IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Asset-level assessment of climate physical risk matters for adaptation finance[1]

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[1] This contribution was prepared for the workshop. The views expressed are those of the authors and do not necessarily reflect the views of the Central Bank of the Republic of Türkiye, the BIS, the IFC or the other central banks and institutions represented at the event.

Asset-level assessment of climate physical risk matters for adaptation finance

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Climate Change Data Workshop - May 2024, Izmir

Motivation and contribution

Motivation

- Main **knowledge gaps** remain in climate physical risk assessment, hindering **capital reallocation** (Kreibiehl et al., 2022) low-carbon transition (Battiston et al., 2021)
- **Delayed action** on adaptation and mitigation leads to higher climate risks and failure to close the **adaptation gap** (UNEP, 2021)

Contributions of this paper

- A transparent **methodology**: from asset-level physical risk to financial valuation of securities
- Risk emerges from **interplay** of acute and chronic impacts on assets, assets' location and role in firm's revenues
- **Results**: neglecting asset-level dimension and tail risks can lead to underestimation of losses and non-coherent investment decisions

Literature and knowledge gaps

- **Asset-level data** (e.g. production plants): non standardized, proprietary; no consolidation (financial, climate, extrafin. info)
- **Plants' ownership** information: not standardized, difficult to reconstruct chain of ownership due to complexity of ownership networks (Garcia-Bernardo et al., 2017)
- **(Mis)pricing**: contrasting evidence, mostly for past disasters (Beirne et al., 2021, Giglio et al., 2021, Garbarino and Guin, 2021, Nguyen et al., 2022)
- Addressing these challenges is key to identify **policy responses** (Hallegatte et al., 2020), **financing needs** (GCA, 2021) and **instruments** (Mullan and Ranger, 2022) to fill the adaptation gap

CITE OUR PAPER!

G. Bressan, A. Duranovic, I. Monasterolo, and S. Battiston, Asset-level assessment of climate physical risk matters for adaptation finance, early ssrn 4062275 (2022), forthcoming (2024) on **Nature Communications**.

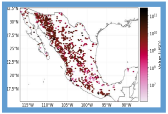
Are physical risks priced? Examples from the literature

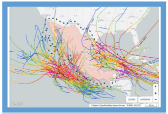
- Several studies investigated **market pricing** of physical risks:
  - (Acharya et al., 2022) find that **heath stress** is most relevant for municipal bonds, non-investment grade bonds, and equity starting 2013-2015 (physical risk data **427**[1] and **SEAGLAS**[2])
  - (Gostlow, 2021) finds that **hurricanes** command a positive risk premium and **heath stress** a negative risk premium (data: **427**)
  - (Nguyen et al., 2022) document a positive sea-level risk premium for mortgages (data: **NOAA**[3])
- **Disagreement** due to data **limitations**: aggregate physical risk scores (eg. MSCI 427) diverge even within the same measurement method (Hain et al., 2022)!
- Most studies are **backward looking** (past data) but future climate will be much different: need to work with scenarios

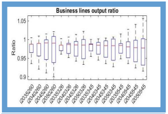
[1] https://www.moodys.com/web/en/us/capabilities/esg.html
[2] (Hsiang et al., 2017)
[3] https://www.noaa.gov/

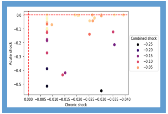
Methodological framework

Database model | **Asset-level probabilistic climate risk assessment** | **Macroeconomic impacts** | **Climate financial valuation adjustment** | **Climate financial risk assessment**









Panel B: underestimation of portfolio losses

Compared cases	Underestimation range (%)
Chronic vs. tail acute (asset-level, RP250)	73.2-79.3
Chronic vs. chronic and tail acute (asset-level, RP250)	78.8-82.2
Average acute (asset-level, EAL) vs. tail acute (asset-level, RP250)	96.7-97.7

Database model

- Data collection: asset type, location, capacity, residual life, prices (Refinitiv Eikon, S&P, etc)
- Reconstruction of global firms and European investors' ownership chain
- Data harmonization across providers
- Missing values: estimation of capacity, asset coordinates, etc

Asset-level probabilistic climate risk assessment

- Tropical cyclones impacts in Mexico from CLIMADA (Aznar-Siguan et al., 2022)
- Tracks adjusted for climate impact scenarios
- Hazard, area-specific damage function: assess direct damages on physical assets across different return periods (RP)

