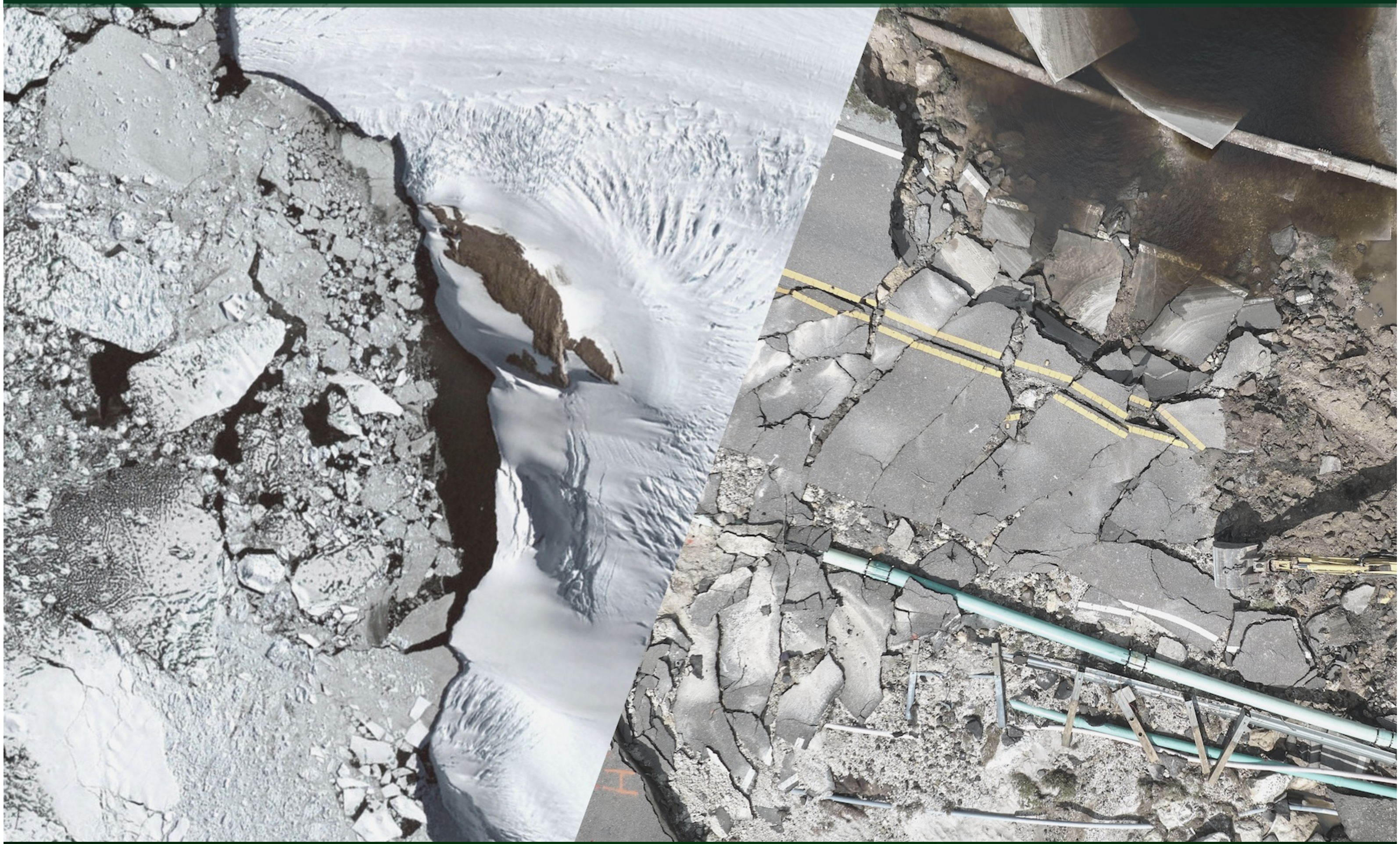
It's getting physical

Some investors in infrastructure could lose more than half of their portfolio to physical climate risks by 2050



EDHEC Infrastructure & Private Assets Research Institute

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About the EDHEC Infrastructure & Private Assets Research Institute

Since 2019, and with the support of the Monetary Authority of Singapore (MAS), the EDHEC Infrastructure & Private Assets Research Institute has been developing ground-breaking research to document the risks and financial performance of investments in unlisted infrastructure equity and debt, as well as the climate impacts and risks of these essential assets. The indices and benchmarks produced by EDHEC are recognised by the European Securities and Markets Authority (ESMA) and used by investors representing USD400bn in infrastructure assets under management. The data produced by the institute is grounded in modern financial theory and the principles of fair value accounting, which are key pillars of sound financial risk management. Through its work, the institute has shown that it is possible to measure market dynamics in private and illiquid markets and produce credible measures of the risk-adjusted performance of private assets that makes them comparable to other asset classes. The same data is used by policy makers and prudential authorities including the G20, the OECD, IAIS, and more. Since 2023, new research efforts have allowed this financial database to be complemented with a unique set of climate data for unlisted infrastructure, which is at the heart of the climate transition, since it represents more than 60% of total Scope 1, 2, and 3 greenhouse gas emissions. Whether it involves a dedicated green taxonomy or measurement of the exposure and quantification of transition and physical risk at the sub-asset level, the granularity, depth, and quality of the EDHEC Infrastructure & Private Assets data make it a unique reference point for public and private decision-makers.

EDHEC Business School's integration of climate change and sustainability issues into financial decisions is not limited to the infrastructure asset class. As a leading academic institution committed to future generations, EDHEC is deeply engaged in producing research that can contribute to the fight against climate change. While the work of the EDHEC Infrastructure & Private Assets Institute aims to make the future consequences of climate change fathomable for investors in private markets, EDHEC-Risk Climate Impact Institute is advancing modelling of climate-related financial risks and extending climate scenario analysis to serve investors across asset classes as well as non-financial corporations. It is also seeking to apply financial innovation to the facilitation of mitigation and adaptation investments.

The two research institutes are also cooperating to develop a deep knowledge base on climate change vulnerabilities affecting real assets, the role of technology in mitigating climate risks, and current and future technological options for decarbonising economic activities. This knowledge base bridges a key gap between extremely granular technical knowledge and high-level policy and investment views that often remain oblivious to what low-carbon alignment can or cannot achieve. This work provides a reality check on claims of net zero.

Executive Summary

This research note shows that the physical risks created by climate change are not limited to a distant future for investors in infrastructure, some of whom could well lose more than 50% of the value of their portfolio to physical climate risk before 2050 in the event of runaway climate change. Moreover, the average investor will also lose twice as much to extreme weather, mostly in OECD countries, compared to a low carbon scenario.

The numbers are significant: over the past two decades, institutional investors have increasingly allocated capital to private, mostly unlisted, infrastructure companies like toll roads, airports, power plants and pipelines. infraMetrics tracks a universe representing approximately USD4.1 trillion of enterprise value and USD2.2 trillion of market capitalisation at current market prices in 25 key markets.

Floods and storms are the most common types of climate-related events, but extreme temperature events are also on the rise as global warming increasing their frequency and intensity. If climate change speeds up, these trends are also forecast to become more frequent and more severe.nUsing a very granular database of asset-level physical risk estimates and financial data, we find that the impact of runaway Climate Change on the value of infrastructure investments before 2050 is significant. We also find that if no serious measures are taken, financial losses from physical risk (which are never zero) would be twice as high than in a low carbon scenario, for all investors.

In this note, we describe our approach to measure baseline physical risks (today) and how physical risks would materialise from that baseline in different climate scenarios in terms of their impact on cash flows and discount rates at the asset level. We also look at how physical risks, despite being asset specific, are not easily diversified for most investors, some of whom could have a high concentration of such risks in their portfolios. To analyse the low diversification profile of portfolios and physical risk exposure, we built thousands of random portfolios and examine the degree of extreme risk in several climate scenarios. This is a novel approach in the analysis of physical risk.

Our research shows that the effect of extreme climate events is negative across all sectors. The cost of physical risks within the "Current Policies" scenario represents, on average, 4.4% of the total NAV of the assets in our reference database by 2050. However, the maximum losses could be much higher. The most severely impacted sectors in terms of NAV are the Transport sector (with a maximum loss of -97%) and the Energy & Water Resources sector (with a maximum loss of -40%). The maximum NAV loss due to extreme climate events, on average cross all super class sectors (eight in total following the TICCS® classification), is -27%.

