Global Infrastructure Resilience

Capturing the Resilience Dividend

Looking forward: How to monitor progress towards infrastructure resilience

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Pillar 4:
Assess Global Progress in Closing the Infrastructure Resilience Gap

Baseline for monitoring progress

Prepared for:

Coalition for Disaster Resilient Infrastructure

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1 BACKGROUND

The Coalition for Disaster Resilient Infrastructure (CDRI) was launched by the Government of India in September 2019 at the UN Climate Action Summit. The CDRI is a partnership of national governments, UN agencies and programs, multilateral development banks and financing mechanisms, the private sector, and knowledge institutions that aims to promote the resilience of new and existing infrastructure systems to climate and disaster risks, thereby ensuring sustainable development. The CDRI intends to publish a biennial Flagship report on Disaster and Climate Resilient Infrastructure. The report will be CDRI's principal vehicle for engaging and focusing the attention of a global audience of political leaders, policy makers, practitioners, and researchers.

The Flagship report will contribute to the development of the Strategic Priorities of the CDRI around Research and Knowledge Management and Communication and Partnerships. The Flagship report is expected to be launched in April 2023 with intermediary outputs to be ready in late 2022 coinciding with COP28. The report is envisaged to be based on five key pillars:

- Pillar 1 Global Infrastructure Risk Model
- Pillar 2 Global Infrastructure Resilience Index
- Pillar 3 Nature Based Solutions
- Pillar 4 Progress Monitoring
- Pillar 5 Financing Infrastructure Resilience

Pillar 4 focuses on the design and implementation of a Global Infrastructure Resilience Index (GIRI), which will be based on the Global Infrastructure Multi-Hazard Risk Model (Pillar 2) of the CDRI project and sets of social, economic, environmental, political indicators that give count of the resilience of countries through representing the performance of capacities to resist, respond and recover from the occurrence of events. The GIRI will be developed at country level, and it comprehends the different hazards included in the risk model, infrastructure of different sectors (power and energy, transport, telecommunications, roads, water and sanitation, oil and gas) and buildings.

Given the technical and scientific base of both, the risk model and the GIRI, different knowledge capacities are required to develop and calculate the results and given the desirable relevance of a robust and defendable outcome, it is a product developed within the activities performed by Ingeniar: Risk Intelligence. The development of the Pillar 4 chapter is based on the results and background paper that will be delivered by Ingeniar: Risk intelligence.

This report describes the design of the Global Infrastructure Resilience Index - GIRI, as a baseline for monitoring progress in disaster and climate infrastructure resilience. The report includes a review of the concept of resilience in infrastructure, mentions some composite indicators, and indexes available at global, national, and local levels for measuring resilience. Contains a review of the indicators of the Sendai Monitoring and the Sustainable Development Goals, and the limitations to use them as inputs for the GIRI. The next section depicts the conceptual framework and the methodology designed for the GIRI and the indicators considered for the construction of the composite indicator. The final section presents the results obtained at global level for the countries evaluated in the project.

2 A REVIEW OF THE RESILIENCE CONCEPT

The concept of resilience has gained significant attention in various fields over the past two decades. Initially rooted in material science, resilience was defined as the ability to absorb impact. However, its interpretation has evolved across diverse disciplines such as ecology, psychology, socioecological systems research, disaster risk management, and critical infrastructure protection (Young, 1807; Singer, 1951; Timoshenko, 1953, Alexander, 2013; Xue et al., 2018, Holling, 1973; Pimm, 1984, Carpenter, 2001, Bonanno et al., 2006, Cardona, 2001; Bruneau et al., 2003; Adger et al., 2005; Cutter et al., 2008, Boin and McConnell, 2007, Guo et al., 2021; Poulin & Kane, 2021. Different schools of thought have generated a range of definitions and disagreements on its usage. Despite lacking a consensus on its precise meaning, the resilience concept holds potential for addressing global challenges like globalization, digitalization, and climate variability, safeguarding essential societal assets.

However, criticisms have arisen due to the lack of clarity surrounding the term, leading some to view it as a mere buzzword (Linkov et al., 2014). The proliferation of definitions has contributed to the confusion, prompting the need to select an appropriate framework for defining assessment approaches. In the infrastructure context, resilience can be understood as a multifaceted concept that encompasses various domains, including social and economic, assets, services, sustainability, systemic and financial or fiscal resilience. It has been perceived as both an ability and a performance, varying between a quality, objective, process, or set of capacities. While some describe it as a measure or degree of recovery, recent literature predominantly views resilience as a capacity. Thus, resilience can be measured or monitored as an outcome (Biringer et al., 2013; Wied et al., 2020; Mottahedi et al., 2021)., but it can also be seen as a process or system's ability to resist, adapt, respond, recover, and transform (Kanno et al., 2019).

There are also multiple definitions and measurement approaches; (e.g., based on analytical and multi-criteria models, dashboards, indexes, or composite indicators and ratings, based on expert opinion or surveys, among other techniques). Regarding disasters, many of these approaches are related to the community, urban centers, environment, climate change, development sectors, networks or lifelines, and critical infrastructures, considering dependencies and territorial levels. Although high-resolution and detailed factors can be included in these technical approaches based on performance and attributes, any resilience assessment will not always be complete and can only be an operational image for monitoring and follow-up periodically, using proxies. This is particularly true when the scope is a national-scale assessment, where only a relative analysis is feasible for disaster risk management, climate change adaptation, and resilience management advocacy.

In the realm of disaster risk, UNDRR defines resilience as the ability of a system or at-risk community to absorb, adapt to, and withstand the consequences of hazards efficiently, including recovery through risk management. It's highlighted that a lack of resilience can contribute to vulnerability. A comprehensive resilience approach involves risk reduction, timely coping, effective post-event response, recovery, adaptation, and transformation.

Enhancing resilience is acknowledged as a valid strategy for reducing risk. Resilience building overlaps with vulnerability reduction, as both address different sides of the same coin. Although the exact relationship between vulnerability and resilience remains debated, it is agreed that resilience contributes to vulnerability reduction. Resilience management doesn't only focus on specific hazards but aims to enhance a system's ability to adapt, recover, and self-improve under any disruption. This holistic approach considers long-term development and adaptive capacity, emphasizing recovery, learning, and adaptation processes.

"Specified resilience" pertains to a system's ability to manage characteristics or functions in response to specific disruptive events (S. R. Carpenter et al., 2012; B. H. Walker & Pearson, 2007).. It is framed as "resilience of what to what" (S. Carpenter et al., 2001) or "resilience regarding what" and "against what." (Tamberg et al., 2022), For instance, it could refer to crop production's resilience against rainfall variation or a power system's capacity against extreme wind events.

2.1 RELATIONSHIP BETWEEN RESILIENCE AND INFRASTRUCTURE

Infrastructure plays a crucial role in supporting social and economic development, but its effectiveness is contingent upon its resilience. This means that major investments in new infrastructure must be accompanied by investments in resilience in order to prevent increased contingent liabilities and unreliable public services. When disasters occur, the true cost of neglecting or undervaluing resilience becomes apparent, as long-standing risk factors suddenly become visible and tangible.

Resilient infrastructure and infrastructure for resilience are related but distinct concepts. Resilient infrastructure refers to infrastructure that can absorb, adapt, and transform to changing conditions and continue providing essential services to households, communities, and businesses. Asset, service, and sustainable resilience are closely associated with resilient infrastructure. On the other hand, infrastructure for resilience refers to considerations that should be included when investing in infrastructure to achieve sustainable growth. It includes socio-economic, environmental, and governance strengthening considerations, as well as whether the way infrastructure is provided contributes or erodes systemic resilience. The concept of fiscal resilience bridges both resilient infrastructure and infrastructure for resilience. Asset loss and damage and service disruption have negative fiscal effects, particularly in weak economies. Fiscal health also influences the capacity to strengthen assets, service, and sustainable resilience.

The Global Infrastructure Resilience Index (GIRI) is a composite indicator that attempts to measure infrastructure resilience by combining financial risk metrics with three sets of social, economic, environmental, and political indicators representing the capacity to absorb, respond, and restore. The index can be disaggregated by its different indicators to monitor changes over time, with progress in these indicators being related to resilience domains such as Technical, Organizational, Social, Economic (Bruneau et al. 2003), and Ecological or Ecosystemic (TOSEE).

2.2 TOOLS FOR MEASURING RESILIENCE

To measure progress towards sustainable development, global frameworks such as the Sustainable Development Goals (SDGs), the Paris Agreement on Climate Change, and the Sendai Framework for Disaster Risk Reduction 2015-2030 have adopted sets of targets and indicators.

Numerous approaches have been suggested for evaluating vulnerabilities and issues related to disasters, utilizing a combination of indicators and metrics. Scholars such as Cutter (1994), Bates (1992), Tucker et al. (1994), Davidson (1997), Puente (1999), Cardona and Yamin (1997), Cardona (2001), Barbat and

Cardona (2003), Cardona et al. (2003a, b), UNDP (2004), the World Bank (2004), Carreño et al. (2005, 2007a, 2017, 2018), Salgado et al. (2016), Jaramillo et al. (2016), and others, have endeavored to quantify vulnerability and aspects linked to risk, utilizing both quantitative and qualitative indicators. In these studies, vulnerability and disaster risk are assessed from diverse perspectives, employing methods that are generally analogous in approach but divergent in intent and extent. Several strategies, rooted in indicators, exist for gauging and monitoring disaster risk management or resilience, with various methodologies resembling those elucidated by Khazai et al. (2015), Lacambra and Guerrero (2017), and JRC (2017). While indicators provide simplified representations of complex systems, they are only indirect measures of reality. Multiple sets of indicators are needed to represent different domains of an issue and identify which domains contribute to the problem.

For measuring resilience, several different initiatives have attempted to develop indicators, mainly at the local and community level. Also, commonly accepted metrics are not yet available, although there are many assessment techniques in the current context, such as the Critical Infrastructure Resilience Index (CIRI) , IMPROVER Technical Resilience Analysis (ITRA) and Organizational Resilience Analysis (IORA) , the Resilience Measurement Index (RMI) , the Critical Infrastructure Resilience Evaluation (CIRE) , the Benchmark Resilience Tool (BRT) , the Organizational Resilience Health Check (ORHC) , the Resilience Analysis Grid (RAG) , the OECD Guidelines for Resilience System Analysis , the Resilience Management and Matrix Audit Toolkit , the Resilience Maturity Model Tool , among many others.

Surveys, on the other hand, provide in-depth information, particularly when quantitative information is unavailable. The Risk Management Index (RMI) and Index of Governance and Public Policy in Disaster Risk Management (iGOPP) are examples of surveys that have been used to benchmark disaster risk management. The Sendai Framework also uses surveys to obtain qualitative nature-based information. Initiatives have attempted to develop indicators and other tools for measuring resilience, such as the Critical Infrastructure Resilience Index (CIRI) and the Resilience Management and Matrix Audit Toolkit. Many of these methods have been reviewed due to overlap and diversity, and efforts have been made to develop glossaries for resilience-related terms in critical infrastructure. Complementary use of indicators and surveys can help measure progress towards agreed targets.

In summary, there is extensive literature on disaster risk and resilience frameworks and measurement methods based on indicators, composite indexes, and other tools and approaches, regarding communities and critical infrastructures. Many of them have been reviewed due to overlap and diversity (Curt and Tacnet, 2018; Gillespie-Marthaler et al., 2018; Dianat et al., 2020; Rød et al., 2020; GCA, 2021; FEMA, 2022; Derakhshan et al., 2022; Graveline and Germain, 2022; Zuzak et al., 2022). In addition, many efforts have been done on regard to the development of glossaries regarding resilience-related terms for critical infrastructure.

These tools and approaches can be used to assess the resilience of communities, organizations, and critical infrastructure systems to natural disasters, climate change, and other hazards. They provide a framework for identifying and prioritizing risk, assessing the effectiveness of risk management plans, and improving resilience through continuous improvement.

2.2.1 The SDG and Sendai Monitor

The Sendai Framework and the Sustainable Development Goals (SDGs) aim to promote resilience in societies through disaster and risk management, as well as development initiatives, represented in 17 different goals. Coherent and integrated actions can help achieve efficiency, identify inconsistencies, and promote synergy in implementing these agendas. To ensure coherence with SDG targets, Sendai Framework indicators were developed. Integrating sustainability with disaster risk reduction can contribute to reducing vulnerability, strengthening resilience, and implementing effective actions. However, data availability remains a significant challenge for many countries. Monitoring progress is essential and can only be done through data and information. Adequate financial and human resources are required to develop this infrastructure. National governments and the international community must prioritize funding statistical development. While progress has been made in the availability of comparable data for SDGs monitoring, the geographic coverage is limited, and fewer countries have been reporting on the Sendai Framework since 2017.

Three global frameworks were agreed in 2015: the 2030 Agenda for Sustainable Development, structured around a set of Sustainable Development Goals (SDGs); the Paris Agreement on Climate Change and the Sendai Framework for Disaster Risk Reduction 2015-2030. Each of these frameworks adopted or created sets of targets and indicators to measure progress, which, in principle, could provide a basis for monitoring infrastructure resilience.

The mid-term reviews of the SDG and the Sendai Framework unfortunately show that most of the indicators are not yet available in all countries. The development of the information and data infrastructure needed to fill this gap will require greater investment of financial and human resources to support statistical development (UN, 2022).

Figure 1 shows that the number of countries with data to inform the indicators of each SDG is less than 100 across all the SDG. Except for SDG 3, 6,7, 9 and 15 it is less than 60 countries. While the SDG indicators include data that could be extremely valuable for measuring and monitoring infrastructure resilience, global comparative coverage is still a future aspiration rather than a present reality.

