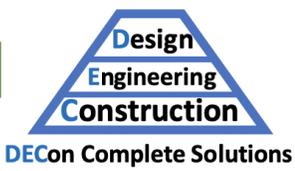




Vision Zero India: Integrating Safety, Sustainability and Technology in Infra



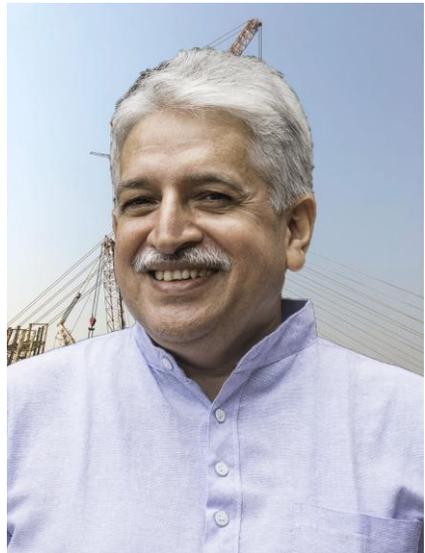
5th – 6th February 2026

Venue: Hotel The Ashok, New Delhi , INDIA

Life-Cycle Impact Analysis: A Strategic Enabler for Vision Zero India

V N Heggade

Founder & CEO of DECon Complete Solutions

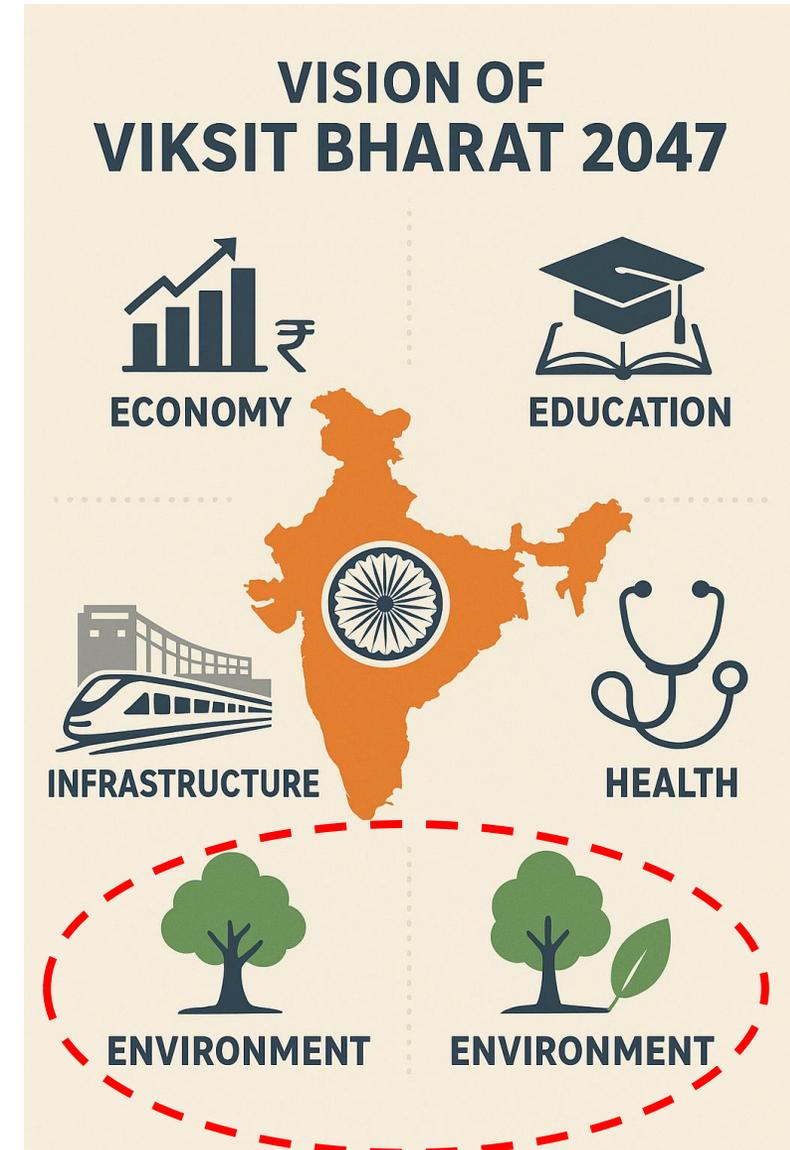


V.N. Heggade, Former Chief Executive Officer (CEO) of STUP Consultants & former Executive Director of Gammon is a senior professional with a rich experience of nearly four decades in Construction sector in the areas of Design Management, Technical Management, Site Management, Project Management & Contract Management of Highways, Bridges, Energy structures like Chimneys & Cooling towers, Environmental, Marine and Hydraulic structures.