Moreover, most investors in infrastructure hold a few individual assets and therefore have potentially high concentration in physical risks. Investors who hold direct stakes in infrastructure assets, be they fund managers or asset owners, usually have fewer than 20 investments. The average asset owner typically has fewer than 10 direct stakes. As such, when an investor finds themselves exposed to the riskiest assets in the same portfolio, losses can mount to 27% in the orderly transition scenario and to 54% in the "Hot House" scenario.

2050 is still 30 years away and past the investment horizon of investment funds, but many are now exposed to much longer-term investments. Moreover, the next generation of funds will pick up the same assets.

Climate change risks are already material for a number of investors in infrastructure assets even if these are located in developed economies. This challenges the intuition of many investors that these risks would impact first and foremost the poorer populations of the global south. Instead, the reverse is true: more value will be destroyed in places where more valuable assets exist. It should also be noted that our loss estimates can be considered very conservative in the light of the very limited impact of physical risk on the economy implied by the scenario used by the Network for Greening of the Financial System (NGFS). A 'too little, too late' scenario, by which emissions keep rising and climate change happens faster, would show a rapidly decreasing value of infrastructure assets due to their loss of future revenues, itself the result of a less active economy, mostly due to chronic heat.

This focus on the materiality of the physical risks allows climate risk to be seen not solely as the result of a public policy decision but as a reality that, without action from all stakeholders, including governments, will have a very significant impact on the value of investments.

Authors

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Contents

1. Introduction

Unlucky investors in infrastructure could lose more than 50% of the value of their portfolio to physical climate risk by 2050 in the event of runaway climate change. The average investor could lose twice as much value due to extreme weather than in a low carbon scenario. These losses would also involve impact investments that are mostly located in OECD countries.

Climate Change is the rise of global temperatures above pre-industrial levels due to human activities and the release of greenhouse gases into the atmosphere. It materialises as the combination of chronic weather patterns e.g., heat, and extreme weather events e.g., floods, that can have a direct impact on the physical assets that enable economic activities, including infrastructure.

The adverse effects of climate change involve direct damage to assets and indirect impacts from supply chain disruption, both increasing companies' maintenance and repair costs and climate event-related insurance premiums. The financial performance of companies may also be affected by changes in water availability, sourcing, and quality; food security; and extreme temperature changes affecting organisations' premises, operations, supply chain, transport needs, and employee safety (TCFD, 2017).

Floods and storms are the most common types of climate-related events, accounting for 44% and 28% of all climate events from 2000 to 2019, respectively (UNODR, 2020). Furthermore, the UN Office for Disaster Risk Reduction (UNODR) reported that the number of major flood events has more than doubled, while the incidence of storms grew by 40% during the same period. Extreme temperature events accounted for 6% of all climate events during this period, and it was the third largest, by the count of occurrences, climate change-related event.

However, global warming is increasing the frequency and intensity of weather events. According to the Intergovernmental Panel on Climate Change (IPCC) (IPCC_AR, 2023), the frequency and intensity of weather events, such as heavy precipitation and heatwaves, have increased significantly since 1950. The frequency of marine heatwaves doubled from 1980, and the proportion of category 3–5 tropical cyclone occurrences has likely increased over the last four decades (IPCC_AR, 2023).

At 1.5°C global warming, heavy precipitation and flooding events are projected to intensify and become more frequent in most regions. At 2°C or above, these changes will expand to more regions and/or become more significant. Europe, for example, is expected to experience days above 35°C and 40°C above the world median in the near and long term (see Table 5). North America will experience precipitation levels higher than in Europe in the near (25% higher), medium (49% higher), and long term (47% higher). Other projected changes include the intensification of tropical cyclones and/or extratropical storms and weather increases in aridity and fire weather.

The importance of such "physical risks" is often downplayed because they are expected to occur mostly beyond the relevant horizon for most investors (after 2050) and to be specific to certain locations and asset types. Moreover, the perception that only less advanced economies would suffer from the physical consequences of Climate Change due to a lack of economic resilience, including in terms of infrastructure, is pervasive.

In this note, we show that holding this view would be misguided. Using a very granular database of asset-level physical risk estimates and financial data, we find that the impact of runaway Climate Change on the value of infrastructure investments before 2050 is significant, could be very high for some investors, and could lead to losses exceeding 50%, including in advanced economies. We also find that if no serious measures are taken to cope with Climate Change, financial losses from physical risk (which are never zero) would be twice as high than in a low carbon scenario, for *all* investors.

The rest of this note describes our approach and provides details of measurements of baseline physical risks (today), how physical risks would materialise from that baseline in different climate scenarios in terms of cash flows and discount rates at the asset level. Finally, we examine how physical risks, despite being asset specific, are not easily diversified for most investors, some of whom could have a high concentration of such risks in their portfolios.

2. Approach & key findings

To determine the potential impact of physical risks for investors in infrastructure by 2050 in the event of a "Hot House" climate scenario, we follow these steps:

1. We first measure baseline physical risks (today) at the asset level for hundreds of individual infrastructure investments currently held in the portfolios of institutional investors. Using very granular geographic, hazard and vulnerability data, we find a large dispersion of exposures to baseline physical risks due to storms, floods, and cyclones, from 0 to 86% Value-at-Risk (at the 99% confidence level).

2. We then estimate the impact of physical risks on infrastructure asset values by 2050 in the so-called "Hot House" Network for Greening the Financial System (NGFS) scenarios, that is, climate scenarios with limited to no transition to a low carbon economy and the most physical risk. We focus on the scenario called "Current Policies", which is the most easily interpreted and which is the one that will occur if nothing serious is done to really ensure transition to a low-carbon economy. Despite a limited impact of physical risk at the macro-level by 2050 in NGFS scenarios, we find that physical risk creates a range of negative outcomes at the level of individual infrastructure assets, long before 2050. On average, valuations drop by 10%, and some outcomes are very negative: some assets' valuations can drop by close to 100% in the most extreme cases.

3. We then examine the potential portfolio diversification of asset-level physical risks. While these risks tend to be independent due to their spatial nature and the dispersion of infrastructure assets in space, with climate change, they become linked by increases in both frequency and severity of such events in most locations. With no upside to physical risks (to offset losses), diversification can only be achieved through investing in a larger number of assets that are less exposed to such risks. However, most investors in infrastructure do not hold a representative portfolio, but instead hold a few individual assets and have therefore potentially high concentration in physical risks. We find that many investors who hold direct stakes in infrastructure assets, be they fund managers or asset owners, usually have fewer than 20 investments today. The average asset owner typically has fewer than 10 direct stakes.

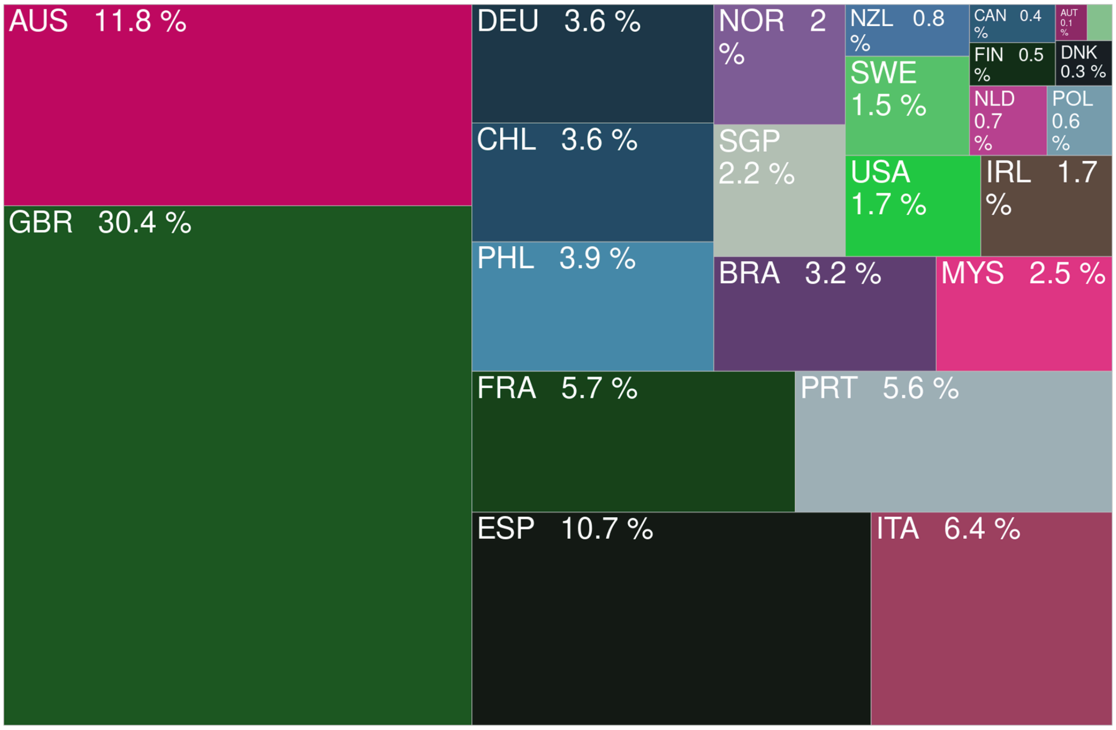
4. To measure the likely losses of investors in infrastructure due to physical risk in a Hot House scenario, we build thousands of random portfolios using hundreds of assets for which we have estimated the impact of physical risk by 2050 in the Hot House scenario. We find that some unlucky investors find themselves exposed to the riskier assets in terms of physical risk and could lose more than 50% of their portfolio before 2050. We also show that a typical investor with 10-15 investments would lose about 25% of portfolio value to physical risk, or twice as much as under a low carbon scenario.