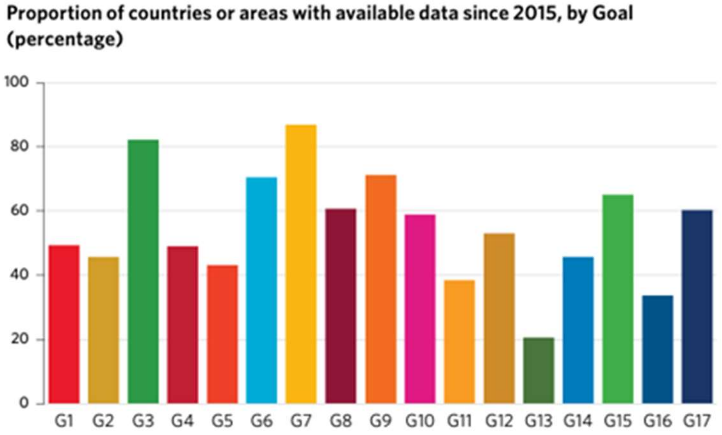

Figure 1: Proportion of countries or areas with available data since 2015, by Goal. Source: United Nations, 2022

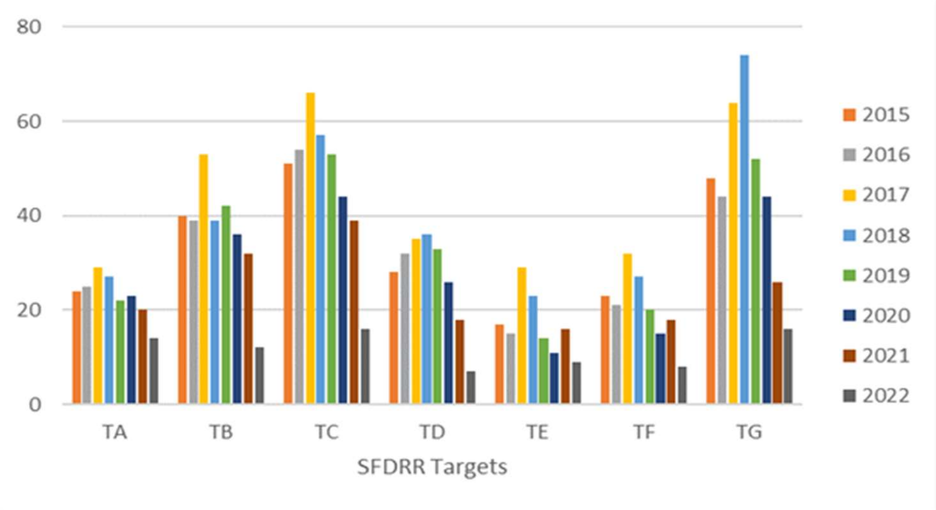

Figure 2: Evolution of country reporting by SFDRR Target. Source: Own elaboration based on the Sendai Monitor (UNDRR, n.d.)

Figure 2 shows that in the case of the Sendai Framework for Action, the number of countries reporting back across Targets A – G, has steadily declined since 2017. In 2021 and 2022 less than 20 countries have reported on the indicators chosen to measure Target D (Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030). This is not a statistically significant or useful sample, on which to base global monitoring of progress towards infrastructure resilience.

Until the coverage of data dramatically improves, the indicators proposed by the SDGs and Sendai Framework cannot be used to measure progress in resilient infrastructure. However, when better data coverage is achieved they could make a very useful contribution.

The GIRI (Global Infrastructure Resilience Index) serves as a complement to the progress monitoring tools of the SDGs and the Sendai Framework. The GIRI focuses on infrastructure resilience from the performance perspective, as well as social, economic, and environmental variables that can aggravate conditions or provide capacities during external shocks or disturbances. Due to insufficient data availability, many indicators designed for the SDGs cannot be included in the GIRI index. Similarly, there is limited information on the Sendai Framework, making it challenging to include its indicators in the GIRI index. However, both the Sendai Framework and the GIRI index can complement each other. It is essential to note that the GIRI index's proposed indicators can be replaced when better ones become available. Therefore, the index's results can significantly contribute to the reporting of these agendas once more data is available.

2.2.2 Composite indicators, and indexes available at global, national, and local levels for measuring resilience

As mentioned in previous sections, there is a wide availability of indicators around the world for disasters, disaster risk, vulnerability, sustainable development, resilience measurement. This section shortly describes a few indicators that served as a base for the construction of the GIRI index.

2.2.2.1 *The Holistic Risk Evaluation*

The holistic risk approach robustly addresses hazards and contextual conditions, acknowledging their intricate interconnectedness. Hazards refer to potential events with the capacity for destructive impact on exposed elements, constituting what is known as exposure. This exposure is marked by both physical vulnerability and contextual circumstances that amplify or exacerbate physical damage. These contextual factors align with socio-economic indicators denoting insufficient resilience and social fragility. The amalgamation of these factors yields the likelihood of impact, often referred to as risk. The disaster itself materializes as a manifestation of the hazard, resulting in a disrupted state of exposure that requires post-event management measures.

This understanding encapsulates both physical facets and inherent societal attributes, which contribute to either exacerbating or mitigating the impact of hazardous events, while influencing community resilience. This methodology aligns with Cardona's suggestion (2001), as referenced in Bankoff et al. (2004), that vulnerability originates from:

- Physical fragility or exposure: Reflecting the susceptibility of human settlements to be impacted by hazardous events due to their geographical positioning and limited physical resilience.

- Socio-economic fragility: Representing the predisposition to experience harm due to levels of marginalization and social segregation within human settlements, coupled with unfavorable socio-economic conditions.

- Lack of resilience: Indicating constraints in accessing and utilizing resources within human settlements, as well as an incapacity to effectively respond to the impact.

Effectively addressing risk necessitates the establishment of a comprehensive risk management system, rooted in an institutional structure that advocates for and promotes public policies, strategies, and corrective and proactive actions. These actions are directed at intervening in vulnerable elements and societal conditions that contribute to risk formation or escalation, along with the creation of hazards (whether anthropogenic or technological). Similarly, within the risk management framework, emergency response and recovery plans predicated on risk assessments must be defined, allowing for swift and effective responses in the event of a disaster. From a management standpoint, risk studies enhance decision-making by driving effective risk management through actionable insights and the identification of vulnerabilities in exposed elements, as well as tracking their evolution over time (Cardona, 2001; Carreño, 2006; Carreño et al., 2007).

Recent years have witnessed comprehensive risk evaluations focused on seismic hazards and vulnerabilities in urban areas. These evaluations have been conducted globally for various cities, such as references to Carreño et al. (2007), Birkmann et al. (2013), Marulanda et al. (2013), Jaramillo (2014), and Salgado-Gálvez et al. (2016). Country-level assessments are also evident, demonstrated by Marulanda et al (2020), Daniell et al. (2010) and Burton and Silva (2014), as well as on a global scale, exemplified by UNDRR (2017). These evaluations have proven valuable in assessing, comparing, and communicating risk, while propelling effective interventions to address vulnerability across its varied dimensions. Furthermore, this approach has been incorporated into tools, guidebooks, and databases designed for earthquake risk assessment, as highlighted by Burton et al. (2014) and Khazai et al. (2015). Recently, FEMA (2020) undertook a study in the USA, aligning with the conceptual principles of this methodology.

This relative and multi-criteria analysis perspective regards risk as an aggregation of potential consequences arising from factors such as physical exposure (potential damage and losses) to a given hazard, alongside the underlying factors that contribute to these consequences and the inability to manage them. This understanding suggests that undesired effects can be mitigated or prevented through intervention in triggering and causal factors. The assessment encompasses variables of diverse natures, often challenging to address through simple functions. Therefore, the use of proxies or "representations" – which can manifest as indexes or indicators – is occasionally necessary. This implies that vulnerability might encompass several components, reflecting physical susceptibility and fragility (exposure) - factors that hinge on the nature and severity of the event - as well as elements indicating social fragility and a lack of resilience. The latter refers to the incapacity to anticipate, recover from, and absorb the impact, which is not solely reliant on or determined by the effects and consequences of the event.

This methodology provides a streamlined perspective on a multidimensional concept, aiming to enhance understanding among diverse stakeholders by offering a coherent framework encompassing social, economic, environmental, and cultural aspects. It's important to note that, generally, indicators do not encompass the entirety of risk management measures, as these require integrated models for conception. Nonetheless, the primary strength of this approach lies in its ability to retrospectively analyze outcomes. This involves breaking down results to identify factors that should be prioritized for risk reduction actions, as well as assessing the effectiveness or ineffectiveness of past measures. This marks the first instance of employing this methodology to consider hazards, exposure, and socio-economic descriptors at a specific geographical level. This approach allows for the identification of risk drivers associated with the socio-economic context, surpassing mere physical vulnerability of exposed assets. The outcomes derived from this evaluation support risk communication and cross-municipality benchmarking, thereby stimulating effective interventions addressing vulnerability in its various dimensions.

Figure 3 depicts the conceptual framework employed in the comprehensive assessment of disaster risk undertaken for UN GAR 2017 (UNDRR, 2017). Within this approach, hazards are potential events that could cause detrimental impacts on the constructed environment (i.e., urban exposure). These hazards are characterized by the physical vulnerability of human settlements in various countries, along with contextual factors that can either amplify or worsen the resulting physical damages. These contextual factors can be linked to socioeconomic indicators unique to each country.

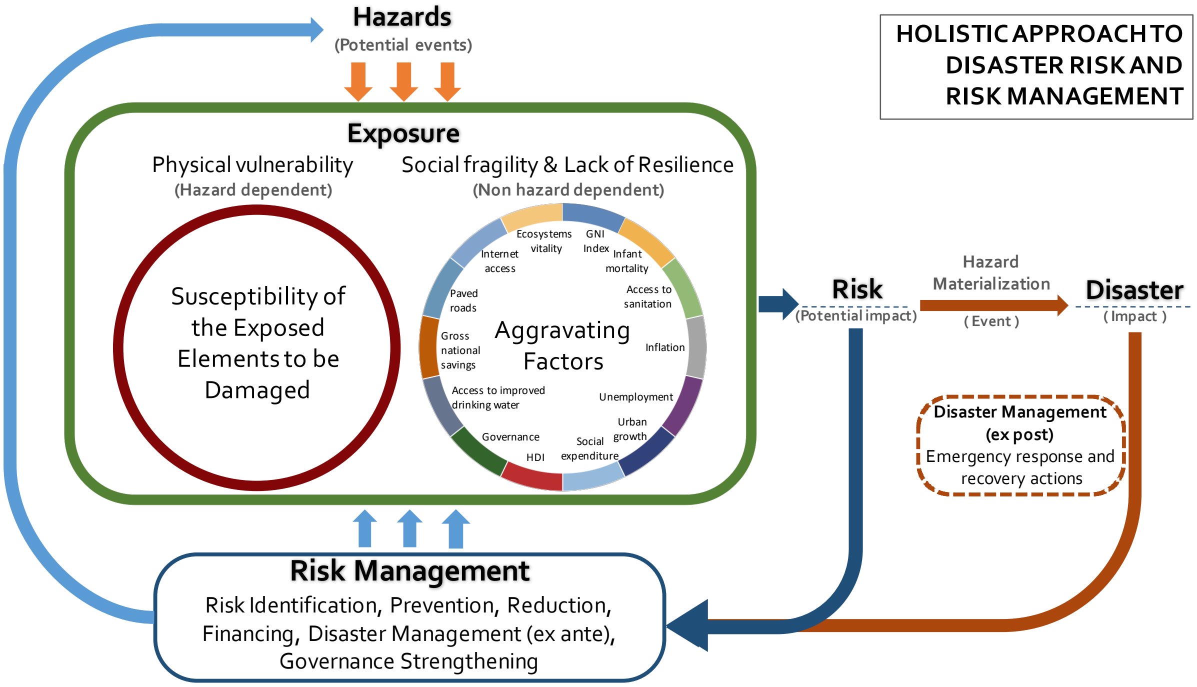

Figure 3. Conceptual framework of the holistic approach to disaster risk assessment and management (Cardona, 2001); used at UNDRR (2017) and UNGRD (2018).

The amalgamation of these elements gives rise to the probability of damage and loss, forming the basis for a probabilistic risk assessment. The actual occurrence of a disaster emerges as a manifestation of the hazard, leading to a disrupted state of exposure. This state necessitates post-event management measures. Consequently, effectively addressing disaster risk and promoting resilience demands the establishment of a comprehensive risk management system. This system should rest upon an institutional framework that facilitates and advocates for public policies, strategies, as well as corrective and anticipatory actions. These measures are targeted at intervening in the vulnerable elements and conditions within society that contribute to the generation or escalation of disaster risk, as well as the creation of hazards (both anthropogenic and technological).

Likewise, as an integral component of the disaster risk management and adaptation framework, it becomes imperative to formulate emergency response and recovery plans and activities that hinge on resilience performance. These plans and actions enable swift and efficient responses in the aftermath of a disaster occurrence.

Hence, this comprehensive approach to risk and resilience effectively tackles both hazards and the contextual conditions, recognizing their inherent interconnectedness. It takes into account not only the physical aspects but also the intrinsic characteristics of society, which establish varying degrees of vulnerability or strength. These conditions, in turn, either amplify or diminish the impact of hazardous events and influence the ability of communities to manage and recover from adverse outcomes.

Also, if the objective is to measure resilience, which entails evaluating capacity through indicators to anticipate, recover from, and absorb impacts, this capacity isn't always solely contingent on or limited to the direct effects and outcomes of the event. Instead, it rests on governance, preparedness, responsiveness, and the operational capabilities for restoration and adaptation.

This methodology, already employed at the global scale, offers a streamlined perspective of a multidimensional concept, aiming to enhance its comprehension among various stakeholders. It fosters a coherent framework that addresses social, economic, environmental, and cultural facets. It's worth noting that while indicators in general do not encompass the entirety of disaster risk management measures, since these should be designed using integrated models, the primary strength of this approach lies in its ability to retrospectively analyze outcomes. This involves breaking down results to identify factors that require prioritization for risk reduction and adaptation actions, while also assessing the effectiveness or ineffectiveness of past measures. This approach permits the identification of risk drivers tied to the socio-economic context, surpassing the mere physical vulnerability of exposed assets. The results derived from this evaluation facilitate risk communication and cross-country benchmarking, thereby encouraging effective actions to address vulnerability conditions across their various dimensions, encompassing fragility, weaknesses, and deficiencies.

2.2.2.2 National Risk Index (NRI)

The National Risk Index (NRI)[1] is a tool developed by the Federal Emergency Management Agency (FEMA) in the United States to assess and rank the risks associated with natural hazards at the community level. It provides a comprehensive view of risk by considering multiple hazards and their potential impacts on communities across the country.

The NRI considers various factors, including hazards, physical exposure to hazards, vulnerability of the population and built environment, and the ability to cope with and recover from disasters. It integrates data related to hazards such as hurricanes, earthquakes, floods, tornadoes, and more, along with socio-economic and demographic information about the population.

The key components of the National Risk Index include:

Hazard: This considers the likelihood and intensity of different hazards occurring in a particular area, such as the frequency of hurricanes or the seismic activity of earthquakes.

Socio-Economic Vulnerability: This assesses the vulnerability of the population and built environment to the impacts of hazards. Factors like poverty rates, housing quality, and education levels are considered.

Community Resilience: This evaluates the ability of a community to prepare for, respond to, and recover from disasters. It takes into account factors like emergency planning, access to healthcare, and community resources.

The NRI combines these components to generate an overall risk score for each community. Higher scores indicate higher levels of risk. The index can be used to identify areas that are most vulnerable to multiple hazards and can help guide resource allocation, disaster mitigation efforts, and emergency planning at local, state, and national levels.