He is a recipient of around 19 National recognitions in addition to an International prize & fellowship from IABSE & fib Zurich. He has more than 240 publications including papers in journals, conference presentations & chapters in guidelines to his credit and is a member of various IRC (Indian Roads Congress) and BIS (Bureau Of Indian Standards) committees. He is also a member of TG 10.1 of Federation Internationale Du Beton, which is a special Task Group working on FIB Model code 2020.

Under his convenorship of sub committee IRC B-5.3, a special guidelines on carbon neutrality for steel bridges was brought out. Recently he is selected as "AICTE distinguished professional". He is a Fellow of Indian National Academy of Engineering (FNAE).

- “When India celebrates 100 years of independence in 2047, how will we be remembered – as a nation that **dreamt big**, or as a nation that **built big**?”
- **Infrastructure is the backbone of development:** Roads, Railways, Ports, Airports, Digital, Energy, Urban.
- **70% of India’s 2047 economy will rely on infra built in next 21 years.**
- **Key Goals:**
 - \$30–35 trillion economy by 2047.
 - World-class infrastructure matching G7 standards.
 - **Sustainable, resilient and Vision Zero growth.**



Four Pillars of Infrastructure

Physical

- Highway
- Rail
- Airports
- Logistics hubs

Digital

- 6G
- AI-driven smart cities
- Rural digital inclusion

Social

- Education
- Healthcare
- Housing
- Urban amenities

Sustainable

- Renewable energy
- EV ecosystem
- Carbon-neutral

Vision of a developed India by 2047 must rest on sustainable, resilient infrastructure



Comparative infrastructure Overview (1947 → 2025 → 2047)

