International Transport Forum

Transport Network Resilience

Guidance for Incorporating Resilience in Cost-Benefit Analyses

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Research Report

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How to Use This Document: A Policymaker's Guide

Purpose of this document

This document is part of a series developed by the ITF Working Group on Transport Network Resilience. The purpose of these outputs is to help policymakers and other stakeholders understand, assess, and strengthen the resilience of transport systems to critical disruptions.

What this document covers

This document:

- Explains how resilience can be systematically integrated into transport cost–benefit analysis (CBA), addressing disruptions such as extreme weather, infrastructure failure, pandemics, cyber-attacks and geopolitical shocks, which may be insufficiently captured in traditional appraisal methods.
- Provides step-by-step guidance aligned with standard CBA practice, showing where and how resilience considerations can be incorporated across key appraisal stages (e.g. defining alternatives, selecting impacts, handling uncertainty, monetisation, discounting, and sensitivity analysis).
- Discusses methods to deal with uncertainty and low-probability/high-impact events, including scenario analysis, decision trees, real options analysis, Monte Carlo simulation, and complementary tools such as vulnerability screening.
- Illustrates international good practice through transport examples, drawing on experience from the European Union, Japan, the Netherlands, New Zealand, Sweden, the United Kingdom, and the United States to show how resilience is already being considered in transport appraisal.

How policymakers can use it

- **For strategy and policy design:** Use the guidelines to ensure that national or regional transport investment frameworks explicitly recognise resilience as a core appraisal dimension, alongside efficiency, safety, and environmental performance. This helps avoid underinvestment in measures that reduce long-term disruption risks.
- **For project appraisal and funding decisions:** Apply the guidance when reviewing CBAs for major transport projects to assess whether resilience benefits (e.g. avoided disruption costs, faster recovery, network redundancy) have been properly identified, valued, or transparently reported when monetisation is not feasible.
- **For dealing with uncertainty in long-lived infrastructure investments:** Use the proposed approaches (scenario analysis, sensitivity testing, declining discount rates, and real-options thinking) to make more robust decisions under deep uncertainty, particularly for climate-exposed or strategically critical transport assets.

Key takeaways

- Resilience is not external to CBA but can be embedded within existing appraisal frameworks, provided uncertainty, disruptions, and system-wide monetised and non-monetised impacts are explicitly addressed.
- Traditional CBA outputs such as net present value (NPV) and benefit-cost ratio (BCR) may underestimate resilient options when low-probability but high-impact events are not fully monetised; decision makers should therefore interpret results alongside structured qualitative and risk-based evidence.
- Stakeholder consultation on assumptions, uncertainty, and non-monetised impacts improves legitimacy and decision quality, supporting better long-term investment choices for resilient transport systems.

Introduction

Many countries rely on cost-benefit analysis (CBA) as a key method for evaluating transport investments. National transport investment decisions in many countries are informed by formal CBA guidelines. Examples include the UK Department for Transport's guidelines for CBA (UK DfT, 2025a) the Dutch MKBA guidelines[1] (MKBA, 2026), (CPB/PBL, 2013) , Sweden's ASEK guidelines (Swedish TA, "ASEK 8.0," 2024),and several others. At the European level, the European Commission's (EC) CBA guidelines for transport is primarily structured under the Connecting Europe Facility (CEF)(EC INEAEuropean Climate, 2022), which builds on the EC Directorate-General for Regional and Urban Policy's guide to CBA of investment projects (EC DG REGIO"EU CBA," 20154) and should be read in conjunction with it because it serves as a general reference for the preparation of a CBA. The U.S. Department of Transportation ("US DOT CBA ," 2025) also provides transport-specific CBA guidelines for federal road, rail and multimodal funding programmes.

CBA is an established economic approach used to compare the costs and benefits of a given project, providing a quantitative measure of whether the project's realisation is beneficial for society. This method identifies, quantifies, and monetises the incremental costs and benefits associated with a project over its lifespan (Boardman et al., 2018). However, resilience – defined as the ability of systems to prevent, withstand, and quickly recover from disruptions – is often overlooked in standard CBA procedures. This omission is due in part to uncertainties about the likelihood, scale, and cost of potential disruptions. For example, extreme weather events are difficult to predict and quantify. Some critics argue that resilience cannot be meaningfully incorporated into CBAs, while others suggest alternative models.

Nevertheless, across international transport CBA guidelines, robustness and resilience are increasingly recognised as important considerations, although they are rarely fully monetised in a systematic way. Most guidelines address robustness primarily through sensitivity analysis and scenario testing, examining how project outcomes change under variations in demand, costs, or external conditions. This approach is intended to inform decision makers about the vulnerability of project performance to uncertainty rather than to explicitly value resilience benefits. For example, UK Department for Transport's *Transport Analysis Guidance: The Transport Appraisal Process* manual notes: "The sensitivity tests or alternative scenarios are used to provide important information about the robustness of a proposal. If traffic levels/patronage and the resulting appraisal do not vary significantly between the sensitivity tests or alternative scenarios examined, this demonstrates that the project is not sensitive to external uncertainties. Conversely, if there are significant variations in patronage, the decision maker will have a clear view of the risks the project faces, and the analyst can explore ways of mitigating those risks" (UK DfT"TAG TAP," 2025c).

Several countries complement sensitivity testing with qualitative or semi-quantitative assessments of vulnerability and risk. For example, some guidelines explicitly require identification of whether transport projects are exposed to rare but high-impact events, such as extreme weather or major network disruptions, and a description of the consequences if limited rerouting or redundancy is available. In such cases, resilience effects may be reported as non-monetised impacts when conventional travel-time or cost calculations are insufficient to capture the scale of disruption. In Sweden, the ASEK guidelines recommend explicitly considering vulnerability in cases where there is a risk of large and prolonged transport disruptions due to limited diversion options, even if these effects cannot be monetised and must be reported as non-calculated impacts.