We return to each step below.

Investment Data

Over the past few decades, institutional investors have increasingly allocated capital to private, mostly unlisted, infrastructure companies like toll roads, airports, power plants and pipelines. Today, this investment represents approximately USD4.1T of enterprise value and USD2.2T of

Figure 1: Country of location and global share of assets in the sample of physical risk data



Source: infraMetrics®

market capitalisation at current market prices in 25 key markets, according to InfraMetrics, a data provider.

The sample of infrastructure companies for which we analyse the impact of physical risk in this note includes 700+ companies for which asset-level climate risk estimates are available in the infraMetrics data platform. This sample is representative of the above mentioned universe both in terms of geography and TICCS segments i.e., business model, activity and corporate structure and represents c.USD850b of enterprise value.

As a result, most of our sample is located in advanced economies as illustrated by Figure 1, which shows the countries in which the assets included in this analysis are located: North America, Europe, Australia and some parts of Latin America and South-East Asia.

3. Baseline: Physical Risks Today

The physical risks created by Climate Change are the result of future changes in weather patterns. Still, the assessment of the impact of such changes requires a starting point, or baseline i.e., the exposure of an asset today.

By 2050, infrastructure assets are mostly exposed to acute events of flooding and storms. The acute impact of heat on asset life is limited and its impact on revenues due to operational stoppages are also very limited and mostly only relevant to Australian assets. In this note, we focus on floods, storms, and cyclones.

Baseline physical risk is estimated by combining high-granularity asset-level data taking into account the exact physical footprint of the assets and the different types of physical components involved e.g., runways, taxiways and terminal buildings for an airport. This data is then combined with high-resolution hazard model data such as a 30x30m flood model for a 100-year event (a 1% probability event today) and a damage function, which is specific to the type of asset and hazard and determines to what extent a certain event would damage or destroy the asset in a particular location. Once the proportional physical damage for a given event today is known, it can be converted into a financial value (as a share of total assets) and into an expected cost, given the baseline probability of the extreme weather event. This is detailed in Appendix A.1 and illustrated in Figure 2 for an airport in the UK.

One of the important findings of this analysis of baseline physical risks is their dispersion: while many infrastructure assets have limited to no exposure to extreme weather events today, a large number of other such assets do, and sometimes have quite large exposures.

Blanc-Brude and Marcelo (2022) have shown in a study dedicated to US airports that some assets are already exposed to almost complete annihilation by floods. Famously, the Miami airport, which can be c.75% destroyed by a 2% probability flood event today. [1]

Figure 3 illustrates this fact for our sample of 500+ infrastructure companies located primarily in OECD countries and across all infrastructure activity sectors. We see that some assets are already exposed to large risks, irrespective of size or sector. In other words, the exposure to baseline physical risk is highly asset specific and as such, it can be found anywhere in infrastructure portfolios. This high level of dispersion and sometimes very high level of risk present in baseline estimates is also illustrated in table 4 which shows the range of estimated damage factors for floods, storms, and cyclones (see Appendix A.1).

Next, we consider how climate change might impact the level of physical risk in infrastructure investors' portfolios by 2050.

1 - In a now infamous speech, the former head of sustainable investment at HSBC AM, Stuart Kirk, said, "who cares if Miami is under 6 foot of water?", arguing that climate change was not a material risk for investors. EDHEC published a response demonstrating the fallacy of his positions.

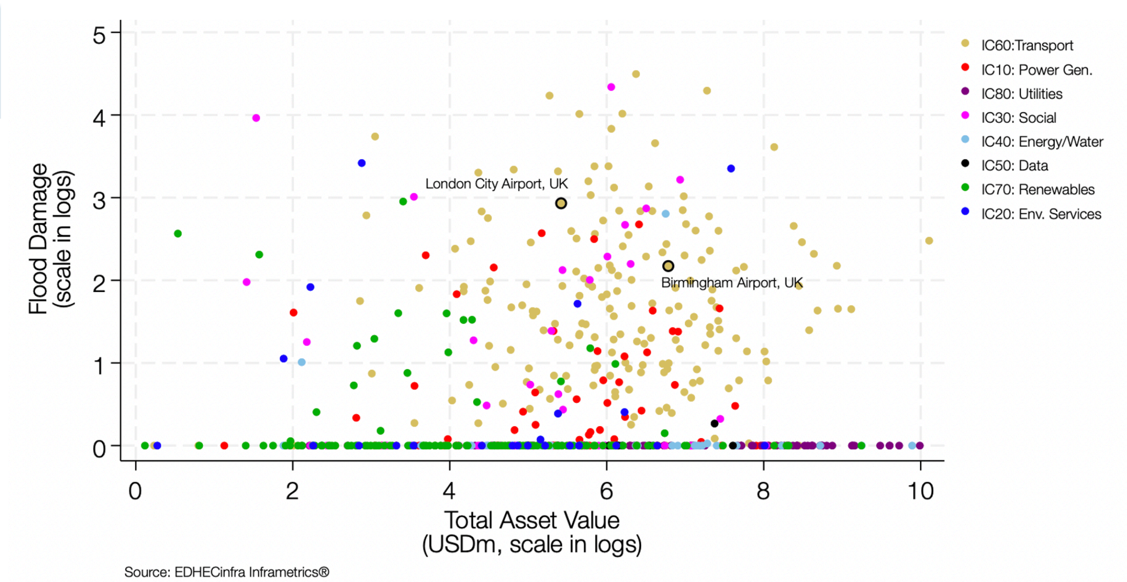
Figure 2: Baseline Flood Risk Metrics (100-year event), Birmingham Airport, UK

Physical Risk Metrics

- Physical Damage from a 100-year flood event: 7.8%
- PVaR (*Damage* X *Total Asset Value*): USD 68.7 million
- Expected loss from a 100-year flood event (*PVaR* X *1%*): USD 0.68 million

Source: infraMetrics®

Figure 3: Baseline Physical Value at Risk, 100-year flood



Source: infraMetrics®

4. Hot House: Physical Risk and Climate Change by 2050

To understand the impact of climate change on physical risks and asset values for investors in infrastructure by 2050, we take the following approach: we use the highest physical risk scenario produced by the Network for Greening the Financial System or NGFS, a group of prudential and international institutions that set the standard for the modelling of the economic consequences of climate change (More details on NGFS scenarios are provided in Appendix A.2).

In this "Hot House/Current Policies" scenario, which corresponds to the probable trajectory if we continue with the policies implemented currently and if no serious measure is taken by all stakeholders to dramatically reverse the current trend in greenhouse gas emissions, we estimate the future asset value of several hundred infrastructure companies by projecting their future cash flows and estimating their future discount rates based on the expected evolution of their financials. We then measure the impact on valuations of the baseline climate exposures described above and of their expected evolution in this scenario. The process followed to project and compute the future cash flows and financials of each firm is described in detail in Appendix A.3. We summarise the key points here:

- **Calibration**: Each NGFS scenario produces forecasts of GDP, inflation, carbon prices, interest rates etc. We calibrate the sensitivity of the asset financials to changes in macro-economic variables, which allows us to forecast the value of each investment's total assets, revenues, OPEX, profits, etc. in the current policies (CP) scenario. See Appendix A.3.1 for details.