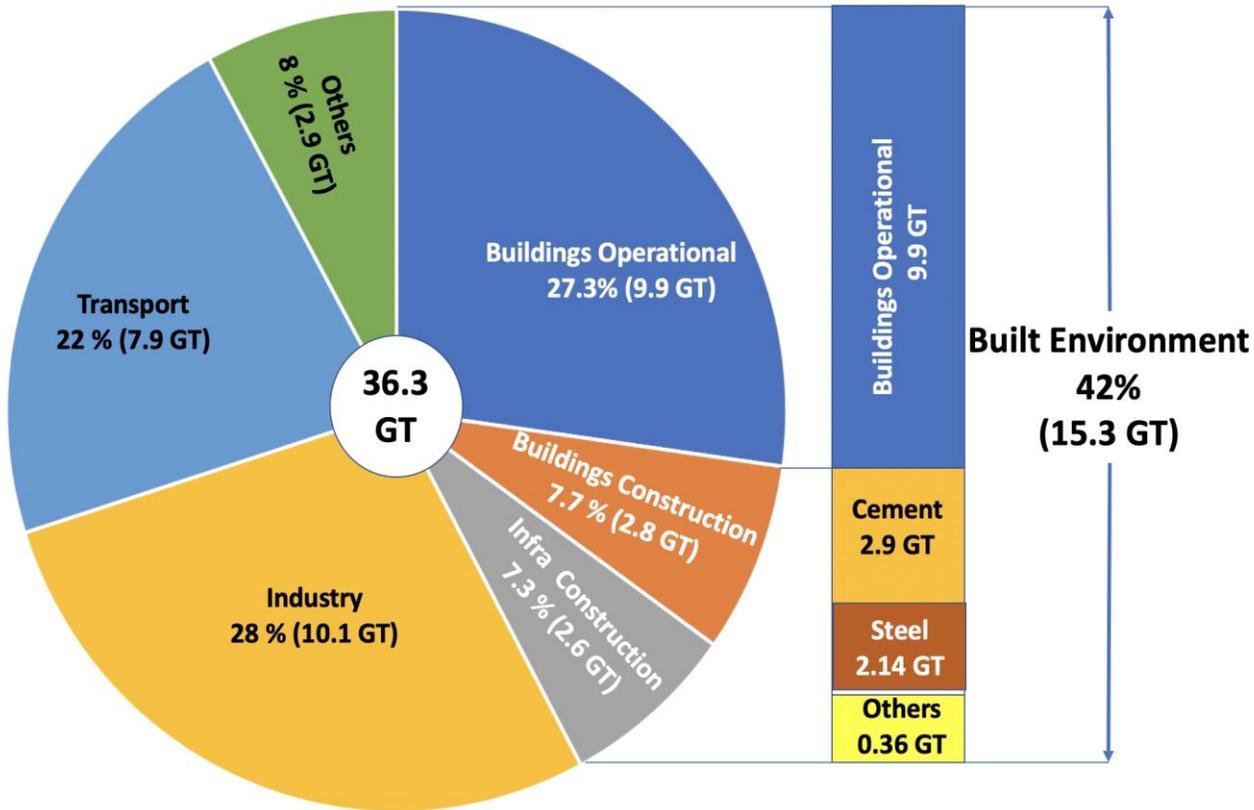


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Sector	1947 	2025 	2047 <u>(Vision Zero)</u>
Roads & Highways	0.4M km , mostly unpaved	> 6.3M km , expressways	Smart, green corridors
Railways	55,000 km, steam engines	68,000 km, Vande Bharat, HSR	100% electrified, HSR network
Power & Energy	1,350 MW installed	> 425 GW capacity, renewables rising	Net-zero, 70%+ renewables
Water & Sanitation	Limited piped water, poor sanitation	Tap water to 70% , ODF (Open Defecation Free) villages	Universal safe water, 100% recycling
Urban Development	Few planned cities , widespread slums	100+ Smart Cities , metro in 20+ cities	Inclusive, net-zero cities
Ports & Aviation	Colonial ports , rare air travel	12 major ports , 140+ airports	Global logistics hub, carbon-neutral airports
Digital Infrastructure	Practically non-existent	1.2B mobiles , UPI, Digital India	6G, AI & quantum hub
Bridges & Mega Structures	Colonial-built bridges	Chenab Bridge , Atal Tunnel, MTHL, Namaste signature Bridge	Leader in mega resilient structures

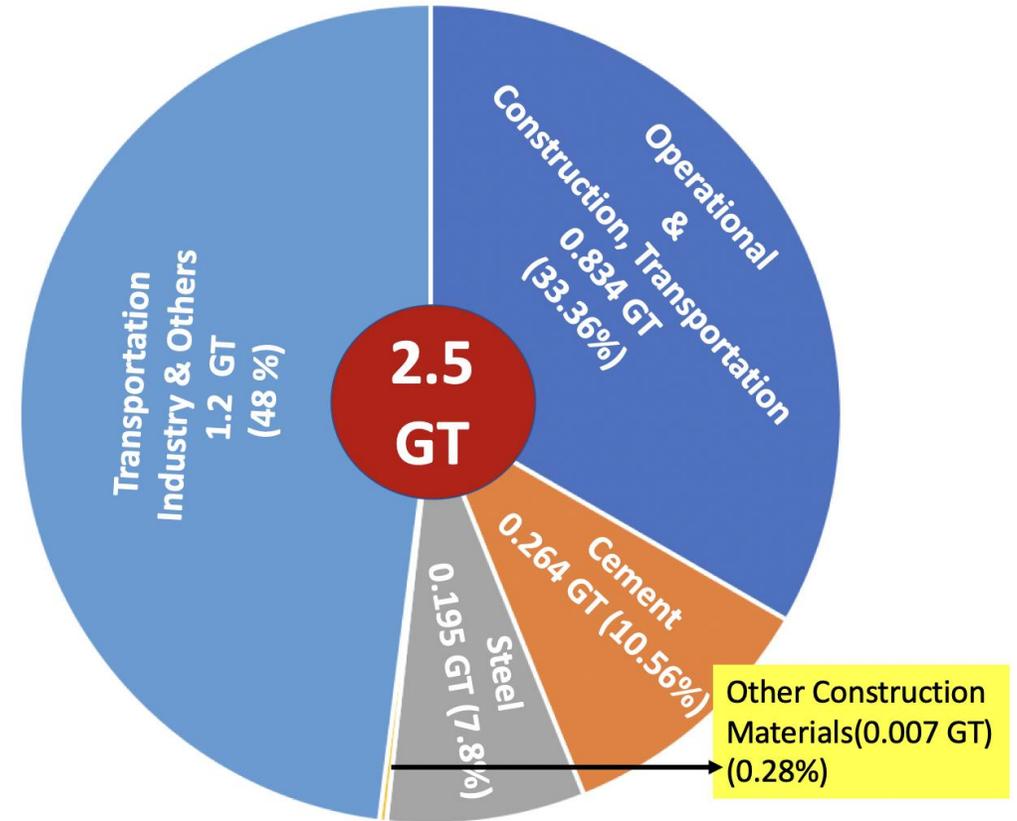
Urgent need for Vision Zero in built environment

