Do Investors Care about Carbon Offsets?

Yeow Hwee Chua
Nanyang Technological University

Liuyang She
Nanyang Technological University

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Background

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- Voluntary in nature.
- Globally, demand for carbon offsets has surged, with the voluntary carbon market reaching $2.4 billion in 2023, nearly five times its 2020 size.
- Carbon offset has become an important tool to achieve net-zero emissions targets.

Example: Apple

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- But there are concerns.

How Apple made its first 'carbon neutral' product

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Catherine Clifford
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KEY POINTS

- In September, Apple announced its next smartwatch models would all have a "carbon neutral" option.
- Apple reduced the carbon dioxide emissions associated with making and selling a single smartwatch from 36.7 kg to 8.1 kg by changing its operations.
- For the emissions Apple could not abate completely, Apple compensated by purchasing forestry carbon offsets, a move that some say undermines the credibility of the "carbon neutral" labeling.

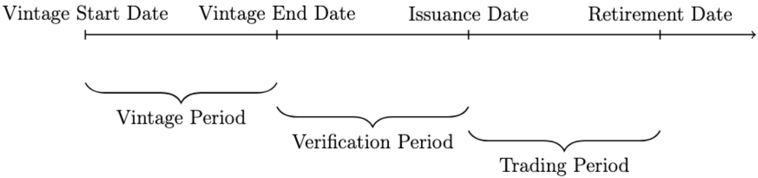
Commentary

Commentary: Apple's climate claims deserve scrutiny

The tech giant is a leader in setting high environmental standards, but it continues to rely on overhyped offsets to meet its goals, says Bloomberg Opinion columnist Mark Gongloff.

- How do investors perceive carbon offsets?

Transaction of Carbon Offsets



- Vintage: the period during which the associated carbon reduction or removal occurred.
- Issuance: offsets are issued as tradable assets by certifying organizations such as Verra and Gold Standard.
- Retirement: offsets are finally used and permanently removed from circulation.

Types of Carbon Offsets

- Carbon offsets are fundamentally heterogeneous, differing widely in their characteristics and impact.

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- One main difference is offset quality:
  1. Reduction (a.k.a. avoidance) vs. removal offsets
     - Reduction offsets have been criticized for delivering limited environmental benefits (West et al., 2023).
     - Removal offsets are valuable for achieving long-term, net-negative emissions goals (Heal, 2024).

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     - Removal offsets are valuable for achieving long-term, net-negative emissions goals (Heal, 2024).
  2. Offsets with recent vintage vs. older vintage
     - Older vintages often fall short of contemporary standards for additionality and verification (Trencher et al., 2024).

This Paper

- Investigate investors' preferences by analyzing stock price reactions to the retirement of carbon offsets.
- Examine the relationship between temperature anomalies and carbon offset demand to validate their preferences.
- Explain our empirical findings by a simple signaling game.

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- Examine the relationship between temperature anomalies and carbon offset demand to validate their preferences.
- Explain our empirical findings by a simple signaling game.

- Key Findings:
  1. Investors care about carbon offsets and prioritize quality over quantity.
  2. Firms strategically reduce the total amount but retire more high-quality carbon offsets during extreme weather events.

Contribution to Literature

1. <u>Voluntary Carbon Market:</u>
   - Engler et al. (2023), Kim et al. (2024), Calel et al. (2025), etc.

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3. Effects of Temperature:
   - Dell et al. (2012), Marchiori et al. (2012), Liao and Junco (2022), Lehr and Rehdanz (2024), etc.

   Contribution: Connect temperature anomalies, climate change beliefs, and companies' voluntary environmental engagement.

Conceptual Framework: Credible Signals

- Investors often face uncertainty about firms' actual environmental practices (e.g., Avramov et al., 2022).
- Carbon offset retirements $\implies$ Credible signals of a firm's environmental commitment.
  1. It is measurable for firms' commitment.
  2. Transparency and accountability.

Conceptual Framework: Credible Signals

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- Carbon offset retirements $\implies$ Credible signals of a firm's environmental commitment.
  1. It is measurable for firms' commitment.
  2. Transparency and accountability.

- Testable Implications:
  1. Investors would respond positively to the retirements.
  2. Climate change concern $\uparrow$ $\implies$ Benefits of being "green" $\uparrow$ $\implies$ Retirements $\uparrow$.

Conceptual Framework: Greenwashing

- Carbon offset retirements $\implies$ Greenwashing.
    1. Overstating the impact of their carbon offset initiatives.
    2. Retiring offsets from projects that provide minimal or unverifiable environmental benefits.

