example of methane flaring, with complete datasets for emissions points and asset ownership for the entire U.S., illustrates the tractability of *geofinancial engineering* and how it might be executed via financial trading platforms. We also discuss the data gaps, open issues, and possible unintended consequences of advancing this new climate mitigation strategy.

Acknowledgments

Jonathan Foley's "Breaking the Cycle of Climate Inaction" blog post (October 2013) calling for a science-based approach that finds *planet levers* to climate solutions sparked the idea of *geofinancial engineering* as a potentially powerful example of such a lever. Extensive conversations with Edwin Lennox also informed the development of the *geofinancial engineering* approach and are gratefully acknowledged.

Figure 1: Methane plume detected from space. Sempra Energy (SRE) Aliso Canyon Disaster (2016); Photo: NASA Earth Observatory



Introduction

Climate experts estimate that burning known and extractable fossil fuel reserves would lead to dramatic climate change, far beyond the threshold necessary to stabilize the climate at 2 °C above pre-industrial levels (Blanco et al. 2014). More specifically, in a poll of climate scientists, 92% of expert panelists believe that if all the world's current fossil fuel reserves are burned, it is likely or very likely that Earth's average temperature will increase to levels not experienced for millions of years (≥ 3 °C of warming versus pre-industrial levels).[1]

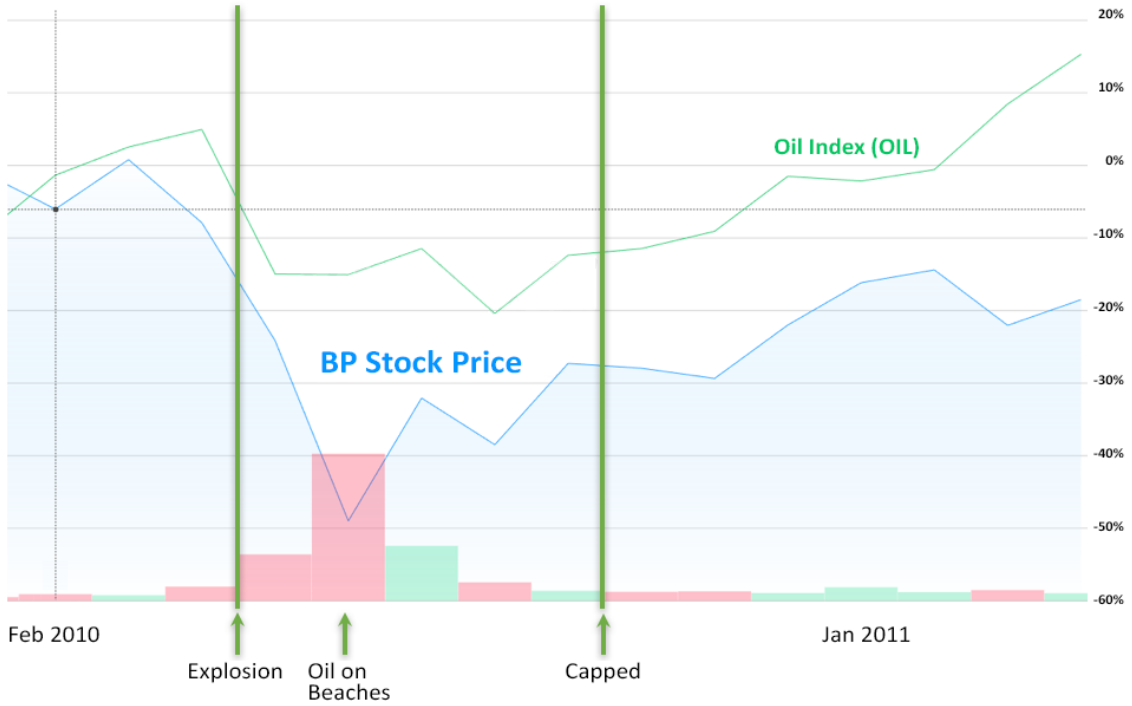
Reducing emissions remains a substantial challenge even for those actors who want to do so. Limiting global temperature rise to 2 °C above pre-industrial levels may require shifting $3 trillion per year for the next 23 years from the fossil-based to the green economy (Tweed 2016). Meanwhile, the recent withdrawal of the United States from the Paris Climate Agreement has injected global policy with a renewed sense of uncertainty over whether emissions will be regulated to the degree necessary. But even if the U.S. were to keep its commitment, the Paris goals are insufficient to avoid substantial, worldwide climate impacts.

Additional levers beyond governmental policy are necessary to improve the odds of averting catastrophic climate change, and financial market pressure is already playing a central role. While long-term institutional investors such as sovereign wealth and pension funds are integrating climate change considerations into their investment decisions, such efforts fall well short of this challenge (SIF Foundation 2016). One of the main reasons for this shortfall is the difficulty of connecting specific investment assets, such as stocks of publicly traded companies, to the negative consequences of companies' actions. However, if such environmental externalities can be both quantified and attributed to a given company or asset in near real-time, then asset prices may begin to more accurately reflect the costs of irresponsible behaviors.

This is not merely hypothetical. Environmental disasters have already affected market sentiment and stock prices – and, in the case of the British Petroleum (BP) Deepwater Horizon disaster of 2010, even inspired blockbuster movies. When impacts are vivid – explosions and oil slicks on Gulf Coast beaches reported live on CNN – movement of stock price for the company responsible can be swift and dramatic (Figure 2). This stock price change is consistent with a rational concern about expected financial consequences for the company's assets (e.g. lost oil) and liabilities (cleanup costs and damages) – and is not necessarily influenced by the decisions of environmentally responsible investors.

[1] Full results of the Vision Prize Poll of Climate Scientists, led by two of the authors (Kriss and Kriss 2015), can be found at http://poll.visionprize.com.

Figure 2: BP stock price before and after the Deepwater Horizon disaster.



