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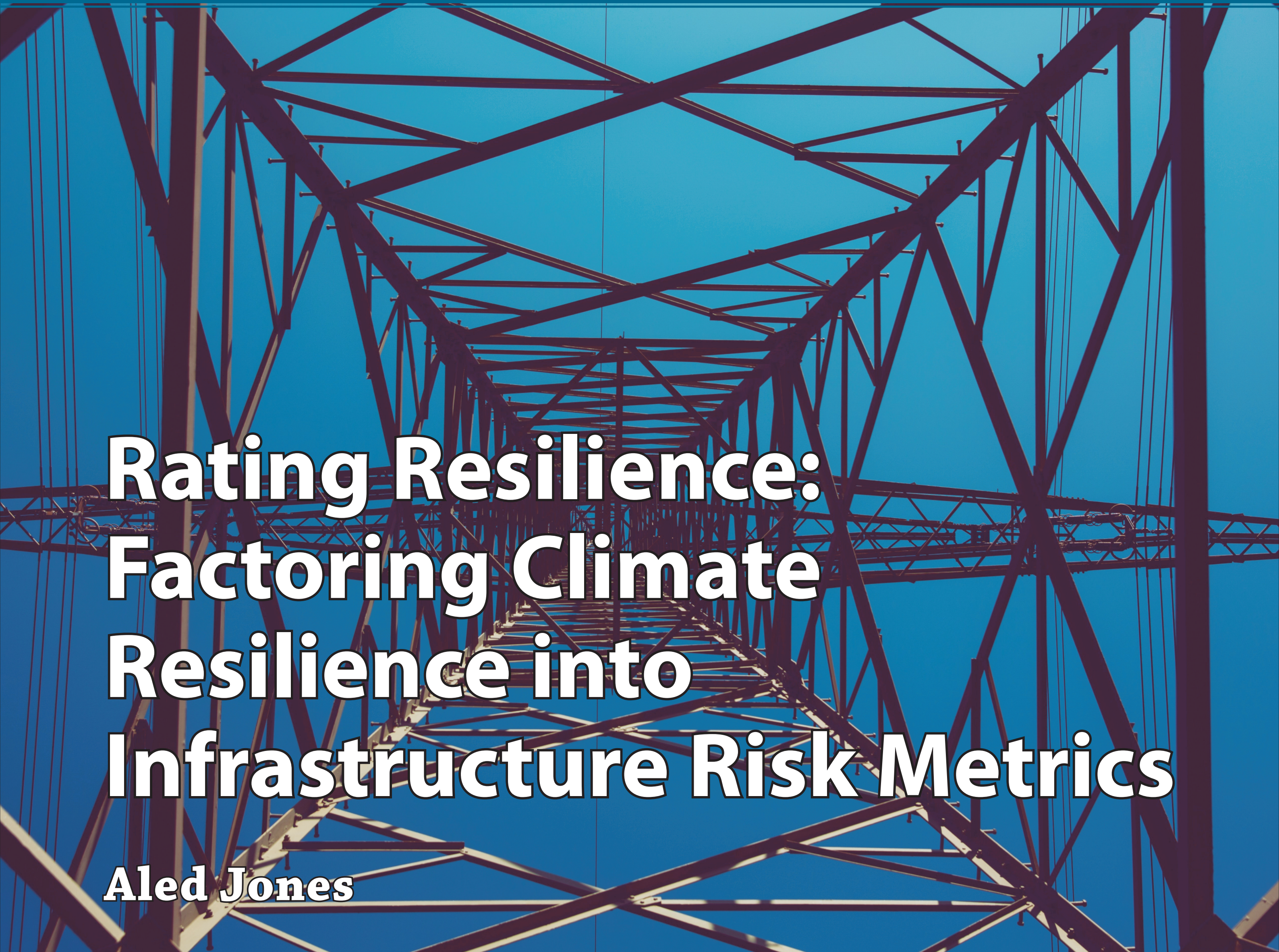

Rating Resilience: Factoring Climate Resilience into Infrastructure Risk Metrics

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ABSTRACT

This paper proposes a framework for defining risk metrics to capture climate resilience in infrastructure assets. It first outlines the risks that infrastructure is exposed to under a future of climate change, before summarising some of the current approaches used by large investment organisations to measure the resilience of this infrastructure. Finally, the paper proposes a method to develop a framework for risk metrics that build on these approaches.