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  1. Overstating the impact of their carbon offset initiatives.
  2. Retiring offsets from projects that provide minimal or unverifiable environmental benefits.

- Testable Implications:
  1. The market response should be muted or negative.

Data

- Carbon offsets: transaction-level data of carbon offset retirements from the ESGpedia platform, developed by STACS.
- Types of offset projects: matching with Voluntary Registry Offsets Database using project names.
- Country-by-year level variables: Temperature, GDP per capita, urbanization, emissions per capita, and carbon pricing policies from Our World in Data. Precipitation data is collected from Climate Change Knowledge Portal, World Bank.

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- $\Longrightarrow$ A final dataset of 8,709 carbon offset retirement records from 2009 to 2022 (2,810 retirements by public firms and 5,899 by other entities).

Event Study Methodology

- The OLS market model on an estimation window of 200 trading days ([–220, –21]):

$$R_{it} = \alpha_i + \beta_i \times GlobalIndex_t + \epsilon_{it} \quad (1)$$

- The estimated stock return of firm i on day t can be obtained:

$$\hat{R}_{it} = \hat{\alpha}_i + \hat{\beta}_i \times GlobalIndex_t \quad (2)$$

- The abnormal daily return (AR) of firm i on day t can be calculated as follows:

$$AR_{it} = R_{it} - \hat{R}_{it} \quad (3)$$

- Summing the abnormal returns within the event windows to obtain cumulative abnormal returns (CARs).

Stock Market Reaction to Carbon Offset Retirement

- Stock market data: Compustat.
- Event windows [–20, –11], [–10, –1], [0, 15] [16, 30], [31, 60].
- Require no other retirements within [-280, 60].
- 205 public firms with 236 carbon offset retirement dates.

Event time	CAR	Std. err.
[-20,-11]	0.452	0.406
$[-10, -1]$	-0.427	0.475
$[0, 15]$	1.126**	0.560
$[16, 30]$	-0.149	0.568
$[31, 60]$	0.582	0.817

- Positive CAR for [0, 15] $\Longrightarrow$ Investors value carbon offset retirements.
- Insignificant CARs for other intervals $\Longrightarrow$ Our results are not driven by unrelated trends.

Heterogeneous Effects

	CAR	Std. err.
Panel A: Removal vs. Reduction		
Removal offsets (N=55)	1.941**	0.896
Reduction offsets (N=181)	0.879	0.677
Panel B: Recent vs. Past		
Offsets with recent vintage (N=146)	1.221**	0.611
Offsets with past vintage (N=90)	0.972	1.087
Panel C: Above- vs. Below-median		
Offset amount above-median (N=118)	0.928	0.687
Offset amount below-median (N=118)	1.325	0.886
Panel D: First-time vs. Seasoned		
First-time carbon offset retirement (N=196)	1.203*	0.636
Seasoned carbon offset retirement (N=40)	0.748	1.097

- Investors view the retirement of high-quality offsets as a credible signal.
- They care more about the quality over quantity
- Greater response to first-time retirements supports signaling theory.

Robustness

	CAR	Std. err.
1. Global three-factor model of Fama and French	0.983*	0.562
2. Country-specific market indices	1.370**	0.549
3. Industry-adjusted CARs	0.824*	0.499
4. Precision-weighted CARs	0.890*	0.455
5. Clustered standard error at firm level	1.126**	0.542
6. Cross-sectional correlation	1.126*	0.599
7. Excluding countries with offset retirement subsidies	1.544**	0.627
8. Excluding confounding events	1.732**	0.683
9. Accounting for pre-release information	1.224**	0.589
10. Event window with longer periods	1.350**	0.597
11. Event window with shorter periods	0.696*	0.383
12. Including events not on trading days	1.121**	0.539

Firms' Salience and Offset Retirements

- Extreme Temperature $\implies$ Public concerns about climate change $\uparrow$ (Herrnstadt and Muehlegger, 2014).
- Climate change concern $\uparrow$ $\implies$ Investors' preferences for "green" initiatives $\uparrow$ (Pastor et al., 2021; Ardia et al., 2023).

- Suppose investors view high-quality retirements as credible signals for "green":
    1. Demand for high-quality offsets would increase during periods of extreme temperature.
    2. Aggregate quantity of retired offsets may decrease.