- **Projecting cash flows**: we take into account the impact of physical risk by reducing the value of total assets and of revenues and by increasing borrowing (leverage) to cover higher capital costs. Appendix A.3.2 describes the exact relationship between expected damages and financial variables.

  Initially, the impact of physical risk is simply the expected cost of physical risk described above in the baseline case: the combination of a probability of extreme weather event and its damage. In a CP scenario, the probability of extreme weather events and their impact are expected to increase compared to today, which also increases the impact of these risks on financials.

- **Discounting**: the future discount rate in the scenario is estimated using the infraMetrics equity risk premia model, which takes several key financial metrics as its inputs to represent traditional pricing factors: total assets, leverage, profits, etc (see details in Appendix A.4 on the infraMetrics model).

Even in the Hot House case, these scenarios (and others) posit a limited impact of climate-change induced physical risks at the macroeconomic levels before 2050. In the Hot House scenario carbon emissions are stabilised but do not decrease below their current level. Hence, at the macro level, the effects of increasing global mean temperatures on productivity and economic output (GDP) only compound after 2050. As a result, GDP grows fast under both orderly and Hot House scenarios until 2050 as shown in table 6. It follows that the initial

Table 1: Average Impact of Physical Risk on NAV within the Current Policies NGFS Scenario in different TICCS segments

TICCS®	Activity Name	Mean	Min	Max
IC10	Power Generation x-Renewables	-1.5%	0.0%	-6.4%
IC20	Environmental Services	-2.2%	-0.1%	-18.2%
IC30	Social Infrastructure	-2.4%	0.0%	-13.1%
IC40	Energy and Water Resources	-7.5%	-0.9%	-40.7%
IC50	Data Infrastructure	-3.7%	-0.4%	-5.7%
IC60	Transport	-10.9%	0.0%	-97.8%
IC70	Renewable Power	-1.5%	-0.1%	-7.2%
IC80	Network Utilities	-5.4%	-0.5%	-26.1%
	AVERAGE	**-4.4%**	**-0.3%**	**-26.9%**

calibration described above has a limited impact on the future asset values since the CP scenario shows continued increased in GDP and limited inflation. There is indeed no "macro-effect" of physical risk before 2050.

Nevertheless, individual climate risks are expected to continue to evolve even before 2050. As a result, infrastructure companies exposed to baseline physical risks see their probability and intensity increase continuously in a Hot House world: the global mean temperature increase exceeds 3°C in the Current Policies scenario.

According to IPCC, in an RCP7.0 world i.e., the NGFS Hot House world, physical risks are multiplied by about 2 by 2050, and by 4 to 6 by the end of the century. These numbers are consistent across various chronic risks, including sea level rise and sea surface temperature, snowfall and number of frost days, maximum temperatures and number of days beyond 40°C.

These numbers are consistent with a yearly growth of 2 to 2.5%. Other research suggests that river flood damage in Europe could rise by a factor of about 6 $\pm$ 2 by the end of the century, in the absence of climate mitigation (i.e., an expected 3°C GMT increase) see Dottori et al. (2023). This is consistent with a growth of about 2.3 $\pm$ 0.5% per year until 2100. Consistently with these assessments, we thus assume that *damages* and *probabilities* grow by 2.5% per year on average in the Current Policies scenario (3.2°C GMT increase, see AppendixA.2) with some regional variations also sourced from IPCC.

To measure this impact, we estimate asset values in the CP scenario with and without asset-level damage factors for floods, storms, and cyclones. Thus, we control for the effect of the scenario at the macro level (which includes some but limited physical risk) and isolate the effect of micro-level factors, given the expected increase in the intensity and frequency of hazards.

At the microeconomic level, the cost of physical risks within the CP scenario represents, on average, 4.4% of the total NAV of the assets in our *reference* database by 2050, with important variations across sectors, as shown in Table 1. The average maximum loss is -27% and we see that the effect of extreme climate events is negative across all sectors, impacting the NAV of transport (-10% on average with a maximum of -97%) and the energy and water resources sector (-7% on average, with a maximum of -40%) the most. For example, the negative impact of physical risk on NAV in the transport sector would be four times greater than in the renewable power sector (at a -5.5% loss).

These results are consistent with the notion that certain sectors are ultimately more exposed to climate hazards, like transport assets. Still, we see that all sectors are impacted by physical risks even before 2050 i.e., before the impact of physical risk at the macro level starts reducing asset values through the main business channel: the demand for infrastructure services.

Moreover, while the average loss of value due to physical risk alone reached 24% for the most exposed segment (i.e., transport assets), individual cases can be much larger, as table 4 shows (Appendix).

Hence, it is possible for some investors to be exposed to very significant climate risks despite these being considered limited in aggregate before 2050.

To determine the extent to which investor may be exposed to such risk, we first review the number of assets held by investors in infrastructure companies to determine a typical portfolio profile in terms of number of assets and sector exposures and propose an analysis using random combinations of assets to show how risky an infrastructure portfolio can be when it comes to physical risk.

5. The Concentration of Physical Risks

Infrastructure investors typically do not have a lot of assets in a given portfolio. Of course, some may invest through funds and increase the number of underlying assets to which they are exposed, but individual managers or direct investors tend to have only a few assets in a portfolio. It follows that infrastructure portfolios are generally not very diversified, with a limited average number of assets directly held per investor.

Our review of the data (see Table 3) suggests that asset managers hold only a few assets (23 infrastructure assets on average) but across multiple funds, whereas asset owners directly hold even fewer assets (8 on average). We see that asset owners typically have a dozen assets or fewer while managers who invest through one or multiple funds have more assets in their global portfolio (all funds combined) but still not a large number of assets.

This suggests that even if assets had equal weights in the portfolio, which is unlikely, directly held individual assets in an asset owner portfolio would typically make up at least 12.5% of the portfolio's value (assuming 8 assets on average). Therefore, it could only take one or two assets to be significantly exposed to physical risk. In practice, infrastructure portfolios can be highly concentrated in a very small number of large assets e.g., utilities, and some much smaller ones e.g., wind farms.

Of course, infrastructure assets are usually located in different places and as such the correlation between extreme weather events for the assets in a portfolio is likely to be very low in the baseline. Still, with climate change, the conditional correlation of these events must increase since their probability increases simultaneously and for the same reason (climate change).

It remains that direct infrastructure portfolios, whether they are funds or direct investments, remain heavily under-diversified.

To capture this low diversification profile, we build thousands of random portfolios of the 500+ assets we can price in the Current Policy (Hot House) and the Below 2°C (Orderly) scenario and examine the degree of extreme risk (max portfolio loss) in the two scenarios depending on the number of assets in the portfolio. This is a novel approach in the analysis of physical risk. The methodology to create random portfolios is derived from the infraMetrics fund benchmark and is described in Appendix A.5.

Table 2 and Figure 4 show the range of maximum losses due to physical risk: the difference in value by 2050 between the same portfolios with and without asset-level physical risks. For a given portfolio size, which varies between 5 and 20 assets, the level of losses solely due to physical risk factors is twice as large in the CP scenario, due to the increase in the intensity and frequency of weather-related damages.

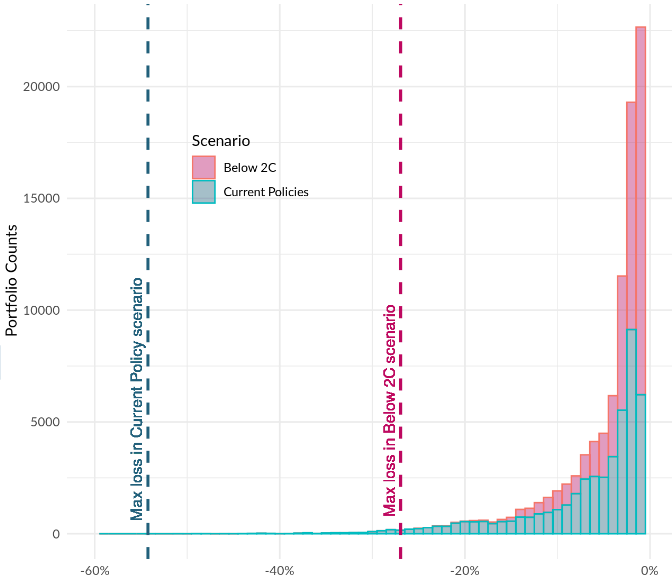
In the most extreme cases, when an investor finds themselves exposed to the riskiest assets in the same portfolio, losses can mount to 27% in the orderly transition scenario and to 54% in the Hot House scenario. Figure 5 illustrates these results for simulations using different portfolio vintages that would be fully invested by 2022.

