AI for Climate Finance



ClimateChangeAI Summer School

Malte Toetzke, Aug 11, 2026
Technical University of Munich
Max Planck Institute for Innovation and Competition

What to expect from this lecture

What this lecture is not

- A comprehensive introduction to climate finance
- A detailed overview of financial instruments (e.g., green bonds, project finance)
- A deep dive into specific AI or machine-learning methods

What you will learn

By the end of this lecture, you should be able to:

- Understand why finance is critical for climate mitigation and adaptation
- Understand how AI can inform financial policy and investment decisions
- Understand the risks and limitations of AI applications in finance

Main goal

Inspiring you to develop your own AI applications that address real-world challenges in climate finance

Scan to vote
Code **3214 6094**

„Climate action is fundamentally a capital allocation problem“

Agree

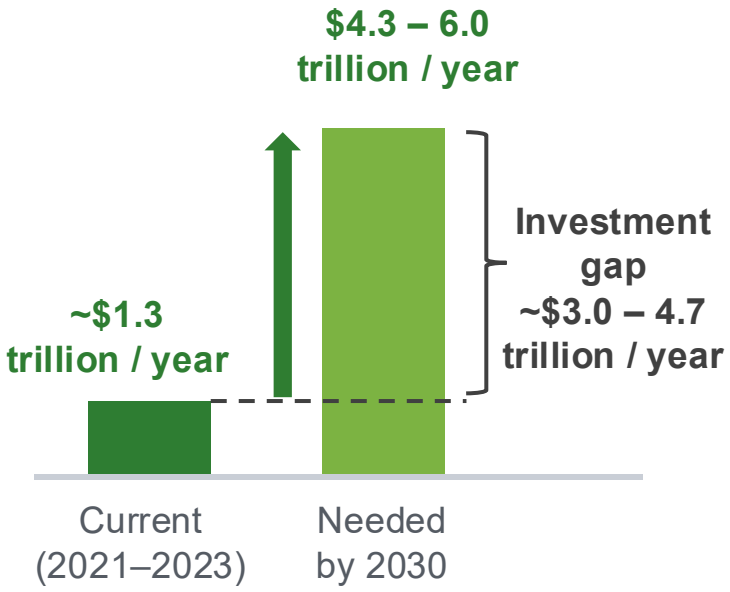
Not sure

Disagree

Climate finance is costly, but the costs of inaction are much higher

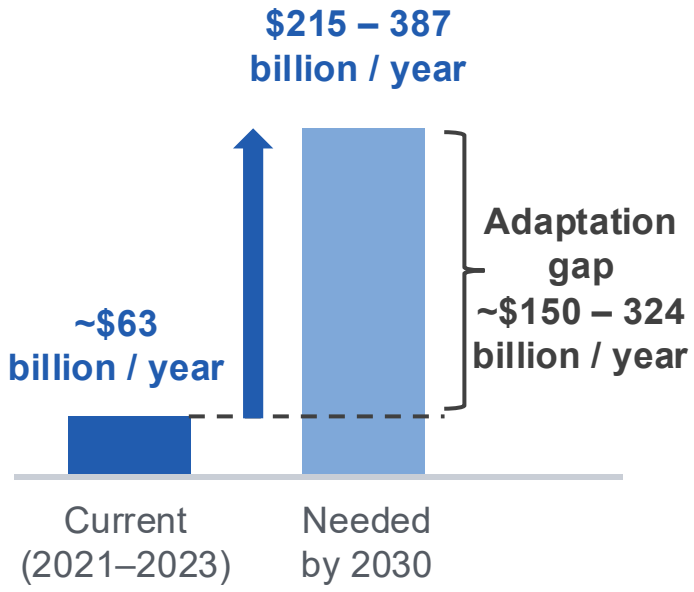
MITIGATION

Global mitigation finance



ADAPTATION

Global adaptation finance



We are facing a **multi-trillion dollar finance gap**

Mitigation and adaptation needs **4–6x more finance** than what currently flows

However,…

Investments needed are estimated to be **5x lower** compared to the **financial damages from business as usual**

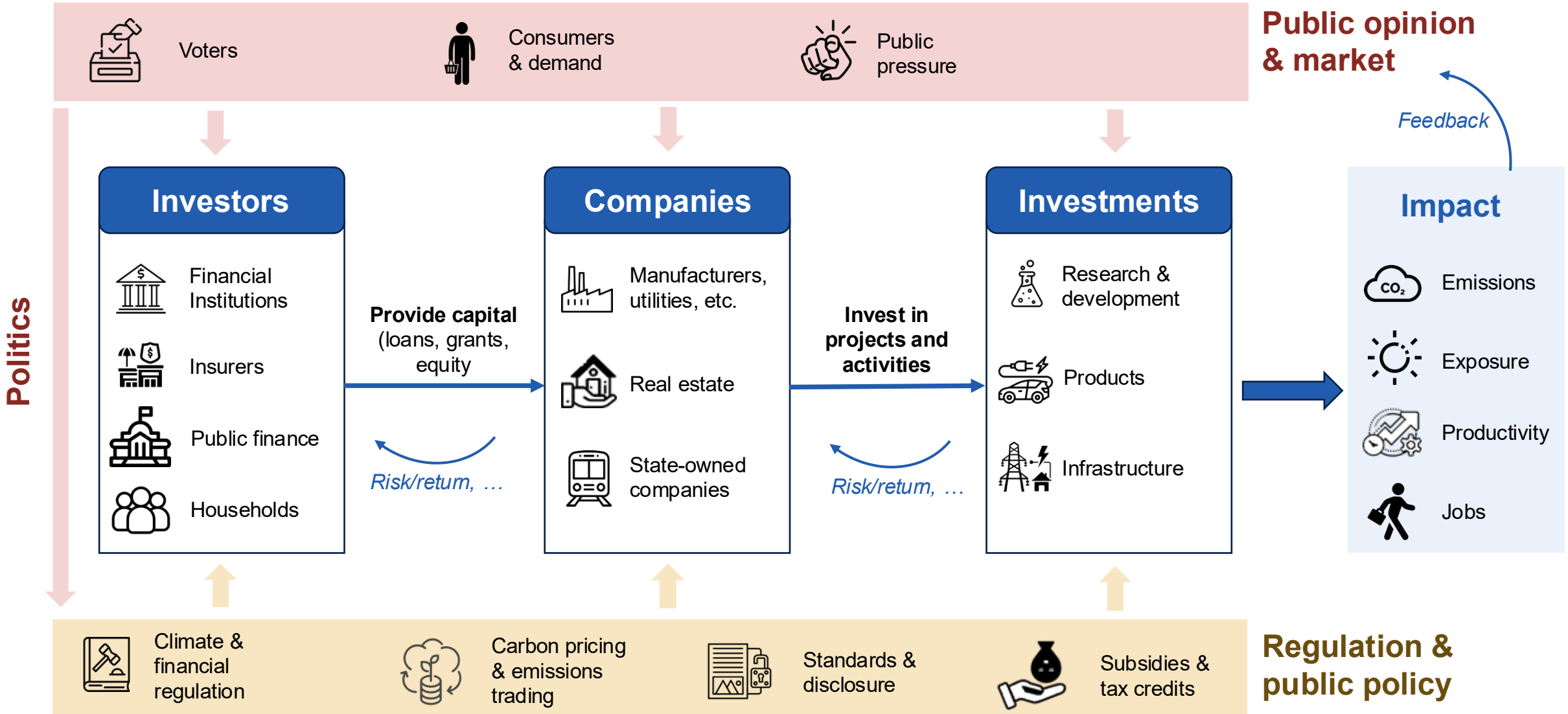
Sources: Climate Policy Initiative (2024), Global Landscape of Climate Finance 2024; UNEP (2023), Adaptation Gap Report (2023); IPCC AR6 WGIII (2022), Ch. 15.

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What is the most important driver for climate action?

- Regulation
- Consumer behavior
- Financial allocation
- Innovation

A simplified view: Transformations need investment, investments need incentives



Climate finance requires information and transparency, …and this is where AI can help

Figure 1.4: Data coverage in Global Landscape, 2022

	Private	Public International	Public Domestic	Unknown
MITIGATION				
Energy	279 ↑	30	262	n/a
Transport	257	24	122	n/a
Buildings & Infrastructure	161 ↑	8	86 ↑	n/a
Agriculture, Forestry & Other Land Use	<1	2	4	n/a
Industry	<1	9	5	11 ↑
Waste	13	0.1	8	n/a
Water & Wastewater	<1	2	8	n/a
Others & Cross-sectoral	<1	15	1	<1
ADAPTATION	6 ↑ 48-60	37	33	n/a
DUAL BENEFITS	10 ↑	47	17	n/a

USD billion

Tracked | Limited tracking | Not tracked | ↑ Complemented with new data sources

Note: In addition to the sectors listed above, the 'Information Communications and Technology' and 'Unknown' sectors made up USD 3.5bn of finance in 2022. The untracked private adaptation values (for consumer and household finance) are estimates from CPI's 'Tracking and Mobilizing Private Sector Climate Adaptation Finance' report

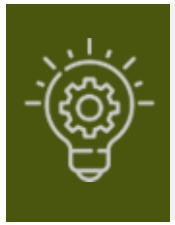
Source: Climate Policy Initiative



International climate finance:
Where is mitigation and adaptation finance flowing?



Financial markets:
Where are climate-related investment risks and opportunities?



Climate innovation:
How can finance effectively accelerate climate solutions?

Use cases for AI in climate finance



Information Extraction

Extracting financially relevant information from unstructured data sources

Example tasks

- *Extracting information from company reports and financial disclosures*
- *Identifying impact zones of extreme weather events from satellite images*



Prediction

Predicting future events or quantities under uncertainty

Example tasks

- *Predicting financial risks (e.g., physical risks, market risks, regulatory risks)*
- *Predicting carbon prices*



Causal Modeling

Estimating effects of investment decisions and interventions

Example tasks

- *Estimating the effects of policies and public interventions on investments*
- *Pricing the effectiveness of adaptation strategies*

In 1–3 words: the most promising use case for AI in climate finance?



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Predicting carbon prices

Rating startups

Deep dive

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Deep dive

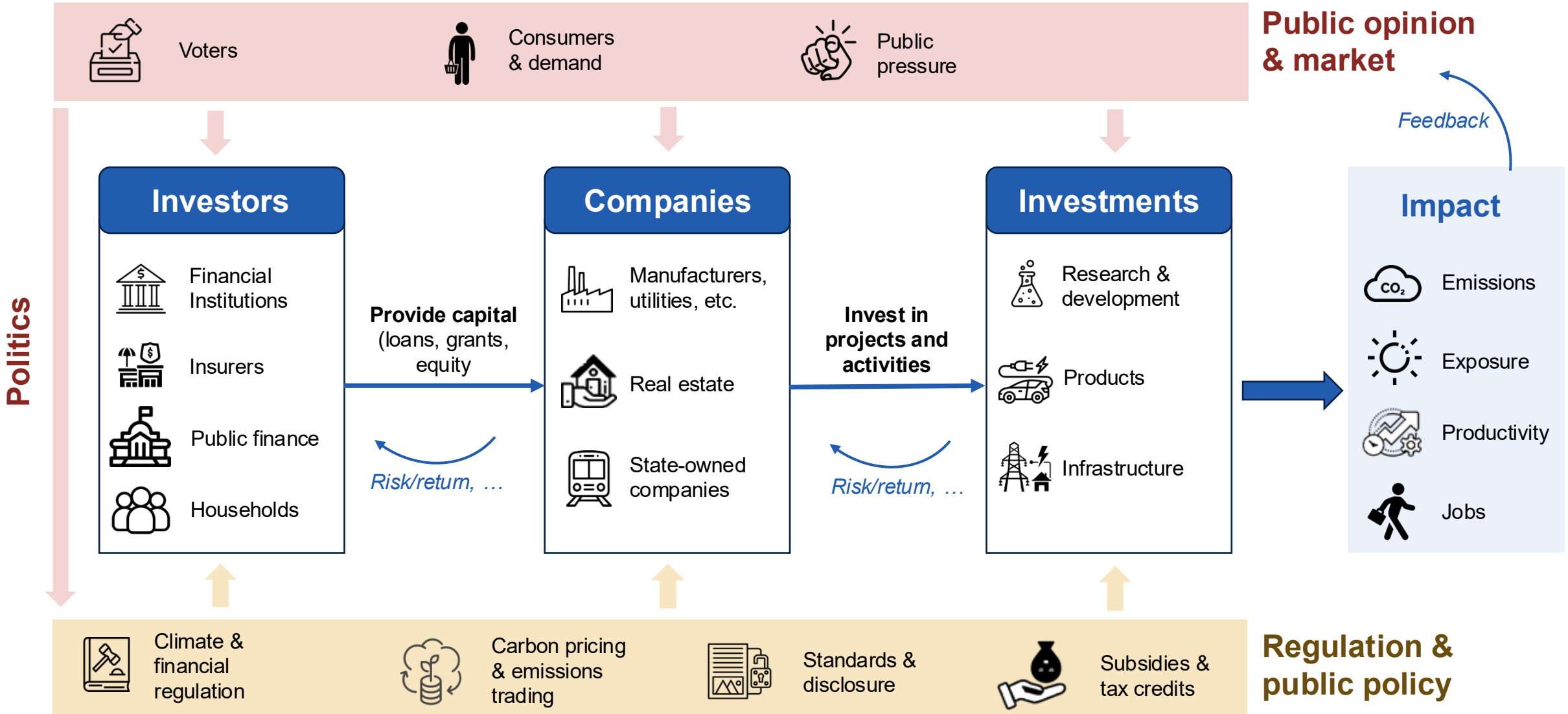
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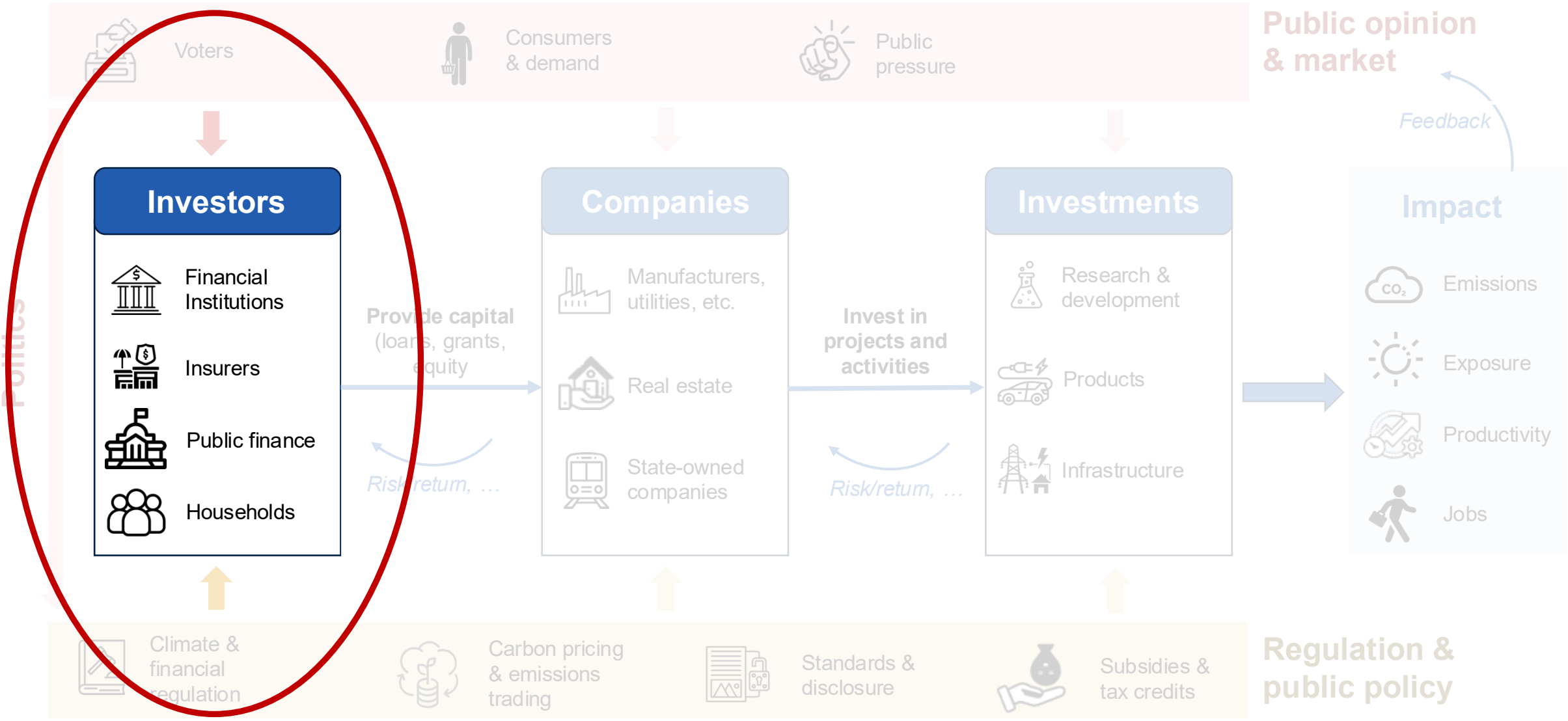
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A simplified view: Transformations need investment, investments need incentives