Firms' Salience and Offset Retirements

- Formally, we estimate the following baseline equation:

$$Y_{it} = \theta_0 + \theta_1 Temp_{it} + \theta_2 Temp_{it}^2 + \theta_3 Prec_{it} + \theta_4 Prec_{it}^2 + FE + Controls + \epsilon_{it}$$

- Y_{it}: Log(amount of retired carbon offsets) for transaction i in year t.
- $Temp_{it}$ and $Temp_{it}^2$: temperature anomalies and squared terms.
- $Prec_{it}$ and $Prec_{it}^2$: precipitation anomalies and squared terms.
- FE: year, country, firm, and sector fixed effects.
- $Controls$: GDP per capita, urbanization, climate change policies, and CO2 emissions per capita.
- ϵ_{it}: clustered at the country level.

Firms' Salience and Offset Retirements

Dep. Var.:	Log(Offset Demand) (1)	Log(Offset Demand) (2)
Temp. Anomaly	0.598*	0.532**
	(0.306)	(0.253)
Temp. Anomaly sq.	-0.479*	-0.476
	(0.272)	(0.284)
Precipitation Anomaly	-0.00364**	-0.00449***
	(0.00137)	(0.00144)
Precipitation Anomaly sq.	1.90e-05**	1.75e-05*
	(7.34e-06)	(9.82e-06)
Control Variables	N	Y
Year Fixed Effects	Y	Y
Country Fixed Effects	Y	Y
Firm and Sector Fixed Effects	Y	Y
Observations	2,677	2,677
R-squared	0.559	0.567

- A weak inverted-U relationship $\Longrightarrow$ Total volume of retired offsets $\downarrow$ during extreme weather events.

Firms' Salience and Offset Retirements

Dep. Var.:	Log(Offset Demand) (1)	Log(Offset Demand) (2)
Temp. Anomaly	1.145***	0.716**
	(0.225)	(0.301)
Temp. Anomaly sq.	-1.086***	-0.883***
	(0.303)	(0.304)
Temp. Anomaly $\times \mathbb{1}$(Removal)	-2.768***	
	(0.869)	
Temp. Anomaly sq. $\times \mathbb{1}$(Removal)	2.472**	
	(0.974)	
Temp. Anomaly $\times \mathbb{1}$(Recent)		-0.224
		(0.275)
Temp. Anomaly sq. $\times \mathbb{1}$(Recent)		0.682**
		(0.316)
Control Variables	Y	Y
Year Fixed Effects	Y	Y
Country Fixed Effects	Y	Y
Firm and Sector Fixed Effects	Y	Y
Observations	2,677	2,677
R-squared	0.573	0.569

- During extreme temperatures $\implies$ firms retire more high-quality offsets (Removal/Recent) $\implies$ seen as credible signals by investors

A Simple Signaling Model - Setup

- Two agents:
  - A firm (can be green or brown).
  - A green investor (seeks to invest in green firms).
- Firm's type:
  - Green (genuinely committed to sustainability).
  - Brown (primarily engaged in greenwashing).
  - Firm's type is private information.
  - Nature assigns type: $Pr(G) = q$ and $Pr(B) = 1 - q$.

A Simple Signaling Model - Setup

- Timing of decisions in each period:
  1. Firm decides whether to participate in the Voluntary Carbon Market (VCM).
  2. If **NOT participate**, the period ends.
  3. If **participate**, firm chooses:
     - High-quality offsets.
     - Large quantity of offsets.
  4. Green investor observes the firm's choice and updates beliefs about the firm's type, $\mu(t|m)$.
  5. Investor decides whether to invest, $a \in A = \{0, 1\}$.

A Simple Signaling Model - Payoffs

- Green investor's payoff:

$$U_I(t,a) = \begin{cases} \kappa & \text{if } t = G, a = 1 \quad \text{(reward)} \\ -\omega & \text{if } t = B, a = 1 \quad \text{(penalty)} \\ 0 & \text{if } a = 0 \quad \text{(no investment)} \end{cases}$$

- Firm's payoff:

$$U_F(t,m,a(m)) = \begin{cases} \eta_t - c & \text{if } m = Quality, a = 1 \\ \rho_t - c & \text{if } m = Quantity, a = 1 \\ \phi_t - c & \text{if } m = Quantity, a = 0 \\ -c & \text{if } m = Quality, a = 0 \\ 0 & \text{if no participation} \end{cases}$$

- κ: Reward for investing in green firms.
- ω: Penalty for investing in brown firms.
- η_t: Reputation benefit for type t.
- ρ_t: Combined outsourcing and reputation benefit.
- ϕ_t: Outsourcing benefit for type t.
- c: Cost of participating in the VCM.