A smaller number of guidelines go further by allowing explicit valuation of resilience benefits, particularly where projects reduce expected damage costs, service outages, or emergency repair costs associated with disruptive events. These approaches typically rely on estimating the frequency and severity of hazards and the resulting user and asset costs avoided due to increased robustness. However, they also acknowledge substantial methodological uncertainty, especially for low-probability, long-term risks and for future climate-related impacts. For example, in the United States, federal CBA guidance ("US DOT CBA ," 2025) recognises resilience-related benefits for transport projects that improve the ability of infrastructure to withstand extreme events, allowing avoided user costs, repair costs and detour costs to be monetised where sufficient data exist. The New Zealand government(New Zealand TATransport Agency Waka Kotahi, 2025) also provides more advanced treatment with its transport appraisal framework by including procedures for quantitatively incorporating robustness and resilience effects and offering simplified methods for certain types of resilience improvements. However, even in these cases, the guidelines acknowledge significant uncertainty, especially when dealing with low-probability events and long-term risks.

Despite these concerns, CBA remains a widely used tool, making it crucial to explore how resilience can be integrated into these analyses to strengthen the resilience of transport systems. The discussion in this report highlights that benefits of resilience exist. Raising awareness of those benefits among policymakers and stakeholders, and finding ways to include them in the CBA despite the challenges, is essential. Ignoring resilience in an era marked by disruptions from extreme weather, geopolitical tensions, pandemics and rapid technological change can lead to transport infrastructure that may be cost-efficient in the short term but potentially vulnerable and expensive in the long run.

Hence, resilience should be incorporated into CBAs and other decision making tools such as cost-effectiveness analysis, multi-criteria analysis, and stakeholder analysis. Although this report focuses on ex ante CBAs, it also recommends conducting ex post CBAs as part of impact assessments to compare predicted impacts with actual outcomes. This document does not constitute a CBA guideline, as such guidelines already exist. The ten steps discussed here are common to most CBA guidelines and are therefore not unique. What is unique to this document is that it outlines concrete ways of incorporating resilience into some critical steps of a traditional CBA process.

Incorporating resilience into CBA

For each of the key steps of the CBA process, specific guidance is provided on how resilience considerations can be systematically integrated into existing CBA guidelines.

1. Specify Alternative Projects that Include Resilient Measures

Depending on the context, CBAs for many transport infrastructure projects may not include resilience as a default criterion at conception. CBAs typically compare situations *with* and *without* a project, defining only a "base case" and a "project case”. By contrast, resilience considerations in CBA require defining *alternative* project designs that incorporate robustness or adaptability. This requires structuring the analysis to compare multiple resilience strategies – such as prevention-oriented investments (robust infrastructure) and adaptation-oriented measures (rapid recovery systems).

For example, in the case of building a coastal highway, one option could be a regular road design, while an alternative might include flood resilience measures such as raised roadbeds and storm surge barriers. The European Commission’s CBA guide emphasises comparing scenarios with and without such resilience measures, especially in coastal infrastructure planning(“EC DG REGIO, 2015EU CBA,” 2014).

Some concrete examples where resilience has been incorporated into transport infrastructure are:

- In the Netherlands, flood risk management measures – including elevated road sections and flood barriers – have been systematically integrated into transport infrastructure planning as part of programs such as the Delta Programme and Room for the River (Netherlands “CPB NL,” 2017); (“ Dutch Water Sector,” n.d.2019)).
- The New York state Metropolitan Transportation Authority (MTA) released a *Climate Resilience Roadmap* in 2024 (with an update in 2025) that describes how MTA will adapt its transport systems to climate change over the next ten years and highlights the work already done since Hurricane Sandy in 2012 to make transport infrastructure more robust (“MTA,” 2024;) (“MTA Update,” 2025).

Given the choice between preventive measures (focusing on robustness) and adaptive measures (prioritising rapid recovery), **it is ideal to include at least two alternative projects in resilience-focused CBAs: one focused on prevention and the other on adaptation.**

2. Determine Whose Benefits and Costs Count

Before starting a CBA, it is important to determine whose benefits and costs are to be considered. Every CBA requires a clear definition of whose welfare is considered – also known as “standing” (Boardman et al., 2018). This includes geographic boundaries (local, national, or supranational), demographic inclusion (citizens, residents, tourists, migrants), and the treatment of individual preferences. Key questions include:

- **Jurisdictional Boundaries**: Are these boundaries local or national? Or should supra-national boundaries be considered, especially in globally connected transport systems? For example: The transport infrastructure linking multiple countries in the European Union (e.g. cross-border rail and road links such as Fehmarnbelt Fixed Link between Denmark and Germany) may warrant a CBA that considers cross-border impacts and regional cooperation (EC, n.d.).

- **Standing of Individuals**: Who within the jurisdiction should have standing? This could include not only citizens and residents but also international tourists and foreign firms. For example: In evaluating a port expansion project, stakeholders may include not only local citizens but also international shipping companies, tourists, and neighbouring regions that rely on the port infrastructure.
- **Preferences**: Standing should generally be given to the choices consumers make unless there is strong empirical evidence that they are systematically making serious errors of judgment (Boardman et al., 2018)

The issue of standing is quite often contentious. While national governments usually take only national (i.e., domestic) costs and benefits into account, critics argue that issues that have significant impacts on residents of other countries should be analysed from a global perspective. On the other hand, local governments typically want to consider only benefits and costs to local residents and to ignore costs and benefits borne by residents of adjacent municipalities or higher levels of government (Boardman et al., 2018). For instance, flood protection upgrades to a locally managed rail corridor may appear unjustified in a municipal CBA because most disruption costs accrue to through-passengers, freight operators, or neighbouring regions. When extreme weather events occur, however, the resulting network-wide service interruptions, freight delays, and economic losses far exceed the locally assessed impacts, illustrating how narrow definitions of standing can lead to underinvestment in system-level resilience.

Hence, for resilience to be meaningfully incorporated into transport CBAs, the definition of standing should extend beyond a single administrative or jurisdictional level. A useful rule of thumb is that all actors who are likely to be disturbed or impacted by an intervention – directly or indirectly, and particularly under disruptive events – should be considered. While CBAs are often conducted at a specific scale, such as local or national, resilience-related impacts frequently materialise across multiple spatial and governance levels. For example, in the Netherlands, national CBAs are commonly applied to major rail projects, including cross-border connections to Germany. However, disruptions to such links may generate significant local, international, or even system-wide impacts that are not fully captured when analysis is confined to a single national perspective. To address this challenge, Dutch CBA guidelines and EU appraisal guidance require that the primary welfare perspective of the CBA (e.g. national or local) should be clearly defined, while impacts occurring outside this boundary – such as local, cross-border, or system-wide effects – are explicitly identified and transparently reported.