BACKGROUND

Climate change is already affecting the weather, ecosystem services and the well-being of humans and the environment around the world. The number of extreme weather events and changes to climate events are now increasing at faster rates, which is further projected to only increase with time. Adapting to this new future climate and building a resilient infrastructure is vital in sustaining our existence (Smith et al., 2001). Previous studies suggest that the level of investment needed to adapt to climate change and build resilience could be anywhere between US$25 and US$100 billion over the next 20 years, based on a median climate change scenario (Fankhauser, 2009). Disaster Risk Management (DRM) has received significant attention in recent years, not least through the Sendai Framework (Aitsi-Selmi et al., 2015). At the same time, the number of legal and political mandates for incorporating climate change information into decision-making is now drawing more attention.

The IPCC defines "adaptation" as the "adjustment in natural or human systems in response to actual or expected climate stimuli and their effects, which moderates harm or exploits beneficial opportunities." (IPCC, 2007). Conversely, "maladaptation" is commonly defined as a situation that may arise in situations when actions "lead to increased risk of climate-related outcomes, increased vulnerability to climate change, or diminished welfare now or in the future." (IPCC, 2014). Enterprises engaging in adaptation should consider and evaluate the consequences of their actions, both deliberate and inadvertent. It is also necessary to regularly review these actions as scientific knowledge improves, to ensure that adaptation efforts do not unduly compromise or undermine desired objectives or result in unwanted consequences.

In recent years, there has been a significant surge in the amount of finance available for supporting adaptation, for example, the Green Climate Fund, multi- and bilateral donors, and renewed interest from national governments (Preston et al., 2011; Termeer et al., 2012). As the level of funding has increased to satisfy the need for adaptation so has the need for comprehensive method syntheses and adaptation guidance to (i) ensure adaptation is taking place at the right time, at the right place and at the right rate; (ii) diagnose and ensure areas of high risk or significant vulnerability are sufficiently addressed; (iii) enable the effective comparison of adaptation projects in space and time; (iv) ensure resources and support for adaptation is being effectively utilised and resulting in tangible action; and (v) inform current gaps and deficiencies in research, practice and policy, including governance structures (Pielke et al., 2007; Berrang-Ford et al., 2011; Biesbroek et al., 2013).

The use of metrics to inform the management of climate change related investments is ever increasing. While occasionally, these are driven by individual firms, most often, they form part of a wider, community-level approach. For example, several groups have been set up to facilitate access to data and metrics, including the Global Reporting Initiative (GRI), the Asset Owners Disclosure Project (AODP) and the Carbon Disclosure Project (CDP). Such voluntary initiatives allow investors to collaborate and form coalitions, which have much more impact than individual organisations do. The CDP represents investments of over US$100 trillion. However, there is little evidence that these initiatives have driven real change in either investments or policy (Kolk, Levy & Pinske, 2008), although there is some evidence that there is a learning effect within firms that take part in these reporting initiatives (Matisoff, Noonan & O'Brien, 2013). Historically, such initiatives have focused on reporting climate change mitigation efforts, not resilience and adaptation.

With regards to mitigation, an important policy request from investors has been for a price to be put on carbon (IIGCC, 2011). So far, there has been no real move towards a global carbon price, although various regions have adopted policies to create local markets for carbon. In the absence of a global carbon price, the private sector has expressed some reluctance in significantly increasing investments due to a perception of increased risk (Jones, 2015). To counter some of this perception, the public sector is creating public–private partnerships (PPPs) and opportunities for blended finance (Vivid Economics, 2014). Investing alongside the public sector will lower the risk and increase market opportunities. However, most such PPPs focus on institutional investors, while the largest portion of current investments come from corporates and project developers (Vivid Economics, 2014). PPPs are often used to explore the development of metrics.

The challenge of transforming the investment landscape from a fossil-fuel economy to a low-carbon one has led many to explore the path-dependent nature of those investments (Lovio et al., 2011). There must be a significant and active process of driving the required change in investment landscape, to move away from this "carbon lock in." (Kemp-Benedict, 2014). However, in the absence of such a drive away from the high-carbon pathway at the scale required, there is an increased perception of material financial risk resulting from climate change (Jones et al., 2013).