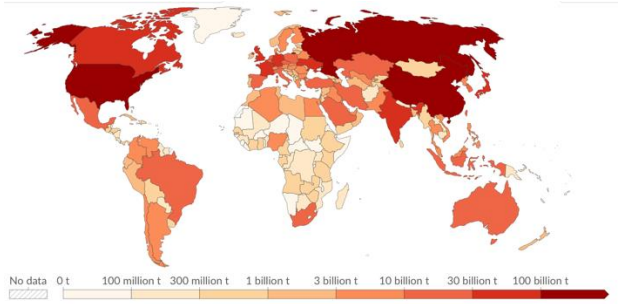



Voters
Consumers & demand
Public pressure
Public opinion & market
Feedback
Investors
Financial Institutions
Insurers
Public finance
Households
Provide capital (loans, grants, equity
Risk/return, …
Companies
Manufacturers, utilities, etc.
Real estate
State-owned companies
Invest in projects and activities
Risk/return, …
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Products
Infrastructure
Impact
Emissions
Exposure
Productivity
Jobs
Climate & financial regulation
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Standards & disclosure
Subsidies & tax credits
Regulation & public policy

Why international climate finance is important

(Historic) Responsibility

Who put the CO2 in the atmosphere?

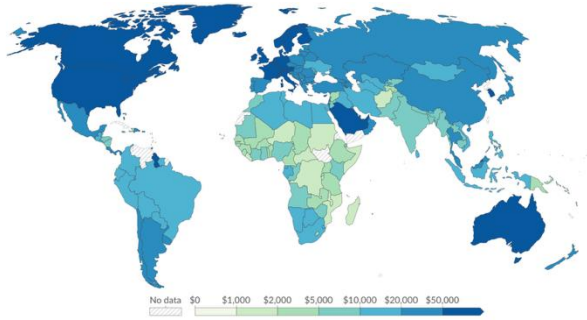


Historical cumulative CO_2 emissions (1750–2024)

https://ourworldindata.org/co2-emissions-metrics

Ability (to Pay)

Who can afford to pay for climate action?

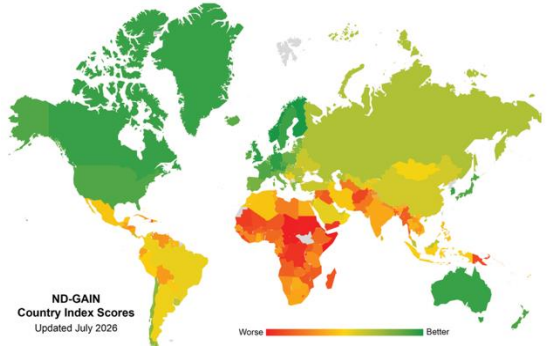


GDP per capita (2024)

https://ourworldindata.org/grapher/gdp-per-capita-worldbank

Vulnerability

Who is most vulnerable to climate impacts?

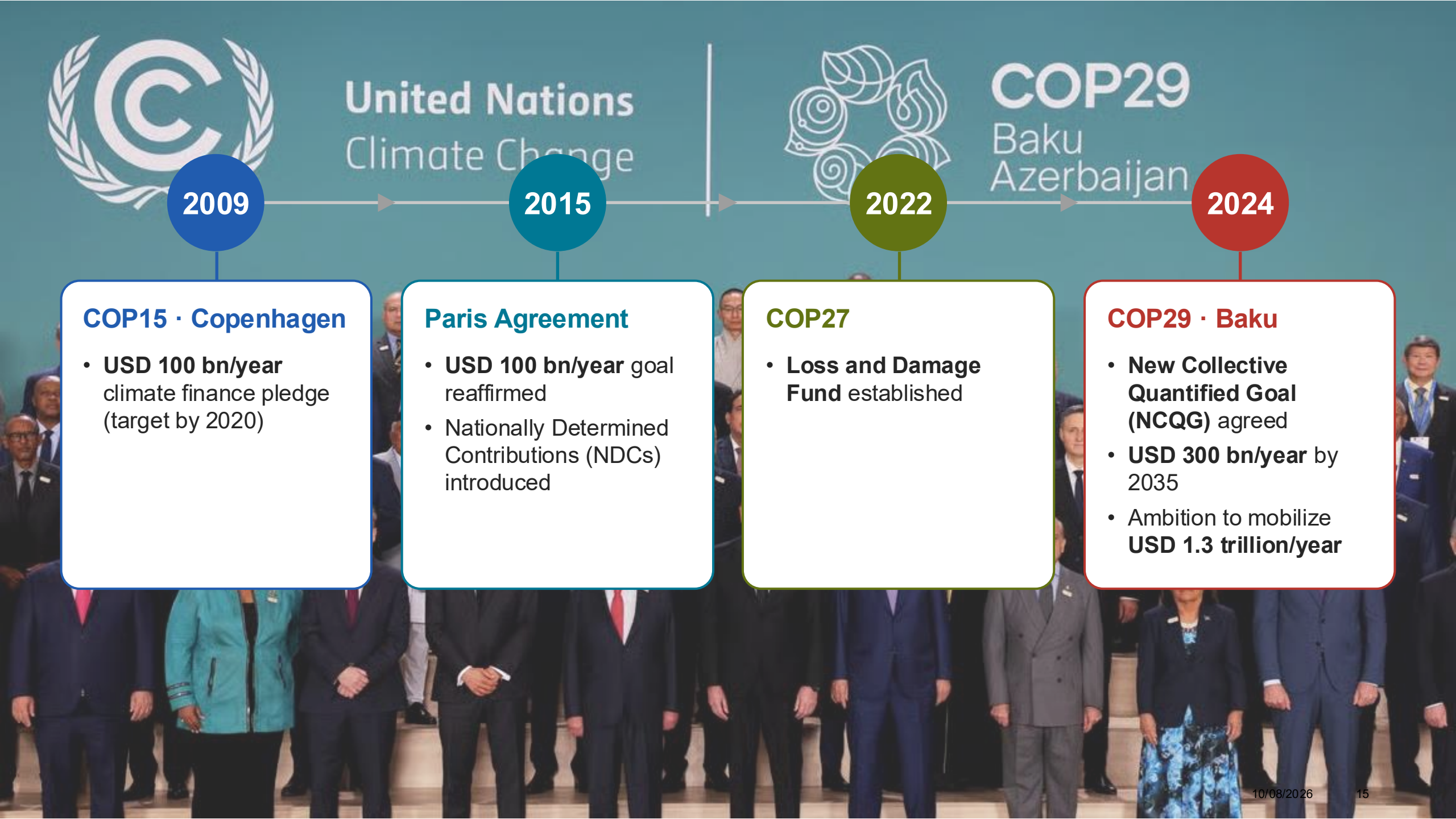


ND-GAIN Country Index Scores (2026)

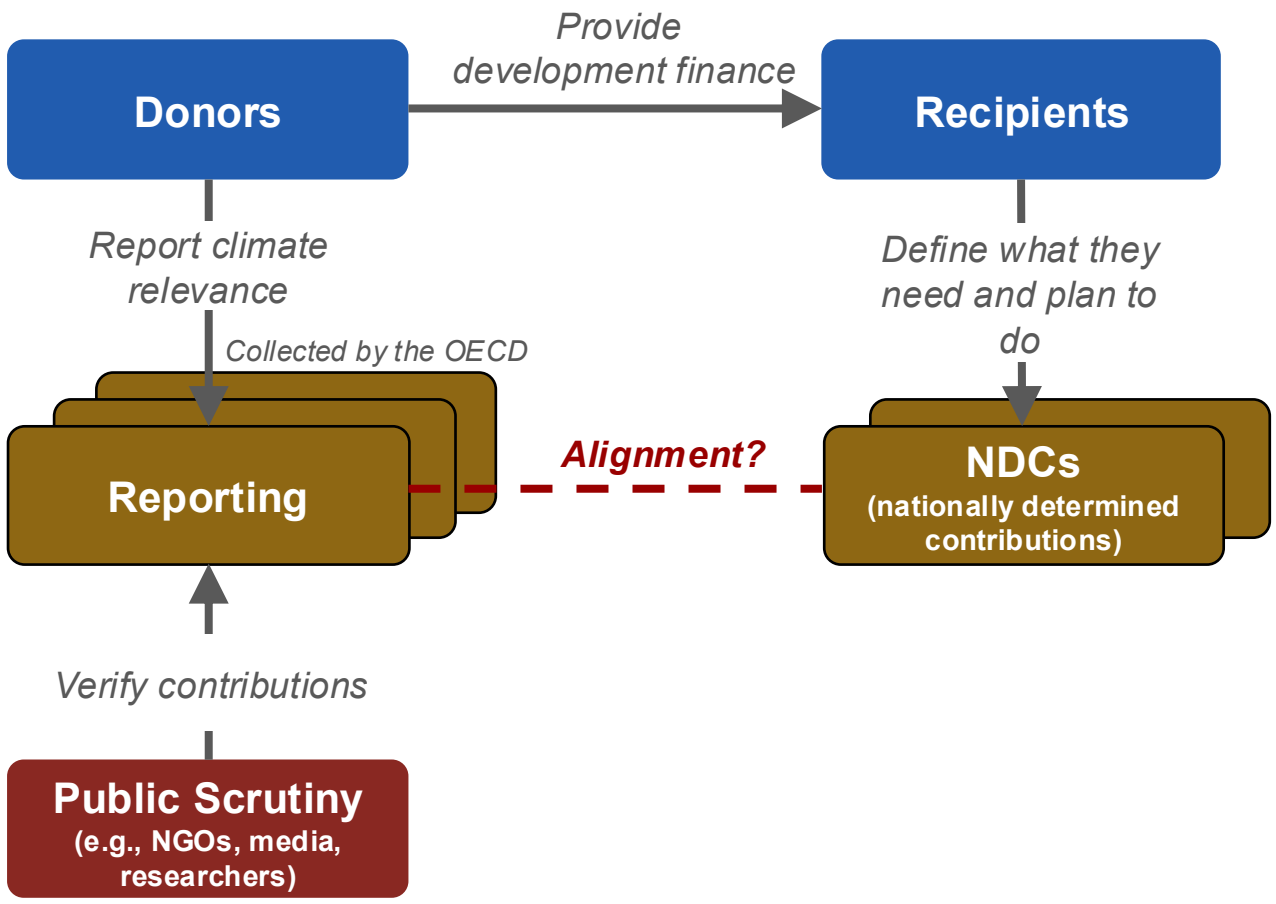
https://gain.nd.edu/our-work/country-index/

International climate finance aims to provide **financial resources** from countries with greater **responsibility** and **capability** to support countries with greater **vulnerability**

International climate finance is **key to finance mitigation and adaptation activities** in developing countries, especially for those countries with limited access to financing


United Nations
Climate Change
COP29
Baku
Azerbaijan
2009
2015
2022
2024
COP15 · Copenhagen
• USD 100 bn/year climate finance pledge (target by 2020)
Paris Agreement
• USD 100 bn/year goal reaffirmed
• Nationally Determined Contributions (NDCs) introduced
COP27
• Loss and Damage Fund established
COP29 · Baku
• New Collective Quantified Goal (NCQG) agreed
• USD 300 bn/year by 2035
• Ambition to mobilize USD 1.3 trillion/year

How is climate finance tracked and verified against needs and commitments?



Consistency

What counts as climate finance?

Individual reporting by donors

Granularity

What activities are financed?

Limited detail on activities and goals

Verification

Are the reported numbers correct?

Millions of reports to verify

Toetzke et al (2022)

Reported international climate finance is heavily contested

Are reports of climate adaptation finance being exaggerated?

Journalism from the Thomson Reuters Foundation

https://www.context.news/climate-justice/are-reports-of-climate-adaptation-finance-being-exaggerated?