Similarly, **resilience investments may impose costs at one level (e.g. national funding) while generating benefits at another (e.g. local users, adjacent regions, or international supply chains). Best practice suggests that even when a CBA is formally conducted at a local or national level, analysts should explicitly identify and, where possible, assess impacts at other relevant scales.** This is particularly important for resilience where neglecting cross-border, interregional, or distributional effects can lead to underestimation of benefits and suboptimal investment decisions, despite the analytical complexity involved. Best appraisal therefore requires that these multi-level and distributional impacts are systematically described and, where feasible, quantified or monetised, even when they fall outside the formal scope of the core CBA.

3. Quantify Costs and Benefits Over Time

In this step, the impacts of the project and alternative projects are listed as costs (i.e. resources required) and benefits (i.e. outputs). These need to be quantified, and only those impacts that affect individuals with standing are considered relevant in a CBA. **For resilience projects, benefits often extend beyond the usual travel-time savings or accident reductions.** They may include avoided losses from service disruptions, reduced repair costs, and the continuity of transport services and rapid recovery in the case of disruptions. These impacts should be clearly defined and measured in the analysis. Moreover, disruptions in one sector can have a cascading effect on other sectors or markets resulting in additional costs. For example, a disruption in the transport sector can impact energy and communications sectors or vice versa (refer to the *Mapping Interdependencies and Interfaces* report published under this Working Group for additional information). In CBA terms this is referred to as indirect effects and must also be captured. While concrete examples of where indirect effects have been captured in CBA are not available, it is important for policy makers reviewing resilience-focused CBAs to be aware of cascading effects, and for analysts to define what the indirect effects of the projects are and make an attempt to quantify them.

Additionally, the valuation of costs and benefits can change over time and therefore should not be assumed to be static in a CBA, especially for infrastructure projects with long lifespans. This means **that resilience-focused CBAs need to incorporate scenario-based valuations, dynamic assessment, and sensitivity analysis,** which are described in Steps 4 and 8 of this report. Transport CBAs will need to anticipate potential long-term developments in technology, demand, regulation, network conditions as well as changes in land-use and climate. These dynamics are particularly relevant for resilience as transport disruptions and reliability shocks can affect both cost structures and the value of service provided to users.

Further, capital and operating costs may evolve as transport assets and systems require additional reinvestment, upgrades, or maintenance to sustain performance and recover from disruptions. For example, digital traffic management systems, rail signalling, or port operations may face increasing costs related to system upgrades, cybersecurity, or operational redundancy as their role in maintaining network reliability grows.

The benefits delivered by transport projects may also change as travel behaviour, logistics patterns and network use evolve over time. Shifts such as increased teleworking, changes in freight routing, or capacity constraints elsewhere in the network can alter congestion, accessibility, and reliability benefits. Under disruption scenarios, these effects are often magnified, as users place greater value on routes and modes that remain operational and predictable.

Finally, key valuation parameters used in transport CBAs – such as travel time, reliability, and operational performance – are not static. Reliability shocks, staff shortages, or recurrent network disturbances can increase the value users attach to dependable travel and robust logistics chains. This underlines the importance of considering how valuations may change over time when assessing transport investments, particularly for long-lived infrastructure where resilience is critical to preserving benefits under adverse conditions.

Box 1. Five-Year Road Program for Disaster Prevention, Mitigation and National Resilience, Ministry of Land, Infrastructure, Transport and Tourism (Japan)

A resilient transport system might focus on reducing disruption times during natural disasters. The benefits include reduced economic losses due to reduced service interruptions and enhanced accessibility for vulnerable populations during emergencies. For instance, Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) formulated a "Five-Year Road Program for Disaster Prevention, Mitigation and National Resilience" in April 2021, and is working to build a national arterial road network that is resilient to disasters by eliminating missing links on high-standard roads, converting temporary two-lane sections to four lanes, and strengthening the redundant network of high-standard roads and national highways under MLIT's jurisdiction that can function as alternatives. Several examples of completed transport projects already exist in Japan that are in line with this national resilience policy. For example, when National Highway 9 in Shimane Prefecture was closed due to a landslide in 2021, the Sanin Expressway – part of a redundant network – absorbed the traffic load, ensuring uninterrupted movement and emergency access. ("MLIT," 2021)

Source: https://www.mlit.go.jp/road/road_e/pdf/ROAD2021cap3_1.pdf

4. Predict Impacts Over Time

All transport projects generate impacts that unfold over time which is referred to as *future uncertainties*. (*Future uncertainty* is distinct from *knowledge uncertainty* which is discussed later in Step 8). Predicting these impacts is inherently challenging, particularly because disruptions are uncertain in their timing, frequency, magnitude, and consequences. Under normal operating conditions, a project's impacts may be relatively straightforward to estimate – for example, a highway upgrade may reduce travel times or vehicle operating costs. However, when resilience is considered, the prediction becomes more complex. A resilient design may not only improve performance under "normal conditions" but also prevent or reduce delays during disruptive events, such as extreme weather or infrastructure failures.

Resilient transport systems can therefore generate benefits over extended periods, especially by maintaining functionality during disruptions. However, both the timing and scale of these benefits are uncertain. While regularly assessing the probability of disruptions can improve the accuracy of predictions, CBAs face limitations when future developments are highly uncertain. For instance, unforeseen events can fundamentally alter long-term trajectories – as illustrated by the COVID-19 pandemic or shifts in global trade routes caused by geopolitical disruptions. In addition, behaviour and preferences may also be affected and create what can be considered a "new normal"("DG for Research and Innovation," 2022). Nevertheless there are ways to deal with future uncertainties within a CBA as discussed below.

Dealing with Uncertainty and Disruptions

To incorporate long-term uncertainty into CBAs, analysts typically rely on multiple scenarios. These scenarios often explore alternative future developments but may not fully capture the consequences of disruptions – particularly low-probability, high-impact events. In disruption contexts, both the likelihood and severity of impacts vary, requiring a structured approach that combines scenarios of disruptive events, their consequences, and the effectiveness of alternative resilience measures.

One method to address this is *decision tree* (or *probability tree*) analysis. Such a decision tree consists of branches and nodes. Each branch is a possible decision path (= alternative solution), and each node is a possible event with a probability (chance). For each possible outcome at the end of a branch, an estimate is made of the associated effects in terms of costs and benefits. This is done by multiplying the probability of each outcome by the associated costs and benefits. For each decision path at the beginning of the tree, a cost-benefit balance is determined by adding the weighted costs and benefits for each branch (in terms of net present value). By comparing the results of the different decision paths, it is possible to determine which one scores best given the chances of a disruption.