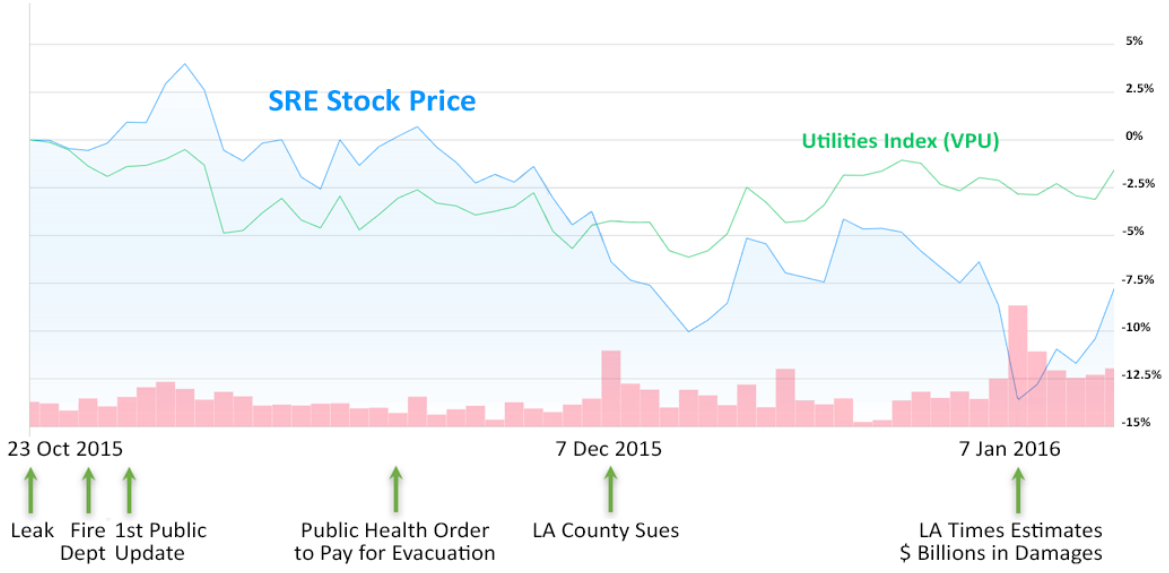
Source: Yahoo Finance 2017

Despite this, climate impacts that are directly attributable to companies are largely invisible to traders and investors or diffuse and unattributable to companies (A. R. Brandt et al. 2014). For instance, consider Aliso Canyon, the California methane blowout disaster in 2015, which was the second largest methane leak in US history. Researchers say the nearly 100,000-ton methane leak is likely to have had a significant impact on California's greenhouse gas (GHG) emission targets for 2015; given methane gas produces 86 times the warming power of carbon dioxide for its first 20 years in the atmosphere, this leak was equal to annual GHG emissions from 572,000 passenger cars (Vaidyanathan 2015; Conley et al. 2016). But release of the colorless and odorless gas was only visible with infrared imaging – not to the naked eye (Figure 1). As shown in Figure 3, at the same time the size and scope of the leak was reported, Sempra (SRE) stock price went up, not down, presumably since the expected impact on the company's assets (lost gas) was not in itself financially material while the environmental implications were not (and could not be) vividly portrayed by the news media. Only when the potential financial consequences of the disaster for Los Angeles County[2] – and, by implication, Sempra's liabilities as the

[2] Estimated by the *Los Angeles Times* on December 7, 2015 to be in the "billions of dollars". The company subsequently reached a plea agreement with Los Angeles County to a single misdemeanor and $4 million fine, and a $8.5 million settlement with Southern California Air Quality Management District. Global warming consequences were not considered in the settlements.

responsible party – became apparent six weeks later, did SRE's stock price underperform its Utilities Index benchmark.

Figure 3: Stock price of Sempra Energy (SRE, owner of Socal Gas) during 2015 Aliso Canyon methane blowout disaster.



Sources: Yahoo Finance, Bartholomew (2016)

When impacts are not visible and financial consequences not readily quantified, environmental disasters may have little to no effect on market sentiment and stock price. Revealing the true impacts of such events[3] to investors could improve the ability of market forces to internalize the costs of bad practices and incentivize responsible behavior. For example, it could make the connection between methane leaks and financial risk from lawsuits much stronger (by giving quantitative evidence to the plaintiffs) and more immediate (hours as opposed to days or months), even when direct financial losses to the company are negligible. Thus, the environmental externalities of these disasters, not just the direct loss in assets, may be more fully and immediately reflected in stock prices.

We propose a new approach – *geofinancial engineering* – that leverages scientific knowledge and financial technology to make environmental risk data actionable for traders and investors. This market pressure may drive positive behavior change in companies, pushing them to reduce emissions that are directly attributable and known to investors. To

[3] Ideally making them visible includes quantifying the liability of the responsible party for impacts on climate systems – perhaps like Environmental Protection Agency ratings for cars and appliances – not just human impacts in the affected regions (e.g. Gulf of Mexico and Los Angeles County).

describe how *geofinancial engineering* would work, we use the example of 'super emitter' methane flaring and venting sites by companies such as Sempra Energy – defined as those sites in the top 1% of emissions in the natural gas supply chain (Zavala-Araiza et al. 2017).[4]

Geofinancial Engineering

We live in the Anthropocene epoch, which means that human activities significantly impact the Earth's geology, climate, and ecosystems (Lewis and Maslin 2015; Waters et al. 2016; Zalasiewicz et al. 2016). This represents an existential threat – as well as an opportunity. *Geofinancial engineering* is the use of financial tools and scientific knowledge to leverage the capital markets to alter human impact on the physical world and thus improve the odds of averting catastrophic climate change.[5] As a market-based initiative, it can operate independently from governmental action or it can amplify the effectiveness of market-based regulation like carbon pricing or emission penalties. Given the recent policy swing from the science-driven Obama administration to the climate denialism of the Trump administration, policy-independent mechanisms are particularly timely.

As a mitigation strategy, *geofinancial engineering* aims to preemptively reduce the prevalence of behaviors that cause the most damage – such as extracting and burning high-carbon fossil fuels, deforestation, methane-intensive agricultural practices, and loss of non-renewable water sources (Figure 4).

Geofinancial engineering aims to improve climate outcomes by increasing the cost of capital for companies engaged in deleterious behavior, and by reducing the cost of capital for more climate-resilient alternatives. Divestment, socially responsible investing (SRI), and impact investing are already entering the mainstream, but making real-time environmental risk data available to climate-agnostic traders and investors – both automated and human – is a new promising area of opportunity for effecting change (Figure 5).

Hedge funds and automated trading systems, in particular, can be influenced to trigger volatility, negative sentiment, and downward price movements.

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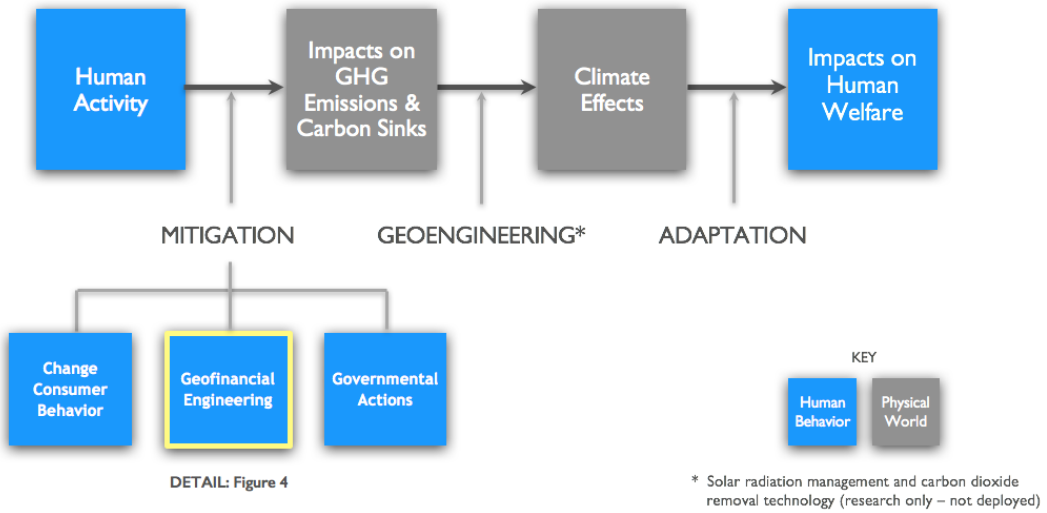
[4] Zavala-Araiza *et al.* find that the top 1% of 'super emitting' sites are responsible for nearly half (44%) of U.S. methane emissions in the natural gas supply chain. A previous study by Brandt *et al* (2016) defined super emitting sites as those in the top 5%, finding they account for over 50% of such emissions.