Rich countries overstating "true value" of climate finance by up to $88 billion, says Oxfam

OXFAM

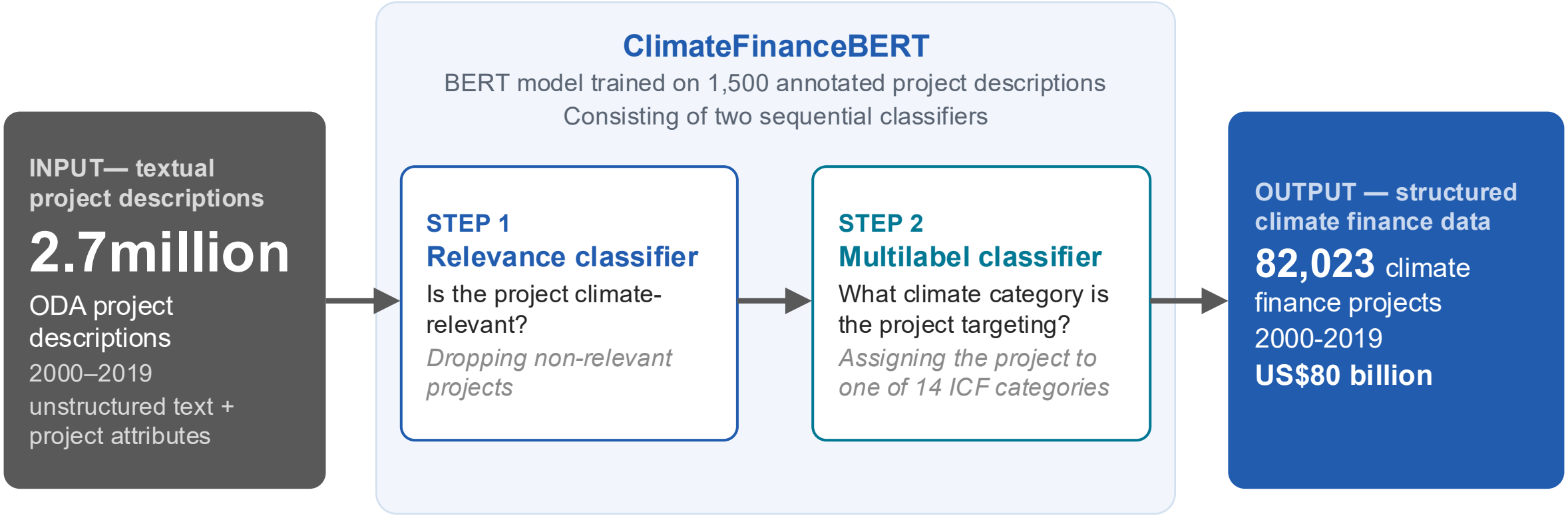
https://www.oxfam.org.uk/media/press-releases/rich-countries-overstating-true-value-of-climate-finance-by-up-to-88-billion-says-oxfam

But tracking what really counts under the banner of climate finance has long been fraught - with some experts dubbing it a "wild west" of vague definitions, questionable projects and inflated accounting.

The Guardian

https://www.theguardian.com/global-development/2025/nov/14/what-exactly-is-climate-finance-who-pays-it-and-who-gets-it?

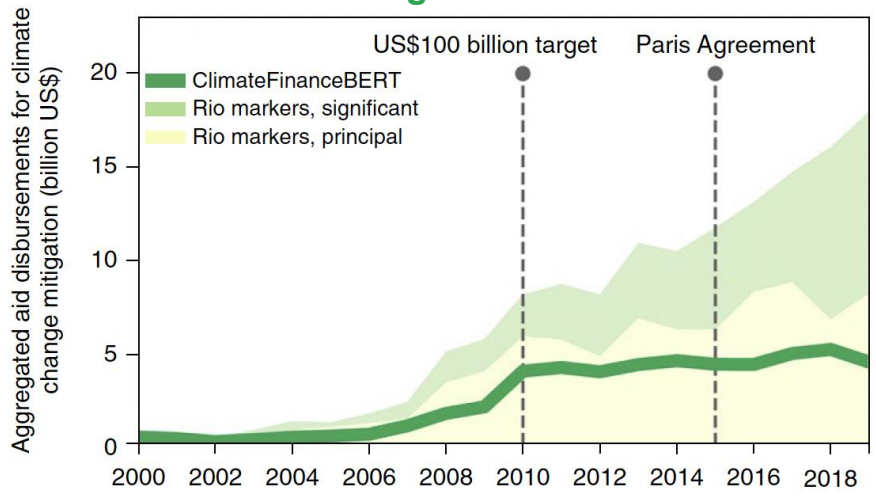
We trained a supervised model to independently classify development finance projects regarding their relevance for climate finance



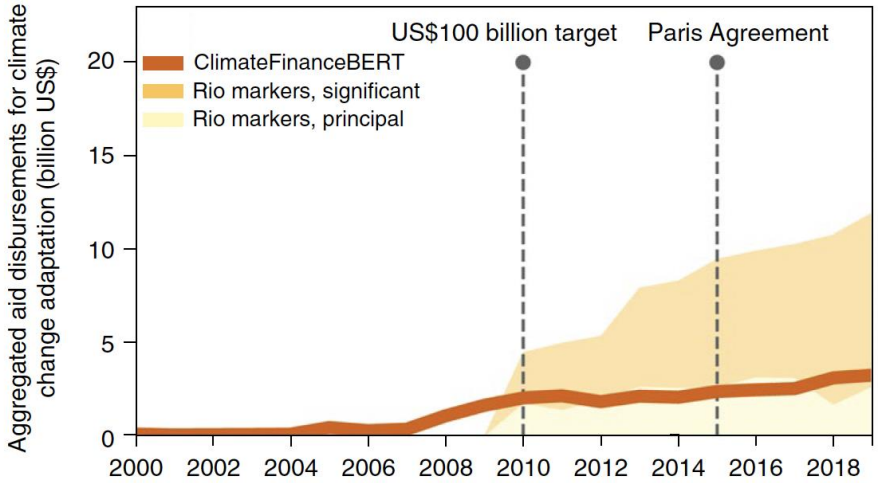
Toetzke et al (2022)

Our results showed substantial deviations from the reported numbers

Mitigation finance



Adaptation finance



Toetzke et al (2022)

Substantially lower than reported

Bilateral climate finance runs **21% below** principal Rio markers and **64% below** principal + significant markers.

Reporting is inconsistent

Evidence of both **over-** and **under-reporting**, varying **across** but also **within donors**

The US$100 bn pledge is in question

Lower volumes highlight the real challenge: providing a consistent definition of what actually counts as climate finance (before pledging numbers)

Contribution, limitations and future work

Main contribution

- **Verification tool:** an independent, replicable re-evaluation of reported climate finance
- **Consistent baseline:** enabling a consistent classification across 2.7 million ODA projects reported from different donor organizations (2000–2019)

Limitations

- **Keyword-sensitive:** BERT model is sensitive to keywords in the project-description
- **Limited context:** Model omits relevant context (e.g., country vulnerability for adaptation)
- **One-dimensional view:** Classification focuses on topics but not on implementation and instruments (e.g., regulation vs. education vs. projects)

Future work

- **Integrate context:** Include country vulnerability for the assessment of adaptation finance
- **Move beyond topics:** Classify instruments used (infrastructure build-up, capacity building, etc.)
- **Link to other sources:** Benchmark provided climate finance against recipients' needs stated in the NDCs

In 1–3 words: what other ideas do you have for AI in international climate finance?

Scan to vote
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XXX

XXX

Break 5 Minutes

Deep dive

International climate finance:
Where is mitigation and adaptation finance flowing?

Financial markets:
Where are climate-related investment risks and opportunities?

Climate innovation:
How can finance effectively accelerate climate solutions?