Real options analysis[2] can complement this approach by explicitly valuing flexibility, i.e. assigning a monetary value to the flexibility built into an investment decision in project design or timing − such as the option to expand, delay, or adapt infrastructure investments as uncertainty is resolved over time. In other words, unlike standard CBA, which typically assumes a fixed investment path, real options analysis recognises that the ability to adapt a decision over time has value in itself, particularly where outcomes are uncertain.

In cases where uncertainty is particularly high or difficult to quantify, complementary tools such as *cost-effectiveness analysis* or *qualitative scenario analysis* may be appropriate. Additionally, *Monte Carlo simulation*[3] can also be used to propagate uncertainty across multiple parameters simultaneously, generating probability distributions of outcomes rather than single-point estimates. While a full Monte Carlo simulation gives a picture of the entire probability distribution, it is often not feasible in practice due to the amount of work involved and the lack of empirical data. Rather, Monte Carlo simulation can be used to supplement scenario analysis by determining the probability distribution of one or more variables in a scenario to obtain an indication of the consequences for the valuation of risk and flexibility.

For resilience-focused CBAs, incorporating probabilistic risk assessment and structured scenario modelling is often essential to ensure that low-frequency but high-impact events are adequately considered.

Scenario Development

The development of scenarios should be flexible and proportionate. Drawing on the UK Transport Analysis Guidance (TAG) Uncertainty Toolkit (UK DfT, 2025b), scenario development typically involves three broad stages:

- Gathering intelligence about the future: identifying relevant uncertainties, key trends, and baseline data.
- Identifying drivers of change: establishing consensus on the most important uncertainties affecting the transport scheme.
- Describing plausible futures: developing narrative descriptions of future conditions and translating them into modelled scenarios.

As a rule of thumb, the effort devoted to uncertainty analysis should be proportionate: the potential benefits of improved decision making should exceed the costs of conducting the analysis.

Implications for Decision Making

Robust decision making requires an explicit understanding of how project outcomes may differ under alternative future assumptions. Presenting uncertainty transparently helps analysts, scheme promoters, and decision makers recognise the risks they face and avoid over-reliance on a single “core” scenario. The UK TAG Uncertainty Toolkit emphasises several key principles:

- The treatment of uncertainty is a core element of transport appraisal and should be considered early in scheme development.
- Appraisal should not focus exclusively on a central scenario; wider "what if" scenarios should be assessed as standard.
- Proportionate techniques should be used to define, measure, and communicate uncertainty.
- Uncertainty should be considered holistically across strategic and economic assessments and throughout the planning process.

Transport models themselves introduce additional uncertainty through data limitations, behavioural assumptions, and model structure, reinforcing the need for careful interpretation of results from a CBA perspective.

Dynamic Assessment and Resilience

Finally, **resilience planning requires a dynamic rather than static approach to appraisal**. The World Bank's *Lifelines* report on resilient infrastructure (Hallegatte et al., 2019) stresses the importance of continuous reassessment of disruption risks arising from natural hazards, extreme weather, and evolving socio-economic conditions. Static CBAs risk underestimating future damages or misallocating resources. Regularly updating risk assessments and assumptions allows decision makers to better prioritise investments and improve the long-term performance and resilience of transport infrastructure.

5. Monetise Impacts

Assigning monetary values to resilience benefits can be complex. Historical disruption data and standard valuation frameworks (such as the UK's TAG, the Netherlands' MKBA, or Sweden's ASEK) can be used to monetise benefits like time saved, lives saved, and accidents avoided. Some resilience benefits, such as biodiversity, may not have direct market values and must be documented qualitatively (New Zealand TATransport Agency Waka Kotahi, 2024). Also, if no one is willing to pay for certain positive resilience impacts, or if markets for resilience do not exist, these non-monetisable impacts must be explicitly acknowledged.

For example, Sweden's ASEK guidelines provide standardised values and methods for conducting CBAs in Sweden's transport sector. These include monetised values for travel time savings, delays, accidents, and environmental impacts. The 2024 edition (Swedish TA" ASEK 8.0," 2024) supports the use of these values to assess the economic benefits of infrastructure upgrades – such as modernised signalling systems – by quantifying avoided delays and improved reliability. This approach helps translate resilience benefits into metrics familiar to policymakers and economists.

One widely used method for the quantitative assessment of resilience is the estimation of disruption costs arising from asset failure under two contrasting scenarios: the business-as-usual (BAU) scenario, where the system continues to operate in its current state without any additional resilience measures, and the *intervention* scenario, where specific strategies are implemented to enhance resilience. *Resilience benefit* is defined as the difference between these two scenarios and directly represents the avoided losses due to the intervention. This benefit may stem from reduced service downtime, lower repair costs, or mitigated socio-economic impacts. However, it must also be acknowledged that resilience benefits may be partially or fully offset by the capital expenditures (CAPEX) required to implement the measures or the operational expenditures (OPEX) associated with their maintenance. Therefore, **resilience analysis should evaluate**

both the avoided disruption costs and the additional financial requirements of interventions. While such an evaluation may indicate higher CAPEX or OPEX costs, **it is worth underscoring that resilience investments could be considered desirable if the social costs of disruption are unacceptable**.

This framework aligns with the Modified Resilience Triangle (MRT) methodology developed by P. Singh et al. (2022), which defines *resilience benefit* as the difference in *expected resilience loss* (ERL) between BAU and intervention scenarios, and expresses this benefit in monetary terms through long-term scenario analysis and NPV calculations. The approach assesses the long-term benefits of resilience investments through *comparative scenario analysis*, explicitly focusing on the difference between BAU and intervention cases. This approach has a long tradition in environmental economics, where it is often labelled the "expected damage" approach. In practice, the method first estimates ERL under the BAU scenario, where the system continues to function without any measures. It then recalculates ERL under intervention scenarios that incorporate selected strategies (e.g. evacuation planning, alternative energy sources, adaptive bridge design). Resilience benefit is thus formulated as:

$$\text{Resilience Benefit} = ERL_{BAU} - ERL_{INTERVENTION}$$

This approach may provide a possibly lower bound of the resilience benefit since it may not capture other intangible benefits from resilience. This methodology has been validated with three different case studies in the abovementioned study by P. Singh et al., as shown in Table 1 below. The City Assisted Evacuation Plan (CAEP) in New Orleans reduced resilience loss by 27% compared to BAU, and by 48% when continuous learning and improvement mechanisms were included. The New Jersey TransitGrid project achieved a 27% reduction in losses with the installation of a microgrid, increasing to 66% in the network expansion scenario. Finally, in the case of the Tex-Wash Bridge in California, the Dynamic Adaptive Planning (DAP) approach delivered far greater benefits than static design alternatives, reducing resilience loss by 92% compared to BAU.