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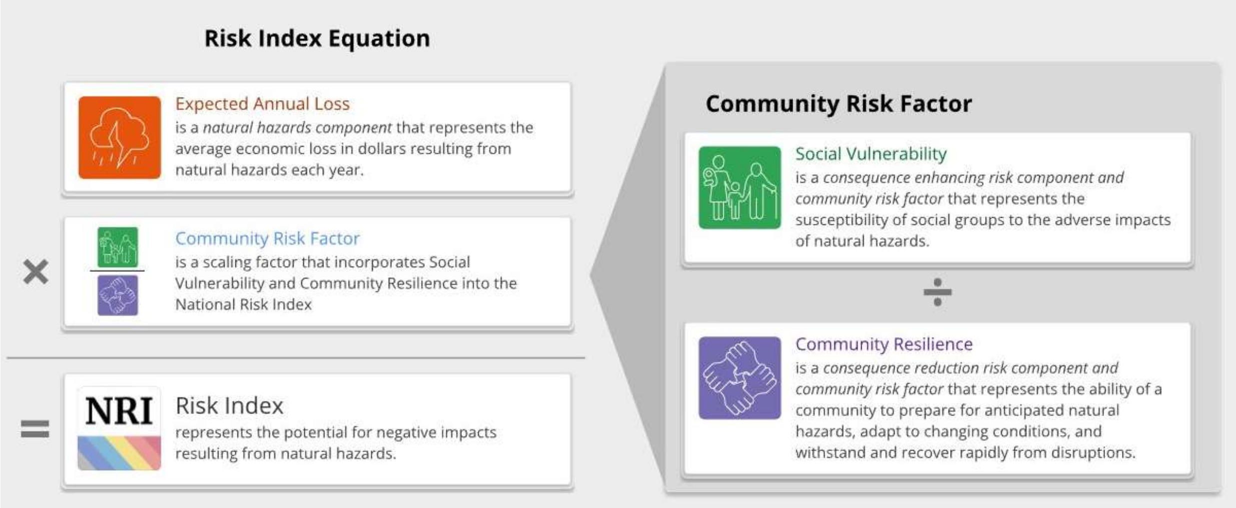
[1] https://hazards.fema.gov/nri/determining-risk

The NRI serves as a valuable tool for decision-makers, emergency managers, and researchers to better understand and address the complex landscape of risks posed by various natural hazards across the United States.



Expected Annual Loss
is a *natural hazards component* that represents the average economic loss in dollars resulting from natural hazards each year.

Community Risk Factor
is a scaling factor that incorporates Social Vulnerability and Community Resilience into the National Risk Index

Risk Index
represents the potential for negative impacts resulting from natural hazards.

Social Vulnerability
is a *consequence enhancing risk component and community risk factor* that represents the susceptibility of social groups to the adverse impacts of natural hazards.

Community Resilience
is a *consequence reduction risk component and community risk factor* that represents the ability of a community to prepare for anticipated natural hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions.

Figure 4. Components of the National Risk Index. Source: https://hazards.fema.gov/nri/determining-risk

2.2.2.3 Social Vulnerability Index (SoVI)

SoVi stands for "Social Vulnerability Index." It is a quantitative measurement used to assess the social vulnerability of communities or populations to the adverse impacts of natural or man-made hazards. The index takes into account various socio-economic, demographic, and infrastructure factors that contribute to a community's susceptibility to such impacts. SoVi helps decision-makers identify areas that might require more targeted disaster preparedness, response, and recovery efforts based on their vulnerability levels.

Social vulnerability pertains to the susceptibility of social groups to adverse consequences stemming from natural hazards, encompassing imbalanced fatalities, injuries, losses, or livelihood disruptions.

As an augmentation of the National Risk Index's risk component, the Social Vulnerability score and rating denote a community's relative level of social vulnerability compared to others at the same tier. The Social Vulnerability score of a community gauges its national ranking or percentile. A heightened Social Vulnerability score corresponds to an elevated Risk Index score.

The Social Vulnerability Index (SoVi) methodology typically involves a multi-dimensional analysis of various socio-economic, demographic, and infrastructural factors that contribute to a community's vulnerability to the adverse impacts of hazards.

It's important to note that different versions of SoVi might utilize slightly different variables, weighting schemes, and mathematical formulas, but the general methodology focuses on assessing and quantifying the multi-dimensional aspects of social vulnerability within a community or region.

2.2.2.4 *INFORM*

The INFORM Risk model is grounded in risk principles established within scientific literature. It delineates three core risk dimensions: hazards and exposure, vulnerability, and lack of coping capacity. These dimensions are intertwined in a harmonizing relationship: the risk pertaining to what (natural and human hazards) and the risk regarding what (population).

The INFORM Risk model harmonizes two significant forces: the hazards & exposure dimension on one side and the vulnerability along with the lack of coping capacity dimensions on the other side. Factors contingent on hazards are accommodated within the hazards & exposure dimension. Conversely, factors not reliant on hazards are divided into two dimensions: vulnerability, which evaluates the resilience of individuals and households in a crisis, and lack of coping capacity, which considers institutional strength.

The INFORM Risk model adopts three vulnerability aspects as per the UNISDR definition. The facets of physical exposure and physical vulnerability are encompassed in the hazards & exposure dimension. The socio-economic system's fragility becomes the vulnerability dimension, while the lack of resilience to adapt and recover is addressed under the lack of coping capacity dimension. This division of vulnerability into three components is beneficial for tracking the outcomes of disaster reduction strategies over time. Disaster risk reduction activities often target specific community-level vulnerabilities and capacities.

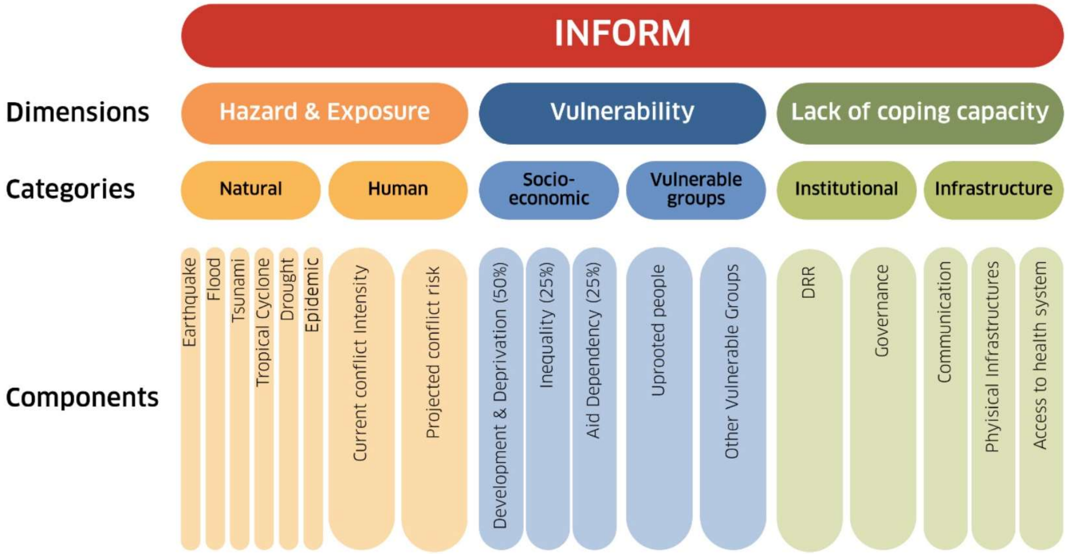


Figure 5. Dimensions, categories and components of the INFORM, Index for Risk Management. Source: Ferrer et al. (2017)

2.2.2.5 *The Disaster Risk Implications on Socio-Economic Development of Countries (DRID)*

The Disaster Risk Implications on Socio-Economic Development of Countries (DRID) index serves as a valuable tool for ranking countries based on the relationship between the projected Average Annual Loss (AAL) and a range of economic, financial, and social expenditures. This index aims to expose the impact of AAL on social spending, domestic investment (capital formation and savings), financial capacity (reserves), and the assets at risk (produced capital or capital stock) within each country. It offers insights into growth and social limitations that might arise due to potential intense future disasters.

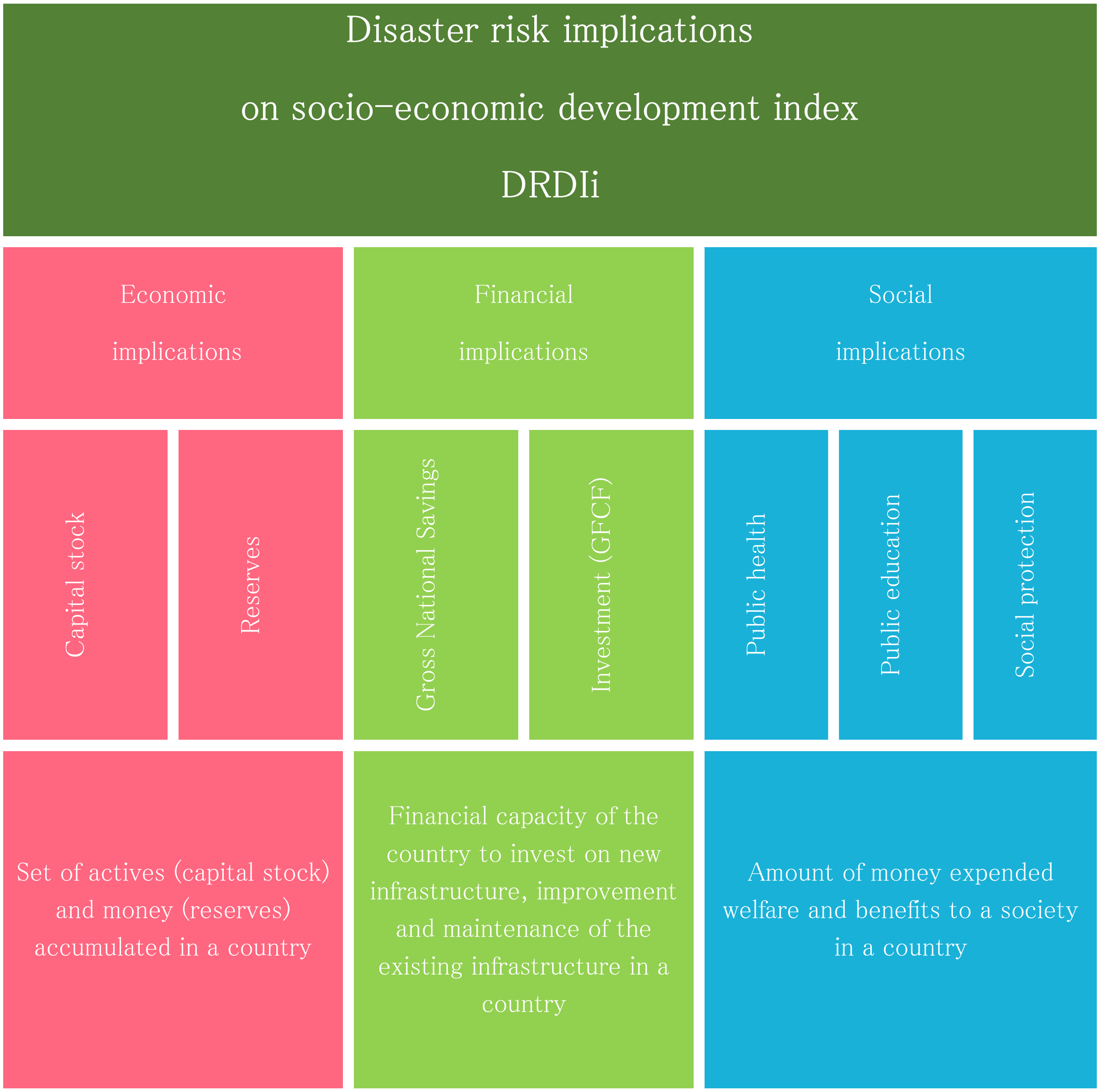


Figure 6. Components and economic variables of the DRDI index Source: UNISDR (2017)

It is important to note that this index is constructed using the average annual losses projected for potential future disasters originating from earthquakes, tsunamis, tropical cyclones, and riverine floods. This does not imply that the same amount of losses occur every year; the actual losses are variable, ranging from years with no losses to those with lower or higher losses. In this context, when average annual losses already strain a country's budget, a major event with significant losses could have a substantial impact on the country.

In the event of disasters, countries can access different budgets within their overall budget. However, to make the risk more apparent, a set of economic variables has been chosen to underscore the significance of the current risk. Looking at these variables together allows for a comprehensive understanding.

Across the three sub-indicators, high values indicate that either the average annual loss is notably high, impacting the country's expenditures and economic well-being, or the country's expenditure and economic capacity are notably low, making them vulnerable to the impact of AAL, or even both.

The sub-indicator related to economic implications is tied to a country's assets and accumulated wealth. A high value here suggests that a substantial portion of assets could be affected, potentially diminishing the use of reserves to address liabilities stemming from disasters.

The financial implications sub-indicator considers a country's growth and financial capability to invest in infrastructure. It is often observed that economically advanced countries allocate a smaller percentage of their GDP to investment due to their existing infrastructure. However, a high value in this sub-indicator indicates how potential losses might impede a country's investment plans, as resources would be redirected toward recovery and reconstruction.

Lastly, the social expenditure sub-indicator, encompassing public health, education, and social protection expenses, reflects how potential losses could impact this budget and potentially compromise societal welfare and benefits due to the challenge of allocating resources simultaneously to social development and disaster recovery.

The index reveals that the ratio of AAL to the capital stock provides meaningful insights into disaster risk, considering both hazard levels and exposure vulnerability on one hand, and a country's economic and financial ability to handle future losses (investment, social expenditure, reserves, and savings) on the other. Higher index values signify that disaster risk might strain these budgets.

DRID is derived from three sub-indicators:

- Disaster Risk Social Implications (DRSI), calculated from the AAL-to-Social Expenditure ratio.
- Disaster Risk Growth and Financial Implications (DRGI), derived from the average AAL-to-Gross Fixed Capital Formation and gross savings ratio.
- Disaster Risk Economic Implications (DREI), obtained from the average AAL-to-Capital Stock and total reserves ratio.

This straightforward approach utilizes indicators to provide a general perspective on how disaster risk affects the socio-economic development of countries.

2.2.2.6 SYSTEM OF INDICATORS OF DISASTER RISK AND DISASTER RISK MANAGEMENT - IDB

A set of four composite indicators has been devised to encompass the core aspects of vulnerability and reflect the progress of each country in risk management. These four indicators are the Disaster Deficit Index (DDI), the Local Disaster Index (LDI), the Prevalent Vulnerability Index (PVI), and the Risk Management Index (RMI).

The Disaster Deficit Index evaluates a country's risk from a macroeconomic and financial viewpoint, considering potential catastrophic events. It necessitates estimating significant impacts during a specified exposure period and evaluating the country's financial capacity to handle such scenarios.

The Local Disaster Index identifies social and environmental risks arising from frequent lower-level events, which often persist chronically at local and subnational levels. These events disproportionately affect socially and economically vulnerable populations and exert substantial adverse effects on national development.

The Prevalent Vulnerability Index comprises a series of indicators that delineate prevailing vulnerability conditions, encompassing exposure in susceptible areas, socio-economic fragilities, and overall lack of social resilience.

The Risk Management Index integrates a set of indicators measuring a country's effectiveness in managing risk. These indicators reflect the actions taken in terms of organization, development, capacity, and institutions to diminish vulnerability and losses, prepare for crises, and efficiently recover from disasters.