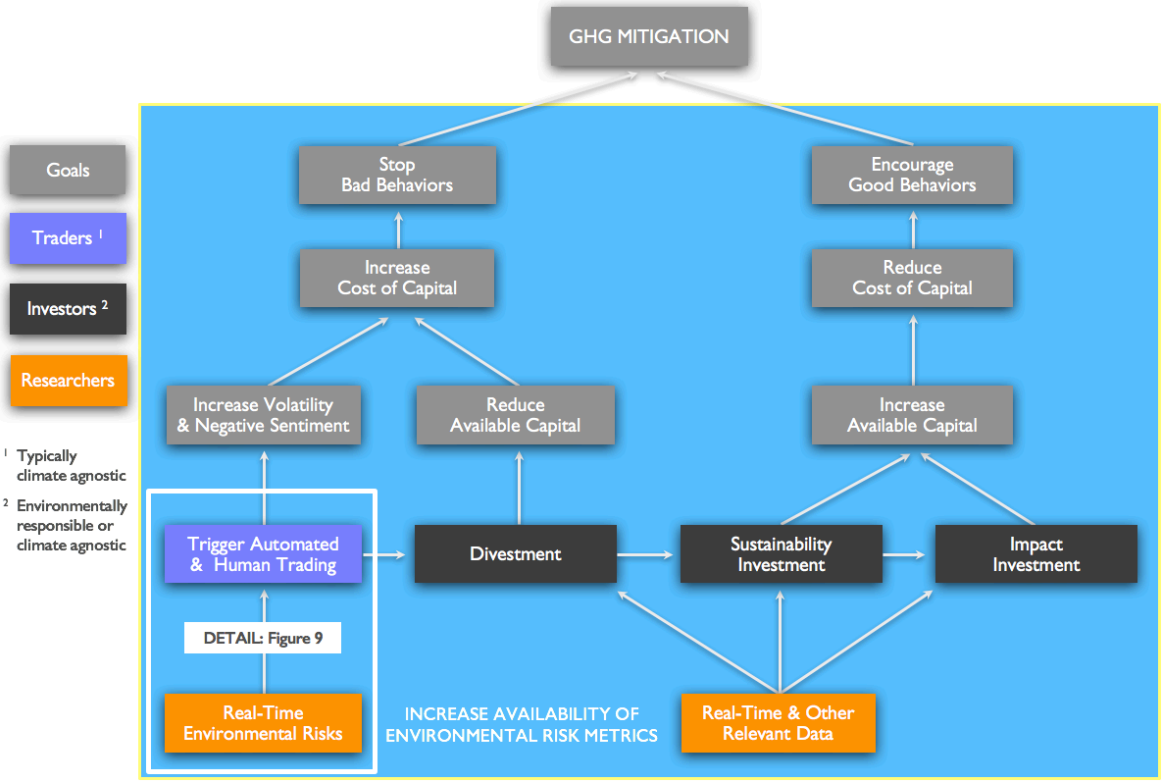
[5] Macroclimate® derived the term from *Financial Engineering* and *Geoengineering*. *Financial Engineering* uses tools and knowledge from the fields of computer science, statistics, economics and applied mathematics to devise new and innovative financial products. *Geoengineering* would alter the physical world to disrupt the connection between burning fossil fuels, and other deleterious behavior, and their climate change impacts – an untested and problematic last resort with wildly uncertain effectiveness, side effects, and financial costs.

Figure 4: Process model showing geofinancial engineering as a complementary alternative to consumer behavior change and governmental actions on greenhouse gas (GHG) mitigation.



Sources: Adapted from macroclimate.com, schema based on K. Ricke (2013)

Figure 5: Detail – Geofinancial Engineering process model.[6]



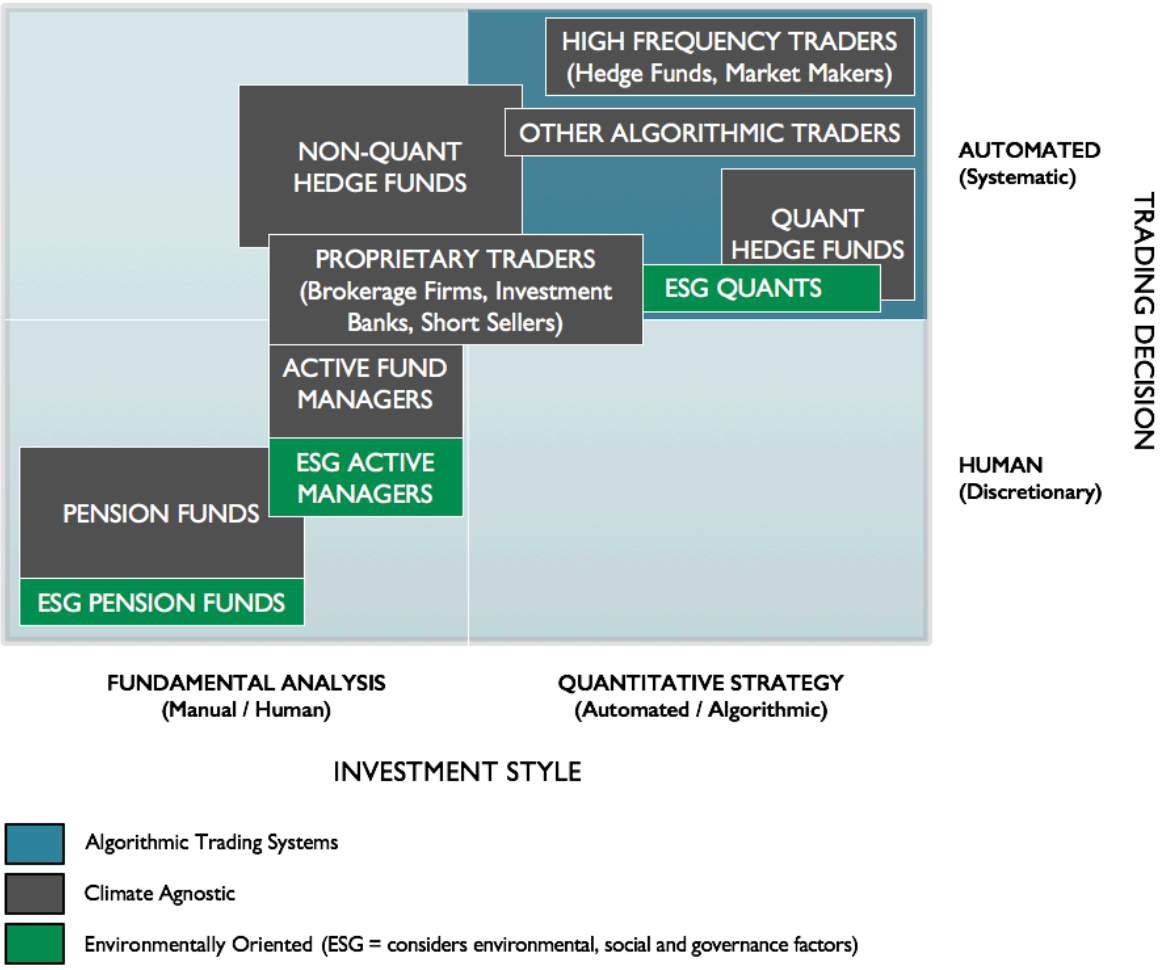
Hedge funds and quantitative, or rules-based, traders seek to exploit perceived short-term inefficiencies in the market, using back-tested models, real-time data feeds, and high-speed automated trading systems. Since these now-pervasive[7] automated data-driven strategies typically have short or ultra-short time horizons and focus more on *signals* than fundamentals of underlying securities, they are – with few exceptions[8] – inherently climate agnostic. We use the term *algorithmic trading systems* to describe this class of market participants, which includes high-frequency traders, other algorithmic and systematic traders, hedge funds, and quant-oriented proprietary traders (Figure 6).

[6] "The main difference between a trader and an investor is the duration for which the person holds the asset. Investors tend to have a longer-term time horizon, while traders tend to hold assets for shorter periods of time to capitalize on short-term trends." (Investopedia 2007)

[7] Automated trading is by now pervasive across a wide variety of financial markets worldwide. For example, it accounts for about two-thirds of the activity in Eurodollars and Treasury futures contracts. Source: Keynote Address of CFTC Commissioner J. Christopher Giancarlo before the 2015 ISDA Annual Asia Pacific Conference (Cespa and Vives 2017).