Macroeconomic impacts

- Matching of asset-level info with sector classification
- Economic impacts by sector, region (ICES)
- Shocks by SSP-RCP scenario combination (2-6.0, 3-2.6, 3-4.5, 5-4.5)
- Impacts expressed as ratio btw baseline (no climate shock) output and climate adjusted output by sector

Climate financial valuation adjustment

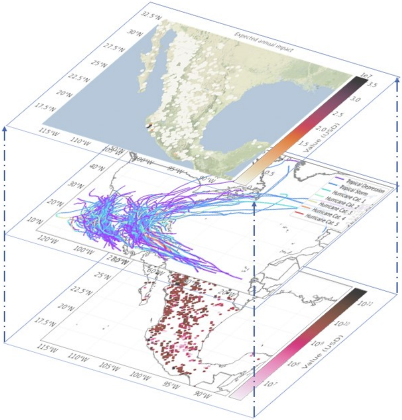
- Shocks cascade from asset impacts to business line, firm and investor's level
- Consideration of climate (chronic + acute) impacts on firms' long-run growth rate
- 3-stages Climate Dividend Discount Model (CDDM) for Climate-adjusted stock valuation

Climate financial risk assessment

- Average portfolio losses and portfolio Value at Risk (VaR) are computed from firm-level equity losses
- The estimation is strengthened using bootstrapping over 15,000 samples
- Assessment of the underestimation of climate-adjusted risk metrics from neglecting tail risk and asset-level data

Figure: Methodological framework for asset-level climate physical risk assessment (Bressan et al., 2022)

Asset-level probabilistic risk assessment - workflow



Impact

- Direct damages computed at different return periods and on average
- Info feeds into equity shocks and valuation adjustments

Hazards

- Tropical cyclones as computed in the CLIMADA model
- Other acute hazards shall be considered in further studies

Geolocalized assets

- Referenced by latitude/longitude
- Defined by asset type (e.g. power plant, mine, etc.)
- Non-financial variables (e.g. capacity, residual life)
- Financial variables (e.g. value)

Figure: Workflow for probabilistic disaster risk assessment for tropical cyclones in Mexico (Bressan et al., 2022).

Asset-level probabilistic risk assessment - hurricanes

- **Assets' geolocations** matched to wind-speed along tracks
- Assets are shocked with a damage function that translates wind speed in plant losses (monetary value):
  - $F_{index} = \frac{v^3}{(1+v^3)}$, $v = \frac{max((W_{spd} - W_{tresh}),0)}{(W_{half} - W_{tresh})}$
  - Where $W_{tresh} = 65km/h$ and $W_{half} = 253km/h$ (Dunz et al., 2021)
- Impact computed as **Expected Annual Impacts (EAI)**:

$$EAI_j = \sum_{i=1}^{N_{ev}} x_{ij} F(E_i), \tag{1}$$

- where X is the impact random variable, E_i an hurricane, F its annual frequency, N_{ev} are the independent events considered.
- Impact also computed for tail events (high **Return Periods (RP)**).

Climate-adjusted financial valuation

- We develop a three stages climate dividend discount model (CDDM)

$$V_0 = \sum_{t=1}^{t_1} \frac{D_t}{(1+r)^t} + \sum_{t=t_1+1}^{t_2} \frac{D_t}{(1+r)^t} + \frac{D_{t_2}(1+g_L)}{(1+r)^{t_2}(r-g_L)} \qquad (2)$$

- D_t dividends, r discount rate, g_L long-run growth rate of dividends.
- Calibration:
  - Between $t = 1$ and t_1 firms' dividends provided by S&P
  - Between t_1 and t_2 Earnings Per Share are multiplied by payout ratio to describe the reversion of dividends
  - From t_2 onward the terminal value is computed.
- CDDM distinguishes short and long run impacts of physical risk.

Chronic and acute physical risks lead to adjustments in g_L

$$\tilde{g}_{L,(I,j)} = g_L \sum_{i=1}^{K_j} \left(\frac{O_{I,j,i}}{O_{B,j,i}} \frac{1}{\delta_{I,j,i}} s_{j,i} \right) \tag{3}$$

Adjustments from g_L to the climate risk-adjusted $\tilde{g}_L$ depend on:

- **Chronic shocks** on sectors and business lines, described by $\frac{O_{I,j}}{O_{B,j}}$:
  - $O_{I,j,i}$ and $O_{B,j,i}$: output trajectories calculated for each business line i of owner j respectively under climate scenario I and baseline B
  - A ratio smaller than 1 implies a negative impact from chronic shock
- **Acute shocks** on assets described by $\frac{1}{\delta_{I,j,i}}$ for j:
  - δ: aggregation of acute shock on firms' assets by business lines
- The impact of both shocks is weighted by $s_{j,i}$, i.e. the **revenue share of the business line**, for all K_j firm's business lines.