Of all asset owners globally, 60 percent—representing US$27 trillion in investment—now incorporate some level of climate risk in their decision-making processes (Asset Owners Disclosure Project, 2017). This represents a significant change between 2016 and 2017 with 45 asset owners adding climate-risk considerations. However, as noted above, the level of investment into mitigation does not match the perceived risk. Within US asset owners, only 0.5 percent of investment is channelled towards low-carbon assets (Asset Owners Disclosure Project, 2017).

CURRENT PRACTICE IN MEASURING RESILIENCE

There are several methods used to categorise resilience practice. These include classifications such as research, plan, networks, legislation, awareness raising, implemented change, training and advocacy (Agrawal & Perrin, 2009) or migration, storage, diversification, pooling and market exchange (Tompkins et al., 2010). Standardised quantified measures for categorising resilience are being proposed by a variety of public and private bodies. These quantified measures are still in their early stages of development.

For example, the Green Climate Fund (2014) has proposed the following quantified measures for adaptation:

- *Environmental effectiveness:* including units of human health (disability-adjusted life years (DALYs)) and units of wealth (US$) saved and enhanced
- *Cost-effectiveness:* US$/DALY and US$ saved
- *Co-benefits:* US$/unit of co-benefit
- *Institutional feasibility:* level of acceptance

Currently, there are limited examples of these metrics in use. Reporting often refers to whether particular projects form part of the National Adaptation Programmes of Action (NAPAs) under the United Nations Framework Convention on Climate Change (UNFCCC). The submitted NAPA documents from each country require some indication of Monitoring and Evaluation (M&E) of adaptation measures, including qualitative and quantitative measures. However, there is currently no consistent approach to M&E.

The UK's Private Infrastructure Development Group (PIDG, 2012) measures adaptation against three classifications:

- Tier 1: Projects in which the principal objective is to facilitate adaptation to climate change and climate vulnerability;
- Tier 2: Projects in which adaptation is a secondary objective and/or is likely to lead to significant climate-change co-benefits;
- Tier 3: Projects that are not designed to facilitate adaptation to climate change or whose impact is not likely to be significant.

Within PIDG's current definition, two aspects of adaptation are covered but not explicitly differentiated. These are (i) project resilience and (ii) community adaptation. It is, however, important to distinguish between infrastructure that is itself resilient to climate change (for example, a building adapted to withstand expected heat waves) and infrastructure that enhances the resilience of the community (for example, flood defences). Any metric used should be able to identify building-adaptive capacity as different from building-adaptation infrastructure. The above measures are aimed at adaptation projects, not the resilience of infrastructure aimed at providing wider adaptation benefits.

As part of their tool to evaluate projects that issue Green Bonds, Standard & Poor's (S&P, 2016) propose a quantified measure of adaptation or resilience. This measure is the ratio of expected adaptation benefit to investment. The adaptation or resilience benefit is the reduction in combined expected financial, humanitarian and ecological damage (all monetised) over some future climate scenario. S&P also incorporated their "view of the adequacy of the third-party data and assumptions used to determine the resilience benefit," (S&P, 2016) although they do not detail how this would be measured or combined with the ratio measure.

Moody's (2017) uses an analytical framework to measure the resilience of different industrial and economic sectors in their environmental, social and governmental approach to credit analysis. Within this framework, Moody's quantifies the level of exposure and resilience separately. The exposure and resilience measures for each sector is different, and therefore, the framework is defined separately for each type of asset. For example, the resilience to climate change of sovereign debt is quantified by using measures of the levels of development, government responsiveness and fiscal flexibility. The exposure to climate risk of sovereign debt is then quantified through diversification of the economy and geographic exposure to weather.

The Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD) considers the physical, liability and transition risks associated with climate change and what constitutes effective financial disclosures across industries. Up to US$43 trillion in global assets are at risk from climate change between 2017 and the end of the century (TCFD, 2017). They identified the following risks that should be accounted for within any metric of resilience (TCFD, 2017):

1. **Policy and Legal**
    a. Increased pricing of GHG emissions
    b. Enhanced emissions
    c. Mandates on and regulation of existing products services
    d. Exposure to litigation
2. **Technology**
    a. Substitution of existing products and services with lower-emission options
    b. Unsuccessful investment in new technologies
    c. The cost of transitioning to low-emissions economy
3. **Markets**
    a. Changing customer behaviour
    b. Uncertainty in market signals
    c. Increased cost of raw materials
4. **Reputation**
    a. Shifts in consumer preferences
    b. Stigmatisation of sector
    c. Increased stakeholder concern or negative feedback
5. **Acute Physical Risks**
    a. Increased severity of extreme weather events, such as cyclones and floods
6. **Chronic Physical Risks**
    a. Changes in precipitation patterns and extreme variability weather patterns
    b. Rising mean temperatures
    c. Rising sea levels

Conversely, the Task Force highlighted the following benefits of investing in resilience (TCFD, 2017):

- Increased market valuation through resilience planning (e.g. infrastructure, land and buildings)
- Increased reliability of supply chain and ability to operate under various conditions
- Increased revenue through new products and services related to ensuring resilience

The Green Bond Assessments, while not credit ratings, apply to bond issues (Moody's, 2016). They use a similar tiered system (See Table 1) to PIDG and use a weighted scorecard that measures five factors, including (weights in brackets):

1. Organisation (15 percent)
2. Use of Proceeds (40 percent)
3. Disclosure on the Use of Proceeds (10 percent)
4. Management of Proceeds (15 percent)
5. Ongoing Reporting and Disclosure (20 percent)

Table 1: Assessment Classification System for Green Bonds (Moody's, 2016)

Gb1	Excellent	Green bond issuer has adopted an excellent approach to manage, administer, allocate proceeds to and report on environmental projects financed with proceeds derived from green bond offerings. Prospects for achieving stated environmental objectives are excellent.
Gb2	Very Good	Green bond issuer has adopted a very good approach to manage, administer, allocate proceeds to and report on environmental projects financed with proceeds derived from green bond offerings. Prospects for achieving stated environmental objectives are very good.
Gb3	Good	Green bond issuer has adopted a good approach to manage, administer, allocate proceeds to and report on environmental projects financed with proceeds derived from green bond offerings. Prospects for achieving stated environmental objectives are good.
Gb4	Fair	Green bond issuer has adopted a fair approach to manage, administer, allocate proceeds to and report on

		environmental projects financed with proceeds derived from green bond offerings. Prospects for achieving stated environmental objectives are fair.
Gb5	Poor	Green bond issuer has adopted a poor approach to manage, administer, allocate proceeds to and report on environmental projects financed with proceeds derived from green bond offerings. Prospects for achieving stated environmental objectives are poor.

TOWARDS A FRAMEWORK FOR METRICS OF RESILIENCE

Socioeconomic and environmental uncertainties have the potential to significantly undermine the desired outcomes of infrastructure investments, particularly in the case of assets that are long-lived or highly dependent on other services/infrastructures, which in turn are climate sensitive and/or easily compromised.

If a particular asset is a) designed with community adaptation in mind or b) particularly vulnerable to climate change, further evaluation of additional quantitative and qualitative performance metrics may be needed to ensure that the asset delivers on its desired outcomes related to adaptation. These metrics can be used to objectively compare as well as individually evaluate the robustness and resilience of current projects and investments, recognising the significant uncertainties underpinning the future evolution of current socioeconomic systems—e.g. demographic changes or development trajectories—and the future climate in which they will likely operate. Even where exposure information (physical climate risk) is available and has been used, there is a clear need to develop the modelling capability to get better and more reproducible results, e.g. the two main current climate exposure models used by industry-predicted non-overlapping exposures (the predicted range of impact of one model was completely different from the range of impact of the other model) following Hurricane Maria.

Ideally, any final quantified metric should be reported as an annual net-benefit each year, for the full lifetime of all investments. Using these figures, it should then be possible to calculate the Net-Present Value or NPV (HM Treasury, 2003, Ranger et al., 2010) using a level of discounting as appropriate for the particular asset type. In addition, complementary metrics such as the Internal Rate of Return (IRR) and asset repayment period, and other non-monetary valuation metrics should be used as required.