A Simple Signaling Model - Assumptions

- To ensure that the model reflects the empirical context, we impose the following assumptions:
  1. $\kappa q - \omega(1-q) = 0$
     $\Longrightarrow$ The investor is indifferent before receiving signals.
  2. $\eta_G \geq \phi_G$, $\eta_B \leq \phi_B$
     $\Longrightarrow$ Firms have contrasting preferences. Green firms prefer reputation over outsourcing, Brown firms prefer outsourcing over reputation.
  3. $\eta_G \geq c$, $\phi_B \geq c$
     $\Longrightarrow$ Participation in the market remains rational.
  4. $\rho_G < 0 < \rho_B$
     $\Longrightarrow$ Quantity is dominated for the green firm.
  5. η_t increases with climate change concerns, where $t \in \{G, B\}$
     $\Longrightarrow$ Investor willingness to pay rises with climate concerns.

A Simple Signaling Model

Proposition 1

In the unique Perfect Bayesian Equilibrium (PBE) that satisfies the intuitive criterion, the green firm retires high-quality carbon offsets, while the brown firm retires a large quantity of carbon offsets.

The green investor chooses to invest only upon observing high-quality retirements, forming posterior beliefs $\mu(G|Quality) = 1$ and $\mu(B|Quantity) = 1$.

A Simple Signaling Model

Proposition 2

When climate change concerns become more salient, a pooling equilibrium may emerge in which both types of firms retire high-quality carbon offsets, provided that the reputation benefits for the brown firm exceed its outsourcing benefits.

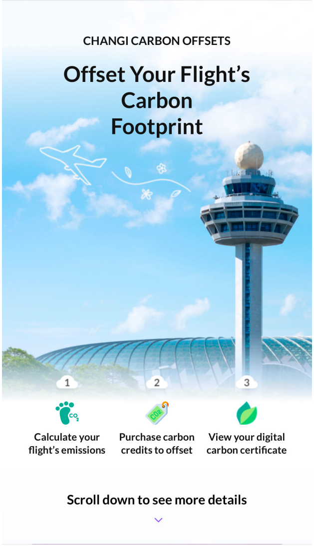
In this pooling equilibrium, the demand for high-quality carbon offsets increases, while the overall quantity of retired offsets decreases.

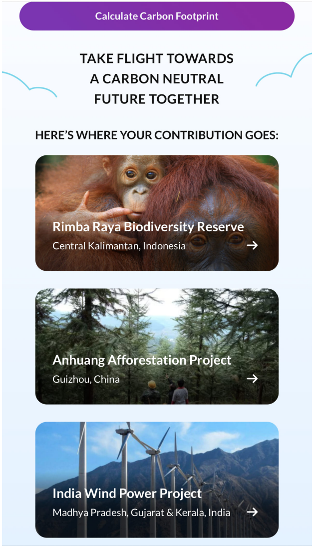
Conclusion

- Investors do care about carbon offsets:
    1. Investors can differentiate high-quality offsets from low-quality ones and prioritizing quality over quantity.
    2. They view high-quality offset retirements as strong signals of a firm's environmental commitment.

- Firms' retirement strategies further support these preferences:
    1. They increase their retirement of high-quality carbon offsets when climate change concerns become more salient.
    2. However, the total volume of retired offsets decreases.

Background


CHANGI CARBON OFFSETS
Offset Your Flight's Carbon Footprint
1
2
3
Calculate your flight's emissions
Purchase carbon credits to offset
View your digital carbon certificate
Scroll down to see more details


Calculate Carbon Footprint
TAKE FLIGHT TOWARDS A CARBON NEUTRAL FUTURE TOGETHER
HERE'S WHERE YOUR CONTRIBUTION GOES:
Rimba Raya Biodiversity Reserve
Central Kalimantan, Indonesia
Anhuang Afforestation Project
Guizhou, China
India Wind Power Project
Madhya Pradesh, Gujarat & Kerala, India

Summary Statistics at Transaction Level

	Obs. (1)	Mean (2)	St.Dev. (3)
Panel A: Carbon Offset			
Carbon Offset Amount	2,810	19,675	63,725
Vintage Duration	2,810	435	362
Verification Duration	2,810	1,079	909
Trading Duration	2,810	553	568
Removal Carbon Offset	2,810	.24	.43
Recent Carbon Offset	2,810	.60	.49
Domestic Carbon Offset	2,810	.04	.18
Panel B: Country-by-year			
Temperature Anomaly	2,810	.510	.437
Rainfall Anomaly	2,810	17.449	87.464
GDP per capita	2,810	46,578.69	10,773.39
Urbanization	2,810	83.666	8.515
CO2 per capita	2,810	10.839	4.615
ETS	2,810	.764	.425
Carbon Tax	2,810	.267	.443

- Anomalies are measured as the deviation from the 1991–2020 mean.