Application to Mexico

- Mexico (MX) is relevant for cascading economic and financial losses: it is exposed to physical risks and has FDI and listed firms with global investors, it is also a main beneficiary of adaptation finance (UNEP, 2021).
- 177 firms (MX + internationally owned) with 1,820 geolocalized assets in MX
- Exposure of European investors (banks, pension funds, etc) to MX firms via 17,147 equity holdings, 290.11 bn USD (June 30, 2020)
- Climate adjusted financial evaluation carried out at the year 2020
- Climate financial risk metrics computed with bootstrap

Acute shocks at the asset level

- Assets are heterogeneously distributed in MX, and differ by sector and productive capacity
- The impact of tropical cyclones increases significantly for higher Representative Concentration Pathway (RCP) scenarios and RP

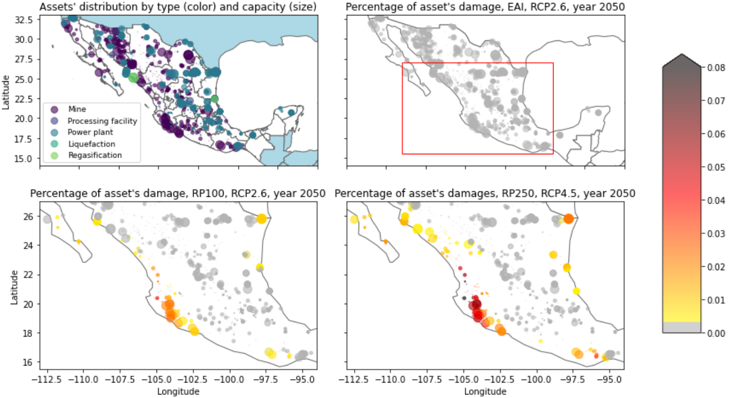


Figure: Assets' distribution and direct impact of hurricanes on assets (Bressan et al., 2022)

Acute vs chronic shocks on firms' stocks

1. Diversified firms (Firm 1) have both acute and chronic shocks depending on share of revenues from assets and geolocations
2. Firms can have similar chronic shock (because same sector) but very different acute shock (due to geolocalization, Firm 2 vs. Firm 3)
3. Firms can have large acute shocks even if operating in different sectors (Firm 3 vs. Firm 4)
4. Firms can be affected by similar large acute shocks but different chronic shock (same pair as above)

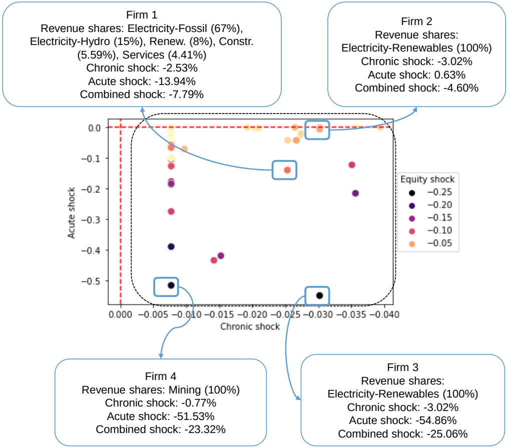


Figure: Scatter plot: for each firm (dot) shows acute, chronic and combined shocks. Scenarios combination SSP3, RCP4.5, year 2040. X-axis: chronic shock (relative change in stock value to no-shock), Y-axis: % of asset damages (Bressan et al., 2022).