Table 1. Case Studies

Case	Problem	Approach	Benefits
New Orleans – CAEP	150,000 people could not evacuate during Hurricane Katrina due to lack of resources and absence of a plan for vulnerable groups.	City Assisted Evacuation Plan (CAEP) – an evacuation plan for carless and vulnerable groups, with continuous learning and improvement.	27% reduction in losses; up to 48% with continuous improvement.
New Jersey – TransitGrid	The collapse of the central power grid during Hurricane Sandy disrupted the entire transit system.	TransitGrid – development of an independent microgrid to power critical parts of the network; featured modularity and redundancy.	27% reduction in losses; up to 66% in expanded scenario.
California – Tex-Wash Bridge	The bridge collapsed due to heavy flooding in 2015, showing the vulnerability of reliance on a single asset.	Dynamic Adaptive Planning (DAP) – bridge design continuously adjusted based on climate projections.	92% reduction in losses (highest benefit, long-term adaptability).

Source: (Singh et al., 2023)

Therefore, the MRT approach (Singh et al., 2023) technically defines resilience benefit as the difference between the BAU scenario and the intervention scenario, and expresses this benefit in monetary terms using the NPV method through long-term scenario analyses. In this respect, the method demonstrates to decision makers that resilience investments not only protect against disasters but also offer net benefits that strengthen economic rationality in the long term, enabling resilience to become a strategic priority.

As an alternative approach, resilience can also be systematically integrated into cost-benefit analyses – and its importance highlighted to decision makers – by adopting the "option and non-use values" method outlined in the UK Department for Transport's TAG guidance on social impact (UK DfT, 2022). This approach reflects the benefits of infrastructure simply existing, even when not actively used, as well as the assurance of having an alternative available in the future. In particular, these values should be considered in the case of "step-change" situations such as the opening of a new line or the closure of an existing mode. Within this framework, risk scenarios (e.g. a line being rendered unusable due to flooding) should be defined, the costs incurred in the absence of an alternative should be calculated, and the costs avoided by having an alternative should be monetised through an *expected value approach*. In addition, individuals' willingness-to-pay for the potential future use of a line (even one that is not used regularly) should be estimated through stated preference surveys or value transfer from the literature, and reported separately in the Appraisal Summary Table[4].

A concrete application of this approach can be seen in the MetroWest Phase 1 project in the United Kingdom, where option and non-use values were explicitly included as a separate benefit item in the cost-benefit analysis, resulting in a monetised value of £25 million (North Somerset District Council, 2019). This example clearly demonstrates how the seemingly intangible benefits of resilience can be measured and incorporated into the CBA framework. In this way, resilience-related benefits are directly monetised alongside traditional user benefits, allowing for a more comprehensive and realistic appraisal of transport projects.

6. Discount Benefits and Costs to Obtain Present Values

It is general practice for CBAs to consider that a project has costs and benefits over an extended period. These costs and benefits may be country-specific and vary based on the mode of transport. Therefore, future values need to be discounted to obtain their present value (PV). But before discounting, the first step is to take inflation into account. According to the United Kingdom's transport analysis guidance (TAG), when applying monetary values to impacts over a long appraisal period in CBA, it is very important to take the effects of inflation into account. Failing to do so will distort the results by placing too much weight on future impacts, where values are higher simply because of inflation. When inflation is not taken into account, values are said to be in 'nominal' prices; and when values are adjusted to account for inflation, they are said to be in 'real' prices. For CBA purposes, all values should be expressed in real prices to stop the effects of inflation distorting the results (UK DfT, 2025a).

Next, there is considerable evidence to show that people prefer to consume goods and services now, rather than in the future. In general, even after adjusting for inflation, people would prefer to have $1 now, rather than $1 in 60 years' time. As the impacts included in CBA are presented in monetary terms, all monetised costs and benefits arising in the future need to be adjusted to take account of this phenomenon, known as 'social time preference' (UK DfT, 2025a).

The technique used to perform this adjustment is known as 'discounting'. This process is separate from that used to adjust for inflation. Adjustments for inflation are made to account for the reduction in what $1 can purchase over time, while discounting is performed to reflect people's preferences for current consumption over future consumption. As discounting is a separate process from accounting for inflation, it should be performed once values are already in real prices. A 'discount rate', which represents the extent to which people prefer current over future consumption, is applied to convert future costs and benefits into their 'present value', i.e. the equivalent value of a future cost or benefit occurring today (UK DfT, 2025a).

Hence, discounting brings future costs and benefits to present value terms, i.e. present value benefits (PVB) and present value costs (PVC) and allows projects to be compared on a consistent basis.

According to the findings in the literature, **discount rates used in traditional CBAs could be adjusted downward to better reflect the long-term advantages of resilience**. In this context, it is recommended to use a declining schedule of discount rates rather than a fixed rate for projects with long-term and intergenerational impacts. According to a 2022 study (Fonseca et al., 2022), adaptation projects typically have their costs concentrated upfront, in the early years of project implementation, while the benefits follow through later on; that is, the benefits will increase in the future due to more avoided impacts. This means that for adaptation projects, raising the discount rate tends to lower the NPV of the resilience option, causing the future benefits of resilient infrastructure to be ignored. Methodological approaches for CBA have recommended the use of declining discount rates over time to capture the issue of intergenerational equity.

While applying a declining discount rate could be relevant for transport investments whose benefits extend well beyond normal appraisal horizons (Mouter, 2018), it is important to consider that different benefits can have different discount rates. In the case of resilience-related measures, benefits may arise from several aspects such as reduced disruption costs, avoided economic losses, improved reliability of access to essential services, and enhanced system recovery. These benefit categories may differ in timing, probability, and distribution over a long time horizon, and therefore may warrant careful consideration when selecting discounting assumptions.

The motive for a declining discount rate is not to make long-term projects more attractive than they are. Rather, this approach could improve the representation of long-term and intergenerational effects without assuming that all benefits should be treated identically in discounting terms.