In other words, an investor that started to build a portfolio or a fund in 2018 and would be fully invested by 2022 and planning to keep assets for another 30 years would be exposed to losses solely due to physical risk ranging from approximately -50% to -10% depending on the number of assets in the portfolio.

Table 2: Maximum, mean, and minimum portfolio loss in simulations (5 vintages)

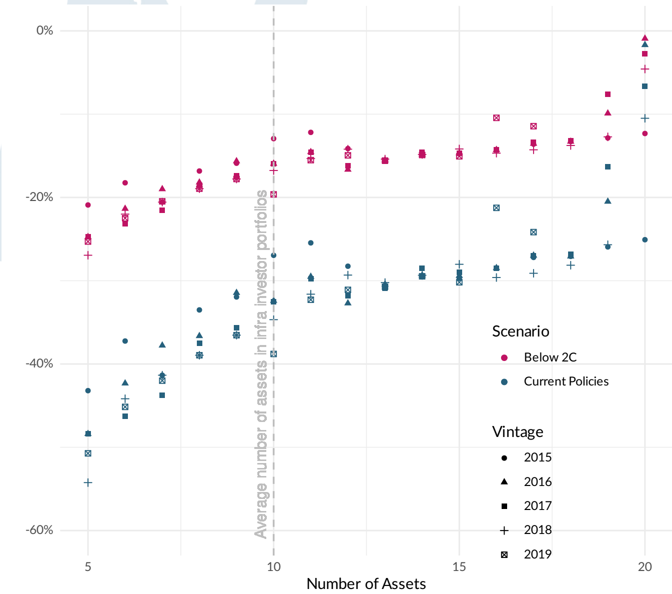
Scenario	Extreme Loss	Mean Loss	Min Loss	N
Below 2ºC	-27%	-3%	-0.2%	45413
Current Policies	-54%	-7%	-0.3%	45413

Figure 4: Histogram of portfolio losses due to physical risk by or before 2050



Source: infraMetrics®

Figure 5: Extreme Portfolio Loss due to physical risk by or before 2050



Source: infraMetrics®

Table 3: Average number of directly held assets in portfolios of different investor peer groups

	Mean Number of Direct Stakes in infrastructure Assets Per Investor	Mean Allocation to Infrastructure Equity	Number of Investors Surveyed
Insurers	5	3%	30
Pension funds	8	7%	66
Sovereign Wealth Funds	12	4%	14
Infra-only Managers	29	100%	107
Multi-Alts Managers	17	23%	187
Total	17	45%	404

Source: infraMetrics Investor Peer Group Research, 2023

6. Conclusions

This note highlights the importance of physical risks and accurate physical risk data for investors in infrastructure, even before 2050, as long as there is some Climate Change.

Of course, 2050 is still 30 years away and past the investment horizon of a number of investors, especially the ubiquitous 10-year investment funds. However, many investors are now exposed to longer-term investments through 20-25-year and evergreen funds, as well as direct investments that are meant to be held to maturity. Moreover, the same LPs who are currently invested in 10-year funds, will find themselves exposed to the same assets in the next generation of infrastructure funds, be they follow-on funds or under new management.

The Task Force on Climate-related Financial Disclosures (TCFD) requires the reporting of material physical risks precisely because these can be material and will necessarily increase in a Hot House world. With this note we have shown that such risks are already material for a number of investors in infrastructure assets even if these are located in developed economies. This materiality in advanced economies, which are mostly in the northern hemisphere, challenges the intuition of many investors and economists that these economic risks impact first and foremost the poorer populations of the global south. Instead, the reverse is true: more value will be destroyed in places where more valuable assets exist.

It should also be noted that our loss estimates can be considered very conservative in the light of the very limited impact of physical risk on the economy implied by the NGFS scenario. A 'too little, too late' scenario by which emissions keep rising and climate change happens faster, does not currently exist in the NGFS data, but would show a rapidly decreasing value of infrastructure assets due to their loss of future revenues, itself the result of a less active economy, mostly due to chronic heat.

Finally, this focus on the materiality of the physical risks allows climate risk to be seen not solely as the result of a public policy decision, as is often the perception for transition risk, which only exists if there is a consensus between governments to tax carbon emissions, but as a reality that, without action from all stakeholders, including governments, will have a very significant impact on the value of investments.

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A. Appendices

A.1 Asset-Level Baseline Physical Risk

To estimate the baseline (contemporary) physical risk exposures of individual infrastructure assets we follow a three-level approach:

First, each asset in the infraMetrics' *reference* dataset is geolocated, and their corresponding physical footprints or shape, including their main physical components, are extracted as geospatial shapefiles.

In parallel, high-resolution hazard models, including floods, extratropical storms, and tropical cyclones across different return periods (100, 50, and 30 years), are transformed into physical damage maps using asset-type damage functions. Damage functions describe the relationship between hazard intensity (e.g., water depth for flooding and wind speed for storms) and expected physical damage. We identified damage functions for 34 asset types.

Second, we use the assets' shapefiles mentioned above to select their corresponding damage values per type of climate hazard from the damage maps generated in the previous step. For example, we extract all the 100-year flood damage values within the shape or polygon representing a given asset (e.g., an airport or a coal-fired power plant) to calculate its average physical damage (see Figure 6).

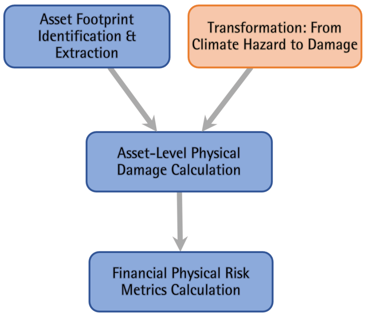
Finally, financial physical risk metrics including physical value at risk (PVaR) and expected loses are calculated by combining the damages (i.e., flood-, cyclone-, and extratropical storm-related) at the asset-level from the previous step with the infraMetrics proprietary financial data for the *reference* dataset. To calculate PVaR and expected losses, we use the total asset book value of each asset. As an example, consider the portfolio of a pension fund that includes 17 assets, two of which (London City Airport and Birmingham Airport, shown in Figure 3) are exposed to 100-year flood events (18% and 8% potential damage, respectively). If these risks materialised together today, they would cost in aggregate US$190 million or 14% of the value of the equity value of the firms, that is, close to 3% of the value of the portfolio.

While infrastructure assets are not all exposed to flood or storm risks, when looking at the asset level, individual variations are large as shown in table 4, meaning that for infrastructure investors, if their portfolios are highly exposed to climate events, the consequences could be much worse. Indeed, flood, cyclone, and extratropical expected damages for the 99% percentile in 2020 exceeded 52%, 17%, and 9%, respectively. Moreover, within this percentile, the expected damage could have been 86%, 18%, and 27% for the most exposed assets. In 2050, combined damage in the 'Hot House' scenario could reach 100% for the 99% percentile.

A.2 NGFS Climate Scenarios

The Network for Greening the Financial System (NGFS) developed a set of six reference climate scenarios that serve as a common ground for financial institutions and regulators to assess and manage financial risks and opportunities associated with climate change. All six scenarios share a common set of assumptions that make a "middle of the road" narrative where social, economic, and technological trends do not shift markedly from historical patterns. This narrative is called the "Shared Socioeconomic Pathway 2" (SSP2). In short, SSP2 assumes that global population growth gradually declines but remains positive, the world's economy continues to grow at a moderate pace, income gaps between regions

Figure 6: Physical Risk Metrics Approach



Source: infraMetrics®

Table 4: Distribution of Physical Risk Damages (Flood, Cyclone, Extratropical Storm) for 500+ infrastructure companies

	Hot House Scenario (All Climate Events)	Baseline 2020 Climate Events (100-year events)			
Percentile	**Combined damage** %	**Flood Damage** %	**Cyclone Damage** %	**Storms Damage** %	
25%	10.5%	0.0%	0.0%	0.0%	
50%	12.3%	0.0%	0.0%	0.0%	
75%	18.0%	3.0%	0.0%	1.0%	
90%	34.7%	9.0%	0.0%	2.0%	
95%	52.6%	16.0%	2.0%	4.0%	
99%	100.0%	52.0%	17.0%	9.0%	
Min	0.0%	0.0%	0.0%	0.0%	
Mean	18.7%	3.4%	1.0%	1.0%	
Max	100.0%	86.0%	18.0%	27.0%	

gradually decrease, and emissions continue to increase until the end of the century. Limited global efforts are foreseen to mitigate climate change.