[8] An emerging group of ESG (Environmental, Social and Governance) quant funds combine quant strategies with sustainability-oriented fundamental analysis (Grene 2016).

Figure 6: Map of selected financial market participants



Divestment, socially responsible investing (SRI), impact investment, and engagement are typically driven by the wish (or pressure) to avoid negative impact or to have positive impact on the environment or society. Increasingly, there is an argument that there might be purely financial risks associated with not taking environmental, social and governance (ESG) factors into account. Those, however, often take the shape of a "Sword of Damocles"[9] in that they are seen as a threat if and when an ESG-linked disaster occurs. *Geofinancial engineering* turns this argument on its head: it aims to feed real-time information on *occurring* disasters into the heart of the financial markets: The Sword is falling already, and the price effect is happening now – in this instant.

[9] An allegory for a situation which causes a prolonged state of impending doom or misfortune.

Such actionable, real-time information can expose and magnify the risks of fossil fuel assets, helping to reshape how the global financial markets view the future of fossil fuel energy. Instead of valuing such assets as essential core holdings, they could and should be priced as an especially risky financial bet given the overwhelming evidence that extracting and burning fossil fuels warms the planet. Even if the worst impacts of such behaviors are still years or decades in the future, the anticipation of those impacts and the market's (or governments') reaction to them can precipitate financial consequences today. The anticipation (or even merely the anticipation of others' anticipation) of reputational liability, customer preferences, tort liability, unfavorable status with institutional investors, stranded assets, regulation, or any other pressure has the potential to move stock prices within seconds, if the data pipeline exists. The infamous 2010 Flash Crash provides a sobering example of the potential for algorithmic trading to trigger devastating high-speed price movements (U.S. Commodity Futures Trading Commission and U.S. Securities & Exchange Commission 2010). In global energy trading markets, algorithmic trading accounts for about one-third to half of crude oil futures trading, exaggerating price moves and steepening volatility (Piotrowski 2015).

Already, fossil fuel energy markets are vulnerable to shocks in confidence and sudden changes in market perceptions driven by events in both political and natural environments. Heightened concerns about wasted capital, stranded assets, and divestiture are now key factors driving short- and long-term price volatility and directional movements of carbon-intensive assets; also affecting this volatility and directional movement are growing investor concerns about reputational risk, lack of transparency, and the rapidly declining cost of renewable alternatives. This was less true five or ten years ago when, even in the U.S., the fossil fuel industry enjoyed wide bipartisan support and economically viable alternatives were just beginning to emerge. Post-Paris, the pro-fossil-fuel Trump administration is an isolated outlier. In short, the capital markets represent the soft underbelly of the fossil fuel industry. Compounding the risk is the fact that ownership of U.S. oil and gas companies is relatively concentrated. For example, pension funds alone owned 29% of all such companies in 2014 (Shapiro and Pham 2014).

In this context, environmental researchers can spur action by traders and investors that can accelerate shifts in the enormous global capital markets – where approximately $350 billion in equities are traded daily (World Federation of Exchanges 2016). Innovative information technology is creating new opportunities to scale these efforts and increase their potential impact, particularly among hedge funds and algorithmic traders. A key point is that financial self-interest is sufficient to drive the behavior of such large and savvy capital markets players, provided that they either: a) plan on holding their assets for the long-term; or b) expect other market players to do so (and hence that those investors will act on climate risk information by taking information on greenhouse gas emissions into

consideration when buying and selling assets). Evidence also suggests that investor-driven shareholder actions affect corporate behavior. For example, facing pressure from both investors and financial regulators, ExxonMobil recently announced that it might write down one-fifth of its untapped oil reserves (*The Economist* 2016).

With this understanding of how financial markets could significantly affect climate-relevant industrial behaviors, we next consider the data available to track a particularly critical greenhouse gas and link it to individual companies.

Data Availability, attribution and delivery

Venting or burning methane accelerates climate change, the global impacts of which are well known and documented. Venting is particularly problematic because methane is a more potent greenhouse gas than CO_2 and accounts for about third of methane emissions, both in the U.S and globally (Turner et al. 2015; Saunois et al. 2016), Both venting and flaring are also an unproductive waste of a non-renewable resource, with venting leaks posing health challenges for local populations that breathe the fumes.

Attributing these harmful practices to the companies responsible in a way that can affect financial markets requires: 1) spatially and temporally *detecting* where and when such venting and flaring took place; 2) *attributing* events to the companies responsible; and 3) *reporting* data to investors and traders in a format that is timely and actionable. We describe current and future potential to detect, attribute, and report company behavior on climate change to investors.

Detection:

Five types of methane indicators could be measured to convey harmful activity to investors and traders. (These indicators are represented by the purple circles in Figure 8.) Depending on latency and resolution, methane sensing data can provide short- and long-term insights on greenhouse gas emissions, which may be useful to investors and traders in different ways. For instance, consistent venting and flaring suggest harmful long-term behavior and can be determined using less frequent data at lower resolution, while gradual changes in venting and flaring activity suggest either improvements or declines in best practices and intent. Significant short-term changes in venting activity, on the other hand, require high spatial and temporal resolution to capture anomalies, which might be early indicators of large-scale disasters and thus may precipitate major shifts in market sentiment and price. Spatial and temporal resolution in greenhouse gas data are both potentially valuable to traders. If attributable to corporate assets, even low-resolution information that is directly indicative of material behavior is potentially actionable.

Figure 7: Process model for attributing short- and long-term 'Super Emitter' behavior to specific publicly traded companies