Moreover, when assessing costs and benefits, CBAs may omit important effects that are difficult to monetise. For example, while well-established values exist for travel time savings, comparable monetary values are often lacking for aspects such as perceived safety, security, or confidence in the reliability of a transport mode during disruptions. **Unlike objective risks, perceived risks cannot be easily quantified and therefore monetised. These non-monetised effects can be particularly relevant for resilience**. To better reflect resilience within CBAs, such impacts should be explicitly identified and incorporated using complementary qualitative or multi-criteria approaches alongside monetised indicators.

7. Present CBA Outcomes

Reporting CBA results in terms of costs and benefits can be done using a number of *metrics*, and the metric chosen can affect how impacts are classified as costs or benefits. The two most commonly used metrics are the *benefit-cost ratio* (BCR) and the *net present value* (NPV). Agencies typically use BCR or both BCR and NPV when conducting CBA.

The primary metric used in reporting CBA results in most circumstances is the BCR, which requires a clear definition of what constitutes the present value of benefits (PVB) and present value of costs (PVC). The BCR is given by PVB/PVC, and so indicates how much benefit is obtained for each unit of cost, with a BCR greater than 1 indicating that the benefits outweigh the costs.

The NPV is simply calculated as the sum of future discounted benefits minus the sum of future discounted costs: PVB – PVC. A positive NPV means that discounted benefits outweigh discounted costs, and in a world with no budgetary constraints there would be a case for taking forward all projects with a positive NPV (provided the *net monetised benefit* outweighed any *net negative non-monetised* factors). It is therefore important to take into account both net monetised and non-monetised benefits and costs.

While standard CBA practice typically prioritises the alternative with the highest NPV, this ranking is conditional on all relevant costs, benefits, and risks being adequately captured and monetised. In practice, however, many resilience-related benefits – particularly those associated with low-probability, high-impact events – are only partially reflected, or entirely excluded, from standard CBA calculations depending on the context. As a result, alternatives that perform better in terms of long-term resilience may appear to have a lower NPV.

If disruption risks, avoided downtime, and system-wide failure costs are explicitly included and monetised, a more resilient option may indeed yield the highest NPV. However, when such risks are not fully quantified – due to data limitations, uncertainty, or methodological constraints – the resulting NPV comparison may be incomplete. In such cases **– where resilience benefits can be monetised, they should be included directly in the CBA and reflected in the NPV; where this is not feasible, resilience should be used as a structured basis for comparing alternatives whose NPVs alone do not capture the full range of long-term impacts**. An example where this is recognised is New Zealand's transport appraisal practice described in Box 2.

Finally, an *appraisal summary table* (AST) is a standardised reporting tool used in transport CBA to present the full range of a project's impacts in a single document. Best practice recommends that AST captures not only impacts that can be expressed in monetary terms, but also those that are quantified in other units or assessed qualitatively, such as effects on the environment, social inclusion, and network reliability. The AST must ensure that impacts which are difficult to monetise are not simply excluded from the appraisal but are transparently reported alongside the core economic analysis, supporting more informed decision making (HM Treasury, 2026). This approach enables decision makers to justify the selection of alternatives with potentially lower calculated NPV or BCR when there is clear evidence that they deliver long-term resilience and risk reduction. In this way, resilience is neither ignored nor treated as a purely qualitative consideration. Instead, it is systematically integrated into decision making.

Box 2. New Zealand's transport evaluation framework

New Zealand's transport evaluation framework acknowledges that certain resilience benefits – such as reduced recovery time after natural hazards, improved network redundancy, or maintained access to critical services – cannot always be robustly expressed in monetary terms. Relying solely on standard monetised CBA outputs may therefore understate the long-term value of more resilient investments and lead to suboptimal decisions. To address this gap, the country's Transport Agency has updated its guidance, replacing their economic evaluation manual with two complementary documents: the *Monetised Benefits and Costs Manual* (New Zealand TA, 2025) and the *Land Transport Benefits Framework* (New Zealand TA, 2024). These manuals provide clear procedures for embedding strategic adjustments when resilience outcomes are significant but not readily monetised. Together, these manuals ensure that resilience considerations are systematically acknowledged in CBA, even when monetary values are insufficient.

Source: https://www.nzta.govt.nz/assets/resources/land-transport-benefits-framework-measures-manual/Land-Transport-Benefits-Framework-measures-manual.pdf ; https://www.nzta.govt.nz/assets/resources/monetised-benefits-and-costs-manual/Monetised-benefits-and-costs-manual-v1.7.4-volume-1-procedures.pdf.

8. Carry out Sensitivity Analysis

In CBA, the effects of uncertainties on the cost-benefit balance are clarified by means of scenarios (to address future uncertainties), a sensitivity analysis (to address knowledge uncertainty) and a risk premium on the discount rate. (*Future* uncertainties and *knowledge* uncertainties are distinct. In this step, knowledge uncertainty is discussed. The discussion of future uncertainties, i.e. scenarios, is covered earlier in step 4.)

Sensitivity analysis tests how changes in assumptions affect the outcomes of the CBA. This is particularly important for resilience projects due to the high level of uncertainty around predicted impacts and the monetisation of those impacts.

For example, if the predicted frequency of flooding is highly uncertain, a sensitivity analysis could test different scenarios based on various flood probabilities (e.g. 1%, 5%, or 10% chance of flooding each year). By testing a range of assumptions – such as disruption probability, climate scenarios, or repair cost estimates – decision makers can identify which assumptions most influence outcomes.

According to UK *TAG Uncertainty Toolkit* (UK DfT, 2025b), sensitivity tests are used to understand the sensitivity of a transport model to different parameters, assumptions, or differences in key drivers, and how this will impact on the assessment of costs and benefits. The *advantages* of sensitivity tests are that they (a) are commonly used and understood and (b) help narrow in on factors specific to the scheme, such as key assumptions or important exogenous factors.

The *disadvantages* of sensitivity tests include:

- They provide no information about the likelihood of different outcomes.
- Standard practice is to run key sensitivities, but thorough testing can be resource intensive.
- They focus on only one dimension of uncertainty in isolation, which risks obscuring additional sources of uncertainty if sensitivities are presented in isolation.