Discount rates are calculated differently, depending on the field of study, sector and even the analyst performing the evaluation. For example, the private sector tends to treat the discount rate as the 'opportunity cost of capital', i.e. its potential value had it been invested elsewhere. Conversely, the public sector often cites the 'social-discount rate', which is calculated using the expected growth rates of consumption combined with some ethical judgments (Ranger et al., 2010). Comprehensive guidance regarding the calculation of appropriate discount rates is available in the Green Book, including the use of declining discount rates for projects that are particularly long lived (HM Treasury, 2003). Discount rates are very important, since the perceived viability of a certain project can be very sensitive to the value of the discount rate applied (Pearce et al., 2006, Boardman et al., 2006).

Furthermore, this exercise should be complemented with scenario testing of different options, environmental states and outcomes, providing a more robust assessment of current and future viability.

The success of resilience or adaptation efforts and projects is closely linked with the ability to predict the future and take anticipatory action to mitigate potential negative impacts. Future socio-environmental systems are characteristically complex and uncertain. Resolving trade-offs and anticipating outcomes becomes more challenging due to a lack of scientific knowledge and consensus on the scale and timing of anticipated changes. This is particularly apparent in the context of climate-change adaptation and the frequency and severity of extreme events (IPCC, 2014). In these situations, scenarios are increasingly utilised to guide decision-making by providing plausible projections of future climate change and its potential impacts.

Unfortunately, scenarios are not always provided with a probability of occurrence, nor is this always possible. Predicted future socioeconomic dynamics are highly uncertain and some environmental processes—such as the impact and rate of methane release from melting permafrost—remain unclear (Schuur et al., 2015). In the case of climate-change adaptation, the calculation of probabilities also requires various subjective judgements to be made regarding the model structure, parameter estimation and the use of empirical observations to constrain predictions (Frame et al., 2005, Solomon, 2007, Tebaldi & Knutti, 2007). Due to the reliance on subjective—and sometimes no—probabilities, climate-change adaptation is almost universally presented as a situation of decision-making under uncertainty.

Additionally, Smith (2007); Stainforth et al., (2007) and others have previously advised researchers and analysts to err on the side of caution when interpreting outputs of climate models in the form of probabilities. The underpinning climate models have previously been proven incompatible and inadequate at the temporal and spatial resolution required to make robust adaptation decisions. However, it has also been highlighted that a lack of probabilistic information or perfect knowledge need not be a hindrance to adaptation or resilience (Dessai et al., 2009).

Scenarios that lack probabilities are incompatible with classical-decision theory, sometimes referred to as *decision-making under risk* (or utility theory). In such cases, alternative evaluation approaches must be sought.

Where probabilities are known and quantifiable, classical-decision theory can provide a powerful suite of tools for guiding decision-making. In many fields and industrial sectors, this remains the dominant approach. However, in recent years, there has been a steady decline in its popularity due to the recognition that it is largely incompatible with decision-making in situations of uncertainty. Unfortunately, evaluating the impact of climate change on an investment portfolio would require one to (i) fully describe and quantify the range of future environmental states and their probability of occurrence, (ii) have an in-depth understanding of how different environmental states and actions combine to produce outcomes; and (iii) have a comprehensive understanding of the net-benefits of these potential actions. This can be complicated in situations where the impacts of climate change emerge indirectly or are due to complex interactions between multiple actors, assets and activities, some of which may be outside one's control. The combination of these factors will require an extensive reliance on subjective probability assessments, over which analysts and decision-makers will likely disagree and dispute each other's claims and assumptions. This will result in further delay and potentially inaction (Polasky et al., 2011).

With respect to the scale and temporal resolution of adaptation investment and projects, most climate-change impacts are highly uncertain (Ranger et al., 2010). In situations of deep uncertainty, scenario planning, thresholds approach and resilience thinking can provide useful frameworks for a broad range of future environmental states. It can be particularly useful to hedge investments so they are not unduly compromised or placed at elevated risk from extreme events, sometimes referred to as "black-swan events." (Quay, 2010). Moreover, these types of approaches help analysts and decision-makers think about key social and environmental feedback effects and threshold boundaries that may negatively affect asset performance. Thus, assessments can be significantly strengthened, and multiple stakeholders can contribute to the process by offering their discrete perspectives, methods and evidence, thereby favouring the use of robust, open and inclusive decision tools such as those presented here.