Acute impacts lead to large losses on firms' stock value

- Black line: equal RP250 and average acute shocks on firms
- Firms below the black line: RP250 shocks are larger than EAI
- RP250: longer tail and larger support of distribution than EAI
- For 35% of firms: acute tail risk (RP250 loss) 3x larger than average losses (measured as EAI). Ignoring acute shocks leads to underestimation of losses on stocks

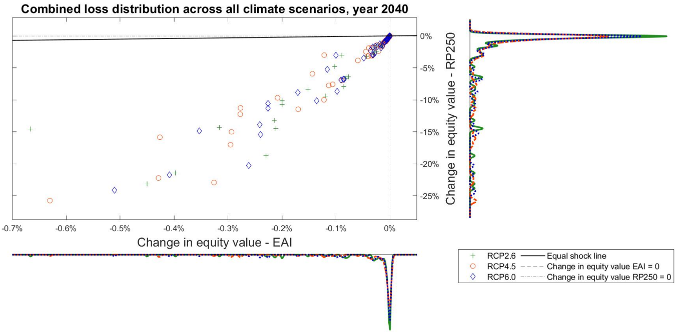


Figure: Scatter plot for the joint EAI and RP250 loss distributions for the year 2040, 86 companies with available asset-level data (Bressan et al., 2022).

Impact of discount rate and growth rate on equity value

- Higher (lower) **discount rate** r, lower (higher) equity losses
- Higher (lower) **growth rate** g_L, higher (lower) equity losses
- Higher (lower) **difference** $r - g_L$, lower (higher) equity losses

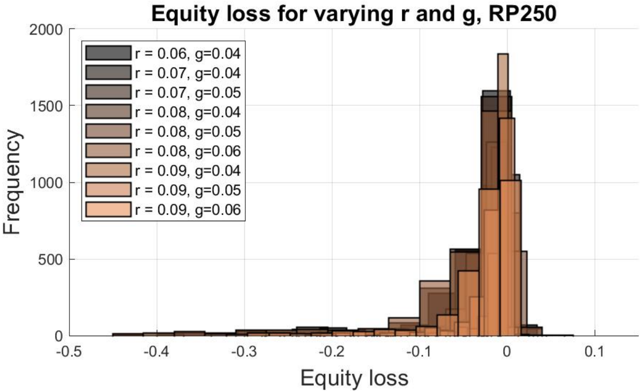


Figure: Sensitivity analysis of company-level losses from physical risk to different combinations of r and g_L (Bressan et al., 2022).

Tail acute risks and underestimation of losses

- How physical risks translate into portfolio losses for investors?
- We compare different futures of physical risks and quantify the underestimation of portfolio losses
- Neglecting acute risk leads to an underestimation of portfolio losses up to 82.2% Neglecting the tail component of acute risk (RP250) leads to an underestimation of portfolio losses up to 97.6%

Compared physical risk futures	**Underestimation range (%)**
Chronic vs. tail acute (asset-level, RP250)	73.2-79.3
Chronic vs. chronic and tail acute (asset-level, RP250)	78.8-82.2
Average acute (asset-level, EAI) vs. tail acute (asset-level, RP250)	96.7-97.4

Table: Underestimation of portfolio losses, scenario SSP3-RCP4.5, year 2040 (Bressan et al., 2022).

Asset-level data and underestimation of losses

- We compute results for the same firms as if asset information was not available, i.e. we measure physical risk at companies' MX HQ
- We quantify the underestimation of portfolio losses using firm-level instead of asset-level data
- Neglecting asset-level impacts leads to an underestimation of losses up to 70.8% for investors' portfolios

Case	**Underestimation range (%) firm-level vs. asset-level**
Acute RP250 (tail)	67.4-92.3
Chronic and acute RP250 (tail)	58.0-70.8

Table: Underestimation of portfolio losses (cont'd), scenario SSP3-RCP4.5, year 2040(Bressan et al., 2022).

Conclusions

- We introduce a **science-based methodology** to assess asset-level physical risks and loss cascades, with tail acute and chronic scenarios
- The methodology includes a CDDM model to integrate climate physical risk into **financial valuation adjustment** (stocks)
- Results:
  - neglecting the **tail component** of acute risk can lead to up to 97% underestimation of portfolio losses
  - neglecting **asset-level data** can lead to up to 70% underestimation of portfolio losses
- Thus, considering tail risk and asset-level info is crucial for **climate financial risk management** and to inform **adaptation finance**.

References:

Acharya, V. V., Johnson, T., Sundaresan, S., & Tomunen, T. (2022). *Is physical climate risk priced? evidence from regional variation in exposure to heat stress* (tech. rep.). National Bureau of Economic Research.

Battiston, S., Monasterolo, I., Riahi, K., & van Ruijven, B. J. (2021). Accounting for finance is key for climate mitigation pathways. *Science*, *372*(6545), 918–920.