Let’s change perspective

From how finance shapes climate action, to how climate change affect investments

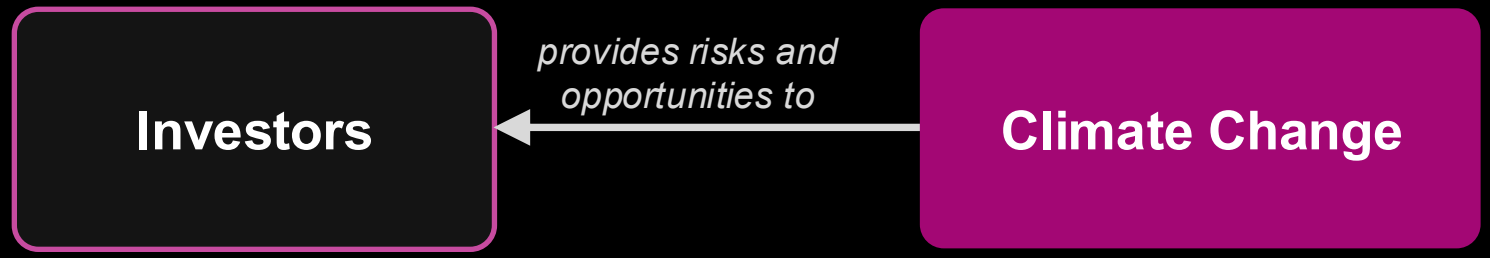
1 - The finance lens

How finance provides for climate action

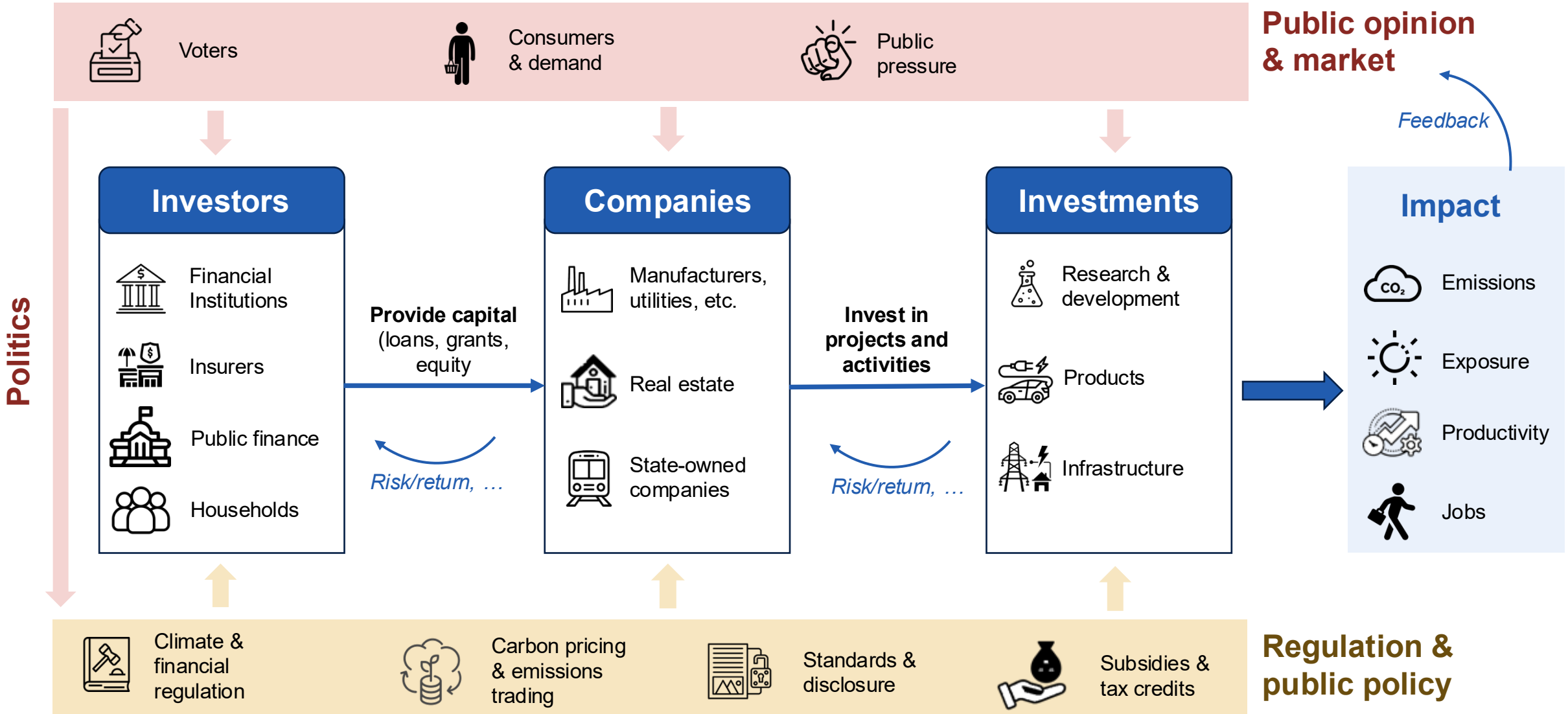


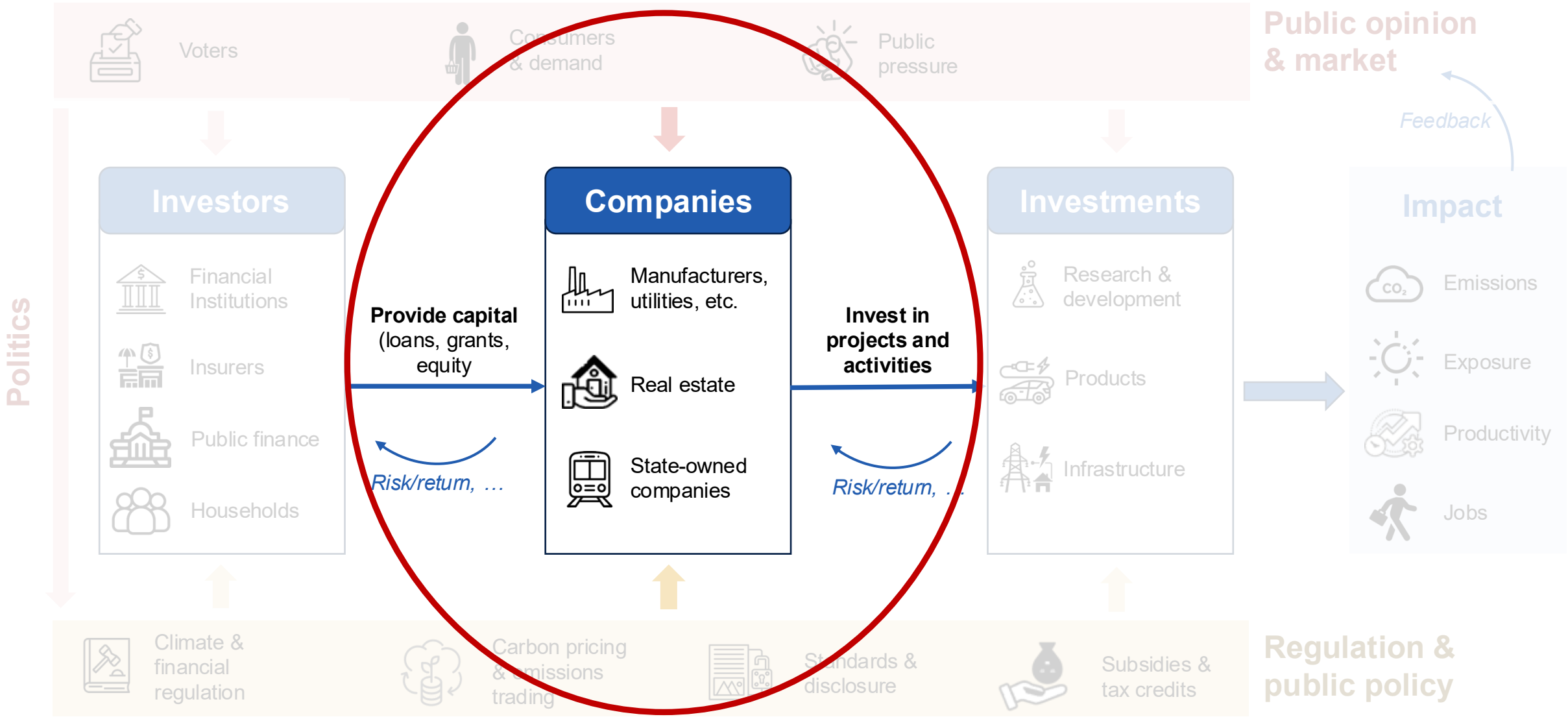
2 - The investor lens

How climate action creates risk and opportunity



A simplified view: Transformations need investment, investments need incentives

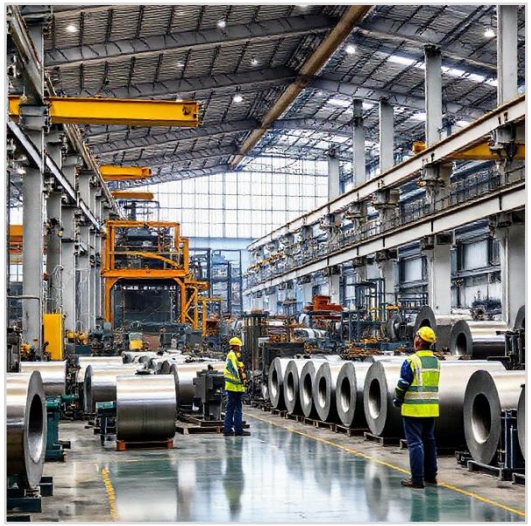



Voters
Consumers & demand
Public pressure
Public opinion & market
Feedback
Politics
Investors
Financial Institutions
Insurers
Public finance
Households
Provide capital (loans, grants, equity
Risk/return, …
Companies
Manufacturers, utilities, etc.
Real estate
State-owned companies
Invest in projects and activities
Risk/return, …
Investments
Research & development
Products
Infrastructure
Impact
Emissions
Exposure
Productivity
Jobs
Climate & financial regulation
Carbon pricing & emissions trading
Standards & disclosure
Subsidies & tax credits
Regulation & public policy

Climate-related financial risks

Transition risks

How will the climate transition affect my investments?



- Technology risks
- Policy risks
- Market risks

Image source: pt-alexindo.com

Physical risks

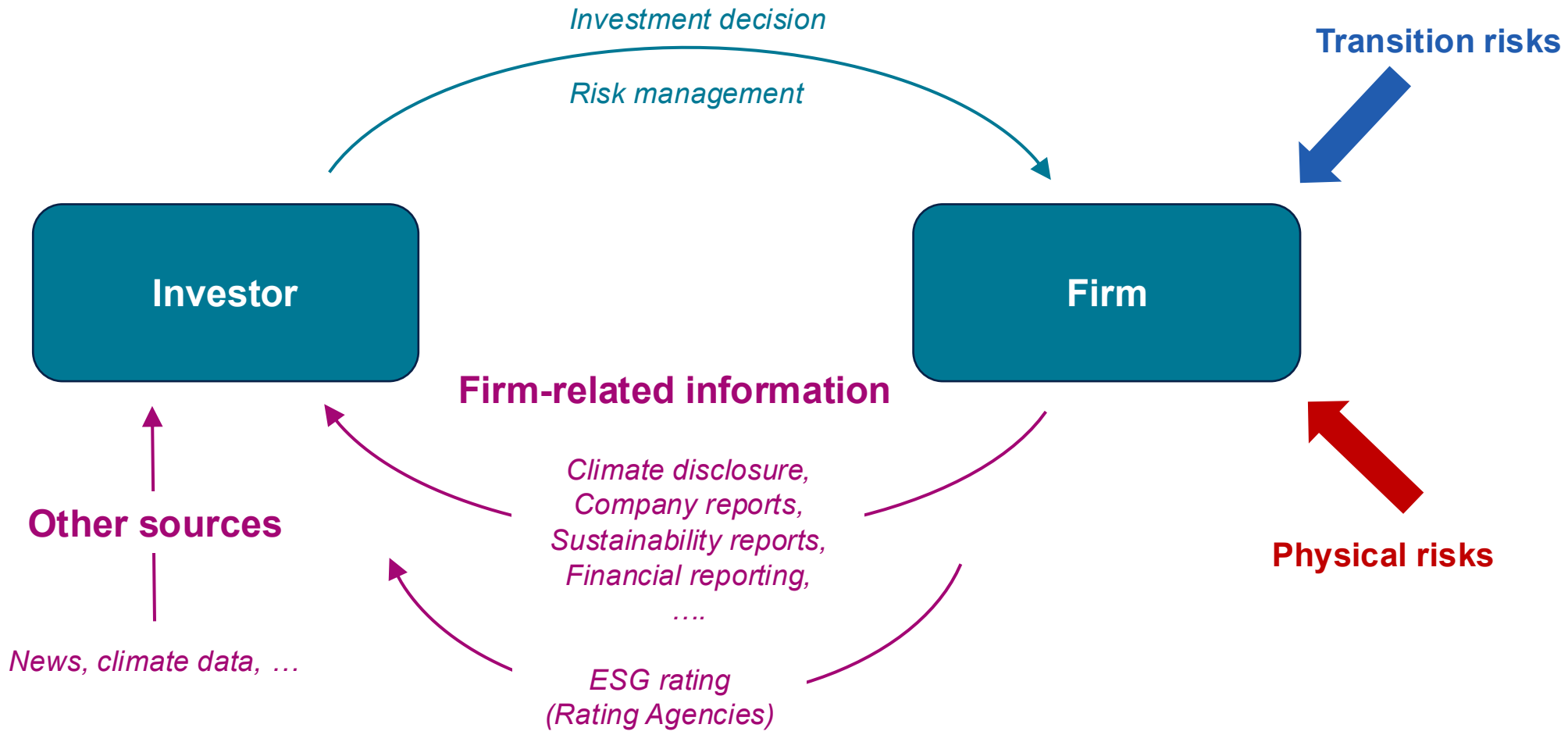
How will impacts of climate change affect my investments?



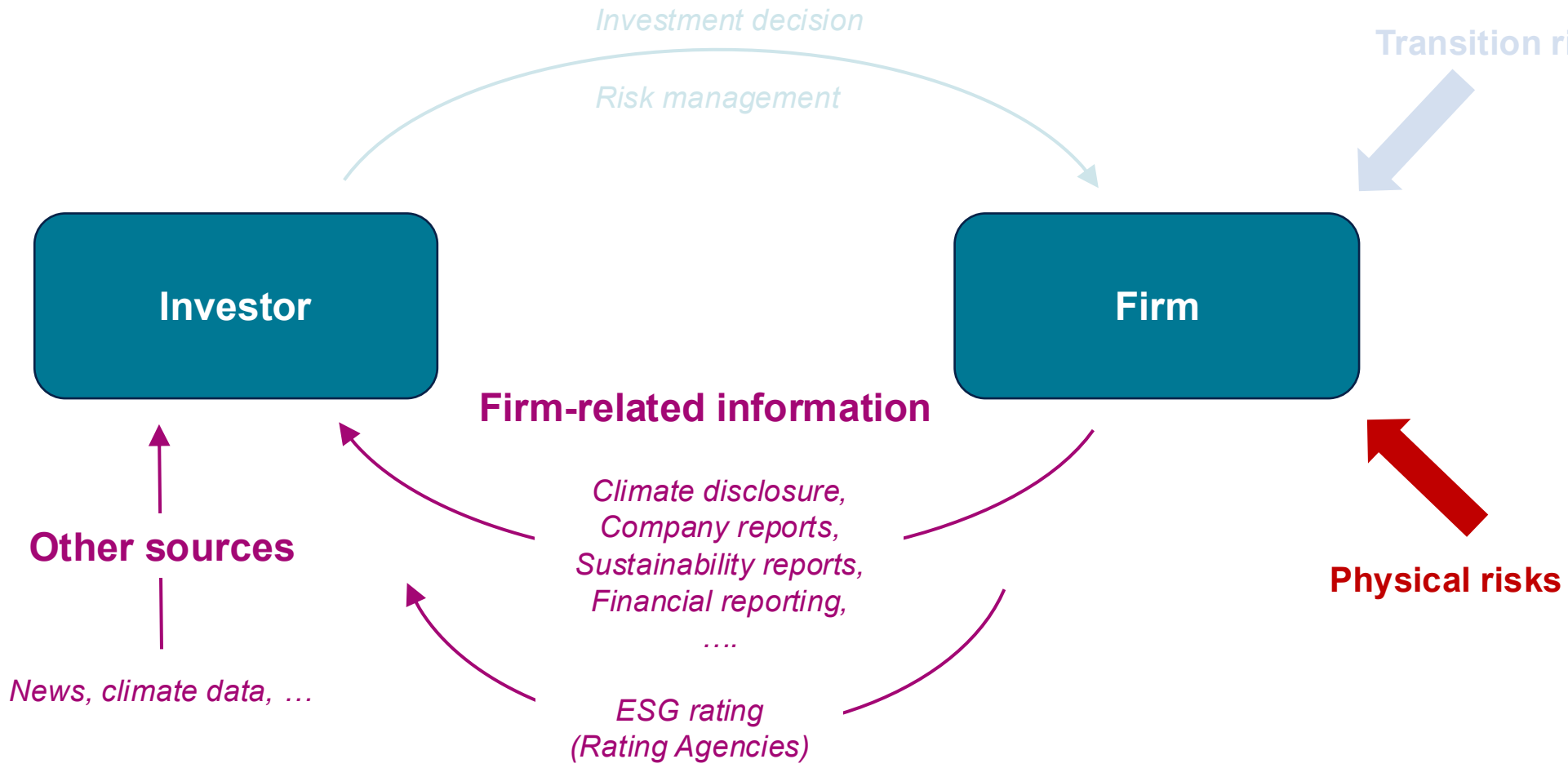
- Extreme weather
- Chronic climate change

Image source: environmentamerica.org

Taxonomy from the TCFD framework (2017)



The growing **volume** and **complexity** of climate-related information creates opportunities for **AI** to channel this information into decision-relevant evidence



The growing **volume** and **complexity** of climate-related information creates opportunities for **AI** to channel this information into decision-relevant evidence

Due to climate change, extreme weather events are **increasing in frequency** and **severity**

Hurricane Helene (2024)



79$ billion in physical damages

Northern California Wildfires (2017)



30$ billion in physical damages

Firm-level financial impacts from extreme weather events have gained great attention among investors, insurers, and policymakers (Krueger et al, 2020; Stroebel and Wurgler, 2021)

To what extend are firms **impacted** by extreme weather events?

What about financial impacts **beyond physical damage** (e.g. supply-chain disruptions, demand shocks)?

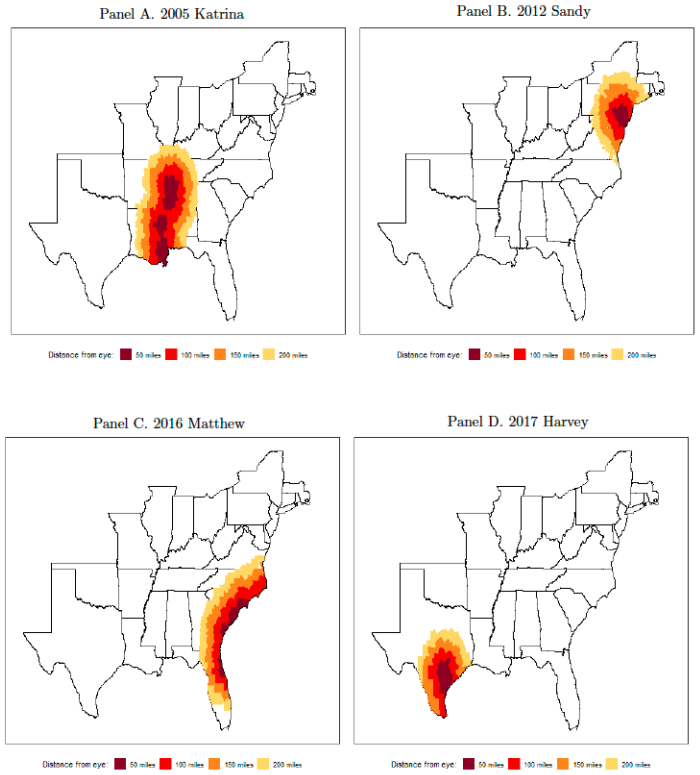
How do **financial markets react** to firm-level impacts?

https%3A%2F%2Fde.wikipedia.org%2Fwiki%2FHurrikan_Helene&ved=0CBYQjRxqFwoTCKDS-qDsxZUDFQAAAAAdAAAAABBq&opi=89978449

https%3A%2F%2Fwww.theguardian.com%2Fus-news%2F2020%2Fjul%2F21%2Fcalifornia-wildfires-gold-hog-mineral-susanville&ved=0CBYQjRxqFwoTCKCij8nsxZUDFQAAAAAdAAAAABBq&opi=89978449

To estimate firm-level financial impacts from extreme weather events, we first need to know whether firms have been impacted

Geospatial approaches



Kruttli et al. (2024)

Indicate whether firms have been impacted (or not), by mapping firm asset locations onto "impact zones" of extreme weather events (Kruttli et al., 2024; Addoum et al., 2020, 2023)

- **Highly simplified approximation** whether firms have been impacted
- **Miss indirect effects** via supply chains, demand shocks (Barrot & Sauvagnat, 2016; Pankratz & Schiller, 2024)
- **Exclude mobile/diffuse assets** like transportation fleets, electricity grids, or railway networks
- **Not applicable for many event types** (e.g., winter storms, heat waves)

Idea: Analyze firm-level disclosures of material events

What are material event disclosures?

Firms listed on U.S. stock exchanges must file an 8-K with the Securities and Exchange Commission (SEC) to disclose material events that may affect investors.