The NGFS scenarios complement the SSP2's assumptions with scenario-specific climate policies. In practice, climate policies are proxied as a carbon tax, of which severity, time of implementation, and coordination across sectors and countries differ across scenarios. The pace of technological development and levels of Carbon Dioxide Removal technologies also differ across scenarios. NGFS scenarios are paired in 3 categories that represent different levels of climate-related risks (transition risks VS physical risks):

- **Orderly scenarios**: global warming remains contained (low physical risks) while avoiding heavy transition risks. To achieve this, climate policies are applied immediately and in a coordinated manner.
- **Disorderly scenarios**: policies are applied either too late (Delayed Transition) or in a disorganised manner (Divergent Net Zero). Containing global warming below 2°C therefore requires much stronger policies than in the orderly scenarios. While containing physical risks, these scenarios thus entail high transition risks.
- **Hot House World scenarios**: climate policies remain the same as they are today (Current Policies), or become more stringent, but at every country's discretion (Nationally Determined Contributions or NDC). Transition risks are low, but at the cost of high physical risks. Global warming is not contained.

It should be noted that due to their reliance on SSP2 ("middle of the road") none of the NGFS scenarios are truly a worst case. With less optimistic assumptions about the availability of certain technologies like Carbon Capture on an industrial scale, the same scenarios would produce much less positive economic forecasts.

A.3 Forecasting of Asset-Level Financials within NGFS Scenarios

Our projections of the impact of climate change on asset values are based on the NGFS scenarios: a series of climate policy scenarios built on top of a socio-economic narrative (SSP2) and several climate change pathway scenarios (RCPs). These scenarios fall into three groups: either 1/ an order transition with limited transition risk and limited physical risk, 2/ a disorderly transition, which increases the uncertainty of the policy pathway and its consequences, is more much costly to the economy, but also achieves limited physical risks, or 3/ a 'Hot House world' in which climate policy ambitions are muted and climate change does take place i.e., physical risk increases.

We introduce a model loosely inspired by Alogoskoufis et al. (2021) consisting of two parts: (i) a calibration part based on historical data, where we regress equations relating financial and macroeconomic variables (GDP and Inflation); and (ii) a projection part where we integrate climate risks into the calibrated equations to make scenario-dependent projections of the financial variables.

A.3.1 Calibration of the model equations

The calibration part includes 3 regressions for Total Assets, Revenues, and Operating Expenses (OPEX). The models use GDP and Inflation as regressors. To ensure stationarity and thus avoid spurious correlations, we consider the growth rates of all the variables rather than their raw values, except for Inflation. We then log-transform the variables to better estimate elasticities, after topping them by 1 to limit the occurrence of negative numbers.

Corporate and Project companies

Infrastructure companies belong to two main categories: Corporate companies are multi-project firms akin to corporate-governance structures found in other industrial sectors, while Project companies are single-project or project-financed firms with a limited lifetime (more details here). Because both entities can exhibit fundamental differences in behaviour, we perform separate regression analyses. We find that the same model structure applies to both, except for a key difference in the equation for Total Assets. However, and expectedly, we find important differences in the regression coefficients for both categories and relatedly in the projections of financial variables.

Total Assets

We assume that Total Assets follow an auto-regressive pattern, and that their growth is correlated with GDP growth and Inflation. Regression analysis support these assumptions (see Table 5). For Corporate companies, the equation for Total Assets reads:

$$\begin{aligned} \mathit{Total\ Assets}^{i,t} = \alpha + \beta_1\ \mathit{Total\ Assets}^{i,t-1} + \\ \beta_2\ \mathit{GDP}^{i,t-1} + \beta_3\ \mathit{Inflation}^{i,t-1} \end{aligned}$$

where i and t are indexes for company and year (time), respectively. Note that GDP and Inflation are taken at the country level and thus do not have an i index.

To account for devaluation, we add a term coined as "Percent Lifetime", that captures the expected decrease in Total Assets for Project companies, and its regression coefficient is negative.

$$\begin{aligned} \mathit{Total\ Assets}^{i,t} = \alpha + \beta_1\ \mathit{Total\ Assets}^{i,t-1} + \\ \beta_2\ \mathit{GDP}^{i,t-1} + \beta_3\ \mathit{Inflation}^{i,t-1} + \beta_4\ \mathit{PctLifeTime}^{i,t} \end{aligned}$$

Revenues

We expect the Revenues of corporate companies to correlate with Total Assets. In fact, we find that the regression coefficient of Total Assets growth is highly significant, while the coefficient of lagged Revenue growth, when added, is not significant. This suggests that Revenue growth is well and sufficiently explained by the growth in Total Assets:

$$\mathit{Revenues}_s^{i,t} = \beta\ \mathit{Total\ Assets}_s^{i,t}$$

The GDP and Inflation effects on Revenues are reflected in their effect on Total Assets.

Operating expenses (OPEX)

Likewise, OPEX are expected to grow with the size (Total Assets) of the business, and we find a significant correlation coefficient of Total Assets growth with OPEX:

$$Opex_s^{i,t} = \beta \; Total\ Assets_s^{i,t}$$

Similarly, as for Revenues, the effects of GDP and/or Inflation on OPEX are included in the Total Assets term. Note that we did not add intercepts in the regressions for Revenues and OPEX, since there are no revenues or expenses in the absence of Total Assets.

A.3.2 Scenario-dependent projections of financial variables

As long as the relationships between asset-level financial and macroeconomic variables described above hold in the future (until 2050), we can use the calibrated equations above to forecast Total Assets, Revenues, and OPEX, using the NGFS' GDP and Inflation forecasts. NGFS provides such forecasts for six distinct climate scenarios with different levels of climate risks. An index s is added to the equations to denote scenarios. On top of macroeconomic forecasts, expected damages (physical risks) and additional costs related to the price of carbon and energy (transition risks) must be considered in the estimated forecasts of financial variables.

We estimate the impact of climate-change-driven hazards on physical assets (Marcelo and Blanc-Brude, 2022). This impact is quantified, for any single company, by a damage factor D representing the portion of the asset that would be "destroyed" upon the occurrence of a given hazard. Damage factors are calculated for 100-year flood, cyclone, and extratropical storm hazards. The probability of occurrence of any of these events is ρ = 1% (as in the equations below). Importantly, D and ρ are expected to change (and likely increase) in scenarios where efforts to mitigate climate change are insufficient.

NGFS scenarios assume that climate goals are met (i.e., physical risks are mitigated, and the temperature rise remains below 2°C) in the orderly and disorderly scenarios. Following this assumption, we assume that D and ρ remain constant in those 4 scenarios. In other words, the baseline physical risks are unchanged. In the Hot House world scenarios, however, climate goals are not met, and the global mean temperature increase is expected to exceed 3°C in the Current Policies scenario, and to be about 2.6°C in the NDC scenario (NGFS, 2022). Recent research showed that river flood damage in Europe could rise by a factor of about 6 ± 2 by the end of the century, in the absence of climate mitigation (i.e., an expected 3°C GMT increase) (Dottori et al., 2023). This is consistent with a growth of about 2.3 ± 0.5% per year until 2100. Consistently with these assessments, we thus assume that D and ρ grow by 2% per year in the NDC scenario (2.6°C GMT increase), and 2.5% per year in the Current Policies scenario (3.2°C GMT increase).

Total Assets and physical risk

Physical risks imply that assets may be damaged in the future by climate-driven hazards. If we assume hazard events to be independent and mutually exclusive (i.e., they cannot occur at the same time), then the expected value of Total Assets can be expressed as:

$$Total\ Assets_{reduced_s}^{i,t} = Total\ Assets_s^{i,t} \left(1 - \rho_s^t D_s^{i,t}\right)$$

where Total Assets are the Total Assets growth as forecast using the regression coefficients, and $D_s^{i,t}$ is the sum of the damage factors by each hazard (currently floods, storms, and cyclones). Note that the mutual exclusivity assumption can also be seen as neglecting the probability that 2 or 3 events occur in the same year since this is 2 and 4 orders of magnitude less likely than the occurrence of a single event.