Beirne, J., Renzhi, N., & Volz, U. (2021). Bracing for the typhoon: climate change and sovereign risk in Southeast Asia. *Sustainable Development*, *29*(3), 537–551.

Bressan, G., Duranovic, A., Monasterolo, I., & Battiston, S. (2022). Asset-level climate physical risk assessment and cascading financial losses. *Available at SSRN.*

Dunz, N., Hrast Essenfelder, A., Mazzocchetti, A., Monasterolo, I., & Raberto, M. (2021). Compounding COVID-19 and climate risks: the interplay of banks' lending and government's policy in the shock recovery. *Journal of Banking & Finance*, 106306.

Garbarino, N., & Guin, B. (2021). High water, no marks? biased lending after extreme weather. *Journal of Financial Stability*, *54*, 100874.

Garcia-Bernardo, J., Fichtner, J., Takes, F. W., & Heemskerk, E. M. (2017). Uncovering offshore financial centers: conduits and sinks in the global corporate ownership network. *Scientific Reports*, *7*(1), 1–10.

GCA. (2021). *Global Center on Adaptation. Adaptation finance in the context of Covid-19. The role of development finance in promoting a resilient recovery* (tech. rep.). Rotterdam.

Giglio, S., Kelly, B., & Stroebel, J. (2021). Climate finance. *Annual Review of Financial Economics*, *13*, 15–36.

Gostlow, G. (2021). Pricing physical climate risk in the cross-section of returns. *Available at SSRN 3501013*.

Hain, L. I., Kölbel, J. F., & Leippold, M. (2022). Let's get physical: comparing metrics of physical climate risk. *Finance Research Letters*, 102406.

Hallegatte, S., Rentschler, J., & Rozenberg, J. (2020). *Adaptation Principles: a guide for designing strategies for climate change adaptation and resilience.* (tech. rep.). World Bank, Washington, DC.

Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., Rasmussen, D. J., Muir-Wood, R., Wilson, P., Oppenheimer, M., Larsen, K., & Houser, T. (2017). Estimating economic damage from climate change in the united states. *Science*, *356*(6345), 1362–1369.

Kreibiehl, S., Yong Jung, T., Battiston, S., Carvajal, P. E., Clapp, C., Dasgupta, D., Dube, N., Jachnik, R., Morita, K., Samargandi, N., & Williams, M. (2022). Investment and finance. In P. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi,

A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate change 2022: mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Mullan, M., & Ranger, N. (2022). Climate-resilient finance and investment. *OECD Environment Working Papers*, (196).

Nguyen, D. D., Ongena, S., Qi, S., & Sila, V. (2022). Climate change risk and the cost of mortgage credit. *Review of Finance*, 1–41.

UNEP. (2021). *United Nations Environment Programme. Adaptation Gap Report 2021: the gathering storm – Adapting to climate change in a post-pandemic world* (tech. rep.). Nairobi.

Appendix

Asset-level probabilistic risk assessment - historical

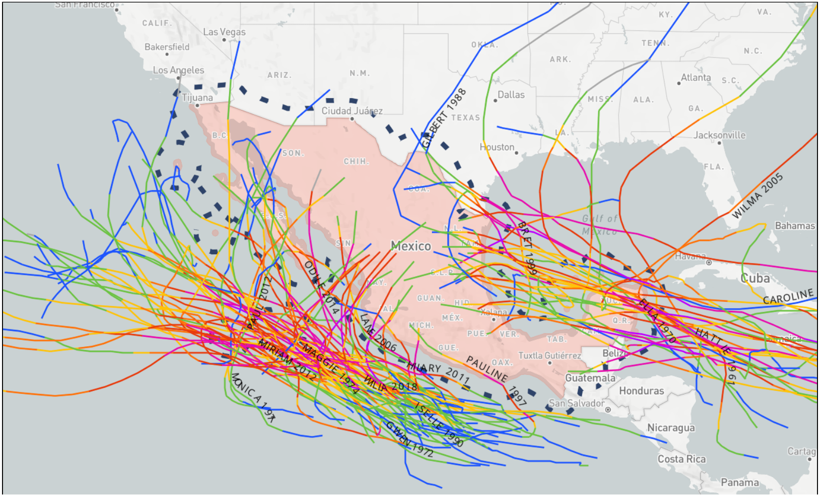


Figure: Historical data for tropical cyclones crossing Mexico. Source: NOAA.