Examples:

- Major lawsuits
- Supply-chain disruptions
- Mergers and acquisitions
- Factory shutdowns
- Damage from hurricanes, floods, wildfires

FORM 8-K

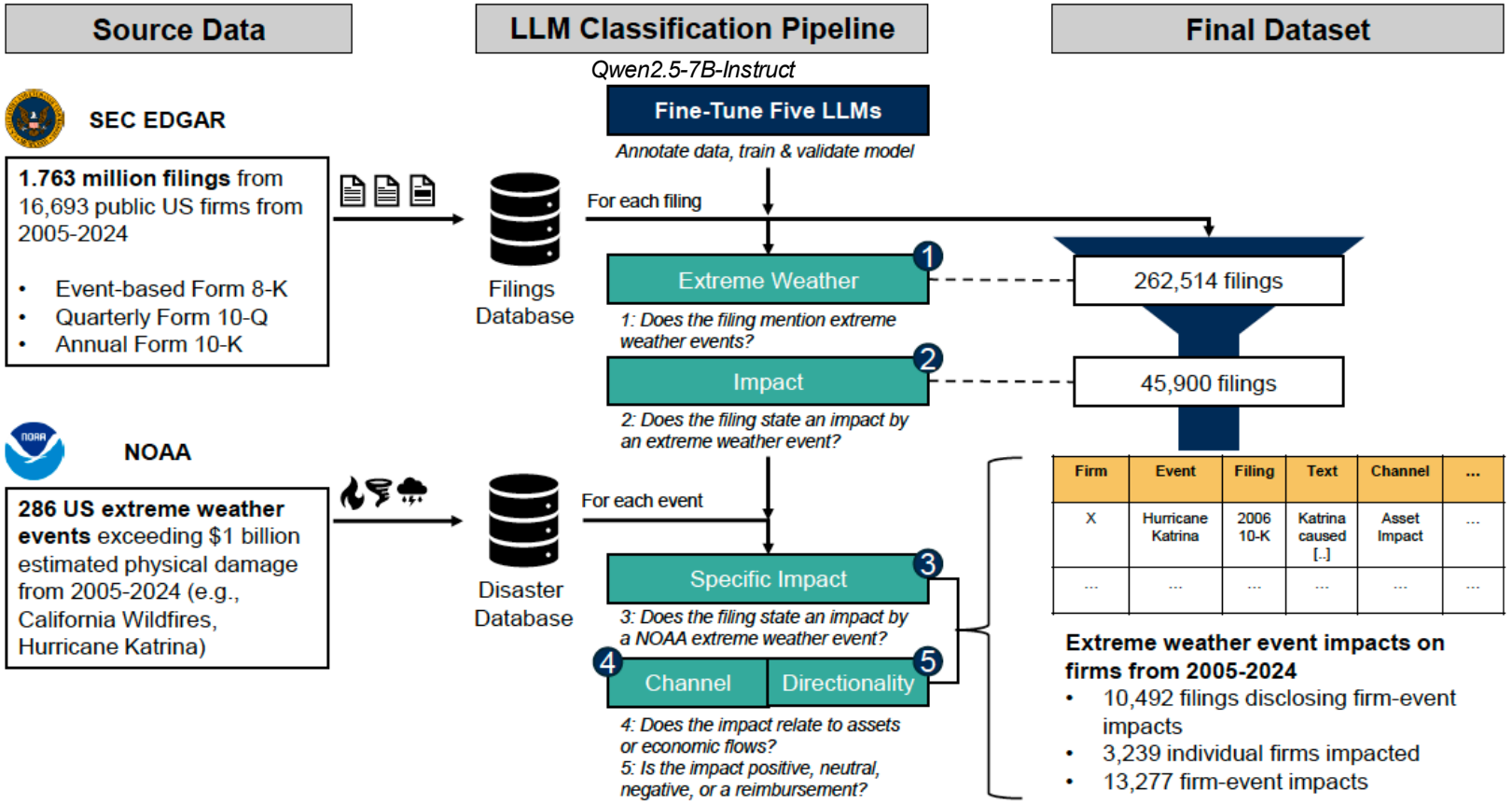
Northwind Turbines Corp.

Item 8.01 Other Events

On Sept. 27, 2024, Hurricane Helene damaged the Company's Gulf Coast refinery, temporarily halting operations.

Thousands of firms submit tens of thousands of filings every year, making manual analysis infeasible

We analyzed public financial disclosures via LLMs to identify firm-level impacts from extreme weather events

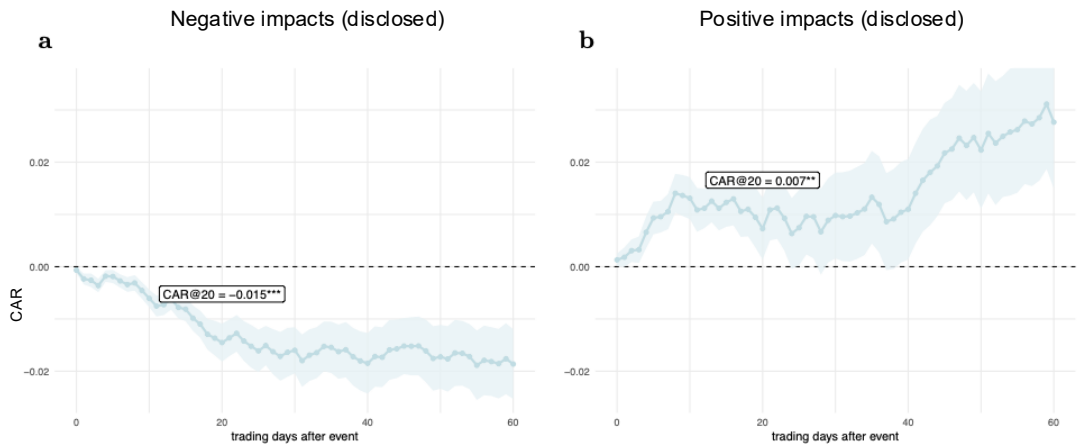


Schimanski et al. (2025)

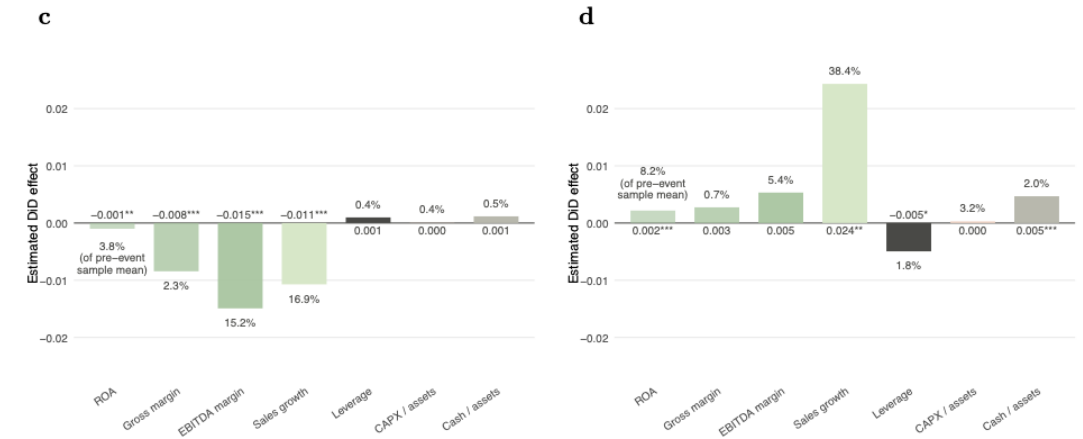
For firms impacted by extreme weather events, we estimate effects on stock market returns and other firm financials

Positive vs. negative

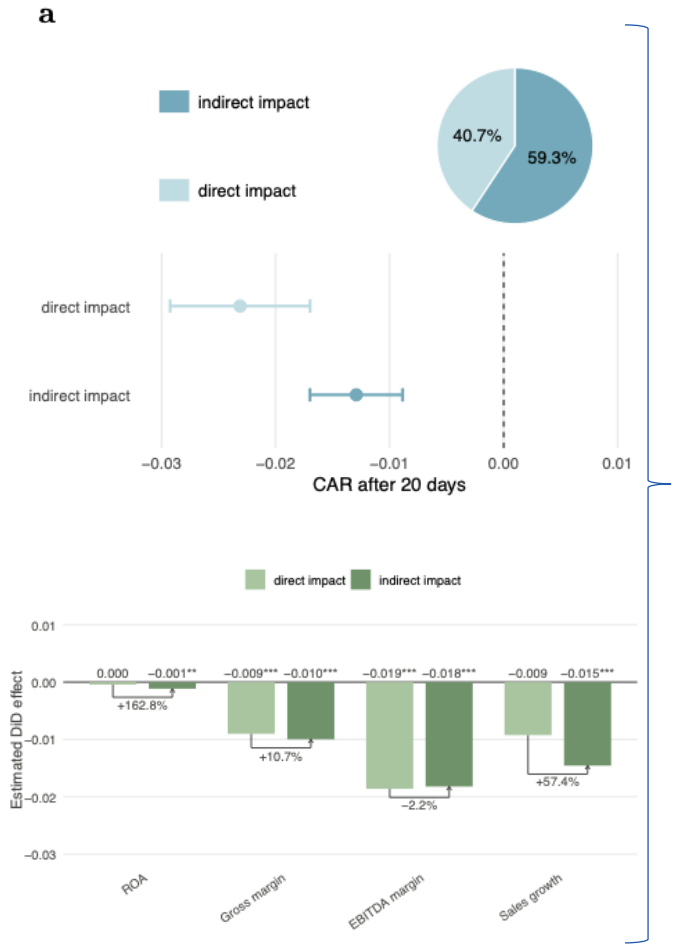
Stock market returns



Firm financials



Direct vs. indirect



Financial markets seem to **systematically underestimate indirect impacts** of extreme weather events

Schimanski et al. (2025)

Contribution, limitations and future research

Contribution

- **Identification tool:** First scalable, firm-level, ex-post identification of realized extreme-weather impacts from filings
- **Different channels:** Captures direct and indirect, negative and positive impacts that geospatial methods miss

Limitations

- **Information source:** Relies on public disclosure of impacts to the SEC (although firms are liable, indirect impacts may be underreported)
- **Scope:** Limited to publicly listed US firms
- **Adaptation:** Does not include firms' preparedness

Future research

- **Granularity:** Extract information on impacted assets, supply-chain steps
- **Adaptation:** Include information on adaptation measures (e.g., from reports) to identify whether firms that invest in adaptation are (1) less likely impacted and (2) financial costs of impacts are lower

Other use cases of AI for analyzing climate-related financial risks

Transition risks

How will the climate transition affect my investments?

Can firms transition?

E.g., Analyzing transition plans

(Colesanti Senni et al. (2025), Transition Pathway Initiative)

Is the transition credible?

E.g., Identifying green washing in reports and public communication

(Bingler et al. (2022))

Who is at the forefront of the transition?

E.g., Analyzing green patents of firms and their fit to the core business

(Cohen et al. (2025), OECD Env-Tech patent classification)

Physical risks

How will impacts of climate change affect my investments?

Which firms are exposed?

E.g., Comparing firm-level assets with extreme weather forecasts

(Oxford Spatial Finance Initiative)

Are firms aware of relevant transition risks?

E.g., Comparing adaptation reports with firm-level exposure

(Sautner et al. (2023), Pankratz et al. (2023))

How prepared are firms?

E.g., Analyzing firm-level adaptation strategies and their effectiveness

Deep dive

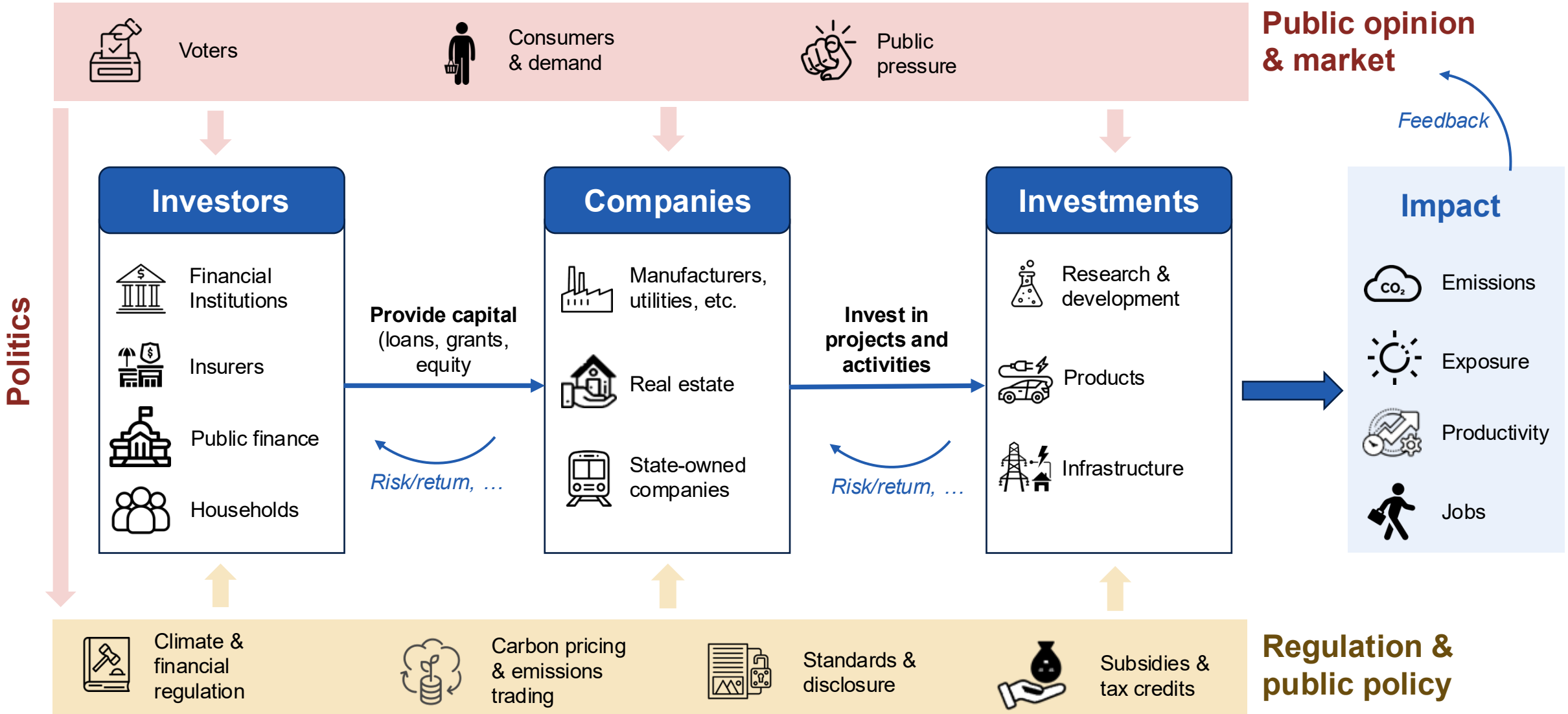
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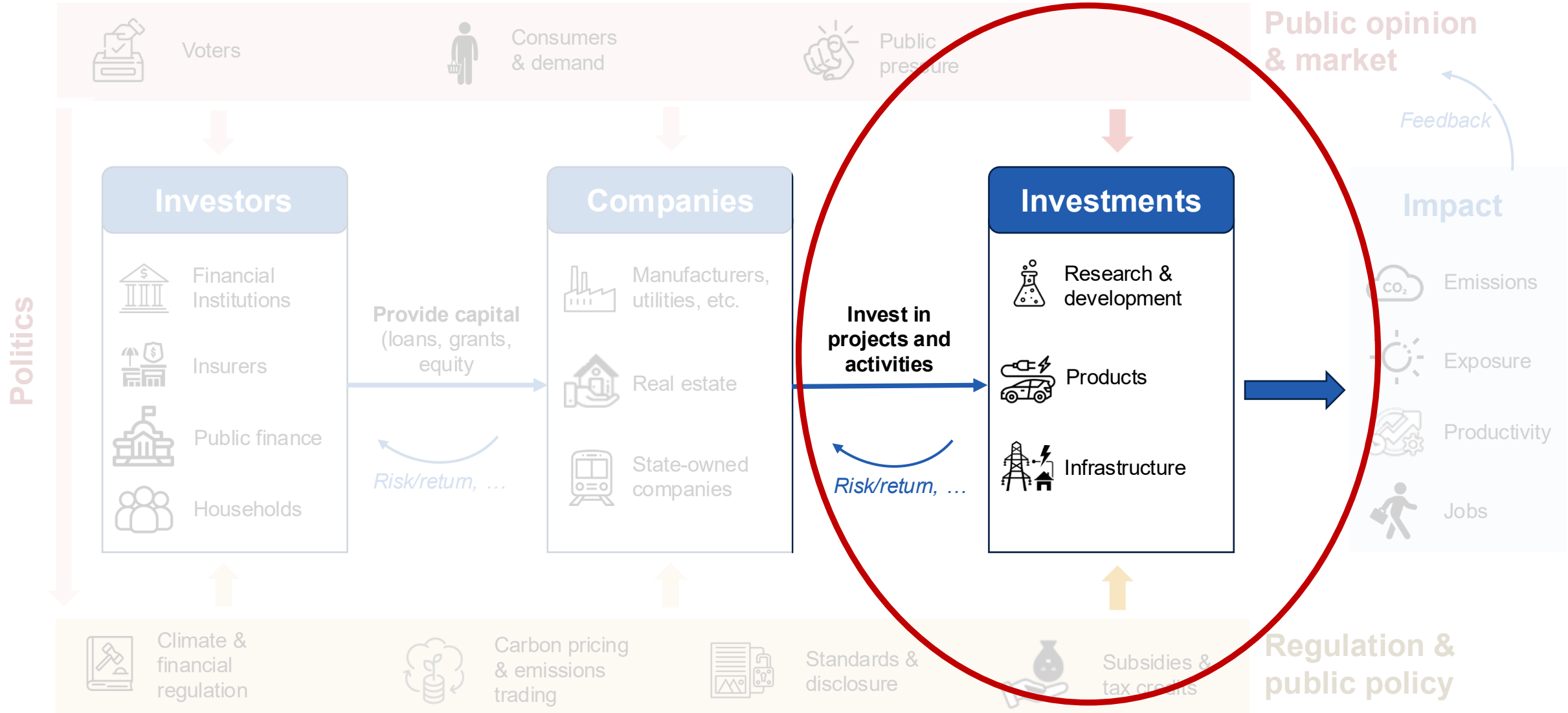
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Provide capital (loans, grants, equity
Risk/return, …
Companies
Manufacturers, utilities, etc.
Real estate
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Finance is key to accelerate innovation of climate technologies from the lab to large-scale diffusion