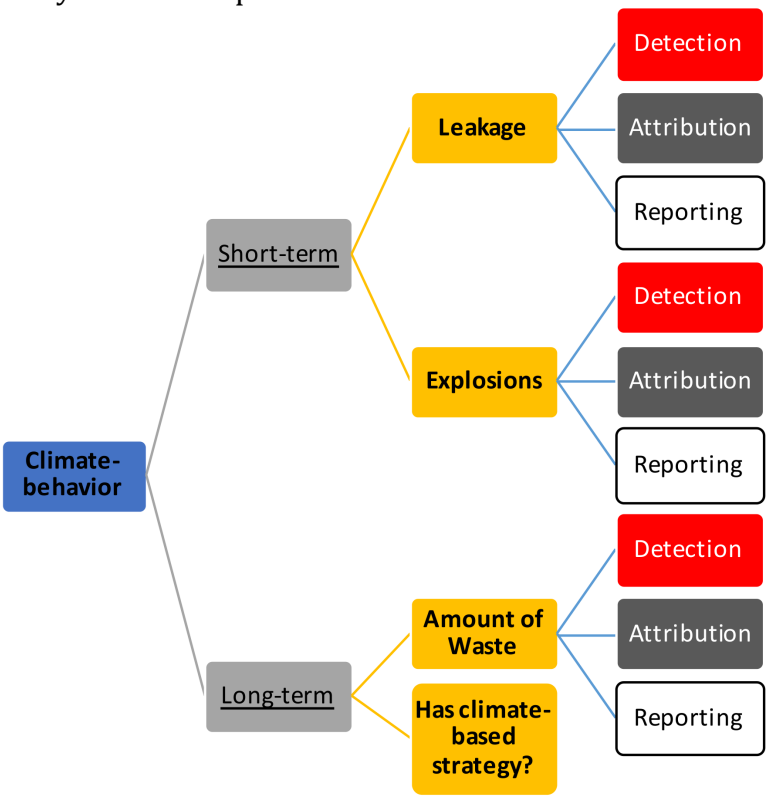
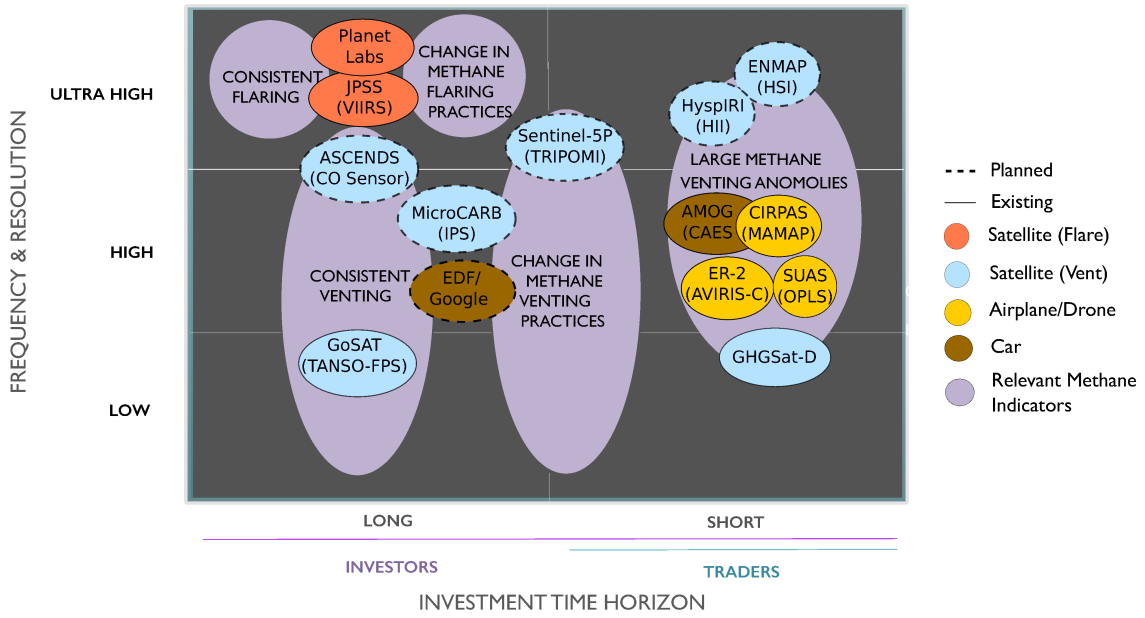


Figure 8: Present and future sensing options for tracking 'Super Emitter' methane flaring and venting.



Several existing remote sensing satellites are currently capable of measuring both methane flares and venting. In particular, the VIIRS satellite can measure flaring at a sufficiently high resolution to track daily changes by flare site and link it directly to the company running the facilities (Elvidge et al. 2013), and private ventures such as Planet Labs satellite constellation can provide even higher resolution data (Planet Labs 2017). Venting is harder to measure since spectrometers must capture the non-visible parts of the spectrum, both using the thermal spectrum (TIR) and short-wavelength infrared (SWIR). Existing satellites, particularly GoSAT (Turner et al. 2015), are capable of measuring at a resolution that can track general trends over time, but none currently in orbit can measure leaks at the temporal/spatial scale and scope necessary to attribute to individual sites. The closest was now-retired EO1 satellite (Figure 1), which was capable of capturing measurements at the required scale – and captured the Aliso Canyon leak (Thompson et al. 2016). But EO1 provided only a small scope where the spectrometer was pointed. A similar "instantaneous field-of-view" (IFOV) satellite was launched in 2016 as a private venture by GHGSat (Germain et al. 2017).

Planned and proposed satellites, particularly the German EnMAP satellite (2019 launch) may for the first time provide a global dataset at the frequency and resolution needed to pinpoint venting emissions by source (Thorpe et al. 2013; Luttenberg and Schaadt 2014;

Tollefson 2016). Local tracking also is available using spectrometers from airplanes and drones, as well as other sensors on ground vehicles (I. Leifer et al. 2013; Gerilowski et al. 2014; Marchese et al. 2015; Perez 2016). Collated together, these sources can be used to build a state-of-the-art, real-time dataset that provides detailed information on all five of these key methane indicators (Brandt et al. 2014; Leifer et al. 2016).

Attribution:

Once data on site-specific emissions is collected, the next step is to attribute the remote sensing methane measurements to the company responsible. The US Energy Information Administration, for instance, provides detailed spatial data on fossil fuel installations and the companies that own them, including stock tickers. By combining these datasets, daily data on facility behavior can be attributed to companies, aggregated, and fed into automated trading systems and/or dashboards, along with conventional financial news and data.[10]

Reporting:

Delivering environmental risk data to investors, human traders, and algorithmic trading systems – in near real-time *before it is generally known* – in a format that seamlessly integrates with their workflow is a way to pull the *geofinancial engineering* lever.

A successful system must create transparency, preferably in near real-time, since knowing about intangible disasters *before others* is what makes the information actionable to hedge fund and algorithmic traders. Knowing first – by a day, an hour or a few hundred milliseconds – can deliver the information advantage they seek. For this reason, we expect that such information would likely be offered on a tiered pricing basis by latency. For example, today high-frequency traders pay very substantial fees for ultra-low latency stock price feeds. By contrast, for the general public such stock price information is typically available for free with a 15-minute lag.

As a case in point, the growing use of Machine Readable News (MRN) as inputs to algorithmic trading systems means that social trends, and even weather events, can have an instantaneous effect on asset prices. Market sentiment exerts a significant influence on investor behavior. Corporate news on select sectors that attract significant media interest

[10] ESG research houses with a specialized climate unit, such as ISS-Ethix, systematically map carbon intense installations (such as factories) and fossil fuel activities to the company level and link them to identifiers of the respective securities. Public data sources – for example, the U.S. Energy Information Administration – also are available for certain industry sectors. (Figure 11) Relatedly, significant efforts are underway by ISS-Ethix, Carbon Delta, Asset-Level Data Initiative and others to map underlying assets to listed companies in order to track "physical" climate risks such as floods, droughts, and storms which might affect company assets and profits.