The indicator framework addresses diverse dimensions of the risk landscape, taking into account factors like potential damages and losses from extreme events, recurrent disasters or losses, social and environmental conditions that heighten susceptibility, economic recovery capability, essential service operation, institutional efficacy, and the functionality of key risk management tools (such as risk identification, prevention, mitigation measures, financial mechanisms, and risk transfer). It also evaluates emergency response readiness and the ability to prepare for and recover from disasters.

- Disaster Deficit Index, DDI

Viewed from a macroeconomic standpoint, the occurrence of disasters, particularly high-impact events, has the potential to induce financial strain within a country. This strain arises due to the abrupt surge in demand for resources required to rehabilitate exposed assets affected by the disasters. Disaster risk stands as a sovereign risk, implying a latent contingent liability that, in numerous instances, profoundly affects fiscal stability. To assess the potential impact of disasters on a country, two composite risk indicators have been employed:

The Disaster Deficit Index (DDI), which gauges a nation's financial capability to manage the economic losses stemming from high-impact events. A supplementary index (designated as DDI') that quantifies the proportion of the anticipated annual loss concerning the country's annual surplus.

The outcomes of the DDI enable decision-makers at the national level to comprehend the economic ramifications of disasters for the country. Such insights underscore the necessity of incorporating this type of information into long-term policies. The DDI outcomes illuminate the pronounced requirement for substantial government resources in the face of disasters. Projected losses amount to twice the available resources, potentially leading to constraints on social and developmental investments, as well as existing budget limitations.To mitigate this macroeconomic risk, strategic measures can be adopted. Establishing a robust financial structure for risk management is crucial, guided by sound loss estimation criteria. This can encompass various approaches, including insurance for public and private assets, disaster reserves, contingency credit agreements, and investments in prevention and mitigation to curtail potential economic losses.

- Risk Management Index, RMI

The purpose behind crafting this index was to evaluate the effectiveness of risk management endeavors. It offers a qualitative assessment of management performance based on predetermined benchmarks or targets that risk management initiatives should strive to attain. The development of the Risk Management

Index (RMI) entailed creating a scale encompassing levels of achievement (Davis 2003; Masure 2003) or determining the "gap" between current circumstances and a defined threshold or conditions in a reference country (Munda 2003).

The RMI was formulated by quantifying four distinct public policies, each comprising six indicators. These policies encompass risk identification, risk reduction, disaster management, and governance with financial protection. Risk identification (RI) gauges individual perceptions, their collective understanding within society, and an objective assessment of risk. Risk reduction (RR) involves preventive and mitigative measures. Disaster management (DM) encompasses response and recovery strategies. Lastly, governance and financial protection (FP) measure the extent of institutionalization and risk transfer.

The RMI is defined as the average of these four composite indicators. Each indicator was assessed across five performance levels: low, incipient, significant, outstanding, and optimal, mapped onto a scale from 1 (low) to 5 (optimal). This methodological approach permits simultaneous utilization of reference levels as "performance targets," allowing for comparison and identification of outcomes or achievements. Government endeavors related to policy formulation, implementation, and evaluation should be guided by these performance targets.

2.2.2.7 Index of Governance and Public Policy in Disaster Risk Management (iGOPP)

The iGOPP aims to bridge these disparities. This index assesses the tangible presence of essential legal, institutional, and budgetary prerequisites that are indispensable for the successful implementation of Disaster Risk Management processes within a specific country. Effective planning necessitates comprehension and, to some extent, quantification. Therefore, as governance concepts are grasped, actionable measures can be formulated to tangibly realize disaster risk management within the region.

While the iGOPP does not directly assess the "performance" of risk management by verifying the practical implementation of associated regulations, it offers a valuable systematic analysis of governance conditions. This organized approach proves highly beneficial for devising contemporary programs and projects within the regulatory and institutional framework that underpins Disaster Risk Management (DRM) as a developmental strategy. It is important to note that the iGOPP does not supplant or replace other indicators pertinent to the subject; instead, it serves to enhance existing methodologies for comprehensive risk assessment and disaster risk management.

The conception of the iGOPP is rooted in the recognition that disaster risk fundamentally intersects with development concerns. Consequently, the index encompasses more than just confirming the presence of explicit regulations within public administration for disaster risk management. It also extends to encompass crucial facets of risk governance, including development, decentralization, land use planning, public investment, monitoring, and other pivotal elements.

The Index has been crafted to assess the concrete presence of legal, institutional, and budgetary prerequisites that are crucial for the effective implementation of Disaster Risk Management (DRM) processes within a particular country.

The practical utility of the iGOPP resides in pinpointing potential deficiencies within a specific country's legal, institutional, and budgetary framework. This identification process assists in directing a nation's endeavors, along with potential support from the Interamerican Development Bank (IDB), towards pertinent facets of governance. This targeted approach aims to reinforce Disaster Risk Management (DRM) public policy choices within the Latin American and Caribbean (LAC) countries.

The iGOPP's design is founded on two core conceptual foundations:

- The conceptual framework of Disaster Risk Management and its primary processes.
- The conceptual framework of Governance and the phases of public policy.

The iGOPP encompasses governance in the context of disaster risk management, built upon six essential reform components: (i) General Governance Framework for DRM, (ii) Risk Identification and Knowledge, (iii) Risk Mitigation, (iv) Disaster Preparedness, (v) Post-Disaster Recovery Planning, and (vi) Financial Protection. These components align with the process-oriented conceptual model of disaster risk management.

- Risk Mitigation:
- Prevent the emergence of new risk conditions
- Alleviate existing risk
- Disaster Management:
- Prepare for response
- Respond and recover
- Financial Protection (retention and transfer of disaster risk)
- Knowledge of disaster risk

The indicator system employed to develop the iGOPP is structured around a matrix that intersects the six DRM reform components and the phases of public policy. Altogether, a total of 241 indicators were assessed and distributed. It consists on "Yes/No" answers, and, a value of 1 indicates the fulfillment of the condition (positive response), while a value of 0 indicates its lack thereof. The year when the regulation came into effect is also recorded because in certain instances, laws might be passed on one date but only become effective on later dates.

Other indicators and indexes found in the literature review are mentioned in the following table. Most of them are mainly focused to community resilience.

Table 1. Indexes and indicators of resilience and community resilience

Community based resilience analysis (CoBRA)	Commissioned by UNDP Drylands Development Centre	• Community and Household Resilience • Study Hypothesis: Individuals are considered resilient as long as they have the minimum necessary resources to consistently meet their basic needs in crisis situations without external assistance. • Mentions 2 groups of methodological models for measuring resilience: o Systemic approach: Range of activities, actors, and processes that constitute the system. o Measuring community-level resilience characteristics: Participatory methodology.

		• Different methodologies for resilience assessment are mentioned:
Copeland, S., Comes, T., Bach, S., Nagenborg, M., Schulte, Y., Doorn, N. (2020). Measuring social resilience: trade-offs, challenges and opportunities for indicator models in transforming societies.	International Journal of Disaster Risk Reduction	• Conceptual Article • Review of Social Indicators for Measuring Resilience • Description of Resilience Concepts and Discussion of How Indicators Have Normative Implications for Communities • Mention Various Studies and Methodologies Related to Resilience • Indicators are outcome, process, or structure-based • Many indicators focus on numbers in relation to the population, not on the service itself. This doesn't necessarily reflect the capacity and quality of the service. • • Some soft factors are difficult to measure and may not necessarily lead to a resilient community. • "Culture" is an often overlooked yet important factor in discussing resilience. • Mass migration due to conflict, macro-economic adaptation after major disasters, minor behavioral changes, or adaptation actions. • Benchmarks (future or idealized scenarios). • Models tend to implicitly emphasize a return to the status quo in their design. • Questions such as: What does the community need to confront threat x? What are the expectations of a community that considers itself resilient against a threat? What should people be able to do?
Fraser et al (2011). Assessing vulnerability to climate change in dryland livelihood systems: conceptual challenges and interdisciplinary solutions		• Critical Factors Influencing Resilience: o Socio-economic assets or Agro-ecosystems (environmental health) o Institutional capacity
2012 Disaster Resilience report		• Summary of 17 Assessment Tools and Systems: • Top-down Tools: o HFA o ResilUS o The San Francisco Planning and Urban Research Association (SPUR) model o The PEOPLES resilience framework o Baseline Resilience Index o BRIC Index • Bottom-up Tools: o NOAAs resilience Index o The Toolkit for Health and Resilience in Vulnerable Environments (THRIVE) o The Communities Advancing Resilience Toolkit (CART) • Four general categories of objectives for community-based resilience measures are identified: critical

		infrastructure, social factors, buildings and structures, and vulnerable populations. • The process of developing a measurement tool begins with identifying a category. Next, objectives for these components must be established before ultimately identifying measures corresponding to those objectives. • A single, one-size measure for all facets of resilience is unlikely to work because the goals and aspirations, compositions, and threats and hazards of communities are different. Rather, a suite of tools with several indicators is needed. • Planning includes measures and indicators, involving the evaluation of physical infrastructure and land used for zoning, but not necessarily accounting for adaptive capacity, social networks, or community risk perceptions.

TANGO Resilience Assessment Framework	DFID Disaster Resilience Framework (2011)	• Conceptualization of Resilience as a Dynamic Process • Approach for Policy-Makers and Practitioners to Understand Resilience. Description of Factors and Processes Influencing Community and Household Vulnerability and Resilience.
Sustainable Livelihoods Framework (SLF)		• Categorization of Potential Resilience Features. • Five main categories: financial, human, natural, physical, and social.
Practical action´s vulnerability to resilience (V2R) framework		• Highlights key areas leading to resilient or vulnerable communities. • Addresses underlying factors that drive vulnerability.
Saja et al.		• Resilience approach divided into 4 parts: o Social capital o Capacity to withstand, adapt, transform o Social community and interconnected dimensions o Structural and cognitive dimensions
Susan Cutter		• Difference between assessment types: indices, scorecards, and tools? • Defines categories for different approaches: o Spatiality (specific assets like infrastructure or an entire community) o Domain (system characteristics or capacities within it) o Method (top-down or bottom-up) • Inherent properties of a system (benchmarking), individual and stakeholders' capacity, communities to learn from and respond to changes as a dynamic process. • 20 key indicators
Norris et al		• 4 groups defined: ○ Capital social (sentido de comunidad, vínculos informales, apoyo social esperado) ○ Competencia comunitaria (habilidad para resolver problemas, flexibilidad y creatividad)

		○ Información y comunicación (fuentes de información fiables, medios de comunicación responsables) ○ Desarrollo económico (nivel y diversidad de los recursos económicos)
Keck and Sakdapolrak		• 4 defined groups: o Social capital (sense of community, informal ties, expected social support) o Community competence (ability to solve problems, flexibility, and creativity) o Information and communication (reliable information sources, responsible media) o Economic development (level and diversity of economic resources)
FAO		• Set of potential variables derived from a number of observable indicators • Weighted sum of factors using Barlett's scoring method. o Social safety nets o Access to basic services o Assets o Income and access to food
Univeristy of Florence (Ciani and Romano, 2013)		• Expands the approach developed by FAO by applying it to a specific event: Hurricane Mitch in Nicaragua • Agricultural resilience index • 11 potential variables: o Income and access to food o Access to basic services o Agricultural assets o Non-agricultural assets o Household production o Technological level o Public transfers o Private transfers o Adaptation capacity o Physical connectivity o Economic connectivity o Demography
Tulane University		• Multi-dimensional approach to analyze resilience and the effects of humanitarian assistance on resilience (outcomes after the 2010 Haiti earthquake). • 3 components: o Characteristics of an individual, household, or community o Extent and nature of the impact o Presence and type of humanitarian response.
USAID	Multi-dimensional approach – Horn of Africa and the Sahel	• Six areas: o Access to income and food o Assets o Social safety nets/social capital o Nutrition and health o Adaptation capacity o Governance
Tufts University/World vision	Captures livelihoods (food security, health status, education level) and the	• 7 indicators of household livelihoods and well-being o Food insecurity and access level o Index of coping strategies o Food consumption score

	dynamic interactions among livelihood strategies, policies and programs, and institutions that enhance or limit household responses.	o Illness score o Value of productive assets o Net debt o Income (daily per capita expenditure)
OXFAM y ACCRA	Multidimensional approaches. Identifies resilience characteristics at the community and household levels, independent of any impact. Uses the Akjure-Foster analysis method: develops various composite indicators based on a number of indicators that reflect different manifestations of the multidimensional construct of interest (e.g., poverty).	• Livelihood viability • Livelihood innovation potential • Contingency resources and access to assistance • Access to natural resources, management, and health • Social response capacity
Hyogo Framework for Action		• Qualitative model that prioritizes risk reduction activities in different countries.
ResilUS		• Quantitative assessment of the recovery of critical services within a community.
The San Francisco Planning and Urban Research Association (SPUR) model		• Semi-quantitative, infrastructure-focused. Assesses the community's capacity for infrastructure recovery following earthquake occurrences.
The PEOPLES resilience framework		• Holistic quantitative and qualitative framework for designing and measuring local-level resilience.
Baseline Resilience Indicators for Communities (BRIC)		• Quantitative measurement of pre-existing community resilience at the county level for comparison among different counties in the USA.
BRIC index		• Evaluates the inherent characteristics of a community that contribute to resilience, such as social and economic capital, ecosystems, infrastructure, and institutional capacity.
National Oceanic and Atmospheric Administration's (NOAA) Coastal Resilience Index		• Designed to assist communities in predicting how well they could resume their normalcy after a disaster. • Consists of a scorecard completed by a community as a qualitative self-assessment that evaluates facilities, critical infrastructure, mitigation measures, and the community's overall plan.
The Toolkit for Health and Resilience in		• This tool is a combination of self-assessment and quantitative information. It is a bottom-up assessment combined with a top-down assessment

Vulnerable Environments (THRIVE)		
The Communities Advancing Resilience Toolkit (CART)		- Developed by the National Consortium for the Study of Terrorism and Responses to Terrorism (START), it focuses on enhancing community resilience through planning and action, emphasizing the building and maintenance of connections within communities.

3 THE RELEVANCE OF RISK ESTIMATION

Strengthening asset resilience is fundamental if new infrastructure investment is to be a motor for social and economic development, rather than a source of increasing contingent liability and future disasters. Identifying and estimating the risk internalised in infrastructure assets is, therefore, a first, and essential, step, towards infrastructure resilience, enabling governments and other infrastructure owners to identify and estimate the contingent liabilities they are responsible for in each sector and territory. Financial risk metrics clarify the economic case for investing in resilience and help identify the most effective strategies.

Infrastructure asset risk reflects the concatenation of geological and climate related hazard, the exposure of infrastructure assets and their vulnerability or susceptibility to loss and damage.