Robustness - Alternative Temperature Data

- **Climate Change Knowledge Portal, World Bank.**

Dep. Var.:	Log(Offset Demand)	Log(Offset Demand)
	(1)	(2)
Temp. Anomaly	0.715**	0.647*
	(0.343)	(0.355)
Temp. Anomaly sq.	-0.662	-0.626
	(0.388)	(0.407)
Precipitation Anomaly	-0.00394***	-0.00465***
	(0.00125)	(0.00133)
Precipitation Anomaly sq.	2.14e-05***	1.92e-05*
	(7.65e-06)	(9.58e-06)
Control Variables	N	Y
Year Fixed Effects	Y	Y
Country Fixed Effects	Y	Y
Firm Fixed Effects	Y	Y
Sector Fixed Effects	Y	Y
Observations	2,677	2,677
R-squared	0.559	0.567

Robustness - Alternative Temperature Data

- **Climate Change Knowledge Portal, World Bank.**

Dep. Var.:	Log(Offset Demand)	Log(Offset Demand)
	(1)	(2)
Temp. Anomaly	1.471***	0.911*
	(0.383)	(0.508)
Temp. Anomaly sq.	-1.418***	-1.077**
	(0.400)	(0.478)
Temp. Anomaly $\times\mathbb{1}$(Removal)	-3.020***	
	(0.791)	
Temp. Anomaly sq. $\times\mathbb{1}$(Removal)	2.741***	
	(0.852)	
Temp. Anomaly $\times\mathbb{1}$(Recent)		-0.332
		(0.460)
Temp. Anomaly sq. $\times\mathbb{1}$(Recent)		0.750*
		(0.439)
Control Variables	Y	Y
Year Fixed Effects	Y	Y
Country Fixed Effects	Y	Y
Firm Fixed Effects	Y	Y
Sector Fixed Effects	Y	Y
Observations	2,677	2,677
R-squared	0.574	0.569

Robustness - Price Effects

Dep. Var.:	Log(Offset Demand)	Log(Offset Demand)
	(1)	(2)
Temp. Anomaly	0.930***	0.909**
	(0.303)	(0.337)
Temp. Anomaly sq.	-0.894***	-1.014**
	(0.302)	(0.402)
Temp. Anomaly $\times \mathbb{1}$(Removal)	-2.615***	
	(0.426)	
Temp. Anomaly sq. $\times \mathbb{1}$(Removal)	2.401***	
	(0.673)	
Temp. Anomaly $\times \mathbb{1}$(Recent)		-0.581*
		(0.324)
Temp. Anomaly sq. $\times \mathbb{1}$(Recent)		0.906**
		(0.427)
Control Variables	Y	Y
Country Fixed Effects	Y	Y
Firm Fixed Effects	Y	Y
Sector Fixed Effects	Y	Y
Type-by-year Fixed Effects	Y	Y
Observations	2,643	2,643
R-squared	0.625	0.622

Robustness - All Retirement Beneficiaries

- All beneficiaries like governments, private firms, non-profits, and public firms.

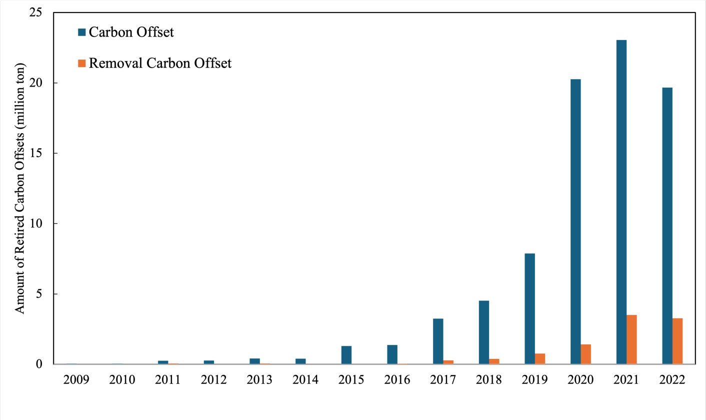
Dep. Var.:	Log(Offset Demand)	Log(Offset Demand)
	(1)	(2)
Temp. Anomaly	0.559***	0.543***
	(0.200)	(0.152)
Temp. Anomaly sq.	-0.402***	-0.366***
	(0.128)	(0.128)
Precipitation Anomaly	-0.000639	-0.000783
	(0.000846)	(0.000827)
Precipitation Anomaly sq.	1.33e-06	-1.45e-07
	(4.14e-06)	(4.69e-06)
Control Variables	Y	Y
Year Fixed Effects	Y	Y
Country Fixed Effects	Y	Y
Firm Fixed Effects	Y	Y
Sector Fixed Effects	Y	Y
Observations	7,817	7,817
R-squared	0.674	0.676