Despite these limitations, sensitivity analysis remains an indispensable tool for resilience-focused CBA. Resilience investments are inherently forward-looking, designed to guard against disruptions that may be rare, uncertain in scale, and difficult to monetise with precision. Sensitivity tests make this uncertainty explicit and traceable, allowing decision makers to evaluate not just whether an investment is worthwhile, but how robust that conclusion is when key assumptions change. In doing so, sensitivity tests help build the evidence base and stakeholder confidence needed to justify resilience investments that might otherwise be difficult to defend on the basis of a single point estimate.

9. Consult Stakeholders

Resilience-focused CBAs can be significantly strengthened through inclusive and well-timed stakeholder engagement. Such engagement helps validate modelling assumptions, identify impacts that may otherwise be overlooked, and increase the legitimacy and acceptance of appraisal outcomes. Relevant stakeholders typically include transport operators, infrastructure owners, local and regional authorities, emergency services, private sector actors, and affected communities. These groups can provide critical insights into disruption costs, realistic service recovery timelines, operational constraints, and resilience priorities that are difficult to capture through modelling alone.

Importantly, stakeholder consultation should be conducted at two key stages of the appraisal process. *Early-stage consultation* is essential to ensure that all relevant impacts – particularly those related to resilience, cascading failures, and extreme events – are correctly identified and described before modelling begins. Expert and industry knowledge at this stage can help define realistic assumptions and avoid systematic omissions. *Late-stage consultation*, after analytical results are available, allows stakeholders to assess whether the model outputs and impact estimates align with real-world experience. This feedback loop is important, as modelling uncertainty is often high in resilience analysis. If assumptions are perceived as incorrect or incomplete, stakeholders may reject results even when the technical analysis is robust.

Such practices are recommended in the Netherlands, notably in the latest user guide for CBA for infrastructure investments by the national government (Netherlands Ministry of Infrastructure and Water Management, 2024). The guidelines state that the impacts that need to be identified depend on the context. They should be based on the problem analysis, the objectives and ambitions that emerge from it, and the choice of measures to achieve them. According to the guidelines, it is advisable to take a broad view of the task and involve all stakeholders in identifying impacts. This will help prevent impacts from being overlooked. It is also essential to discuss what (decision making) information stakeholders expect and explain how this is reflected in the CBA study, the final calculation of social costs and benefits, and in the report – in other words, discussing *which* effects are to be expected and *how* these are measured and valued in the CBA.

Another practice that has been tested in the Netherlands to enhance stakeholder engagement in CBAs is *participatory value evaluation* (PVE) (TU Delft, 2026). PVE allows citizens and stakeholders to engage with policy choices in a structured way by presenting them with alternative options, including expected impacts and relevant constraints. When applied at the beginning of a project, PVE can support the identification and prioritisation of impacts that matter most to stakeholders. When applied again at the end, it can be used to test whether the evaluated impacts and trade-offs align with stakeholder preferences and expectations. In this way, PVE complements technical modelling by improving assumption-setting, increasing transparency, and strengthening the social robustness of resilience-related investment decisions.

Overall, **embedding stakeholder consultation both upstream and downstream of modelling – and complementing it with participatory tools such as PVE – helps ensure that resilience-focused CBAs are analytically sound, context-sensitive, and more likely to be accepted by those affected by the resulting decisions**. For further discussion on acceptability of resilience measures, readers can refer to the deliverable called “*Best Practices for Acceptability of Resilience Measures*” published under this Working Group.

10. Formulate Recommendations and Communicate

A conventional CBA communicates results primarily through summary metrics (e.g. NPV or BRC) which ideally provide insight into why one option performs better than another or how resilience benefits materialise over time. The analysis itself, if reported appropriately, provides transparency. However, resilience investments may still encounter challenges where benefits occur infrequently, under extreme conditions, or far into the future. As a result, decision makers may struggle to interpret whether a lower-NPV option offers greater long-term resilience against uncertainty and systemic risk. In such cases, reliance on headline indicators alone, i.e. NPV or BCRs, may obscure significant differences between alternatives and should not be mechanically applied.

Clear and structured communication is therefore critical, especially where resilience measures increase upfront costs. The UK Department for Transport's Transport Analysis Guidance (TAG) recognises this through the concept of an "*economic narrative*" – a structured qualitative account that sits alongside the quantitative CBA to explain the mechanisms, assumptions and non-monetised impacts of an investment

(UK DfT, 2023; UK DfT, 2025d). Applying this approach to resilience investments and developing a "*resilience narrative*" would mean explaining how resilience investments improve system performance before, during, and after disruptions, helping policymakers and the public understand long-term value even where it cannot be fully captured in monetary terms.

Another example is the *triple dividend of resilience* (TDR) approach developed by the World Resources Institute (Heubaum et al., 2022) which considers avoided losses (first dividend), induced economic or development benefits (second dividend), and additional social and environmental benefits (third dividend) of adaptation actions. According to TDR, the second and third dividends are often highly significant. They can exceed the value of avoided losses and can generate project benefit-cost ratios (BCRs) greater than one even when the value of avoided losses is not considered. Accounting for the full range of benefits demonstrates higher BCRs for adaptation investments than are often assumed.

Further, complementary analytical tools can strengthen both the recommendation process and its communication. Vulnerability screening tools such as the Vulnerability Assessment Scoring Tool (VAST) help explain *where and why* assets or corridors are exposed to risk, while scenario-based tools such as the Resilience Dividend and Recovery tool (RDR) illustrate how resilience measures manage outcomes under specific disruption scenarios (Box 1). When presented alongside CBA results, these tools help translate abstract risk and resilience concepts into tangible system-level effects, such as reduced downtime, faster recovery, or avoided economic losses.

Box 3. Using VAST and RDR to Support Resilience in Cost–Benefit Analysis

Transport CBAs may be complemented by tools where exposure to disruption or systemic failure is significant and not fully captured through standard monetisation. Two such tools developed in the United States by the U.S. Department of Transportation, through the Federal Highway Administration (FHWA), are the Vulnerability Assessment Scoring Tool (VAST) and the Resilience and Disaster Recovery (RDR) Tool Suite.

VAST is a quantitative, indicator-based, vulnerability-screening tool used to identify and prioritise transport assets that are vulnerable to hazards such as flooding, drought, wildfire, high winds and other extreme weather. While VAST does not monetise impacts, it can help to justify why resilience is a relevant appraisal dimension, informs scenario selection, and supports transparent documentation of risk assumptions used in the CBA.