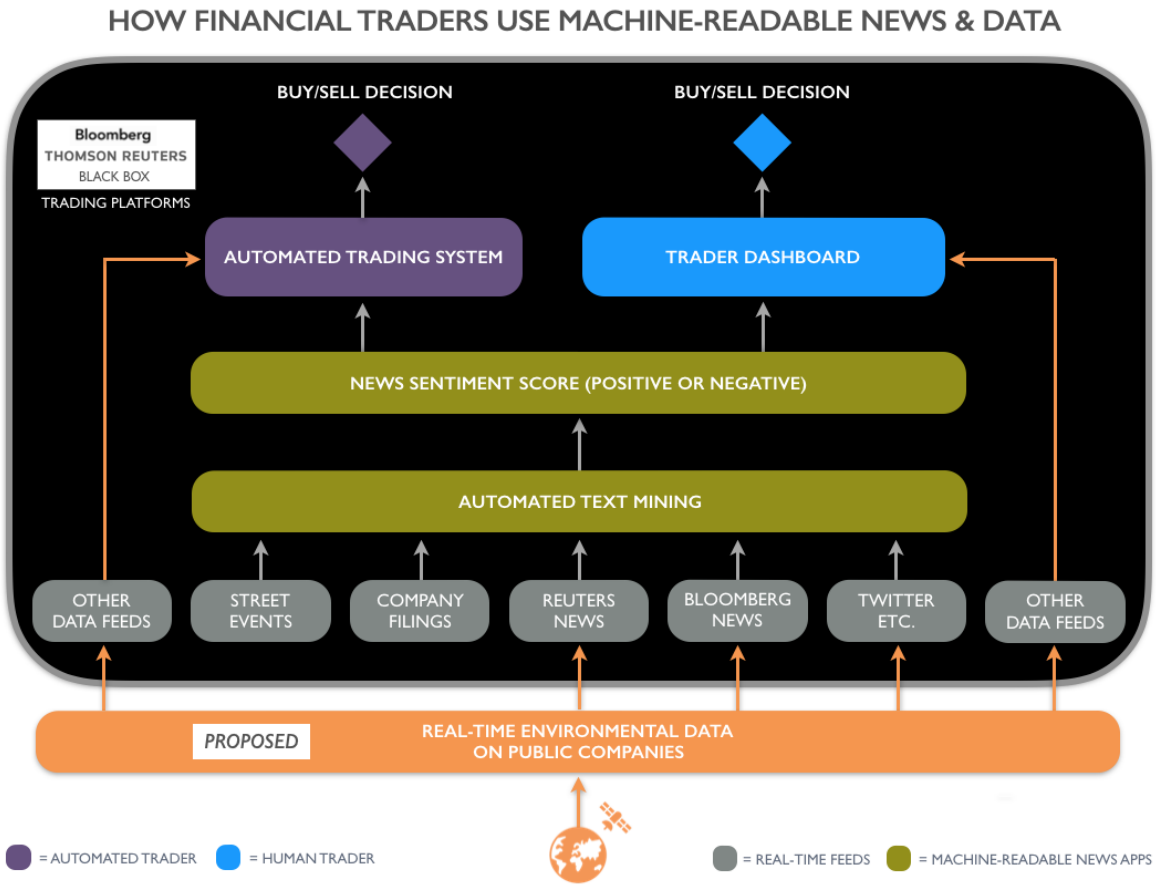
(Depalma 2017), such as the fossil-fuel energy sector, drives market sentiment. In a recent study, for example, abnormal negative stock returns corresponded to news announcements about carbon bubbles, divestment, and related topics. This was especially true for coal companies (Byrd and Cooperman 2016).

Leading financial news providers such as Bloomberg and Thomson Reuters now offer powerful MRN tools that deliver automated sentiment and linguistic analysis on financial news in real-time. Algorithmic trading systems are among the principal users of such tools. Since their trading decisions are often made literally faster than the blink of an eye (less than 300 milliseconds), they use rules-based models with automated circuit breakers – not human traders – to parse and act on new information.

Increasingly, hedge fund and algorithmic strategies seek trading and investment signals from non-traditional sources like social media (Carney 2013) to gain an incremental information advantage. In this context, environmental researchers can trigger shocks in confidence or risk perceptions around investment in fossil fuels or other deleterious behavior. They can do so by delivering timely empirical data and analysis to MRN apps and other analytic tools, amplifying their presence on the financial terminals that drive these apps (Figure 9).

To take advantage of this high-paced financial trader market for methane emissions information, a collator must collect the best available information on methane venting and flaring and translate it into real-time indicators that investors and traders can easily interpret and act upon. We present a step-by-step example in the following section to illustrate how this type of *geofinancial engineering* can work.

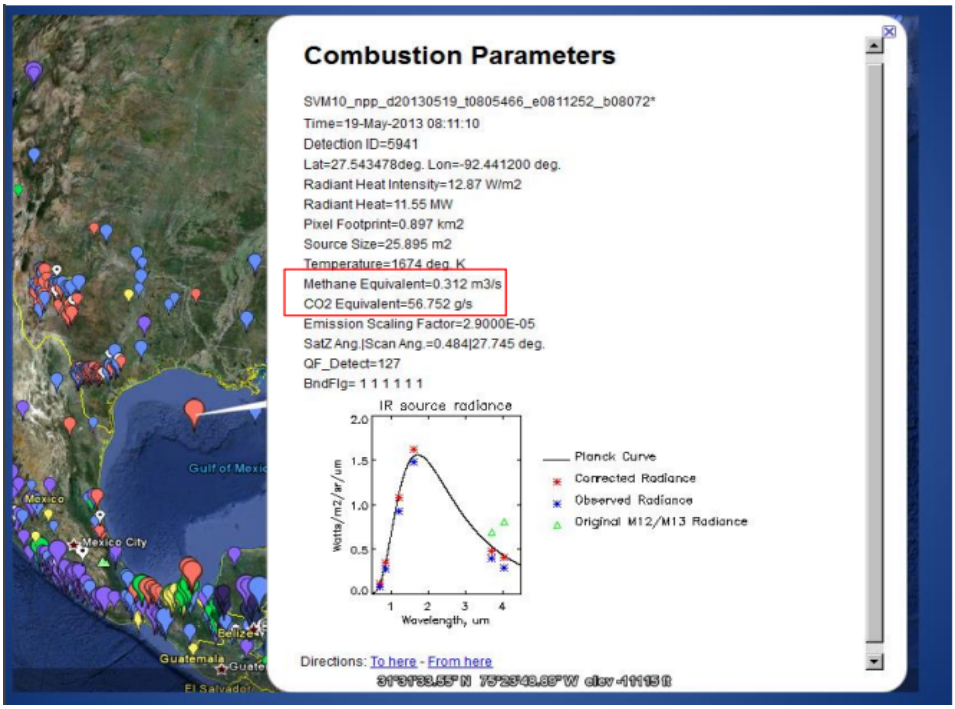
Figure 9: How real-time satellite data on 'Super Emitters' – attributable to specific publicly traded companies – can trigger shocks in confidence or risk perceptions around investment in fossil fuels and/or other deleterious behavior. (Detail of Figure 5)



Hypothetical Case Study: Methane Super Emitter Application

Consider a hypothetical case in which climate-conscious investors care about the rate at which companies are flaring methane, engaging with or divesting from companies with relatively more flaring than their peers. The first step is to *detect* where flaring is happening globally, which requires globally accessible data that captures flaring events at the factory scale. Data from the VIIRS satellite spectrometer has these characteristics and is publicly available daily. Figure 10 shows a screenshot from a presentation by Elvidge et al. (2013) that explains how VIIRS data can be used to calculate daily flares and their respective attributes, including methane emissions and latitude/longitude coordinates.

Figure 10: Methane oil & gas hot spots can be identified by NOAA VIIRS satellite.