Hazard patterns are controlled by geographic features such as tectonic faults, cyclone tracks, and floodplains. Asset risk can be higher in countries that are subject to multiple hazard events of higher frequency and intensity than in others with benign hazard landscapes. Climate change, and drivers such as environmental degradation and changes in land use, modify hazards such as floods, landslides, cyclonic wind and storm surges and droughts. Identifying and mapping hazard at an appropriate scale, including flood-prone areas, areas susceptible to earthquake and rainfall triggered landslides, tsunami inundation zones, areas that experience high earthquake intensities and others (USFS, 2022). normally the first step towards identifying and estimating asset risk.

Risk is configured not only by hazard but also by the density and vulnerability of the exposed population and assets. Vulnerability is associated with the quality of infrastructure governance and the capacity to ensure that infrastructure assets are built to appropriate resilience standards. If building standards are higher, risk may be lower even in countries with high levels of hazard exposure. Conversely, countries with weak infrastructure governance may have higher asset risk than those with stronger governance, even if hazard levels and the value of exposed assets are lower. Vulnerability functions are applied to each kind of exposed infrastructure asset and for hazards of differing frequency and intensity, to estimate the probable levels of loss and damage.

Risk assessments play a pivotal role in enhancing comprehension and awareness of risk levels, aiding key stakeholders in recognizing the imperative of integrating risk considerations into developmental processes. Over the past few decades, public concern has grown significantly, resulting in the widespread acceptance of the necessity to take proactive measures in averting and diminishing risk. However, the lack of a comprehensive understanding of disaster risk can lead to its underestimation, consequently dampening the resolve or enthusiasm to engage in endeavors aimed at risk reduction and prevention. Without quantification, effective management remains elusive; the ability to make informed decisions hinges on proper measurement. Hence, the development of a robust risk management strategy mandates a thorough evaluation of risk.

Although comprehensive risk assessments and technically advanced risk evaluations have bridged a gap in risk comprehension, notably within sectors like the insurance industry, their widespread adoption within the public sector has been limited. Consequently, many decisions have been grounded primarily in common knowledge, trial and error, or non-scientific viewpoints. Regrettably, there remains a nascent grasp of the implications of risk assessment results and their significance.

3.1 PROBABILISTIC RISK METRICS

In the 1990s, the insurance industry adopted probabilistic risk modelling as the best approach to estimate the full spectrum of risk and to generate financial risk metrics in order to calibrate insurance premiums and risk financing mechanisms, such as catastrophe bonds. Probabilistic models simulate future disasters, which based on scientific evidence, could possibly occur, reproducing the physics of the phenomena and recreating the intensity of a large number of synthetic hazard events. In doing so they provide a more complete picture of risk than is possible using historical data alone.

Insurance industry catastrophe models normally estimate risk for particular insurance markets or bundles or assets and are rarely available to governments or infrastructure investors. Open-source global risk assessments have partially addressed this gap, notably the Global Risk Model (UNDRR, 2017). Open risk modelling platforms and initiatives have also emerged, such as the CAPRA Robot (Ingeniar, n.d.), the OASIS Loss Modelling Framework and the Global Risk Modelling Alliance (GRMA) (Oasis Loss Modelling Framework Ltd., 2023; V20 Members, 2023).[2]

The occurrence frequency of catastrophic events varies significantly based on the event type, resulting in generally limited historical data. The relatively brief history of disaster records highlights the unlikeliness of the "worst-case" scenario having already transpired. Consequently, occurrences of substantial losses are infrequent, making it challenging to statistically estimate the likelihood of exceeding such losses. Determining their probabilities requires substantial judgment (Apostolakis, 1990). Within this context, quantifying physical risk doesn't imply precise risk knowledge but rather involves defining pertinent uncertainties. Analytical approaches adeptly capture the complexity of the physical risk problem by logically incorporating and propagating the inherent uncertainty in loss and impact occurrence. Probabilistic risk assessment (PRA), employed in all catastrophe models, emerges as the most suitable tool for this purpose. Given the unpredictability of hazardous events, physical risk models employ event sets to encompass all conceivable ways in which the hazard phenomenon could manifest in the analyzed area, considering both recurrence (frequency) and severity.

To compute risk, another factor comes into play: the loss probability distribution, a function of hazard intensity that describes the vulnerability of exposed elements. Event-based PRA has been extensively applied across different hazards and scales, as seen in works by Grossi & Kunreuther (2005), Jenkins et al. (2012), Cardona et al. (2014), Niño et al. (2015), Salgado-Gálvez et al. (2014, 2015, 2017), Wong (2014),

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[2] https://oasislmf.org/ and https://grma.global/

Jaimes et al. (2015), Quijano et al. (2014), and Bernal et al. (2017). Hazard, exposure, and vulnerability constitute the primary components of PRA, defined as follows:

Hazard model: Encompasses a set of hazard-specific events meticulously representing the hazard. Each event details the frequency of occurrence and the distribution of spatial parameters characterizing intensity as a random variable.

Exposure model: Includes metadata about each exposed element, such as geographic location, replacement value, and building classification. Depending on model resolution, more detailed asset information might be incorporated.

Vulnerability model: Describes vulnerability functions specific to each hazard type and building class. These functions depict structural performance based on hazard intensities, effectively representing the probability distribution of loss in relation to hazard intensity.

A primary risk metric originating from full probabilistic risk assessment is the loss exceedance curve (LEC). This curve, which offers a robust representation of catastrophe risk, has been elaborated upon by Cardona (1986), Ordaz (2000), Grossi & Kunreuther (2005), and Marulanda et al. (2013). The LEC offers a comprehensive probabilistic quantification of risk. While precise future disaster losses are unknowable, a LEC empowers us to ascertain the exceedance probability of various loss amounts over different timeframes. This information aids decision-making processes concerning risk reduction. Various risk metrics derive from the LEC, including the average annual loss (AAL) and the probable maximum loss (PML). AAL, also known as the pure risk premium, consolidates losses over a long time frame into a single, compact metric. It represents the anticipated (average) loss per year across all potential events, encompassing both frequent and infrequent large losses. The AAL is essentially the sum of the product of the expected losses in a specific event and the annual occurrence probability of that event, for all stochastic events considered in the loss model (Ordaz, 2000)

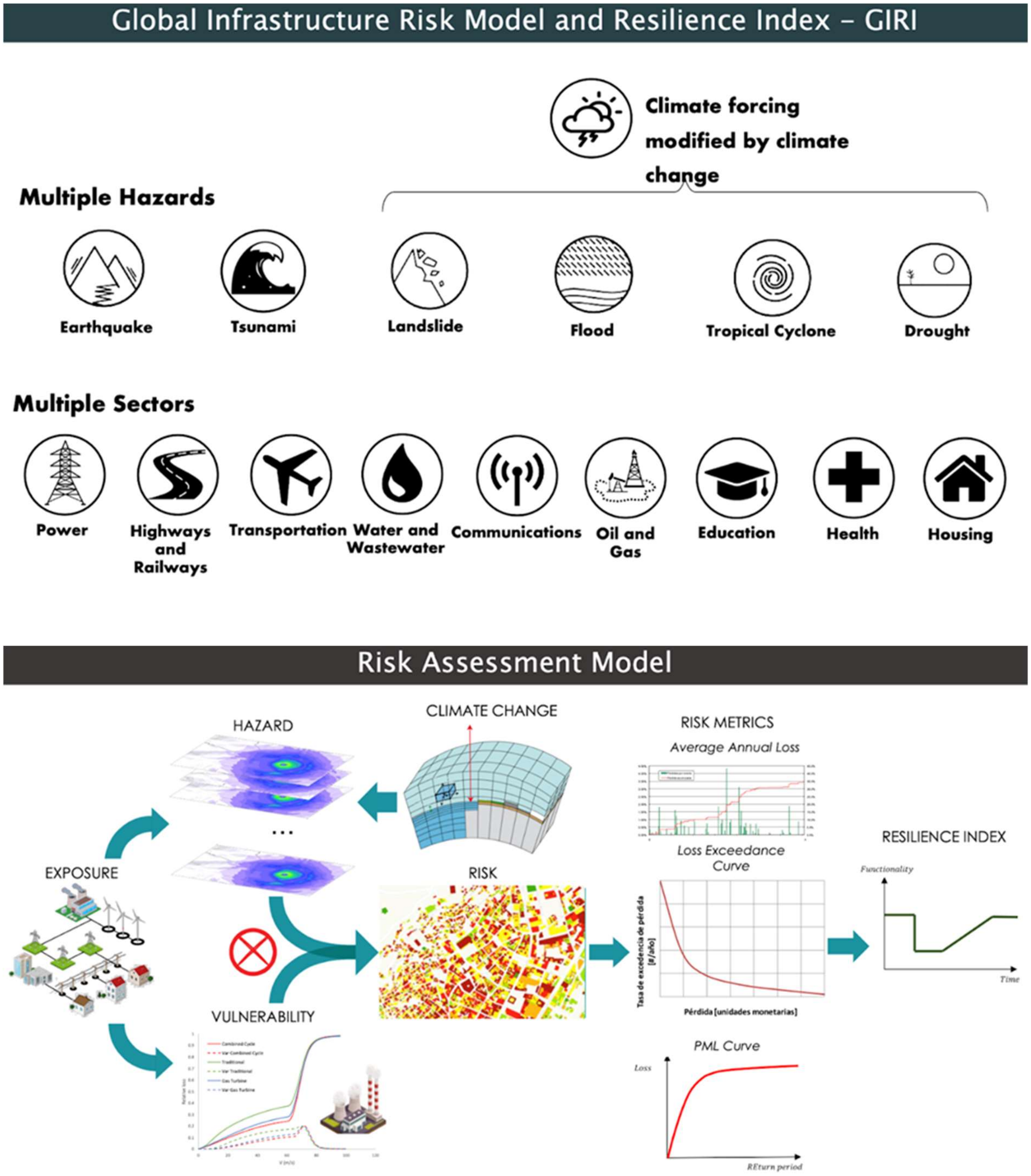

Figure 7. Components of the Global Infrastructure Risk Model and Resilience Index (GIRI). Source: INGENIAR: Risk Intelligence, 2023

4 THE GIRI RESILIENT INFRASTRUCTURE COMPOSITE INDICATOR

In order to monitor how countries are making progress towards infrastructure resilience, it is necessary to define which aspects of resilience can be measured, using what indicators and with which data. While all dimensions of infrastructure resilience are important, asset resilience can be considered particularly fundamental, given that most service disruption is associated with asset loss and damage and sustainability is associated with inadequate operations and maintenance of infrastructure. While the value of service disruption is often many times that of asset loss and damage, ultimately it is an attribute of asset resilience. As such, while the financial risk metrics only measure the contingent liabilities associated with infrastructure assets, in many ways they capture the heart of the problem. The risk of service disruption and interrupted social and economic development are ultimately attributes that magnify of the risk of asset loss and damage.

Measuring infrastructure resilience, therefore, can be understood in terms of the capacity of a country to design, build and manage infrastructure in a way that reduces its vulnerability and exposure to hazard events and that enables it to rapidly respond and recover after an event. Measuring this capacity, makes resilience less of an abstract concept and more tangible and visible to governments, providing additional incentives to invest in resilience and capture the resilience dividend.

Even within the limited scope of asset resilience there is no single intervention that can make infrastructure resilient, but a coordinated set of actions. There are a range of social, economic, political, environmental, and other considerations that influence the capacities of a country to invest in resilience. If countries are to set resilience goals and targets in the context of national resilience policies, strategies, and plans, it is necessary to choose, or to develop indicators that help to measure progress and that reflect the achievement of the targets, or if they are on track to meet them.

The composite indicator that measures infrastructure resilience through combining the financial risk metrics with three different sets of indicators representing the absorptive, adaptive, and transformative capacity to resist and absorb, respond, and restore or recover from hazard events. The index provides an operational picture of resilience based on multi-hazard physical risk in infrastructure systems, aggravated through a range of social, economic, and environmental variables. In this holistic framework, vulnerability, therefore, is considered both in its physical dimension, understood as the susceptibility to damage of the exposed elements, and in a contextual dimension, expressed through a range of other attributes or variables.

It, therefore, measures both, progress in infrastructure resilience and in TOSEE (Technical, Organizational, Social, Economic,[3] and Ecological or Ecosystemic) domains. For example, whether infrastructure and contextual conditions are adequate for absorbing, responding and recovering efficiently and sustainably or whether they are driving to greater negative consequences. In other words, current conditions of the different domains determine how a potential affected area would respond and recover from events, in turn, actual conditions determine the quality of the infrastructure in the future.[4] Infrastructure is not the

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[3] Bruneau et al. 2003

[4] Cardona, 2001, Carreño, et al. 2007

one that defines whether it is driving systemic risk or not, but the well-informed decisions or not, regarding the planning, design, construction, maintenance of infrastructure.

In order to measure the "infrastructure for resilience" it is necessary to understand if the infrastructure investments are governed by principles such as positive impact of infrastructure to achieve sustainable development and growth, economic raise efficiency, social considerations, ecosystem/ecological considerations, which is more oriented to specific projects than to indicators that can capture these requirements.[5] The indicators used for the capacities of resilience can reflect a snapshot of the country situation in different areas or domains (TOSEE), but this situation is not necessarily linked to the existing infrastructure. Also, surveys can support the understanding of whether infrastructure is ensuring sustainability.[6]The SmartResilience EU project aimed to compare and align efforts to measure resilience, and finding common points that promotes standardization activities. This would allow better trace results of resilience assessments. The SmartResilience indicators are based on questions that respond to the expected behaviour of infrastructure if adverse events occur, how the operation of one can impact the operation of others, and how to optimize infrastructure investment[7].

Given that there are intangible aspects of infrastructure resilience, it is required a qualitative analysis where the knowledge of experts can give insights and understanding of these attributes. The Global Infrastructure Resilience Survey (GIRS) developed in the framework of the Global Disaster Resilience Infrastructure project of CDRI, aims to obtain qualitative evidence of the infrastructure resilience resulting from different institutional factors. The results support the understanding of infrastructure management and to feed national and international policy and investment decision-making in relation to infrastructure resilience. Through the analysis of infrastructure management components: policy, accountability and enforcement, financial capacity, institutional stability, disaster response, and maintenance and standards, the GIRS captures and reflects the impediments that specialists and stakeholders may face in the management processes. Despite the challenges and limitations, this survey is a first step and an opportunity for an approach that supports the understanding of infrastructure management beyond top-down infrastructure governance datasets, such as the World Governance Indicators (WGI)[8].

The risk of service disruption and interrupted social and economic development is largely a function of the risk of asset loss and damage. As such, while the financial risk metrics only measure the contingent liabilities associated with infrastructure assets, they do capture an important part of the resilience challenge.

This challenge can be understood in terms of the capacity of a country to design, build and manage infrastructure assets in a way that reduces vulnerability and exposure to hazard events and to have systems in place that enable rapid response to asset loss and effective recovery of damaged assets and interrupted services after an event. Measuring this capacity can make resilience a more tangible and visible concept and may provide additional incentives for governments to invest in resilience and capture the associated dividend.