The RDR Tool Suite enables assessment of transport resilience *return on investment* (ROI) for specific transport assets over a range of potential future conditions and hazard scenarios. This assessment can then be used as a consideration in existing project prioritisation processes. The tool suite utilises established *robust decision making* concepts and addresses deeply uncertain future scenarios. Although not a full CBA tool, RDR provides structured evidence that can be used alongside CBA results, particularly where resilience benefits are uncertain or only partially monetised.

Together, VAST and RDR can complement CBA by strengthening risk identification, supporting interpretation of results, and informing decisions where resilience benefits are significant but only partially monetised.

Source: https://toolkit.climate.gov/tool/vulnerability-assessment-scoring-tool-vast ; https://rosap.ntl.bts.gov/view/dot/63311

In addition, as described in Steps 4 and 8, uncertainty-focused methods can be used to enrich interpretation of CBA results. For example, *Monte Carlo simulation* can be used to supplement scenario analysis by determining the probability distribution of one or more variables in a scenario to obtain an indication of the consequences for the valuation of risk and flexibility. This is particularly relevant for resilience investments, where tail risks dominate welfare outcomes. *Real options analysis*, in turn, supports appraisal of flexible and adaptive strategies – such as phased implementation, upgradeable designs, or deferrable investments. *Sensitivity tests* make knowledge uncertainty explicit and traceable, allowing decision makers to see how robust an investment conclusion is when key assumptions change. These approaches help decision makers understand not only expected performance, but also robustness and adaptability under uncertainty.

Taken together, quantitative CBA outputs, resilience narratives, triple dividend of resilience (TDR), vulnerability and scenario tools (such as VAST and RDR), and uncertainty-focused methods, provide a more complete and transparent basis for recommendations. This integrated approach enables decision makers to move beyond a narrow comparison of point-estimate NPVs or BCR and to make informed, defensible choices that balance cost efficiency with long-term resilience and risk management.

Conclusion: The Role of Cost-Benefit Analysis in Decision Making

How resilient should the (future) transport system be? How to determine that a situation is undesirable from the point of view of resilience and that action needs to be taken? How to prioritise tasks relating to resilience, and how to choose between alternative measures for a task? Which measure contributes most to a resilient transport system, and how can a resilient transport system be built in the most socially cost-efficient way? In order for resilience to play a role in decision making, these are some questions that policymakers should be able to answer.

Social cost-benefit analysis is generally used to address questions related to prioritising tasks, choosing resilient measures, and the issue of efficiency. Although CBA remains a central tool for transport investment decision making, its traditional application is not sufficient to fully capture resilience-related impacts. Increasing exposure to natural and man-made hazards and risks, systemic disruptions, and long-term uncertainty means that transport projects that perform well under normal conditions may generate substantial costs over time if resilience is not adequately considered.

This report demonstrates that resilience can be systematically incorporated into existing CBA practice without replacing established appraisal frameworks. By adapting key steps of the CBA process – such as defining resilient alternatives, broadening the definition of standing, expanding the range of costs and benefits, improving the treatment of uncertainty, and complementing monetised results with qualitative and scenario-based evidence – resilience can be treated as an integral part of economic appraisal.

A key message is that CBA should inform decisions, not determine them automatically. Headline indicators such as NPV and BCR are informative, but their interpretation depends on what is included, how uncertainty is addressed, and which impacts cannot be monetised. Where resilience benefits can be robustly valued, they should be included directly in the CBA; where this is not feasible, complementary tools – such as scenario analysis, vulnerability screening, real options analysis, Monte Carlo simulation, and stakeholder engagement – provide essential evidence for informed judgement.

More broadly, for resilience to meaningfully influence transport investment decisions, it must be articulated as a *policy objective* – clarifying the desired level of system robustness and recovery capability expected, along with explicit criteria to determine when vulnerabilities or risks justify intervention. To conclude, resilience must be integrated into the assessment and prioritisation of projects and programmes, where efficiency considerations remain important but are evaluated alongside long-term risk reduction, adaptability, and system performance under stress.

Notes

[1] *MKBA* stands for Algemene Leidraad Maatschappelijke Kosten-Baten Analyse (General Guidelines for Social Cost-Benefit Analysis), which until 2013 were known as the OEI framework.

[2] Real Options Analysis is an appraisal technique that assigns monetary value to the flexibility built into an investment decision – for example, the option to delay, phase, expand or scale back a project as future uncertainties become clearer. Unlike standard cost-benefit analysis, which typically assumes a fixed investment path, Real Options Analysis recognises that the ability to adapt a decision over time has value in itself, particularly where outcomes are uncertain or irreversible. This approach is recognised in national appraisal frameworks and is known internationally. The UK's HM Treasury Green Book, for instance, includes Real Options Analysis as a recommended method for handling uncertainty in long-term investment decisions.

[3] Monte Carlo simulation is a method based on repeated random sampling of inputs to a deterministic model or calculation procedure, allowing cumulative uncertainties to be integrated into a cost-benefit analysis. Rather than varying one assumption at a time – as in a standard sensitivity analysis – it simultaneously samples across the full range of uncertain parameters, producing a probability distribution of outcomes such as the net present value. This gives decision makers a clearer picture of the range of plausible results and the likelihood of a project remaining beneficial under different conditions.

[4] The Appraisal Summary Table (AST) is a standardised reporting tool used in transport cost-benefit analysis to present the full range of a project's impacts in a single document. It captures not only impacts that can be expressed in monetary terms, but also those that are quantified in other units or assessed qualitatively, such as effects on the environment, social inclusion, and network reliability. The AST ensures that impacts which are difficult to monetise are not simply excluded from the appraisal but are transparently reported alongside the core economic analysis, supporting more informed decision-making.

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Guidance for Incorporating Resilience in Cost-Benefit Analyses

Standard cost–benefit analysis (CBA) was not designed with resilience in mind. High-impact yet low-probability disruptive events such as extreme weather, pandemics, cyberattacks, and geopolitical shocks impose costs that decision-makers may lack an adequate evidence base to justify resilience investment against.

While some national and supra-national agencies already provide guidance on resilience-focused appraisal, it is not standard practice globally. In a highly interconnected world where disruptions in one domain can rapidly cascade across regions and sectors, there is a strong case for resilience-focused CBAs. This report sets out how resilience considerations can be systematically embedded within existing CBA frameworks, drawing on established practice from seven countries.

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