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WORLD

Source : V N Heggade, Roadmap to Net Zero in Built Environment Simplified, 4th R.N. Raikar International Memorial Conference and Ghosh-Mukherjee International Symposium on "Advance of Science & Technology of Concrete", 12 to 14th December 2024, Mumbai, pp 78-97.

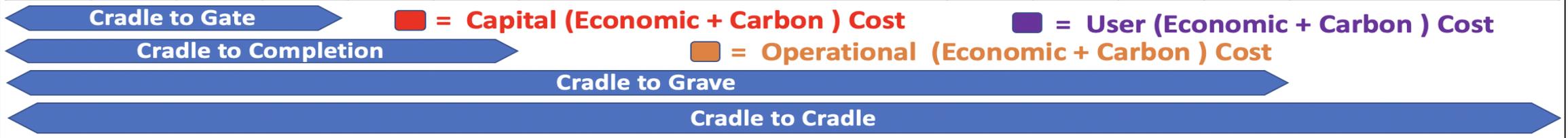


INDIA

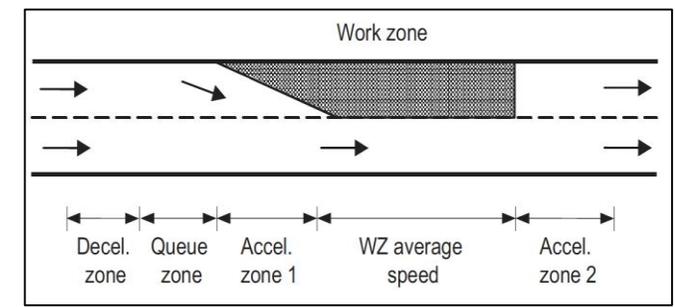
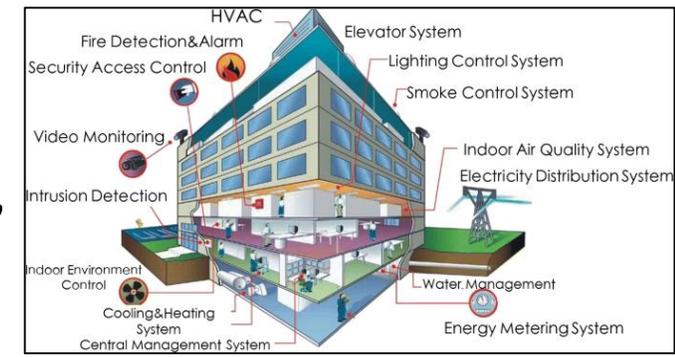
Source : Heggade VN. Carbon abatement strategies for bridges in India Structural Concrete. 2025. <https://doi.org/10.1002/suco.202400602>

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Before use stage						In use stage					End of the life stage				Circularity stage
A0-A5						B1-B9					C1-C4				D
Preconstruction (A0) Production (A1-A3) Construction (A4-A5)						Service of infrastructure					After Service				Input Credit
A0	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Preliminary studies	Raw Materials mining/Supply	Transport of raw materials	Materials Manufacturing	Materials Transport to site	Construction processes	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transportation	Processing for reuse	Disposal	Residual value for Economic Cost : • Salvage Cost • Extended Service life Recovery for Carbon Cost : • Recycle • Reuse
							B6 : Operational Energy								
						B7 : Operational Water									
						B8 : Other Operational									
						B9 : User Utilization									



- Capital Cost (Economic + Carbon):** Includes all costs incurred during the creation, maintenance, and demolition of the asset. The entire **Before Use** and **End of Life** stages are treated as Capital Cost, with some components extending into the **In Use** stage (e.g., major rehabilitation).
- Operational Cost (Economic + Carbon):** Represents energy-related expenses during the service life — such as lighting, heating, ventilation, air-conditioning, water pumping, and vertical transportation (e.g., lifts).
- User Cost (Economic + Carbon):** Refers to costs associated with the *use* of the infrastructure by end users — for instance, vehicle energy consumption on highways and bridges.