Climate transition









Research and development

Demonstration and pilot

Commercialization

Early adoption

Diffusion

Finance is key to accelerate innovation of climate technologies from the lab to large-scale diffusion



Climate transition



Research and development

Demonstration and pilot

Commercialization

Early adoption

Diffusion

„Out of the lab“

(grants)

„Go to market“

(early-stage venture capital)

„Scaling a nieche“

(late-stage venture capital)

„Scaling across markets“

(debt financing)

These are different (types of) investors!

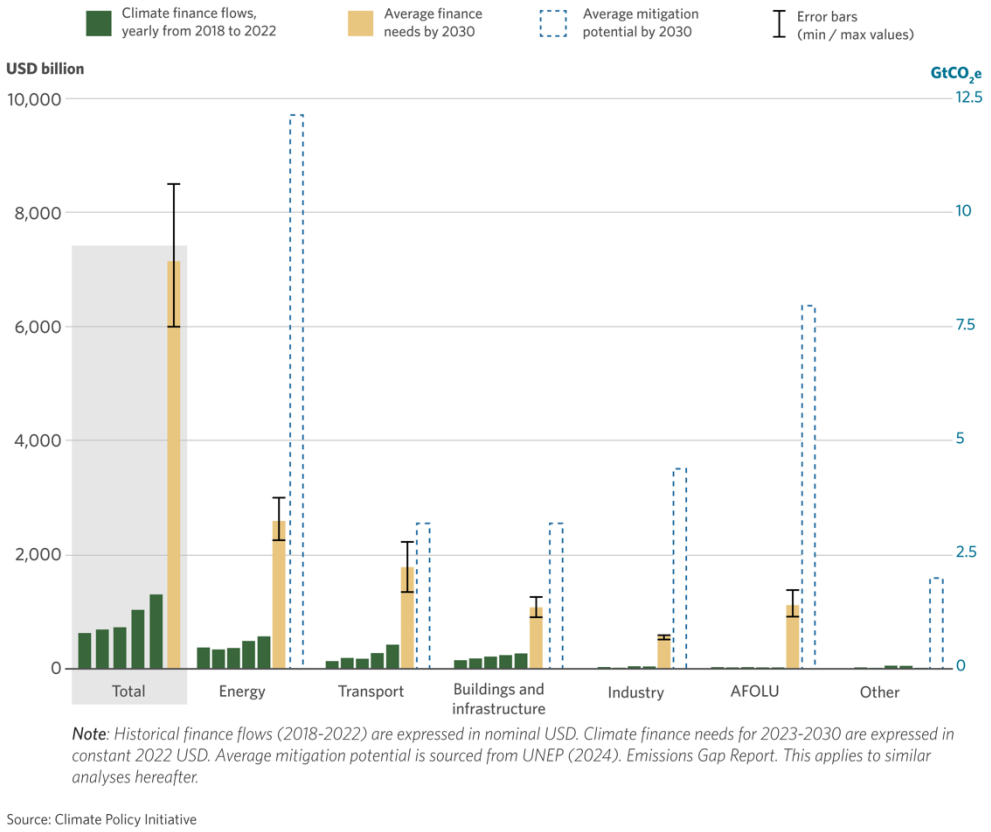
However, several barriers disincentivize investors to allocate finance to climate technologies

High upfront capital requirements for scaling
First commercial plants and manufacturing facilities require billions of dollars before revenues materialize

High technological uncertainty
Many emerging technologies are not yet cost-competitive and future cost curves and technology pathways remain uncertain.

Long investment horizons
Infrastructure and deep-tech investments have long lifetimes and slow payback periods, which are unattractive for many risk capital investors

Policy and regulatory risk
Future carbon prices, subsidies and regulations are uncertain, making future demand and cash flows difficult to predict

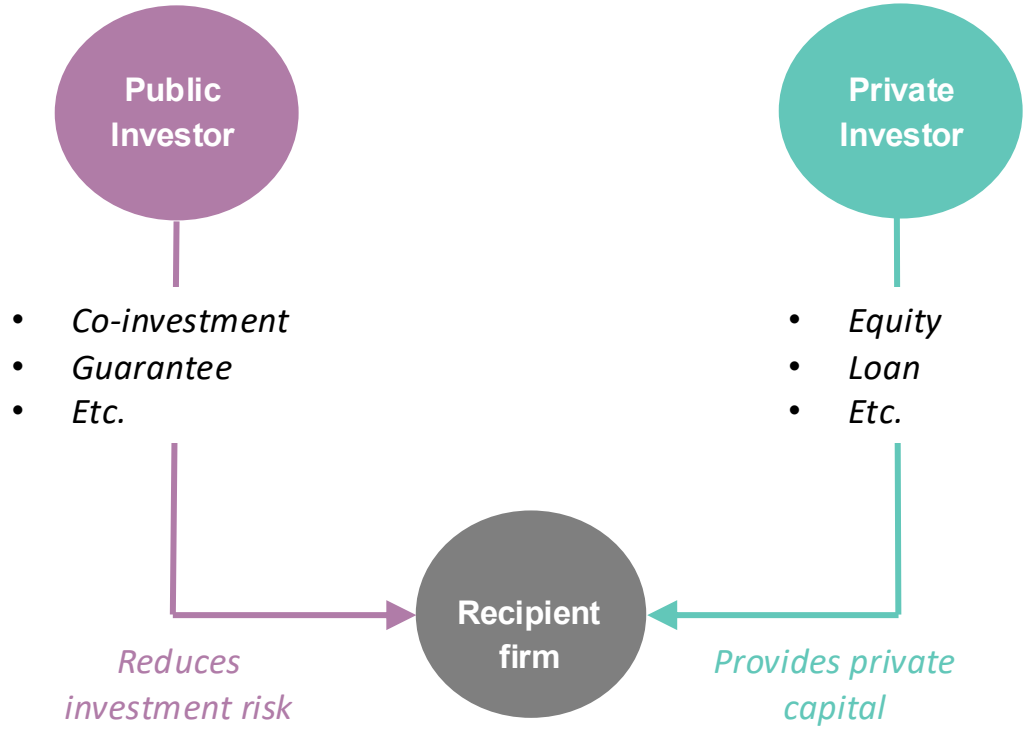


Note: Historical finance flows (2018-2022) are expressed in nominal USD. Climate finance needs for 2023-2030 are expressed in constant 2022 USD. Average mitigation potential is sourced from UNEP (2024). Emissions Gap Report. This applies to similar analyses hereafter.

Source: Climate Policy Initiative

How can public policy mobilize private investment in climate technologies?

Rather than replacing private investments, public investors aim to mobilize private investors through co-investments

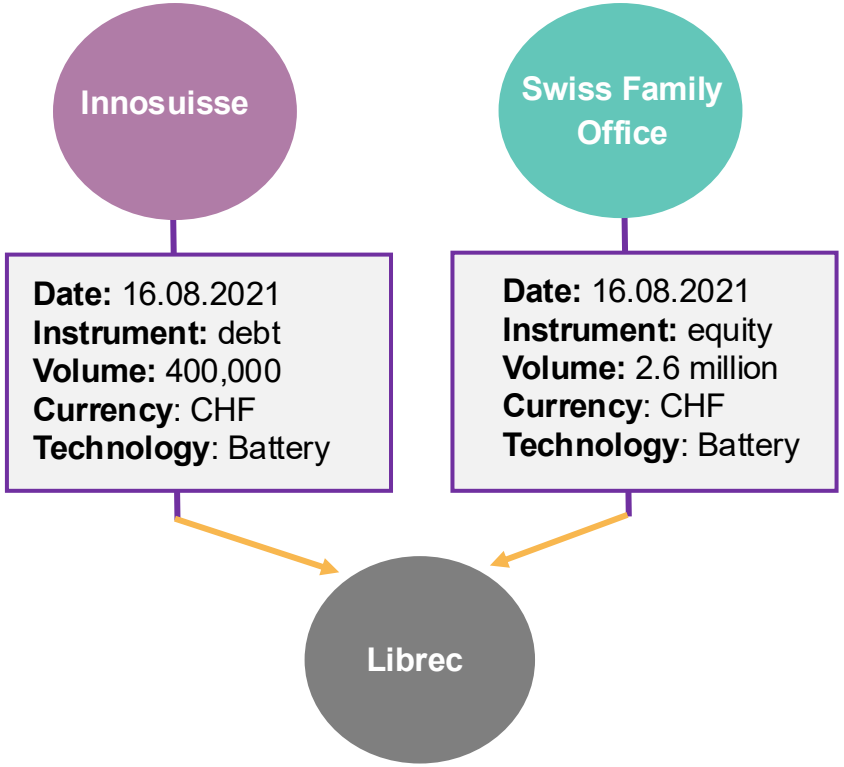


Is public co-financing effective and additional?

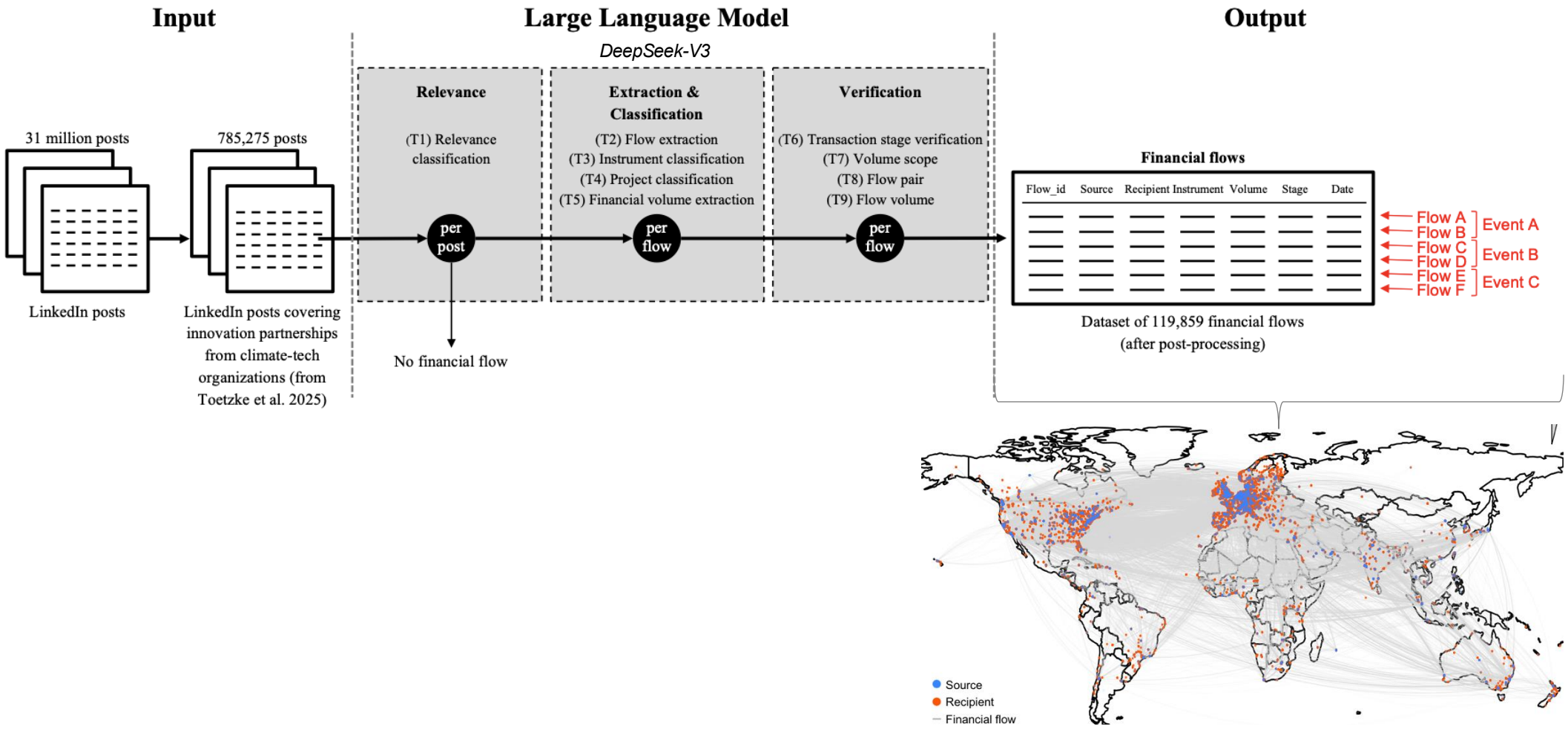
We extracted investment flows into climate technologies from LinkedIn announcements using Large Language Models

LIBREC
Environmental Services
Biberist, Solothurn

Librec raises 2.6 million francs from oversubscribed seed round led by Swiss Family Office, which is accompanied by a 400k loan from innosuisse to advance battery recycling (…).