Revenues and physical risk

The fraction D of Total Assets that are impaired represents a loss of production capacity which should be proportionally reflected in the expected value of Revenues:

$$Revenues_{reduced}{}_s^{i,t} = Revenues_s^{i,t} \left(1 - \rho_s^t D_s^{i,t}\right)$$

where $Revenues_s^{i,t}$ is the Revenue growth as extracted from the regression.

Operating Expenses

On the contrary, impaired Total Assets need to be repaired or replaced, and thus contribute to the overall costs. Moreover, as mentioned above, costs associated with transition risks need to be added:

- the introduction of a carbon tax directly impacts the price of Scope 1 emissions through increases in the price of carbon.
- the increase in carbon price and other policies affect the mix and price of energy, and thus the price of Scope 2 emissions through the price of electricity.

We thus project OPEX using the following equation:

$$Opex_{augmented}{}_s^{i,t} = Opex_s^{i,t} + \rho_s^t D_s^{i,t}\ Total\ Assets_s^{i,t} + \Delta(Carbon)_s^{i,t} + \Delta(Energy)_s^{i,t}$$

where $Opex_s^{i,t}$ are the Opex growth as extracted from the regression and:

$$\Delta(Carbon)_s^{i,t} = (Scope\ 1\ * Carbon\ Price)_s^{i,t} - (Scope\ 1\ * Carbon\ Price)_s^{i,t-1}$$

$$\Delta(Energy)_s^{i,t} = (Scope\ 2\ * Electricity\ Price)_s^{i,t} - (Scope\ 2\ * Electricity\ Price)_s^{i,t-1}$$

Carbon and electricity price projections come from NGFS. Scope 1 and 2 emissions are assumed to grow at the global emissions rate per country, which also come from NGFS.

Total Debt and physical risk

We assume that corporate companies keep the same capital structure over time. This implies that the Total Debt follows the growth rate of Total Assets (as impacted by physical risks). Moreover, companies must raise funds to cover potential damages to Total Assets. These funds are assumed to equal the expected damage to Total Assets to cover the extra costs (see OPEX above):

$$Total\ Debt_s^{i,t} = Total\ Debt_s^{i,t-1} \times Total\ Assets_s^{i,t} / \ Total\ Assets_s^{i,t-1}$$

Investments are added to cover potential future damages:

$$Total\ Debt_{augmented}{}_s^{i,t} = Total\ Debt_s^{i,t} + \rho_s^t D_s^{i,t}\ Total\ Assets_s^{i,t}$$

Leverage and Profitability

From the projections of Total Assets, Revenues, OPEX and Total Debt, we estimate projections of Leverage and Profitability, two other important financial variables needed as inputs of our asset pricing models:

$$Leverage_s^{i,t} = \frac{Total\ Debt_s^{i,t}}{Total\ Assets_s^{i,t}}$$

$$Profitability_s^{i,t} = \frac{(Revenues_s^{i,t} - Opex_s^{i,t})}{Total\ Assets_s^{i,t}}$$

Note that these two equations are not recursive, such that Leverage and Profitability depend directly on the four key underlying financial variables. The impact of climate risks on Leverage and Profitability is thus a direct consequence of the impact of climate risks on the four other variables.

A.4 Asset Pricing

Following the IFRS 13 guidance and modern asset pricing principles, infraMetrics values each infrastructure asset using the income or discounted cash flow (DCF) approach:

where $NAV_{i,t}$ is the Net Asset Value at time *t of asset i*, $DIV_{i,t+\tau}$ is the cash flow of asset *i* at time $t+\tau$, $r_{t+\tau}$ is the discount rate at time *t*, and *T* is the maturity date of the project contract.

In turn, we have:

With $Rf^C_{t+\tau}$ The yield curve *at time t* in country *C*, at the horizon *T* of asset *I, and* $\gamma_{t,i}$, *the* risk premia of asset *i* reflecting the market price at time *t* of the risk of future dividends.

Finally, the risk premia are a function of a limited number of systematic risk factors found in every infrastructure company:

Common factors determine the level of the risk premia of a given investment in two ways:

- How much risk the investment is exposed to e.g., amount of leverage. The amount of risk or exposure, we can call beta (β).
- What price (return) the market is willing to bear to take this risk. The market price of this risk or risk *premia*, we can call lambda (λ).

If companies are exposed to multiple common risk factors, their cost of equity (discount rate) is just a combination of betas and lambdas.

The valuation methodology involves the following steps:

- Arrive at a cash flow forecast at the valuation time i.e., the gross cash flows that are expected to accrue to the owners of the asset.
- Determine the relevant term structure of interest rates that has an equivalent duration (i.e., horizon) to the investment.
- Estimate the market price of risk (risk premia) for the relevant investment at the time of valuation. This is the equity risk premia that are relevant to each infrastructure company.
- Finally, an asset price is computed. Given the estimates of each of these three components in the different climate scenarios, we can compute the valuations of all the infrastructure companies in the respective scenario.

A.4.1 Cash flow forecast

We use infraMetrics' methodology to forecast cash flows in unlisted infrastructure companies. It aims to minimise the multiplication of estimation errors by using the smallest number of variables possible. The free cash flow to equity of infrastructure companies is modelled as a stochastic process described as a two-dimensional state vector (mean and variance). The future free cash flow to equity of each firm is defined as:

$$FCFE_t = CFADS_t - DS_t$$

where DS_t is the senior debt service owned at time t $CFADS_t$ is the cash flow available for debt service at time *t*. This free-cash-flow process is the result of the firm's business model and risk, the choice and evolution of its financial structure, and it ultimately determines the ability of the firm to repay its senior creditors and equity investors. Crucially, infrastructure companies are characterised by limited growth opportunities

Table 5: *Schematic description of the model variables and their inter-relationships*

Predicted Variable	Explanatory variable (expected positive or negative impact)
Total Assets	Lagged Total Assets (>0) Lagged GDP (>0) Lagged Inflation (>0) Percentage of Lifetime (<0) for Projects only Physical risks (<0): fraction of Total Assets lost
Revenues	Total Assets (>0) Physical risks (<0): fraction of Revenues lost
OPEX	Total Assets growth (>0) Physical risks (>0): replacement/repair of Total Assets lost Carbon price (>0): price of Scope 1 emissions Electricity price (>0): price of Scope 2 emissions
Total Debt	Total Assets (>0): same growth Physical risks (>0): investments to cover future Total Assets losses
Leverage	Total Assets (<0) Total Debt (>0)
Profitability	Total Assets (<0) Revenues (>0) OPEX (<0)

Table 6: *Projection of average GDP growth and inflation at different horizons in each NGFS scenario*

Scenario	Horizon 2030	Horizon 2040	Horizon 2050
Below 2ºC	GDP: 1.95 Inflation: 2.88	GDP: 1.7 Inflation: 2.44	GDP: 1.53 Inflation: 2.33
Net Zero 2050	GDP: 1.47 Inflation: 3.55	GDP: 1.57 Inflation: 2.62	GDP: 1.5 Inflation: 2.41
Divergent Net Zero	GDP: 0.75 Inflation: 5.51	GDP: 1.05 Inflation: 3.72	GDP: 1.14 Inflation: 3.04
Delayed Transition	GDP: 1.82 Inflation: 2.62	GDP: 0.89 Inflation: 3.47	GDP: 0.91 Inflation: 3.1
Nationally Determined Contributions	GDP: 1.97 Inflation: 2.68	GDP: 1.59 Inflation: 2.45	GDP: 1.39 Inflation: 2.4
Current Policies	GDP: 2.11 Inflation: 2.56	GDP: 1.71 Inflation: 2.3	GDP: 1.46 Inflation: 2.3

and numerous long-term commitments (to invest only in their core business, to deliver service, etc.) thus making future debt service and equity payouts a direct function of the firm's free cash flow, which cannot be used for other purposes.