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[5] GCA, 2021, UNDRR, 2022

[6] Jovanovic, et al. 2017, Chow and Hall, 2023

[7] Jovanovic et al 2017

[8] Chow and Hall, 2023

Even if the focus is only asset resilience, there is no single intervention that can make infrastructure resilient, but a coordinated set of actions. There are a range of social, economic, political, environmental, and other considerations that influence the capacities of a country to invest in resilience. If countries are to set resilience goals and targets in the context of national resilience policies, strategies, and plans, indicators are required to measure progress and if they are on track to meet the achievement of the targets.

The GIRI composite indicator integrates the financial risk metrics with three different sets of indicators that represent the capacity to resist and absorb, respond, and restore or recover from hazard events. Additionally, the GIRI incorporates an estimated infrastructure gap which accounts for the difference between the infrastructure to meet the SDG and existing infrastructure.

The index offers an operational picture of resilience based on multi-hazard physical risk in infrastructure systems, which is conditioned by the infrastructure gap and further impacted by various social, economic, and environmental factors. Within this holistic framework, vulnerability is considered from a physical perspective (the susceptibility of exposed elements or assets to damage), as well as a contextual perspective, encompassing a range of additional attributes or variables.

The composite indicator maps the global landscape of resilient infrastructure, with a national level of resolution. Nevertheless, the same "arithmetic" can be applied by countries at higher resolutions at the sub-national and local levels.

The composite indicator illustrates how probabilistic risk metrics and social, economic, and other variables can be integrated in a methodology that identifies the levers of change available to countries to strengthen infrastructure resilience.

4.1 METHODOLOGY AND INDICATORS

The GIRI composite indicator has relative values between 0-100. The lowest value (0) indicates that infrastructure has low resilience, and the highest value (100) means resilience is high. The diagram in Figure 8 shows how the GIRI composite indicator can be disaggregated into the three capacities each of which in turn can be disaggregated into component indicators.

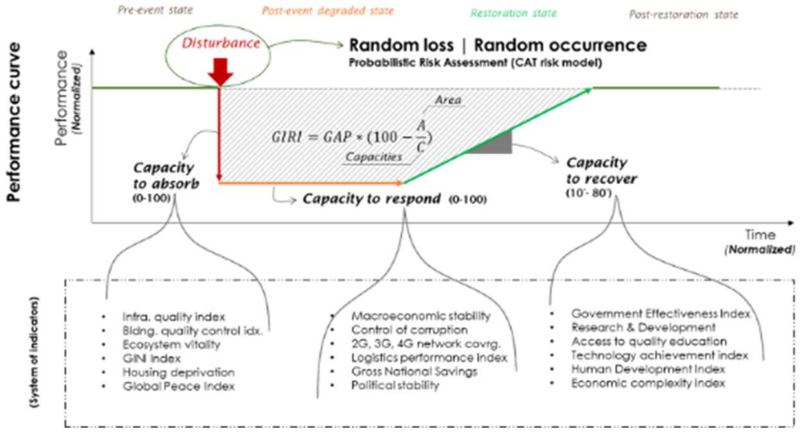

Figure 8: Conceptual framework GIRI

The capacity to absorb is represented as a sudden loss in the performance or capacity of infrastructure assets to provide essential services due to loss and damage, associated with hazard events. This capacity to resist or withstand is conditioned by physical risk, and social and economic variables which may aggravate the potential impact of the hazard events, leading to larger losses in performance (Burton et al., 2014, Birkmann et al. 2013, Carreño et al. 2007, Bruneau, et al. 2003, Cardona, 2001).

The capacity to respond is represented as a horizontal line, whose length represents the ability to respond fast and efficiently. The shorter the line, the higher the capacity to respond following the event, when coping and operations are undertaking as a first phase of recovery.

The recovery stage is assumed to start after the response phase and continues until the assets have been restored and services recovered. The inclination of the slope represents strong (80°) or weak (10°) capacity to restore fast and efficiently.

Figure 9 shows the relationship between a set of *qualities* that would characterize resilient infrastructure, the three capacities described above, and the suite of indicators chosen to measure the capacities. Some indicators can be associated with all three capacities but have been assigned to the capacity with which they seem more closely related.

For example, the quality of infrastructure indicator was assigned to the capacity to resist because in the case of better-quality infrastructure, built to high standards, the drop in performance is likely to be less than in lower-quality infrastructure. Similarly, countries with significant investments in innovation and technology are likely to experience faster and more efficient recovery compared to countries with lower levels of investment in infrastructure and technology.

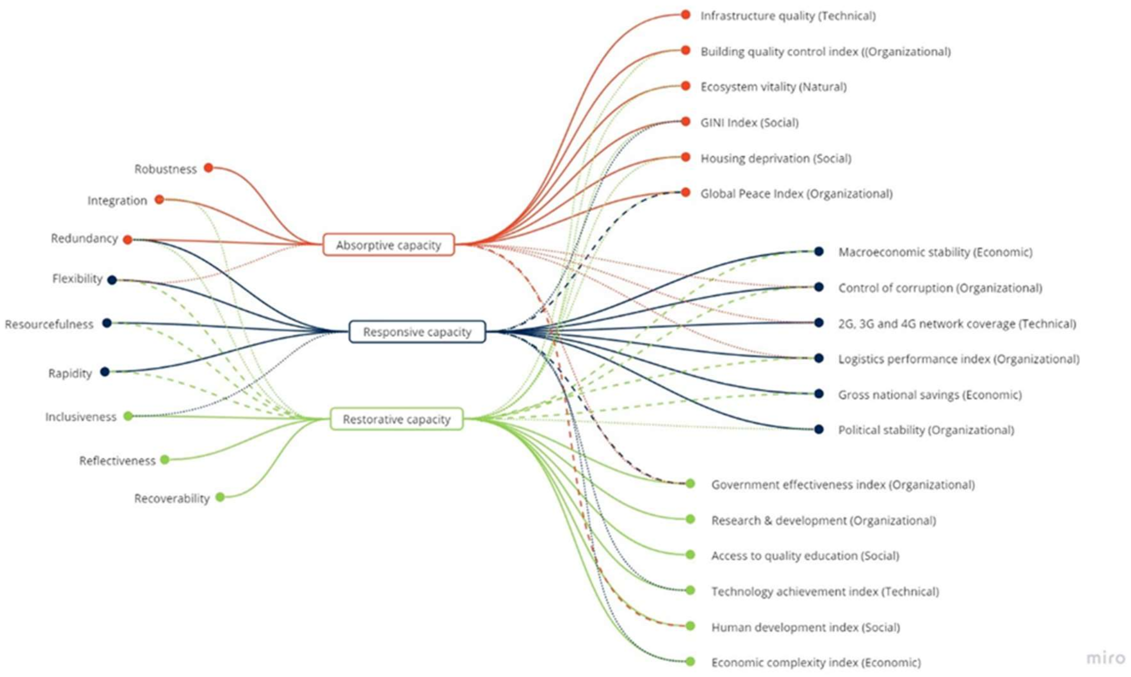

Figure 9. Interconnectedness between the qualities of resilience systems and the three resilience capacities, and between indicators

Six indicators were chosen for each capacity, on the basis of their relevance and the availability of publicly accessible, reliable global data in as many countries as possible. Many other indicators were considered but not chosen because they did not meet these criteria.

The indicators that compose each capacity, including the Average Annual Loss (AAL) are normalised to allow their aggregation, given that each indicator captures different aspects of the society and is quantified in different units. Certain normalizing procedures are needed to standardize the values of each component and convert them into commensurable factors. In this case, transformation functions were used to standardize them. Figure 10 shows examples of this. All indicators were assigned the same weight. For instance, the indicators for the capacity to absorb, and for the capacity to respond range from 0 to 100, where the higher values mean a small drop in performance and rapid and efficient response respectively, and lower values mean a high drop and a low and inefficient response respectively. Inverted scaling was used to provide appropriate measurement.

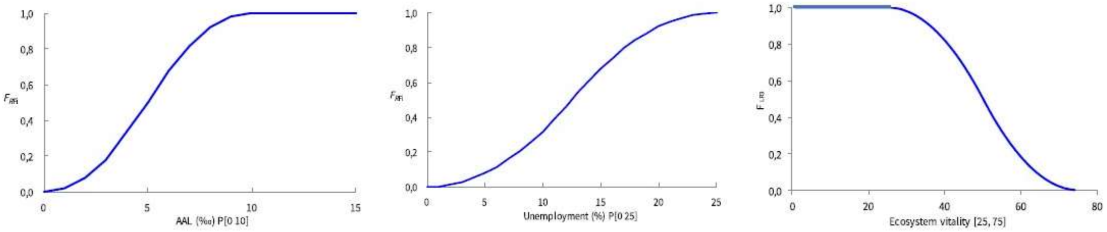

Figure 10. Example of transformation functions for normalizing indicators (Carreño, 2007, Marulanda et al. 2020, Marulanda-Fraume et al. 2022).

4.1.1 Capacity to absorb

The Average Annual Loss (AAL), from the GIRI model is the base input for the GIRI composite indicator. The AAL is a robust metric, which condenses in a single number the overall level of disaster and climate risk, internalised in a country's infrastructure.

The AAL provides insight into potential loss and damage into infrastructure assets, and thus provides a first window to examine the capacity to absorb hazard events of different intensity and frequency. However, while the AAL captures the physical resistance and robustness of an asset, the relative AAL can result in low values due to various factors. These factors include the absence of significant hazards in the country, low vulnerability of the exposed assets, or even the absence of assets themselves. To account for these situations, a factor is applied to the relative AAL, addressing the lack of infrastructure, and indirectly, obsolescence and the lack of redundancy.

The physical risk is aggravated by other contextual variables[9]. The aggravating factor is obtained by combining six contextual indicators, which condition the physical risk:

- **Infrastructure quality** (FM Global, 2023)**:** good quality infrastructure will be reflected in a better performance of the assets when a hazard event occurs.

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[9] Cardona (2001), Carreño et al. (2007)

- **The building quality control index** (World Bank, 2022)**:** This includes variables such as the quality of regulation, of control before, during and after construction, professional liability and insurance regulation, and certification. Good building quality should indicate better building practices, inherent in infrastructure with higher resistance to hazard events.
- **Ecosystem vitality** (Yale Center for Environmental Law & Policy & Center for International Earth Science Information Network Earth Institute, 2022)**:** Healthy ecosystems can lead to more sustainable growth of assets and income, economic development and well-being of people. Ecosystem preservation and restoration can contribute to resilience to climate change and to climate change mitigation. In turn, environmental degradation is a major driver of disaster risk. Low quality and quantity of ecosystem services exacerbates climate change.
- **GINI Index** (World Bank Data, 2023)**:** The GINI index represents the income inequality or the wealth inequality or the consumption inequality within a nation or a social group. More unequal countries are less likely to dedicate resources to strengthen the resilience of infrastructure meant to service disadvantaged social groups. More equal societies are also more resilient. Flatter hierarchies lead to higher cooperation among individuals (Germano and Demetrius, 2014).
- **Housing deprivation** (University of Oxford, 2007): Reflects social and economic inequality and the capacity of governments to deliver safe and affordable housing (SDG11). High rates of housing deprivation are likely to be reflected in significant parts of the population living in unplanned and unregulated settlements with precarious infrastructure with a low capacity to resist hazard events.
- **The Global Peace Index, GPI** (*Vision of Humanity*, n.d.)**:** The index considers international and domestic conflict, social safety and security, and militarization. A positive value may indicate outcomes such as higher per capita growth, better environmental performance, less civil conflict or violent political shocks, as well as infrastructure with higher resistance.

4.1.2 Capacity to respond

The six indicators chosen to represent the capacity to respond represent how well a country performs in disaster response.

- **Macroeconomic stability** (The Legatum Centre for National Prosperity, 2023): measures how robust an economy is. A strong economy means that a government will have more resources available for effective and timely response without having to increase indebtedness.
- **Control of corruption** (World Bank, 2022) Corruption may erode the financial resources available to respond to infrastructure failures and undermine capacities for service restoration.
- **2G, 3G and 4G network coverage** (Groupe Speciale Mobile Association, n.d.; World Bank Data, 2023): Access to wireless communication directly influences effective and timely disaster response. Better network coverage can allow authorities to access real time information on the distribution of asset loss and damage and service disruption and can facilitate communication

between affected households, communities, businesses and the different stakeholders involved in response, including utility providers, emergency services and others.

- **Logistics and performance index** (World Bank Data, 2023)**:** Emergency response requires proper, structured, standardised, and organised logistics in order to respond efficiently and fast. Ineffective logistics can result in underperformance in emergency response and an inability to handle an event fast and efficiently. The LPI consists of both qualitative and quantitative measures that provide an understanding of how well countries do in terms of logistics processes, logistics environment and institutions, constraints hindering smooth flow of logistics activities present at ports, borders or inside the country. It, therefore, measures performance along the whole logistics supply chain within a country. LPI is considered as a vital element in economy's competitiveness (Arvis et al., 2007).

- **Gross National Savings** (World Bank Data, 2022)**:** The national savings rate measures the amount of income that households, businesses, and governments save. It looks at the difference between the nation's income and consumption and is a gauge of a nation's financial health, as investments are generated through savings. Gross National Savings can serve for both, access to resources in case of emergencies, or as a backup to borrow economic resources to respond to emergencies.

- **Political stability** (World Bank, 2022): Political stability and absence of violence measures perceptions of the likelihood that the government will be destabilised or overthrown by unconstitutional or violent means, including politically motivated violence and terrorism. Political instability and violence may undermine response efforts due to the difficulty to access resources, to the lack of strong institutions, that avoid the rapid and efficient interventions.

4.1.3 Capacity to restore

The capacity to restore reflects how well a country can recover from asset damage and service disruption. The better the performance the steeper the line. This is closer related to the depth of the drop in the capacity to absorb than to the length of the response line. The indicators chosen for the capacity to restore infrastructure and to strengthen future resilience are:

- **Government Effectiveness Index** (World Bank, 2022.): captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. This index reflects the capacity of a government to plan and manage a robust recovery of infrastructure assets and essential services.

- **Research & Development** (UN, 1970)**:** According to the OECD R&D intensity is one of several indicators used to measure progress toward achieving SDG 9. SDG 9 seeks to build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

- **Access to quality education** (The Legatum Centre for National Prosperity, n.d.)**:** Access to quality education leads to a country with a higher productivity and therefore a country with a stronger economy. Access to quality education ensures the presence of high qualified professionals that will work towards a robust and quick recovery of infrastructure and services.