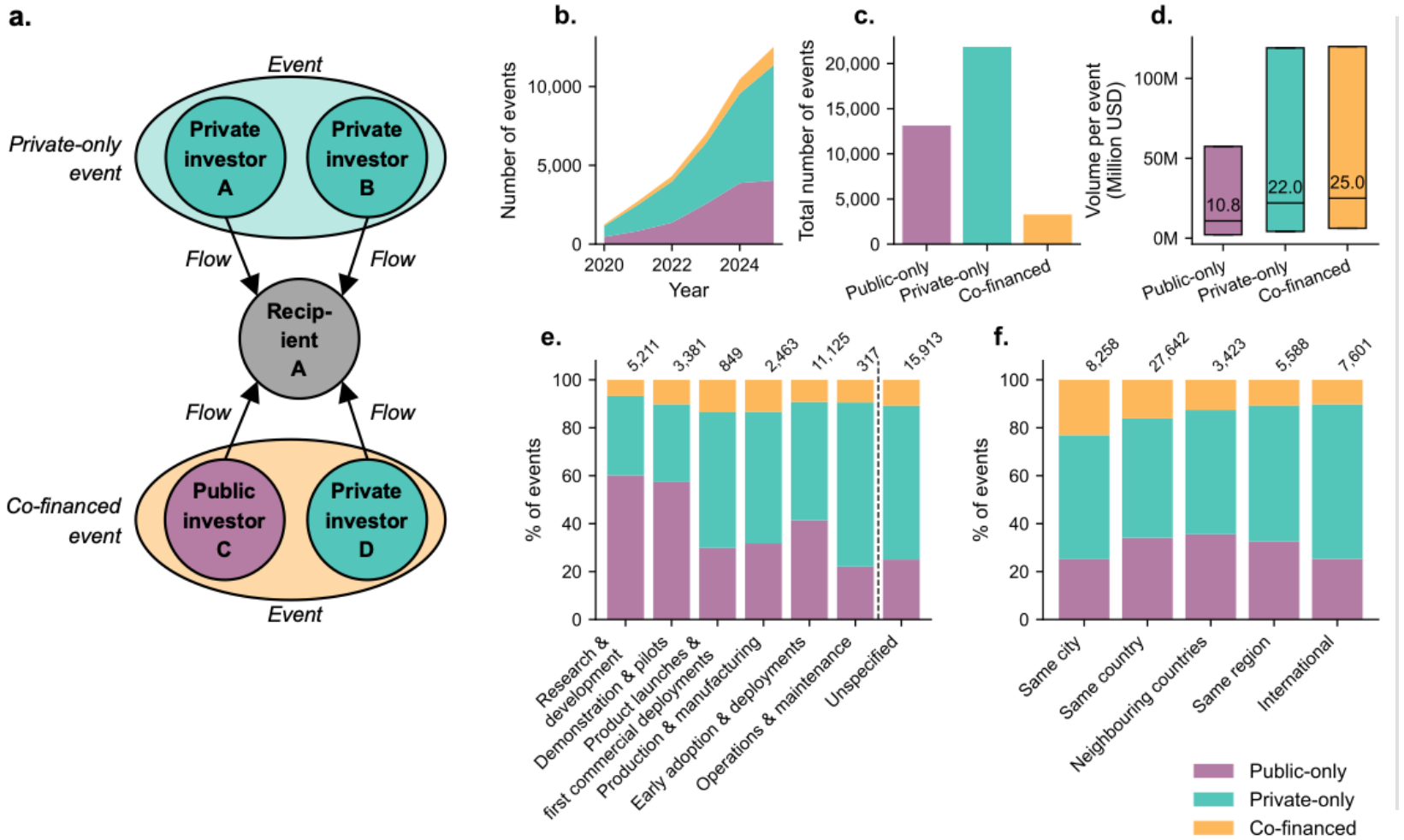
Lehofer, Egli, Toetzke (2026)



Global financial flows into climate technologies (2020—2025)

Lehofer, Egli, Toetzke (2026)

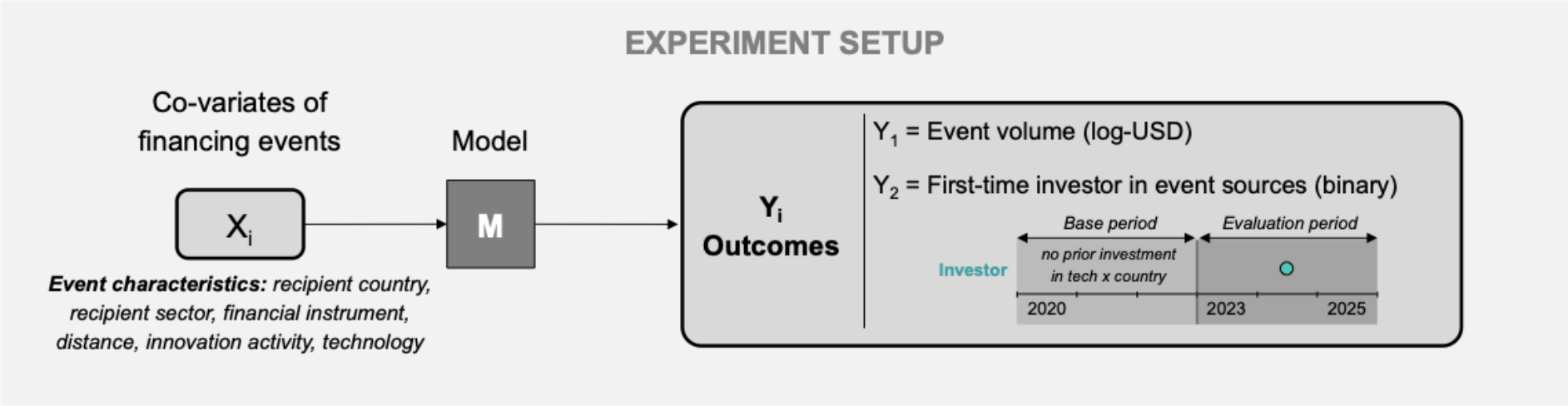
We extracted 100,000 financial flows in climate tech from over 20 million posts of firms

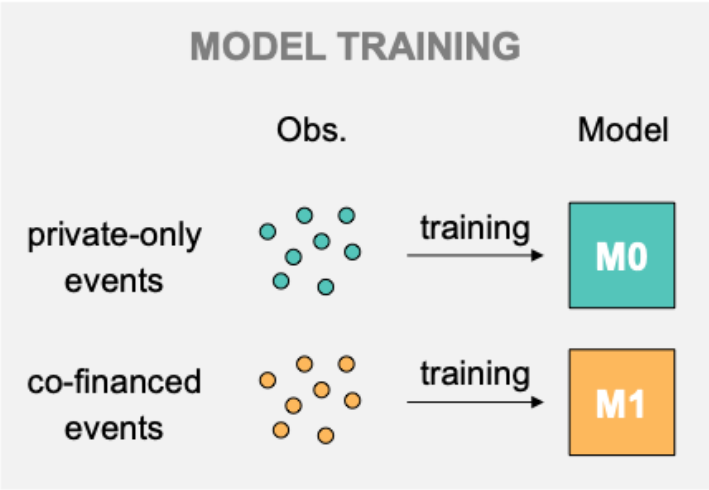


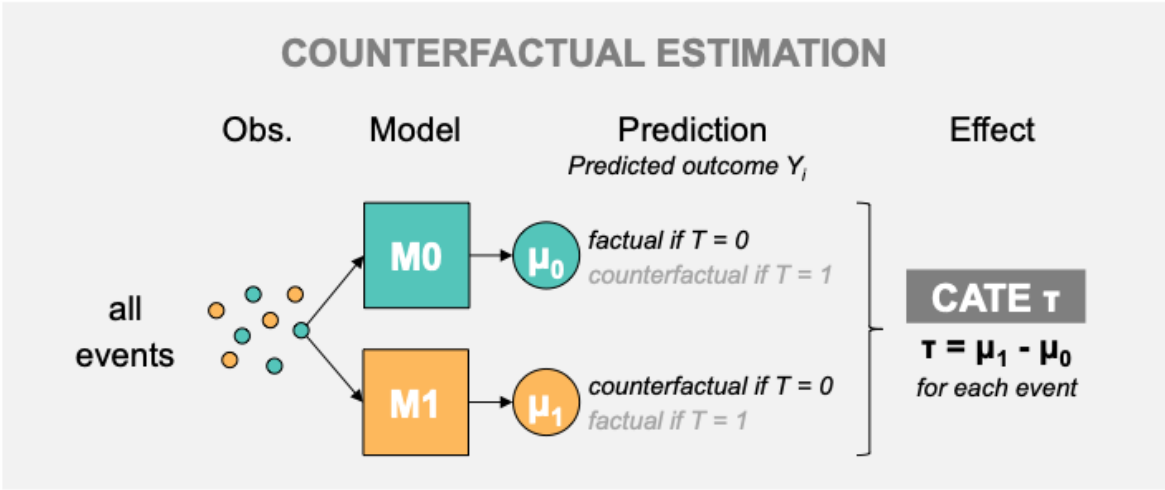
- Does public co-financing mobilize **new investors**? …that are otherwise unlikely to invest
- Does public co-financing result in **higher ticket volumes**? …or crowd out private investments?

Lehofer, Egli, Toetzke (2026)

We use AI to estimate counterfactual outcomes





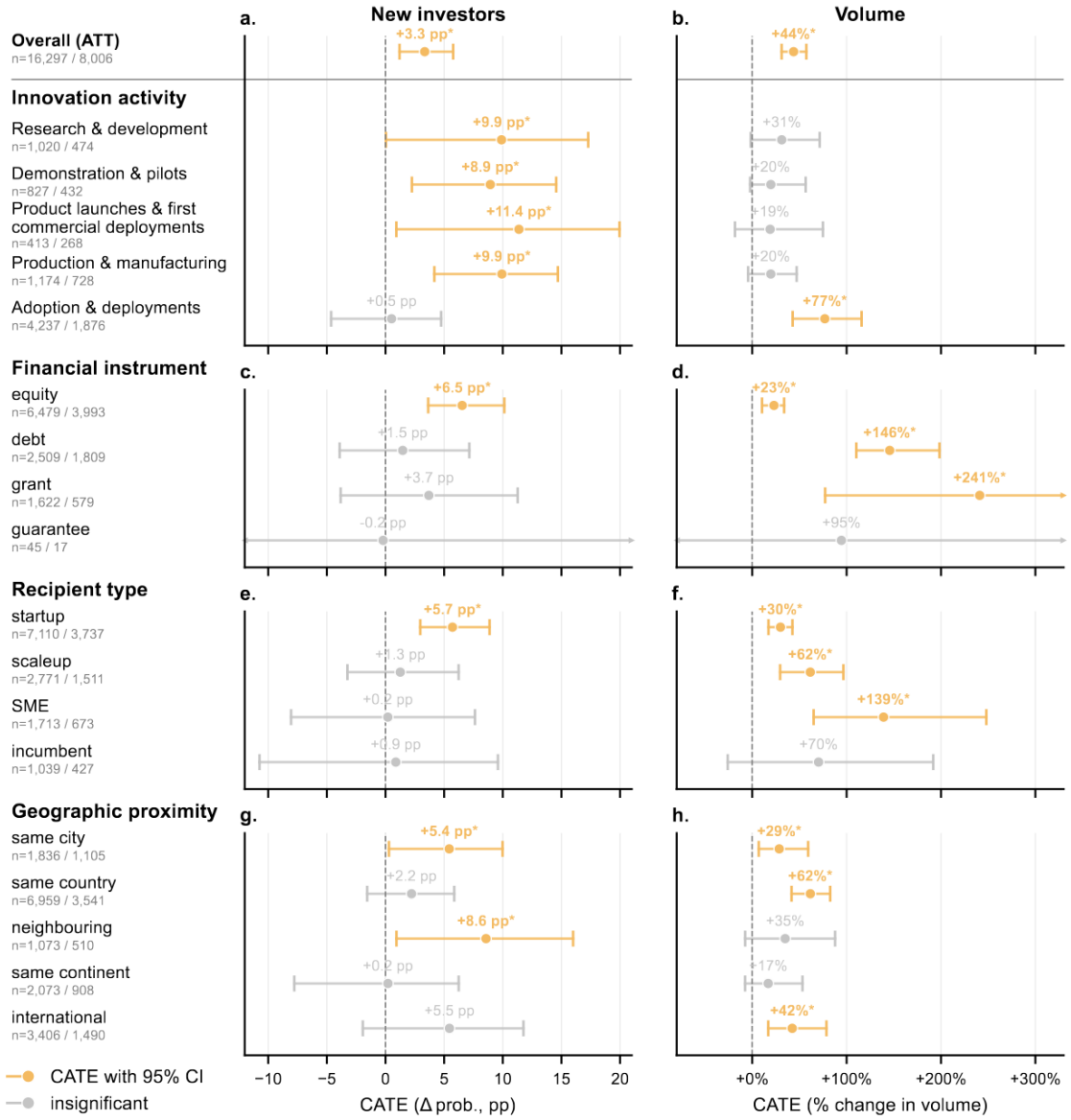


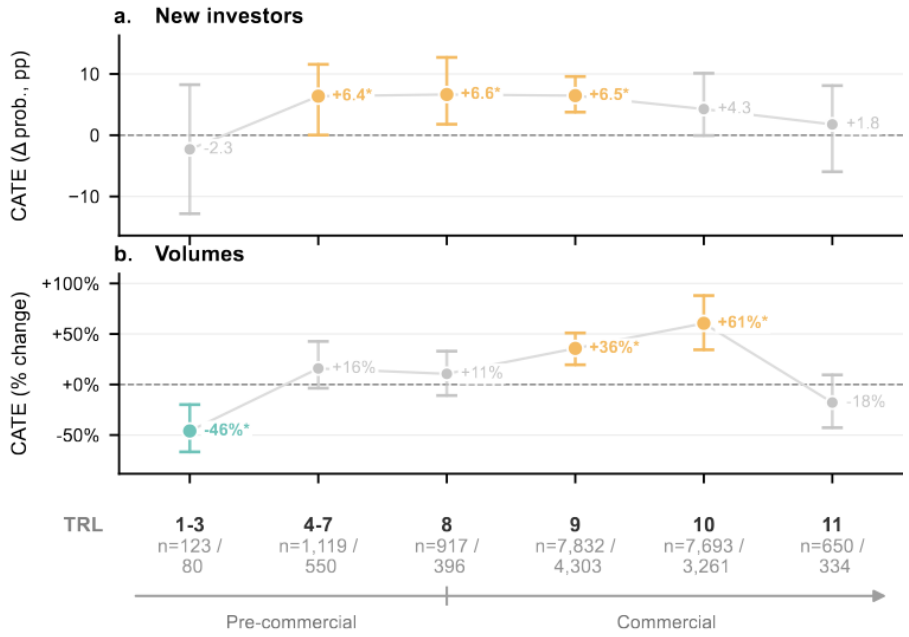
Baseline model:
Gradient boosting decision tree (Ke, 2017)