Challenges for decision-making under uncertainty translate to difficulties in defining the state space, including the number and range of scenarios to include. To overcome such issues, it is generally advised to include only those variables that the investment is highly sensitive to (for example, sea-level rise in the case of coastal flood defences) and to consider plausible best- and worst-case events to characterise the variables.

The same level of attention is required when specifying any quantification method used to inform the decision-making process. It is important to use only those metrics that are decision-relevant and to ensure that non-monetary and other evaluation criteria are utilised in situations where it is difficult to ascribe economic costs to potential impacts.

Finally, it may not be easy to select the number and type of adaptation options that are to be tested. In certain circumstances, the range of potential adaption options could be infinite. Therefore, defining the characteristics of these options requires skills to make sure that the full range of options is explored without having to individually explore every single potential adaptation measure. Any assessment should also include risk-mitigation strategies, potential for flexible adjustment and adaptive management, lead times and asset life time (Ranger et al., 2010). These metrics will be essential in determining the overall efficiency and return on investment as, for example, an adaptive scheme could keep the overall costs of a particular adaptation to a minimum.

The field of decision-making under uncertainty has grown significantly in recent years, and this is in part due to this recognition combined with the growing accessibility to climate-change information in traditionally data-poor regions. Various distinctions can be made between decision methods suited for situations in which there is access to non-unique subjective probabilities, unique but non-additive probabilities, and no probabilities at all (Kelsey & Quiggin, 1992, Gilboa & Schmeidler, 1989, Allen et al., 2006, Gilboa, 2009).

CONCLUSIONS AND RECOMMENDATIONS

There are two very different categories of infrastructure when measuring resilience: infrastructure that is itself resilient to future change and infrastructure that is intended to enhance the resilience of local communities. The two should be treated separately.

Community adaptation will include projects in which there is no current direct adaptation planned but the management process implemented considers future climate risk and is likely to contribute in some way to the community's ability to adapt to future climate conditions. For example, mobile-phone projects in which the provision of communications can be demonstrated as useful in the event of extreme weather or other climate-related disasters through the adoption of a disaster risk-management plan should be quantified within a risk rating.

However, within any metric, a fully quantified approach is not possible, since the future is inherently uncertain. Therefore, it is necessary to adopt a transparent use of scenario analysis. A common approach to the use of such scenarios would be highly beneficial, and if a transparent international process could be set up and managed, this may help build trust in the process and allow metrics to be used across the board.

The future of climate change along a business-as-usual trajectory presents significant dangers to the global society. Scenarios under the more extreme impacts present not just project and infrastructure risk but planetary or existential risk for a functioning economy. Incorporating this into an infrastructural risk rating is meaningless but should nonetheless be a part of the wider discussion in the efforts to mobilise significant capital into resilience (or mitigation) investments.

Any metric to assess the resilience of infrastructure must be used alongside a suite of other metrics to assign a rating. Therefore, it is difficult to suggest a particular route, as each method used for rating is different. For projects that are designed to enhance wider resilience to climate change, key quantified metrics that should be considered include those proposed by the Green Climate Fund (Green Climate Fund, 2014).

- *Environmental effectiveness:* including units of human health (disability-adjusted life years (DALYs)) and units of wealth (US$) saved and enhanced
- *Cost-effectiveness:* US$/DALY and US$ saved
- *Co-benefits:* US$/unit of co-benefit
- *Institutional feasibility:* level of acceptance

To measure and evaluate the resilience of other infrastructure, a two-phased approach is proposed. Phase 1 is a simple measure of whether the project itself contains evidence that climate-change resilience has been considered (or not) within its planning and implementation phases. This evidence should include some discussion on management processes to assess new climate science and scenarios as they emerge and to adapt the infrastructure as needed. In Phase 2, a more qualitative measure must be adopted. Building on the methodologies outlined by TCFD, Moody's and S&P, a financial value at risk should be calculated based on a range of plausible climate scenarios. This should evaluate any aspects of resilience (or options for resilience) put in place for the infrastructure under consideration against the level of exposure (measured through a set of plausible scenarios) of that infrastructure. The interpretation of the value at risk may be qualitatively taken if the uncertainty in the scenarios based on future climate projections, or the uncertainty in adaptation options available, is too great to justify full quantification.ORF

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