- **Definition: (IEC-LCCA)** is a systematic process to estimate the total cost consisting of **Life Cycle Economic Cost (LCEC)** and **Life Cycle Carbon Cost (LCCC)** of a structure or system over its entire life span, including planning, design, construction, operation, maintenance, rehabilitation, and end-of-life.
- IEC-LCCA as a key tool for **achieving sustainability, durability, and performance-based design leading to Net-Zero vision.**

$$\text{ILCC} = \text{LCEC} + \text{LCCC} = (\text{LCC} \times P_c \text{ or } \text{SCC})$$

- ILCC = Integrated Life Cycle Cost (₹ or \$)
- LCEC = Life Cycle Economic Cost (₹ or \$)
- LCCC = Life Cycle Carbon Cost (₹/tCO₂ or \$/tCO₂)
- LCC = Life Cycle Carbon (tCO₂)
- P_c = Unit Carbon Price (₹/tCO₂ or \$/tCO₂)
- SCC = Social Cost of Carbon (₹/tCO₂ or \$/tCO₂)

- The LCEC framework evaluates the total **economic cost** of an infrastructure asset from **cradle to grave, getting the input credit of circularity module D**.
- The total cost is expressed as the **Net Present Value (NPV)** of all future cost streams discounted to the base year. The general formulation is:

$$LCEC = \sum_{A_0}^{A_5} C_A + \sum_{B_1}^{B_9} \frac{C_{Bn}}{(1+r)^n} + \sum_{C_1}^{C_4} \frac{C_{Cn}}{(1+r)^n} - C_r$$

Where,

C_A = **Initial (Capital) Cost** = Cost of the **module A**.

C_{Bn} = **Operation, Maintenance & Restoration** costs of **module B** in the **nth year**.

C_{Cn} = **End-of-Life (EoL)** Costs of **module C** in the **nth year**

r = Discount rate

n = **Number of years from the base year**

C_r = Residual Value of module D

- **Real discount rate:** Adjusted for inflation; reflects the real opportunity cost of capital.
- **Nominal discount rate:** Includes inflation; applied to cost streams expressed in current prices.
- The relationship between the two is given by the Fisher equation:

$$(1 + i) = (1 + r)(1 + f)$$

where:

(i) = nominal rate

(r) = real rate

(f) = inflation rate

Typical guidelines include:

- **Public sector infrastructure:** 3%–6% (real rate), reflecting social time preference rather than commercial profitability.
- **Private sector investments:** 8%–12% (nominal), reflecting weighted average cost of capital and risk premium.
- **Multilateral agencies (e.g., World Bank, ADB):** often recommend 5%–8% as a benchmark for infrastructure evaluation.

For long-lived infrastructure assets (e.g., bridges, dams, metros), a **real discount rate of 4%–5%** is often considered reasonable, aligning with both social and intergenerational equity considerations. **Sensitivity analyses with $\pm 1\%$ – 2% variation** are advisable to assess robustness of results.

- The LCCC framework evaluates the total **monetised carbon impact** of an infrastructure asset from **cradle to grave, getting the input credit from module D**.
- The total carbon cost is expressed as the **Net Present Value (NPV)** of all future emission-related costs discounted to the base year.

$$LCCC = \sum_{A_0}^{A_5} (E_A \times P_{cA}) + \sum_{B_1}^{B_9} \frac{E_{Bn} \times P_{cBn}}{(1+r)^n} + \sum_{C_1}^{C_4} \frac{E_{Cn} \times P_{cCn}}{(1+r)^n} - (E_r \times P_{cr})$$

Where,

E_A = Embodied Carbon Emission (tCO₂e) of module A

E_{Bn} = Operation, Maintenance and Restoration emissions of module B in the nth year