Rebostness check:
Causal forest (Athey, 2019)

Lehofer, Egli, Toetzke (2026)

Co-financing mobilizes new investors in different innovation stages compared to when it mobilizes higher volumes





TRL group	Stage	Typical technologies
TRL 1–3	Research & Proof of Concept	Fundamental research, laboratory experiments, and proof-of-concept technologies (e.g., novel battery chemistries, early DAC materials).
TRL 4–7	Development & Demonstration	Prototype development, pilot plants, and demonstration projects under increasingly realistic operating conditions (e.g., pilot hydrogen electrolysers, CCS demonstration facilities).
TRL 8–10	First Commercial Deployment	First commercial plants and early market deployment where technologies are technically proven but not yet widely adopted (e.g., first green steel plants, SAF production facilities).
TRL 11	Commercial Scale & Diffusion	Mature technologies deployed at scale in competitive markets (e.g., solar PV, onshore wind, lithium-ion batteries, heat pumps).

Contribution, limitations and future work

Main contribution

- **New data source:** first large-scale map of investment flows into climate technologies incl. public co-finance (grants, loans, guarantees) that commercial databases miss
- **Causal evidence:** firm-level counterfactual estimates of whether public co-financing mobilizes private capital
- **Policy targeting:** identifies where co-financing works (TRL, instrument, recipient, geography)

Limitations

- **Selection into disclosure:** only deals announced on LinkedIn are observed
- **Self-reported data:** volumes and instruments come from marketing posts, not audited filings
- **Selection on observables:** causal estimates assume no unobserved drivers of co-financing decisions

Future work

- **Link to outcomes:** connect mobilized finance to deployment, patents, and production capacity
- **Instrument design:** which instruments (guarantee vs. loan vs. equity) mobilize most private capital per public euro
- **Evaluate specific programs that focus on mobilizing private investment**

Other use cases of AI for analyzing innovation finance for climate technologies

Financial input

Mapping and analyzing allocation of finance into firms and innovation activities?

How likely do firms get access to finance?

E.g., Predicting financing rounds based on patents, products, etc. using Crunchbase data and identifying regional biases
(Ross et al. (2021), Ang et al. (2022))

What is the effect of specific policies have on attracting private finance?

E.g., mapping innovation policy onto affected firms to assess firm-level impacts of policies on access to finance

Innovation outcomes

Mapping innovation outcomes and linking them to financial input?

How much finance do firms need to reach certain outcomes?

E.g., Predicting financial inputs based on innovation outcomes (e.g., patents, commercialization, production capacity) and other firm-level data

How fast are technologies learning?

E.g., Tracking efficiency gains of technologies and regional difference to inform investment opportunity (Way et al. (2022))

Where to start: open datasets and AI tools for climate finance

	A — International finance	B — Financial markets	C — Innovation finance
Open datasets	OECD CRS — 2.7M development assistance project descriptions (free) AidData GCDF v3.0 — 21k Chinese-financed development assistance projects Climate Watch — Nationally Determined Contributions (NDC) texts + data (CC BY) Climate Funds Update — multilateral funds	SEC EDGAR — full-text filings of firm financial disclosures Sautner et al. exposure data — Data on firm-level climate change exposure Net Zero Tracker — Net Zero targets overview GeoAsset — open asset databases (steel, cement)	Google Patents BigQuery — CPC Y02 green-tech codes IRENA — renewable cost + capacity data Global Energy Monitor — unit-level asset trackers
Finetuned AI models, tools & code	ClimateBERT — 16 models, 7 datasets (Hugging Face) Climate Policy Radar — NLP search over global climate policies	ClimateBERT — 16 models, 7 datasets (Hugging Face) ChatReport — LLM report analysis (open code) CLIMADA — open physical-risk engine	Climate TRACE — satellite + ML emissions, asset-level (CC BY) MIT tech rates / SFI PCDB — technology learning curves

Important remarks

1 Definitions matter

- Category definitions heavily affect outcomes
- Automation buys consistency, not objectivity
- Annotator disagreement shows whether definitions are clear

2 Finance prices a future the data has not seen

- Model outputs can lead to overconfidence about highly uncertain outcomes
- Work with scenarios

3 Understand the original purpose of your data

- 8-Ks are legal filings. LinkedIn posts are marketing
- Data can contain noise or false claims (green washing)

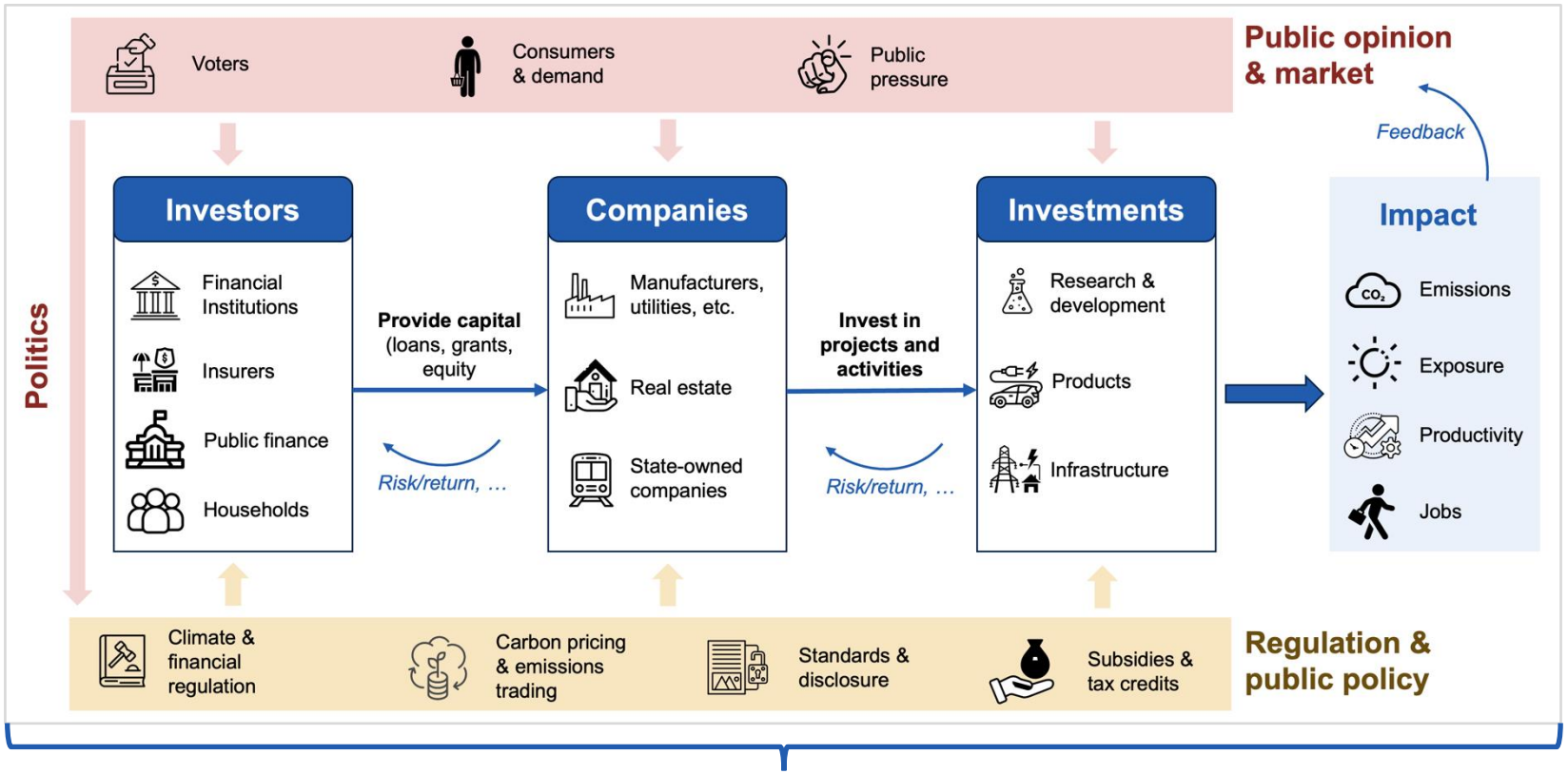
4 The measured respond to being measured

- Once a score matters, the language adapts (e.g., climate finance reporting)
- Prefer signals costly to fake (e.g., patents, financials)

Always validate extracted information and predictions against

- Other datasets
- Expert hypotheses
- Real-world outcomes

Where do results contradict and why ?



- **Mapping financing gaps:** where is finance flowing and where is it still needed?
- **Informing financing decisions:** which firms, technologies or projects are good or bad investments?
- **Evaluating investment impacts:** which investments lead to additional deployment, emissions reductions or greater resilience?

Thank you!

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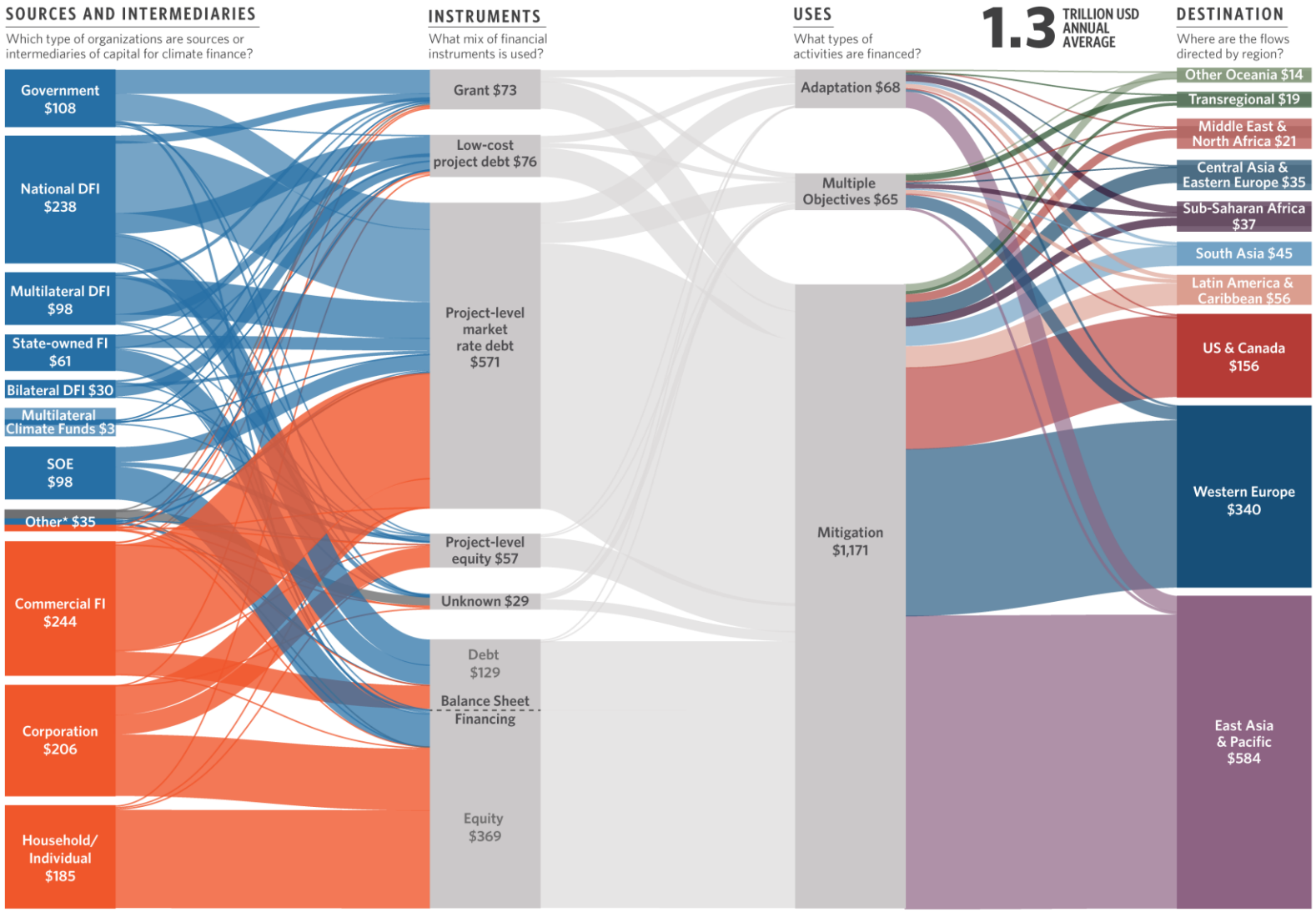
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LANDSCAPE OF CLIMATE FINANCE IN 2021/2022

Global climate finance flows along their life cycle in 2021 and 2022. Values are averages of two years' data to smooth out fluctuations, in USD billions

CLIMATE POLICY INITIATIVE

1.3 TRILLION USD ANNUAL AVERAGE



"Other" public sources include export credit agencies and unknown public funds
"Other" private sources include institutional investors, funds, and unknown

Source: Climate Policy Initiative

The private sector is key:

More than half of provided climate finance comes from private sources

Profitability and risk matters:

The far majority of climate finance is based on debt financing (loans)

Adaptation is still small:

Less than 10% of climate finance is adaptation

Developing countries are underfunded:

Less than 25% of climate finance flows to emerging markets* and LDCs

*excluding China