Robustness - All Retirement Beneficiaries

Dep. Var.:	Log(Offset Demand)	Log(Offset Demand)
	(1)	(2)
Temp. Anomaly	0.627***	0.905***
	(0.149)	(0.206)
Temp. Anomaly sq.	-0.435***	-0.844***
	(0.133)	(0.224)
Temp. Anomaly $\times\mathbb{1}$(Removal)	-0.795**	
	(0.367)	
Temp. Anomaly sq. $\times\mathbb{1}$(Removal)	0.464*	
	(0.246)	
Temp. Anomaly $\times\mathbb{1}$(Recent)		-0.435
		(0.341)
Temp. Anomaly sq. $\times\mathbb{1}$(Recent)		0.718**
		(0.348)
Control Variables	Y	Y
Year Fixed Effects	Y	Y
Country Fixed Effects	Y	Y
Firm Fixed Effects	Y	Y
Sector Fixed Effects	Y	Y
Observations	7,817	7,817
R-squared	0.677	0.677

Additional Figures

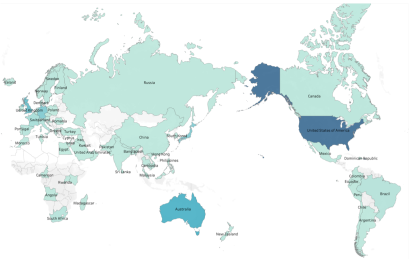
Figure: Carbon Offset Retirements over Time



- Increases in both total retired offsets and removal offsets.
- The share of removal offsets is relatively lower.

Additional Figures

Figure: Carbon Offset Retirements across Countries



(a) Amount of Carbon Offsets

(b) Share of Removal Offsets

- There are substantial regional differences in firms' preferences for carbon offset project types.

Additional Tables

Table: Carbon Offset Retirement by Country

Country	Total Offset Amount	Removal Amount	Removal Share
United States	28,932,128	4,429,060	.153
Australia	14,355,851	282,954	.02
United Kingdom	11,041,605	1,888,838	.171
Germany	7,832,055	1,717,595	.219
Japan	7,561,531	103,593	.014
France	2,937,011	378,916	.129
Italy	1,386,421	7,376	.005
Netherlands	1,261,617	295,548	.234
Brazil	1,159,413	24,445	.021
Switzerland	1,007,676	123,548	.123
South Africa	979,344	85,050	.087
Spain	946,820	42,672	.045
Sweden	692,704	140,569	.203
Canada	534,722	77,867	.146
New Zealand	470,260	44,083	.094
Morocco	348,853	50,020	.143
Austria	263,430	9,923	.038
Finland	202,120	20,475	.101
Luxembourg	145,034	0	0
China	116,852	2,748	.024
India	82,355	2,645	.032
Denmark	82,292	25,046	.304
Egypt	78,256	23,256	.297
Mauritius	53,816	0	0
Norway	42,371	30,320	.716
Others	246,624	68,422	.277

Additional Tables

Table: Carbon Offset Retirement over Time

Year	Total Offset Amount	Removal Amount	Removal Share
2015	1,300,146	23,603	0.018
2016	1,377,761	52,936	0.038
2017	3,246,894	278,745	0.086
2018	4,525,168	385,121	0.085
2019	7,885,115	764,849	0.097
2020	20,267,870	1,419,764	0.070
2021	23,047,682	3,505,454	0.152
2022	19,664,290	3,279,127	0.167

Additional Tables

Table: Correlation Matrix

	Removal	Recent	Above-median	First-time
Removal	1.0000			
Recent	-0.1656	1.0000		
Above-median	0.1241	0.0196	1.0000	
First-time	-0.0181	-0.0059	0.0241	1.0000