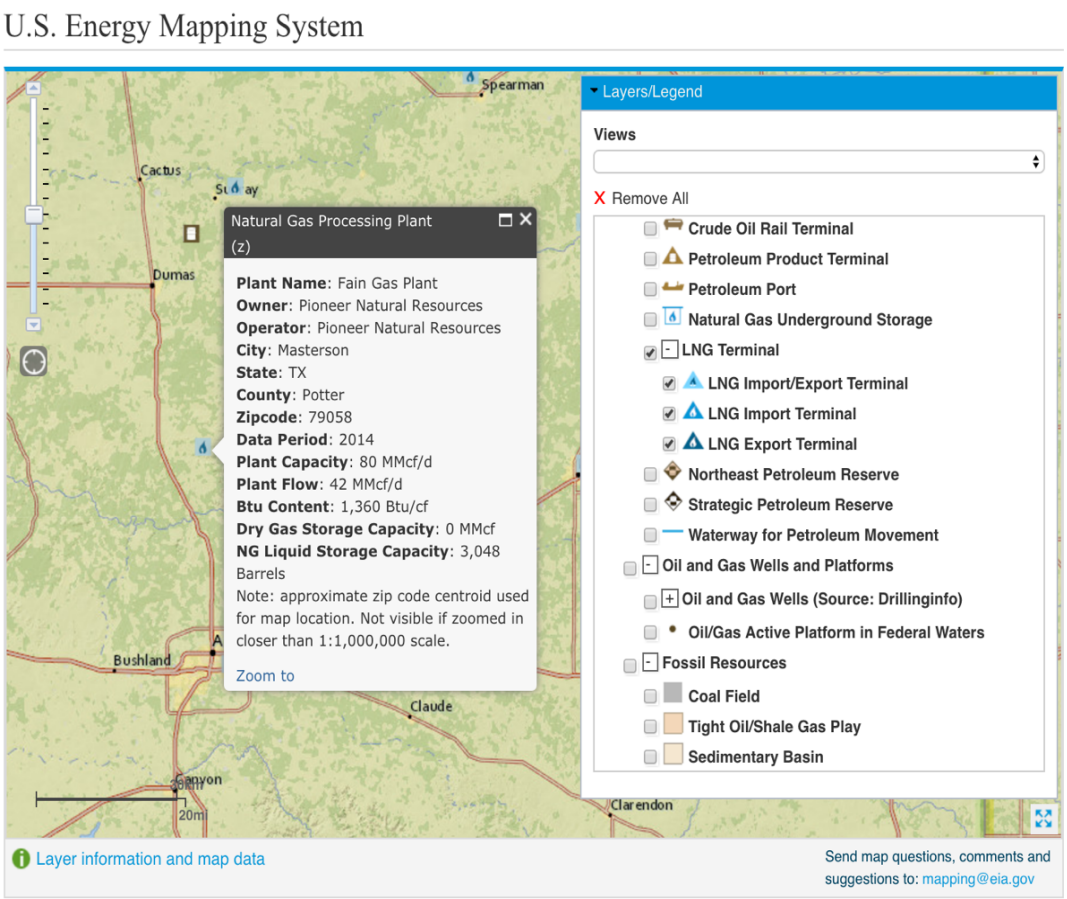


Source: Elvidge et al. (2013)

Next, we need to *attribute* each flare to the facility responsible using spatial coordinates. For the U.S., the Energy Information Agency (EIA) maintains a database with energy-related facilities, which include detailed spatial coordinates as well as company information such as New York Stock Exchange (NYSE) and International Securities Identification Number (ISIN) identifiers (U.S. Energy Information Administration 2017). By overlaying this EIA layer with the VIIRS data, each flaring episode is linked to the company

responsible. Figure 11 is a screenshot of the EIA online tool, showing the information associated with the Fain Gas Plant in Texas. In our hypothetical scenario, if VIIRS detects flares at this site it can be associated with the owner of the plant, Pioneer National Resources, and its stock ticker (PXD) and ISIN (US7237871071). With information on flaring activity per site matched with company identifiers, total flaring activity can be aggregated to calculate behavior across all sites.

Figure 11: Company data associated with Fain Gas Plant in Texas, which, when correlated with VIIRS remote sensing data in our hypothetical example, provides flaring activity per company site.



Source: U.S. Energy Information Administration (2017)

The final step in our hypothetical example is to communicate this flaring activity to investors in an easy to understand manner that can inform their decisions – investment, divestment, or engagement. For instance, real-time daily updates of total GHG emissions from flaring by company can be presented. (Investors would see both flaring indicators from Figure 8: which companies consistently flare the most and which companies have improved or worsened flaring activity over time.) By comparing these data across

companies, investors could decide whether to engage with or to divest from relatively poorly performing companies while perhaps sparing poorly performing companies that are showing improvement in recent weeks and months (suggesting a change in behavior).

While such data may be actionable for investors, they are probably not applicable to hedge funds and algorithmic traders who follow binary buy/sell factors and do not develop views on any given company. For them, we next consider the case of a methane venting "super emitter" disaster such as Aliso Canyon. The EnMAP satellite to be launched in 2019 will have the global coverage and spatial resolution to capture venting incidents such as this every four days. If Aliso Canyon were to happen again in 2020, data from EnMAP cross-referenced with the U.S. EIA information could be fed into trader terminals to alert traders of the increased risk associated with the responsible party, in this case Sempra Energy.

Figure 12 presents a hypothetical *methane risk analyzer* that illustrates how real-time methane risk data on a specific publicly traded company (Sempra Energy) might appear on a climate-agnostic trader's terminal in the near future. Historical time series of past venting anomalies from EnMAP data could be used to estimate a normalized risk score (0-100) from the number of anomalies by company over time. When a new anomaly is detected, this information would be fed into the terminal and immediately affect the risk score, allowing traders to react given the size of the leak, past company behavior, and the risk scores of its peers. Such a dashboard could also include MRN sentiment analysis, tracking of stock price versus methane leaks, and other environmental indicators in real-time, as well as corporate environmental policy scores. Such an app could be programmed to include a notification system that triggers buy/sell trading decisions given pre-selected risk thresholds.

Figure 12: Illustrative example of trader terminal circa 2019 highlighting methane risk for a 'Super Emitter' (Sempra Energy) compared to its peers.

With such a tool, human or automated traders and portfolio managers could use information in several different ways, including:

- Hedge fund and algorithmic trading – Enhance rules-based strategies with automated circuit breakers powered by *methane analyzer* which may anticipate price volatility, sentiment shifts and directional movements based on early indicators of major methane venting anomalies

- Engagement – Trigger efforts by large institutional investors such as pension funds and mutual fund managers to affect directional change at Sempra Energy or its peers via shareholder resolution, proxy votes, disclosures, or other pressures.

Implementation Issues

The examples above highlight a few of the ways *geofinancial engineering* could work, but several key issues are important to consider regardless of the application.

Climate change is a global problem and we live in a global economy. Global data coverage is therefore essential, both for satellite data as well as corresponding company information. Similarly, data resolution must be sufficient to link methane emissions – or other climate-relevant data – to the companies responsible. Moderate confidence levels can still be actionable and better resolution data can increase confidence. Collating data from different sources is another way to increase information reliability, particularly for small, distributed emissions over large areas. For instance, information from short-wavelength (SWIR) spectrometers in the day, thermal (TIR) spectrometers at night, and ground-based sources from airplanes, drones, or cars or stationary remote sensors could improve emissions data confidence in the absence of a "silver bullet" satellite option. A data collation approach may be necessary for spatial information on company assets, connecting multiple data sources (surveys, national accounts, and maps) to improve both accuracy and comprehensiveness. For instance, although attributing emissions to stationary oil and gas assets is fairly straightforward, attributing emissions during the distribution of products is much more difficult (McKain et al. 2015). Similar attribution difficulties may arise for other sectors and GHGs that have spatially distributed emissions as well as asset ownership (for instance livestock and forest products).

Similarly, the temporal dimension of data collection is important. In the case of methane, the more often company venting and flaring is reported the better, as it builds accuracy in readings, allows information to flow to traders more often, and assures that companies cannot easily adjust flaring and venting practices to avoid detection. For instance, satellites that measure methane venting using the short-wavelength infrared (SWIR) spectrometers cannot capture data at night; any venting at this time is undetectable. Similarly, cloudy days can provide an opportunity to flare undetected. And since satellite orbits are predictable, the larger the remote sensing gap, the higher the likelihood that companies can adjust their behavior to exploit those gaps.

For our methane case, VIIRS – with global coverage, a daily time step, and a resolution of 375 m – is sufficient to monitor flaring. Similarly, the planned EnMAP satellite – with global coverage, a four-day time step, and a 12-meter resolution – appears to be the best publicly announced option for venting. Other satellites that can track venting have been proposed, but none are expected to be of the resolution needed for *geofinancial engineering*. (This is particularly true in the U.S. where public funding of such missions is now in question.)