While we cannot model the payouts to equity investors directly, we can use the following indirect, multi-step approach also described in the figure below:

- Estimate CFADS: CFADS of a company follow a well-defined pattern over its life which can be explained using revenues, debt service, revenue growth, and control variables for business risk and sector effects, along with the idiosyncratic effect in each company based on the historical trends. This result, combined with the forecasts of revenue and outstanding debt in the different NGFS scenarios, allows us to estimate CFADS of each infrastructure company in the NGFS scenarios.
- Estimate Retention Rate: similarly, the retention rate of a company, its tendency to retain the free cash, also follows a pattern over its life which can be explained using revenues, and control variables for business risk and sector effects, along with the idiosyncratic effect in each company based on the historical trends.
- Estimate dividend forecast: the dividend forecast is simply the result of the other estimated variables combined as below:

$$Payout_t = (CFADS_t - DS_t) * (1 - RR_t)$$

where DS_t is the senior debt service owned at time t, $CFADS_t$ is the cash flow available for debt service at time t, and RR_t is the retention rate at time t.

As shown in table 7, this approach is accurate when it comes to forecasting the free cash and future dividends of infrastructure companies.

A.4.2 Equity risk premia

We rely on the infraMetrics' asset pricing methodology to estimate equity risk premia for infrastructure companies in each climate scenario. This approach uses insights from modern financial theory and reduces the problem to pricing a limited number of risk factors at the end of each quarter, each of which is relevant to all the firms that have to be priced, only in different amounts (see EDHEC*infra* Asset Pricing Methodology for more technical details at docs.edhecinfra.com/display/AP). Several years of research led to the selection of key risk factors explaining observed transaction prices and their implied expected returns.

a) Leverage (Senior liabilities over total assets)
b) Size (Total Assets)
c) Profitability (Return on Assets before tax)
d) Investment (Capex over Total Assets)
e) Country risk (Term Spread)
f) A range of control variables including business model and industrial activities according to the TICCS® taxonomy of infrastructure companies.

This model determines the market price or premia of each of these factors throughout a historical period of more than 20 years. In order to forecast the equity risk premium of infrastructure companies, we assume that these factor prices are mean-reverting, and their long-term (15-year) averages will serve as a good proxy of the prices in the future. As shown in figure 7, this approach can produce very accurate valuations compared to realised transaction prices with an estimation error within 5% of the transacted price.

Thanks to the forecasting of the financial data described above, we also have the loadings (or betas) for each of these factors for each company, and their deferent values in different NGFS scenarios. As a result, we compute a different estimate of equity risk premium in each scenario that takes into account the drivers of the firm's risk premia. For example, in an orderly transition scenario, an infrastructure company could be less profitable initially due to higher upfront costs and generate more profits later on, but the reverse might be true in the delayed transition scenario. The loadings and price estimates of these risk factors allow us to generate a forecast of equity risk premium of each infrastructure company in the NGFS scenarios at each point in time.

A.4.3 Interest rates

In this exercise, we use the scenario-dependent forecasts of interest rates provided by NiGEM, a global economic model used by NGFS to assess the impact of climate change on various macroeconomic variables, including the interest rates. NiGEM takes NGFS data as inputs, and its predictions thus depend on the IAM considered. Interest rates and equity risk premium together determine the appropriate discount rate (yield) estimate to be used in any given climate scenario.

A.5 Random Portfolio Generation

To build random portfolios of infrastructure assets, we follow the methodology described in Blanc-Brude and Gupta (2022).

The approach mimics the portfolio development process of an investor in illiquid assets like infrastructure. It starts from a pre-defined universe and allows thousands of theoretical investors to buy assets in a given year, taking into account the size of the fund, the likelihood of deploying the capital in that year and the number of investments targeted by the fund. This reproduces the J-curve effect by building portfolios over several years.

The calibration of the approach includes the following aspects:

- Portfolio size: With the ever-growing investor interest in the unlisted infrastructure asset

Table 7: Cash Flow Forecasts Robustness

CFADS	Dividend Growth	
In-sample median absolute error	Out-of-sample mean absolute error	Out-of-sample median absolute error
3%	3%	0.5%

Figure 7: Asset Pricing Robustness

Reported vs estimated valuation ratios (250+ test deals)

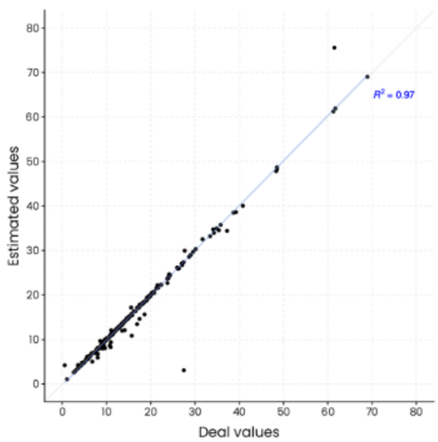
Ratio	Reported Mean	Estimated Mean	Reported Median	Estimated Median	R^2	RMSE*
EV/EBITDA	15.54	15.34	12.98	12.61	0.97	2.27
P/Book	2.37	2.28	1.65	1.59	0.87	0.90
P/Sales	3.35	3.21	2.52	2.32	0.85	1.43

** root mean squared error*

Distribution of estimation errors

10% Quantile	25% Quantile	Median	Mean	75% Quantile	90% Quantile
-5.00%	-1.95%	-0.22%	-0.55%	1.64%	3.85%

Reported vs Estimated EV/Ebitda



Source: infraMetrics®

class, average fund and portfolio sizes have increased from about USD200m in 2000 to more than USD1bn in 2020. We have assumed fund size to be distributed between USD100m to USD2bn, with probabilities that follow the historical average.

- Number of investments: following the results shonws in table 3 for the typical number of assets, we make the assumption of a uniform distribution between 5-20 assets invested. The final number of deals is also impacted by the market activity in any given investment year.
- Deal success rate: For any given investment year, we assume a deal success probability depending on market activity. This determines which funds are eligible to make an investment at any given time. This data is calibrated based on the historical number of deals/number of active investors.
- Investment size: We assume that capital is equally deployed (at the price given by prevailing NAV) to all the randomly selected companies in the fund.

For a given universe, companies eligible for investment are shortlisted. If the investors are eligible to make a deal on that investment date based on a deal success rate assumption, one random company is invested, which becomes unavailable for investment for the rest of the investment period. This process is followed until the fund has invested up to the investment ratio or the fund is abandoned (if its TVPI is less than 1 after 4 years).

Using this approach, we can also see how physical risk can become concentrated in certain portfolios which happen to include assets with greater exposure to extreme weather events.

About Us

The EDHEC Infrastructure & Private Assets Research Institute is a research centre of the EDHEC Business School, one of the best ranked business schools for its programs and research in finance. The institute was created in 2016 with the support of the business school and several key seed partners, including the government of Singapore, Natixis and Meridiam, to spearhead new research in the asset pricing and credit risk of private infrastructure investments.

Thanks to this work, an industry initiative was created in 2019 to contribute even more actively to the development of the infrastructure asset class. Our corporate entity, Scientific Infra and Private Assets Ltd is an ESMA-regulated provider of market indices, benchmarks and valuation analytics for investors in unlisted infrastructure equity and private debt, including the widely used infra300® index. The infraMetrics® platform already provides robust and granular data to investors representing USD400bn of infrastructure AUM (YE2022) as well as prudential regulators and public policy bodies.

In 2020, the institute launched a major new project on the measurement and benchmarking of climate risks and the social acceptability of infrastructure investments. After three years of development, several key research results a major data collection effort, we now publish climate and social risk data in infraMetrics®, alongside our indices and analytics since Q1 2023.

Having achieved market recognition for infrastructure investment benchmarks, EDHECinfra was also renamed "EDHEC Infrastructure & Private Assets Research Institute" to reflect a new ambition for our work, with a focus on private equity and debt. privateMetrics, a new platform, will launch in 2023 and provide asset valuation tools and market indices for investors in private companies worldwide.

While developing an indexing and benchmarking business, the institute continues to develop new research, including new work on the uses of machine learning to process text, accounting and geographic data and create new data on private markets. We are also regularly involved in regulatory and policy matters by providing free access to our unique data to prudential regulators and policy-setting bodies or government departments needing information on the procurement of infrastructure projects, in particular the cost of capital of private investors and the financial risks they face.

The EDHEC Infrastructure and Private Assets Research Institute is also supported in its endeavours by an international advisory board consisting of senior executives from the investment world. Since its creation, EDHEC Infrastructure and Private Assets Institute has published more than 50 academic research papers. Our data is also frequently used by the industry to produce research including by the Boston Consulting Group, BlackRock, Ares Management, PGIM, CBRE and many more. Research at EDHEC is both "for business" and "for good": it has both commercial and social value.

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