- **Technology achievement index** (M. Desai et al., 2002) **:** Reflects the country's technological capacity, including associated human resources. Access to new or enhanced technologies will normally speed up recovery, including the opportunity to use the recovery process to introduce innovations.
- **Human Development Index** (UNDP, 2021)**:** The Human Development Index is a composite index of life expectancy, education, and per capita income indicators which is directly relevant to local and community vulnerability, which in turn influences the recovery process (Raikes, et al. 2021, Hallegatte et al., 2020, UNDP, 2020, Lewis, 2012, UNDP, 2004). A high HDI indicates countries with better levels of education, and hence skills and scientific knowledge, better health systems that provide a basis for sustainable recovery and higher income levels which reflect availability of savings, access to credits, insurance etc.that are critical to effective recovery.
- **Economic complexity index** (MIT Media Lab, 2011) Reflects the overall state of the economy of a country and therefore its capacity to successfully recover from hazard events.

4.2 The GIRI assessment

The GIRI is presented in two formats, as a single numerical value and as a curve. The numerical value represents the ratio of the area of the trapezoid formed by the three capacities to the sum of those capacities, as shown in Fig. 8. This quantitative representation enables the ranking of countries based on their resilience. However, depicting the curve shape provides a more comprehensive understanding of the countries' behaviour in terms of disaster risk resilience. It also offers a clearer illustration of how physical risk and the infrastructure gap influences in the value and shape of the GIRI curve.

4.2.1 Infrastructure gap

The infrastructure gap[10] is defined as the difference between the existing infrastructure and infrastructure needs. The gap reflects implications that are not necessarily reflected in the risk metrics, for example:

- **Lack of capacity** of infrastructure assets to provide services and support social and economic development. This creates system vulnerability and magnifies the effects of hazard impacts.
- **Infrastructure obsolescence**: Outdated or obsolete infrastructure, that has outlived its design life, is more prone to failures and collapses. Insufficient investment in maintenance, modernization, and upgrading of infrastructure increase its fragility and reduce its resilience against threats and adverse events.

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[10] The infrastructure gap is expressed as a percentage of GDP. The data has been sourced from the Global Infrastructure Hub, Asian Development Bank and Infralatam. Due to significant variations in the information and the absence of data for certain countries, regional and income groups averages were calculated to assign values to countries with missing information. For African countries, the African Infrastructure Development Index provided by the African Development Bank was used to adjust the derived factor from the average.

- **Limited diversification and redundancy**: A large infrastructure gap challenges system redundancy, increasing dependence on single infrastructure assets and increasing service vulnerability.
- **Longer recovery time:** A large infrastructure gap may increase the recovery time after an adverse event, reflecting a lack of resources and capabilities for recovery.

In the GIRI assessment, the infrastructure gap factor was used to condition the risk metrics. The infrastructure gap is basically the percentage of GDP of the difference between the actual investment and the investment required to fill the gap. This percentage of GDP is taken as a multiplication factor of the average annual loss, which is then reflected on the physical risk value. Due to significant variations in the information and the absence of data for certain countries, regional and income groups averages were calculated to assign values to countries with missing information. For African countries, the African Infrastructure Development Index provided by the African Development Bank was used to adjust the derived factor from the average.

Countries with a very low infrastructure density may appear to have very low risk. However, this reflects very low exposed value or out-dated or obsolete infrastructure rather than high levels of physical resilience. Without taking the gap into account, hazard prone countries with only incipient infrastructure may appear to have high levels of resilience. Conditioning the risk considering the gap corrects for this factor.

Figure 11 highlights how the risk metrics change after processing taking into account the gap factor. Countries with a greater infrastructure density exhibit less significant changes in their physical risk values compared to countries with a considerable infrastructure gap.

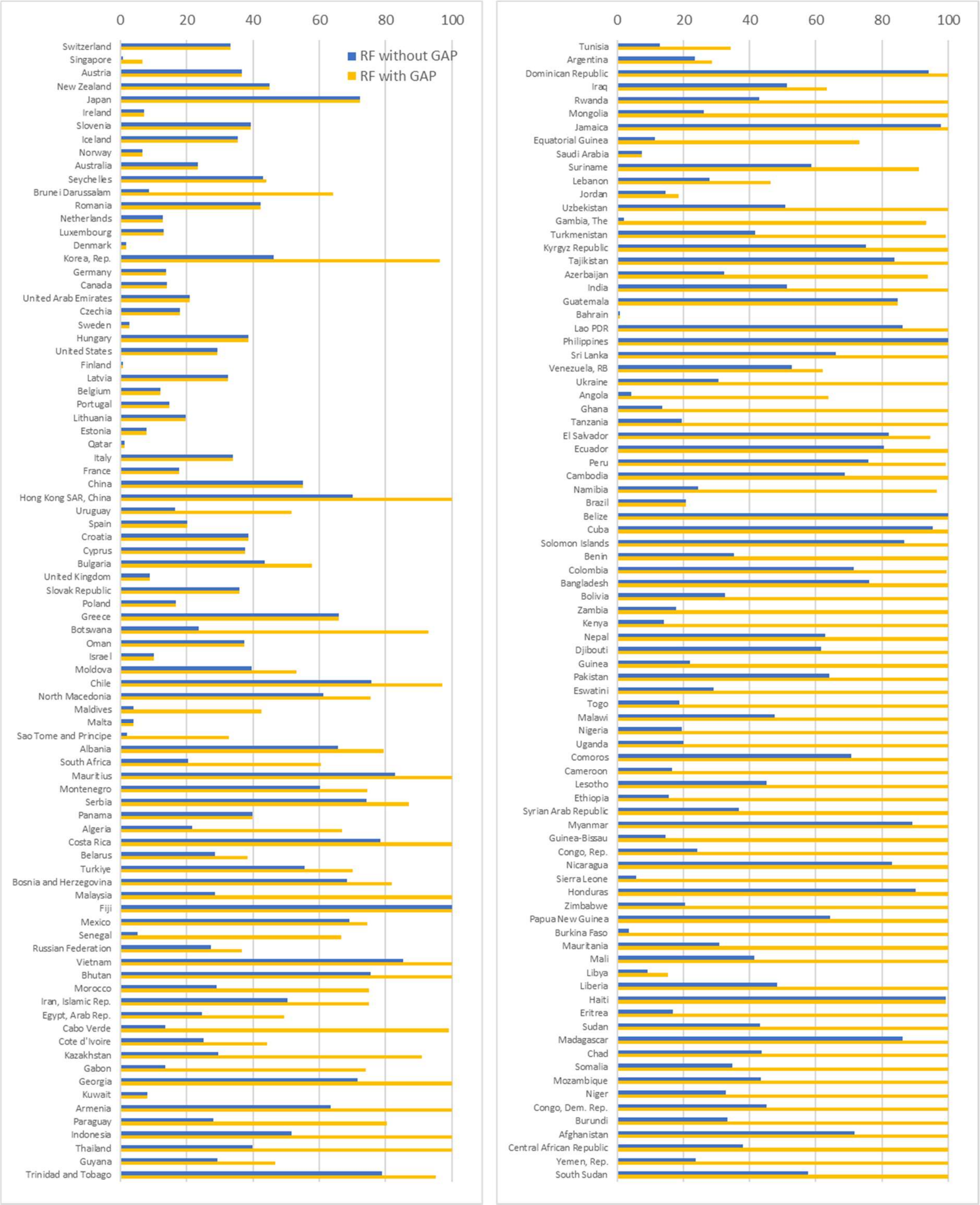


Figure 11. Change of risk metrics after considering a gap infrastructure factor.

4.2.2 INHERENT RESILIENCE

Considering that the GIRI serves as a disaster risk resilience index, it is essential to incorporate metrics that reflect the physical risk. Figure 12 displays curves for Burkina Faso, Honduras, Algeria, Japan, and the United States. The purpose of this figure is to illustrate the concept of inherent or endogenous resilience, wherein a country's assigned value varies based on the level of physical risk it faces.

To demonstrate the impact of physical risk on the GIRI, inherent resilience curves were created for each country. These curves involve adjusting the value of physical risk, ranging from zero to one, while keeping all other GIRI components constant. This process generates GIRI values for each assigned physical risk value, and the curve represents the combination of all these points for a given country. In Figure 12, the blue points correspond to the GIRI values obtained with the current level of physical risk according to the risk model.

The curves reveal that countries experiencing lower physical risk tend to have higher GIRI values, while higher levels of physical risk lead to a decrease in the GIRI. The steepness or flatness of the curve depends on the capacities of each country. For example, Japan demonstrates stronger capacities compared to the United States of America, Honduras, Algeria, and Burkina Faso.

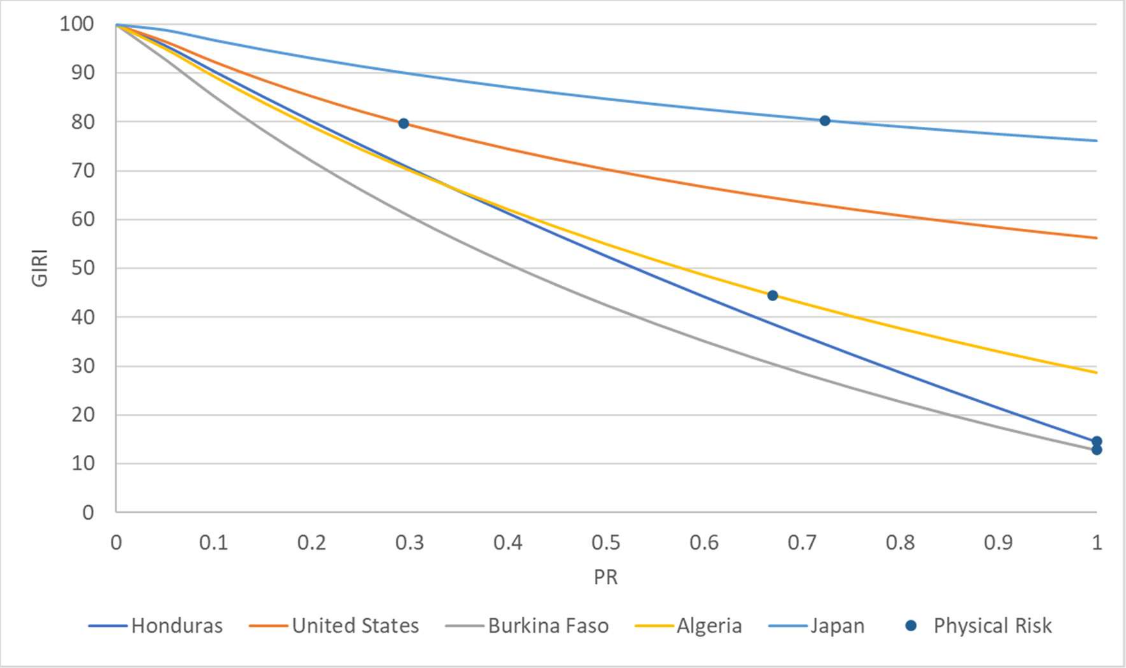


Figure 12. Graphic representation of inherent or endogenous resilience

The figure below showcases the derivative, or rate of change, of the previous resilience performance curves for the same countries. This derivative curve serves as a homomorphism, reflecting the countries' capacities for absorption and recovery. It provides a visual representation of a country's performance in the face of a potential disaster. The y-axis maintains a similarity to performance, while the horizontal axis represents time.

It is important to note that the values resulting from the derivative of inherent resilience do not hold representative significance. However, these figures offer valuable insights into the speed at which a country can restore its infrastructure and services.

In the depicted examples, Japan demonstrates a relatively shorter decline and achieves a faster recovery compared to the other countries presented. Although Honduras experiences a shorter decline than Burkina Faso and Algeria, their capacities enable a more favorable recovery compared to Honduras.

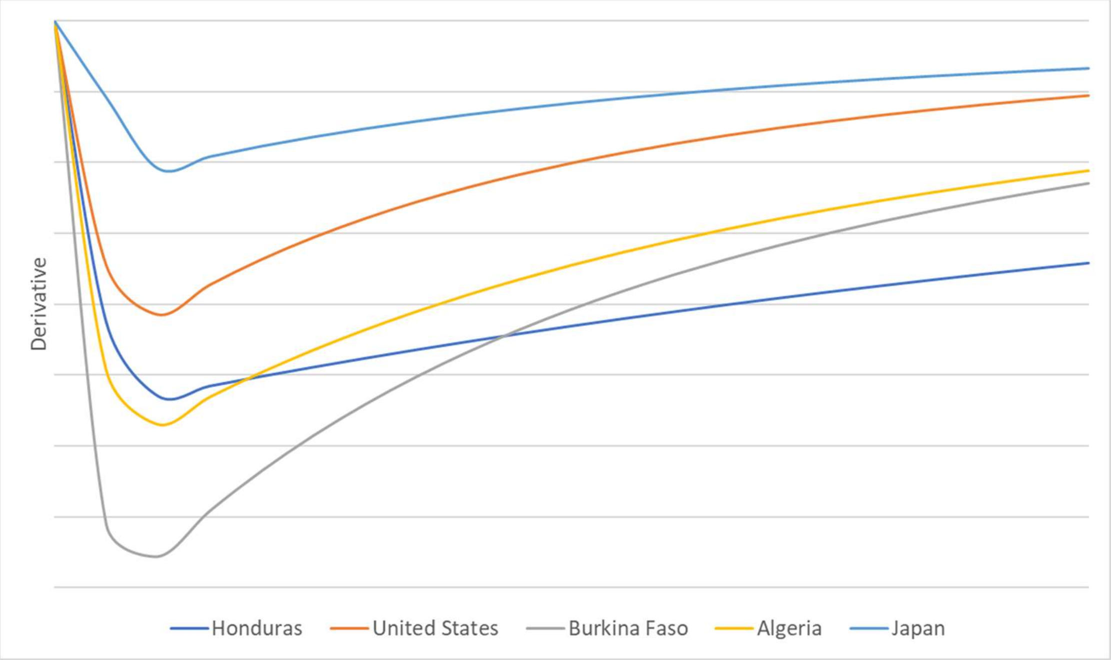
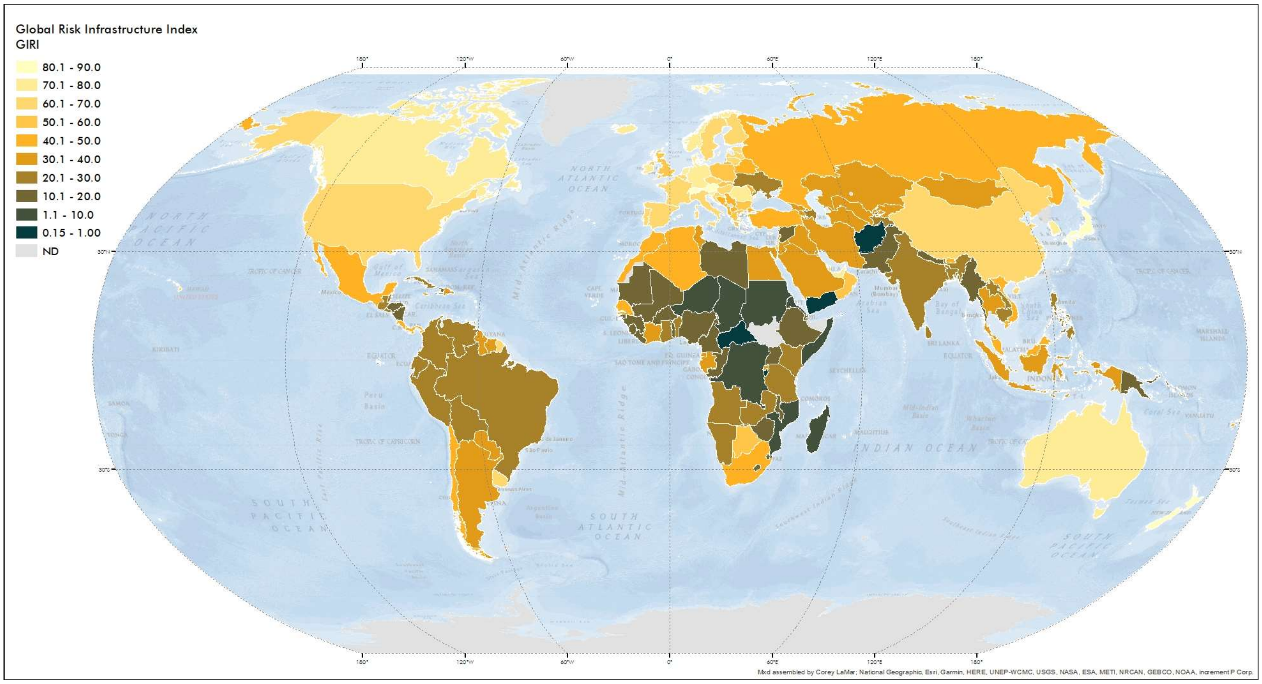