Sample asset-level data: source structure

Asset-level data at source (LNG)

Country	Latitude	Longitude	Main project	Status	Start up	Shareholder/Owner	Type	Production capacity (mtpa)	[...]	Tanker berth ('000 m3 LNG)
Algeria	35.43	2.92	Project Ar.	Operational	1978	Company 1	Onshore	7.87		40-70
Algeria	35.43	2.92	Project Sk.	Operational	2013	Company 1	Onshore	4.50		
Angola	-9.40	20.30	Project An.	Operational	2013	Company 1, Company 2	Onshore	5.20		Up to 210
Argentina	-48.40	-68.29	Project BB.	Operational	2019	Company 4	FLNG	0.50		
Australia	-32.00	148.02	Project CM.	Cancelled		Company 5	FLNG	2.00		
Australia	-22.03	119.84	Project Cr.	Cancelled		Company 6, Company 7	FLNG			
Australia	-32.66	149.05	Project Da.1	Operational	2006	Company 8, Company 9	Onshore	3.70		89-145
Australia	[illegible]	[illegible]	[illegible]	[illegible]		Company 10	Onshore			

Asset-level data at source (mines)

Property ID	Commodity	Development stage	Coutnry	Latitude	Longitude	Status	Owner Name	Production capacity (tonnes)	Value	Start up
36055	Gold	Reserves D	Canada	54.82	-99.81	Inactive	Company 1	NA	23.00	NA
33835	Gold	Target Outl	Canada	51.09	-95.86	Inactive	Company 1	NA	NA	NA
37745	Gold	Reserves D	Canada	50.88	-95.38	Inactive	Company 1	NA	644.50	NA
25942	Gold	Residual Pr	Canada	51.02	-95.64	Active	Company 1	NA	2086.94	2009
30377	Gold	Reserves D	Canada	48.72	-81.18	Active	Company 1	NA	444.72	NA
58164	Gold	Exploratior	Canada	48.43	-81.43	Active	Company 1	NA	NA	NA
79749	Nickel	Target Outl	Australia	-28.51	122.23	Temporarily On Hold	Company 2	NA	NA	NA
36964	Gold	Exploratior	Ghana	4.92	-2.03	Active	Company 2	NA	NA	NA
50681	Coal	Operating	Indonesia	3.52	117.84	Active	Company 3	7000000	21520.00	2013
40185	Coal	Constructic	Australia	-22.03	146.32	Active	Company 3	100000000	888320.00	NA
49752	[illegible]	[illegible]	[illegible]	21.08	84.88	Inactive	Company 3	40000000	127120.00	NA
49749	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Asset-level data at source (real estate)

Property ID	Owner ID	Percent Owned (%)	Primary Property Type	Property Size (sq. m.) - last available	Occupancy Rate (%) - last available	Address Line 1	City	Country	Latitude	Longitude
7283	103085	100	Shopping Center	20266.61	96	715 Crescent Street	Brockton	USA	42.08	-70.99
7292	103085	100	Shopping Center	9927.25	100	8 Mark Plaza	Edwardsville	USA	41.26	-75.91
7297	103085	100	Shopping Center	23752.80	95.1	873 New Loudon Road	Latham	USA	42.75	-73.76
7305	103085	100	Shopping Center	14518.79	100	801-833 East Walnut Stre	Lebanon	USA	40.34	-76.40
21685	103085	100	Shopping Center	16312.75	23	650 Old Willow Avenue	Honesdale	USA	41.55	-75.23
32938	103085	49	Shopping Center	28976.83	83	423 Tarrytown Road	White Plains	USA	41.04	-73.80
32939	103085	100	Shopping Center	8094.46	96.1	18-27 East Main Street	Smithtown	USA	40.85	-73.19
32940	103085	100	Shopping Center	11459.13	94.2	126 East Main Street	Smithtown	USA	40.85	-73.19

Asset-level datasets are **patchy** and follow **different standards** for available datafields, conventions, identifiers

Figure: Sample of asset-level data (LNG, mines, real estate; source data). Sources: Refinitiv, S&P.