However, the private sector already appears to be filling this gap, and with the potential to do so more quickly and at a lower cost than the public sector. The company GHGSat launched its first satellite last year. It contains both SWIR and TIR spectrometers capable of capturing venting at a 5-meter resolution (Germain et al. 2017). Similar to EO1, however, its IFOV scope does not offer global coverage. Another company, Planet Labs, has launched a constellation of "nanosatellites" capable of capturing ~4-meter resolution images of the entire globe daily. But these satellites track visible and near infrared (NIR) spectrums and not SWIR or TIR. Given the value of improved temporal detail and spatial accuracy, one could imagine a cluster of nano-satellites such as the private Planet Labs data that includes spectrometers similar to those of EnMAP or other proposed satellites. This would take what investors in GHGSat have seen – the value of real-time, accurate information on GHG emissions – to the next level. With such potential coverage, traders could act more confidently and quickly upon information fed into their dashboards (see Figure 12). With the expansion of lower-cost launching options from both governments and private entities, the expense of funding such an effort may fall dramatically in the near future (Vance 2017).

Unintended Consequences and Limitations

Privatizing benefits of greenhouse gas reduction is a key strength of the *geofinancial engineering* approach because it drives uptake in a large and diverse marketplace, and large-scale transformation is necessary to prevent catastrophic climate change. But this trading-based approach to altering corporate behavior may also have side effects, downsides and unintended consequences.

The private option to launch and maintain satellites, for example, raises the issue of information equity. Although emissions reductions provide benefits to everyone globally, the financial benefits from such private information might accrue to only a few. Relatedly, traders and hedge funds might pay high prices to secure access to low latency information on an exclusive basis. That *geofinancial engineering* could incite a kind of data arms race may only intensify the need for capital to secure favorable financial returns.

Second, *geofinancial engineering* may shift influence over the carbon market from well-meaning investors (or policy makers) toward socially indifferent traders with little concern for social benefits or the public good. Finally, significant data penetration could cause political pushback with the potential for new laws or regulations that restrict data collection. This could reduce the amount of information available to us.

We propose a collaborative civic-oriented "open data" approach to mitigate some of these concerns. Given the declining cost of launching satellites, privately-funded consortia consisting of NGOs, academic institutions, foundations, and climate impact-oriented tech firms like Google, Tesla, or SpaceX might make such information publicly available. If

coupled with publicly funded satellite data such as VIIRS – which is already available to all – and a freely-accessible platform such as the one illustrated in Figure 12, then all investors, traders, and stakeholders, regardless of their capital resources, could leverage this information to make environmentally sound decisions.

Another important caveat concerns the efficacy of *geofinancial engineering*. Specifically, the newsworthiness or public perception of certain greenhouse gas emissions may not correlate well with the climate impact of different greenhouse gas sources. For instance, venting is far worse than flaring since unburned methane has higher impacts than burned methane, but flaring means more fire, which could be more "newsworthy" and viewed by traders as more likely to move the short-term market. In other words, information may not move the market for the right reason or may incentivize the wrong things. A focus on traceable venting and flaring events also might draw attention away from more disperse methane venting. This is similar to the differential attention to point-source water pollutants despite the predominance and cumulative impacts of non-point sources. Relatedly, a focus on publicly traded "super emitters" could overlook cumulative venting by numerous, smaller emission sources, as well as the many private and state-owned "super emitters" which are shielded from financial market pressure for transparency and accountability. In the latter case, engagement may be the best and only option.

The *geofinancial engineering* possibilities described in this paper do not include all aspects of climate change risk for corporations, notably those risks from climate change itself. Concern about the risks of extreme heat, drought, and deluge to corporate assets is an additional reason why companies might take action to reduce greenhouse gas emissions. We also assume that a variety of market forces, directly from regulation or indirectly from social awareness and social responsibility, are in place, and might even grow, so that investors and traders can exploit these forces for financial gain. If these forces are not present, the information we suggest collecting and distributing might not affect any change in stock price or corporate behavior.

Conclusions

Climate change as an investment consideration is moving from a responsible investor niche into mainstream concepts of general asset management and institutional investing. This is an important statement by investors, but they still may not reach the critical mass needed to move the needle on a company's market value. The financial market sectors that now generate most of the daily trading volume – hedge funds and algorithmic trading systems – are simply not included in today's considerations. This paper, for the first time, sheds light on a powerful but overlooked driver of capital allocation. We propose a concept in which the underlying mechanics could be utilized to change company behavior – not by the uncertain deployment of ethical arguments, but by linking scientific observations with

likely financial risks and mapping that to hedge fund strategies and trading algorithms in real-time.

The paper suggests two different paradigm shifts.

1) Environmental events including disasters and more routine deleterious behavior of companies negatively impacts the prices of securities. Real-time environmental data from satellites will soon be available in such a standardized and systematic manner that it could be fed into hedge fund strategies and trading algorithms to price such information more quickly and systematically. All that is necessary is a mapping of a measurable event to the investable asset. Given that this is a relatively small hurdle, it is likely that such information will impact trading decisions in the near term.
2) In turn, this means that a proactive use of such information could, at least during a phase of uptake, yield an information advantage that might enable financial outperformance.

The proposed concept of *geofinancial engineering* is the logical progression of financial market participants taking non-financial information into account for their investment decisions or mechanics. Investor consideration of climate change started from an ethical perspective, focusing on the positive or negative impact that an investment can have on the climate and calling on a market participants' responsibility. The investor group that very successfully harnessed and grew this momentum early on – the Principles of Responsible Investing (PRI) group – is now over a decade old. Given the Paris Agreement, in which nearly every country in the world agreed to limit global average warming to well below 2 °C versus pre-industrial levels, the topic of climate change also reached those investors solely focused on risk/return considerations; the implications of the Paris Agreement mean massive transitions of economies, industries, and possibly whole societies.

Since such transitions will impact assets and require financing, they bring new investment risks and investable opportunities. Managing or capturing those risks and opportunities today, however, depends on backward-looking data from annual reports, corporate sustainability reports (CSR), and company communication. While such information helps to understand a company or asset holistically, it does not deliver real-time data that can be used by trading applications. At most, such information is complemented with near real-time information from media and blogs as provided by organizations such as RepRisk. That is, climate-harming events make their way into the financial markets once they have been reported on.

Our proposed concept takes the next step: real-time, satellite-captured information relevant to climate change is linked to specific assets and fed into the financial markets. Such information enables climate-conscious investors to better understand new asset-

specific risks and opportunities in their portfolio. But, critically, it also becomes a tradable signal for hedge funds and algorithmic traders and has the potential to dramatically strengthen the connection between negative climate impacts and market movement.

This "real-time" pricing of externalities can apply to both motivated and climate-agnostic traders and investors as long as there are market signals that impose price penalties on the heightened liabilities of corporations engaging in irresponsible behaviors such as excessive methane venting and flaring. Information on these emissions must be attributable to a particular company and be updated in a regular manner that gives an advantage to those traders with new, updated information. These data do not need to be high-precision if they contain some accurate, and therefore actionable, information.

Further research and initial testing of *geofinancial engineering* is needed to improve information collection, analysis, and dissemination. Investments in improved remote and local sensing options should enhance the ability of markets to respond to real-time information using the *geofinancial engineering* tools. In addition to the methane emissions highlighted here, many of the planned remote sensing projects target other key GHGs (Tollefson 2016), but each gas type requires unique attention to the difficulties in tracking emission sources and confirming company attribution. Careful consideration of the indirect effects of *geofinancial engineering* is also critical, particularly since the social need for greenhouse gas emission reduction is considerable and pressure to take action could and should intensify in the near future.

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