Figure 13. Derivative curve as a visual representation of a country's performance in the face of a potential disaster

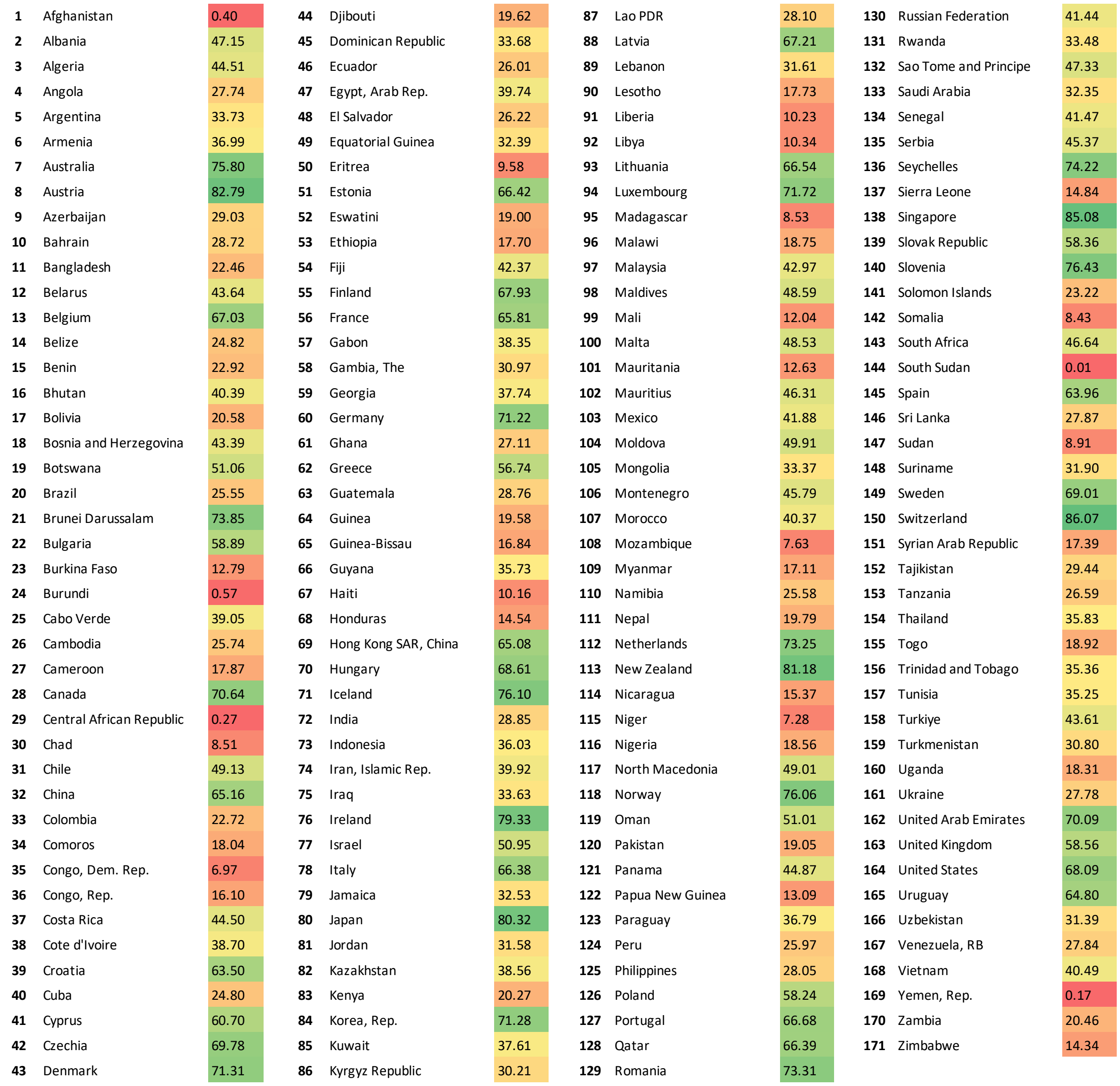
4.3 GIRI RESULTS

The results of the GIRI are valuable for comparing countries, as illustrated in Map 1 and Figure 14. However, it is also important to understand a country's performance across different capacities and the shape of its resilience performance curve. For instance, countries may have similar GIRI values, but their resilience curves can differ, as shown in Figure 15 for the Russian Federation, Senegal, Vietnam, and Mexico. One country may exhibit shortcomings in resistance or absorption capacities but possess stronger response and restorative capacities, resulting in a similar area under the resilience curve compared to a country with a steeper decline but shorter response and restorative capacities.



Map assembled by Corey LaMar; National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Map 1. Results of the Global Risk Infrastructure Index, GIRI



1	Afghanistan	0.40	44	Djibouti	19.62	87	Lao PDR	28.10	130	Russian Federation	41.44
2	Albania	47.15	45	Dominican Republic	33.68	88	Latvia	67.21	131	Rwanda	33.48
3	Algeria	44.51	46	Ecuador	26.01	89	Lebanon	31.61	132	Sao Tome and Principe	47.33
4	Angola	27.74	47	Egypt, Arab Rep.	39.74	90	Lesotho	17.73	133	Saudi Arabia	32.35
5	Argentina	33.73	48	El Salvador	26.22	91	Liberia	10.23	134	Senegal	41.47
6	Armenia	36.99	49	Equatorial Guinea	32.39	92	Libya	10.34	135	Serbia	45.37
7	Australia	75.80	50	Eritrea	9.58	93	Lithuania	66.54	136	Seychelles	74.22
8	Austria	82.79	51	Estonia	66.42	94	Luxembourg	71.72	137	Sierra Leone	14.84
9	Azerbaijan	29.03	52	Eswatini	19.00	95	Madagascar	8.53	138	Singapore	85.08
10	Bahrain	28.72	53	Ethiopia	17.70	96	Malawi	18.75	139	Slovak Republic	58.36
11	Bangladesh	22.46	54	Fiji	42.37	97	Malaysia	42.97	140	Slovenia	76.43
12	Belarus	43.64	55	Finland	67.93	98	Maldives	48.59	141	Solomon Islands	23.22
13	Belgium	67.03	56	France	65.81	99	Mali	12.04	142	Somalia	8.43
14	Belize	24.82	57	Gabon	38.35	100	Malta	48.53	143	South Africa	46.64
15	Benin	22.92	58	Gambia, The	30.97	101	Mauritania	12.63	144	South Sudan	0.01
16	Bhutan	40.39	59	Georgia	37.74	102	Mauritius	46.31	145	Spain	63.96
17	Bolivia	20.58	60	Germany	71.22	103	Mexico	41.88	146	Sri Lanka	27.87
18	Bosnia and Herzegovina	43.39	61	Ghana	27.11	104	Moldova	49.91	147	Sudan	8.91
19	Botswana	51.06	62	Greece	56.74	105	Mongolia	33.37	148	Suriname	31.90
20	Brazil	25.55	63	Guatemala	28.76	106	Montenegro	45.79	149	Sweden	69.01
21	Brunei Darussalam	73.85	64	Guinea	19.58	107	Morocco	40.37	150	Switzerland	86.07
22	Bulgaria	58.89	65	Guinea-Bissau	16.84	108	Mozambique	7.63	151	Syrian Arab Republic	17.39
23	Burkina Faso	12.79	66	Guyana	35.73	109	Myanmar	17.11	152	Tajikistan	29.44
24	Burundi	0.57	67	Haiti	10.16	110	Namibia	25.58	153	Tanzania	26.59
25	Cabo Verde	39.05	68	Honduras	14.54	111	Nepal	19.79	154	Thailand	35.83
26	Cambodia	25.74	69	Hong Kong SAR, China	65.08	112	Netherlands	73.25	155	Togo	18.92
27	Cameroon	17.87	70	Hungary	68.61	113	New Zealand	81.18	156	Trinidad and Tobago	35.36
28	Canada	70.64	71	Iceland	76.10	114	Nicaragua	15.37	157	Tunisia	35.25
29	Central African Republic	0.27	72	India	28.85	115	Niger	7.28	158	Turkiye	43.61
30	Chad	8.51	73	Indonesia	36.03	116	Nigeria	18.56	159	Turkmenistan	30.80
31	Chile	49.13	74	Iran, Islamic Rep.	39.92	117	North Macedonia	49.01	160	Uganda	18.31
32	China	65.16	75	Iraq	33.63	118	Norway	76.06	161	Ukraine	27.78
33	Colombia	22.72	76	Ireland	79.33	119	Oman	51.01	162	United Arab Emirates	70.09
34	Comoros	18.04	77	Israel	50.95	120	Pakistan	19.05	163	United Kingdom	58.56
35	Congo, Dem. Rep.	6.97	78	Italy	66.38	121	Panama	44.87	164	United States	68.09
36	Congo, Rep.	16.10	79	Jamaica	32.53	122	Papua New Guinea	13.09	165	Uruguay	64.80
37	Costa Rica	44.50	80	Japan	80.32	123	Paraguay	36.79	166	Uzbekistan	31.39
38	Cote d'Ivoire	38.70	81	Jordan	31.58	124	Peru	25.97	167	Venezuela, RB	27.84
39	Croatia	63.50	82	Kazakhstan	38.56	125	Philippines	28.05	168	Vietnam	40.49
40	Cuba	24.80	83	Kenya	20.27	126	Poland	58.24	169	Yemen, Rep.	0.17
41	Cyprus	60.70	84	Korea, Rep.	71.28	127	Portugal	66.68	170	Zambia	20.46
42	Czechia	69.78	85	Kuwait	37.61	128	Qatar	66.39	171	Zimbabwe	14.34
43	Denmark	71.31	86	Kyrgyz Republic	30.21	129	Romania	73.31			

Figure 14. Results of the Global Risk Infrastructure Index, GIRI[11]

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[11] The GIRI was calculated for 171 countries which have indicators availability for the capacities considered in the composite indicators. Countries that are not included in the GIRI is because they did not have enough number of indicators available.

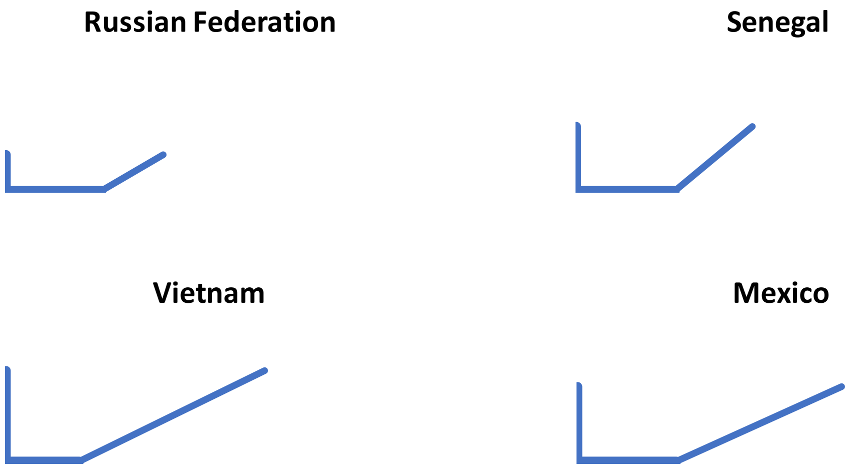

Figure 15. GIRI Resilience performance curves for Russian Federation, Senegal, Vietnam, and Mexico.

Infrastructure resilience today is the outcome of the past decisions and actions. However, resilience can be enhanced, through appropriate investments improving infrastructure robustness, flexibility, redundancy and overall quality, including through enhanced design standards, increased investment in operations and maintenance. Modifying the underlying factors that reflect absorptive, responsive, and restorative capabilities will improve adaptability and transformability. It is important to consider resilience as an attribute of performance rather than a static state of a system. The former approach creates incentives for action, whereas the latter may result in inertia and inaction.

The GIRI composite indicator can be utilized to monitor changes in vulnerability and capacities over time, and it can be disaggregated into risk indicators and individual capability indicators. Viewing resilience as a performance characteristic enhances our understanding of the dynamics of change within each country. A similar approach can be implemented at the sub-national level to track infrastructure resilience using a localized GIRI, which incorporates indicators and surveys to directly capture and measure risk and the capabilities of isolated and systemic infrastructures.

The resulting diagrams shall be the tool to measure resilience in each country based on transformed and commensurable indicators associated to each specific absorptive, responsive, and restorative/adaptive capabilities. A world map can be made as the outcome of the resilience ranking of the countries. In summary, all these issues can be reflected from existing indicators issued for all countries providing an operational picture of the abovementioned capacities.

The GIRI can be used to monitor how capacities change over time, which in turn can be disaggregated by the indicators that compose each capacity. Understanding resilience as a performance characteristic improves understanding of the dynamics of change in each country.

The three aspects considered in the GIRI: qualities, capacities and indicators (physical dimension and contextual dimension) allow identifying in one side, whether existing assets are resilient, if they can provide essential services, on the other side, whether the contextual dimension support resilient infrastructure, or whether it is driving systemic risk. Likewise, the disaggregation of the index to the original indicators allows identifying aspects such as redundancy of systems (i.e. 2G, 3G and 4G network coverage), quality of systems (i.e. Infrastructure quality), systems technology (i.e. technology achievement index), sustainable and fiscal resilience by investing in design, maintenance, implementation, rapid recoverability, among others (i.e. government effectiveness, control of corruption, global peace index), that can reflect the concept of infrastructure for resilience, through providing essential services (service resilience), supporting social and economic development.

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