Business-line data deep dive

Financial statements can be **manually reclassified** to extract companies' revenues by business line, a key input for assessment of climate risk – but this is **extremely time-consuming.**

Name of the company: Teck Resources Ltd
Industrial classification: NACE Rev.2 class 05.10 - 'Mining of lignite'
Total revenue (FY2019): 8997.91 million USD

millions USD	FY2019				
	Business units				
Product types	Steelmaking Coal	Copper	Zinc	Energy	Total
Steelmaking Coal	4163.44	-	-	-	4163.44
Copper	-	1627.07	-	-	1627.07
Zinc	-	122.90	1783.90	-	1906.80
Blended Bitumen	-	-	-	735.12	735.12
Silver	-	18.10	283.49	-	301.59
Lead	-	3.77	297.82	-	301.59
Other	-	89.72	263.89	-	353.61
Intra-segment	-	-	-391.31	-	-391.31
Total	**4163.44**	**1861.56**	**2237.79**	**735.12**	**8997.91**

ICES sectors	Revenue by ICES sector (million USD)	Revenue shares by ICES sector
Coal	4163.44	46%
Oil	735.12	8%
Other industries	3785.01	42%
Other	314.34	3%

Company-level view
- One company
- One sector of economic activity/industry
- One revenue figure

Business lines view
- One company
- Multiple business lines
- Multiple revenue shares reflecting relative importance of business lines

Machine learning can bridge the gap and lift the weight of manual work, allowing for a **scaling up** of the proposed approach.

Estimating revenue shares by business lines reflects the combination of two tasks:
- A **multi-label classification** problem, combining NLP with:
  - Binary relevance, classifier chains, etc.
  - Deep learning.
- A **regression** problem, to assign the corresponding revenue share.

The two tasks, potentially, can be combined and performed in **one-go**

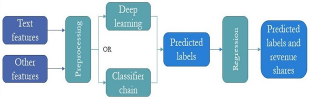


Figure: Business-lines view of a company and possible ML-based extension to automate the task (Bressan et al., 2022)

Cascading climate financial risks

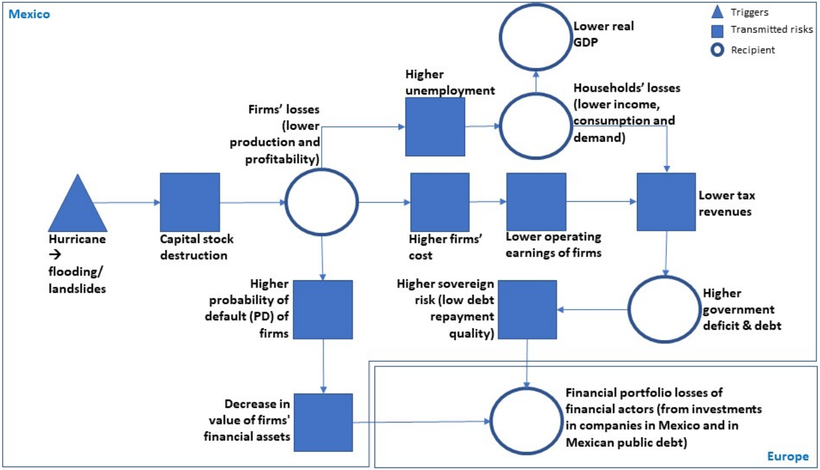


Figure: Cascading climate physical risk to the European financial system.

Cascading climate financial risks

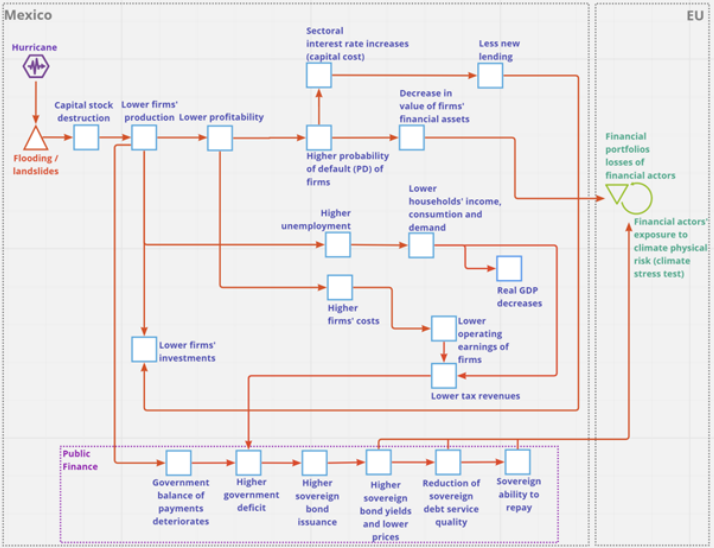


Figure: Cascading climate physical risk to the European financial system.