E_{Cn} = End-of-Life (EoL) emissions of module C in the nth year

P_{cA}, P_{cBn}, P_{cCn} = Carbon price (₹/tCO₂e or \$/tCO₂e) corresponding to respective modules and year

$E_r \times P_{cr}$ = Credit due to residual or avoided emissions (e.g., material reuse or recycling)

r = Discount rate

n = Number of years from the base year

- Monetisation of carbon **emissions converts the physical quantity of GHG emissions (tCO₂e) into economic value**, allowing direct integration of environmental costs into project financial evaluations. **The rationale for monetising the carbon footprint includes:**
 - ✓ **Internalisation of Externalities:** GHG emissions impose climate-related social and economic costs (e.g., extreme weather damage, reduced productivity, health impacts) that are not captured in market prices. Monetisation internalises these costs within infrastructure planning.
 - ✓ **Comparability:** By expressing emissions in monetary units, carbon impacts can be directly compared with economic costs, facilitating combined evaluation of design and maintenance alternatives.
 - ✓ **Policy Alignment:** Supports national commitments to carbon neutrality and aligns project appraisal with global and domestic carbon pricing mechanisms, such as the Indian Carbon Credit Trading Scheme (CCTS).
 - ✓ **Risk and Investment Resilience:** Reflects potential future liabilities associated with carbon taxation or emission regulation, promoting adoption of low-carbon technologies.

The carbon price P_{cr} represents the monetary value assigned to each tonne of CO₂-equivalent emissions and may be determined from one or more of the following sources:

(a) Market-Based Carbon Prices: Derived from compliance or voluntary trading systems.

- ✓ Indian Carbon Credit Trading Scheme (CCTS) (Govt of India, 2023) anticipated ₹1,500–₹3,000/tCO₂e in initial phase

(b) Social Cost of Carbon (SCC): The social cost of carbon (SCC) is a commonly employed metric of the **expected economic damages from carbon dioxide (CO₂) emissions.**

- ✓ According to Ricke et al, India's CSCC (Country level SCC) is the highest (US\$86 per tCO₂ (49–157); 21% of the GSCC (Global SCC)

(c) Shadow or Internal Carbon Pricing: Adopted by organisations or governments for internal evaluation even in absence of regulated markets.

- ✓ Typical range: **\$40–100/tCO₂e** depending on sector and sustainability commitments.
- ✓ The shadow carbon pricing values given for India are **author-derived estimates**.

Shadow price trajectory recommended for India. (\$ = ₹80/-)

Year	Shadow Price (INR/tCO ₂)	Shadow Price (USD/tCO ₂)
2020	₹2,000	\$25
2030	₹3,500	\$43
2040	₹5,000	\$60
2050	₹7,000	\$85

Discounting of carbon cost ensures that future emission-related expenditures are translated to their present value, maintaining consistency with the time value of money principle.

- ✓ **Public infrastructure and policy evaluation: 2%–4% (real rate)** reflecting long-term social time preference.
- ✓ **Private sector appraisal: 5%–8% (nominal)** consistent with opportunity cost of capital.
- ✓ **Social Cost of Carbon studies: 2.5%–3.5% (real)** to avoid undervaluing future climate damages.

For most long-lived infrastructure projects, a **real discount rate of 3%–4%** is considered appropriate for LCCC estimation, ensuring harmonisation with LCEC values used in ILCCA.

- **ILCC** is defined as the algebraic sum of the discounted Life Cycle Economic Cost (LCEC) and the Life Cycle Carbon Cost (LCCC):

$$\mathbf{ILCC = LCEC + LCCC}$$

Expanding the two components, the complete formulation becomes :

$$ILCC = \sum_{A_0}^{A_5} (C_A + E_A P_{cA}) + \sum_{B_1}^{B_9} \frac{(C_{Bn} + E_{Bn} P_{cBn})}{(1+r)^n} + \sum_{C_1}^{C_4} \frac{(C_{Cn} + E_{Cn} P_{cCn})}{(1+r)^n} - (C_r + E_r P_{cr})$$

Where,

C_A, C_{Bn}, C_{Cn} = Economic cost components of modules A, B, and C

E_A, E_{Bn}, E_{Cn} = Carbon emission quantities (tCO₂e) corresponding to the same modules

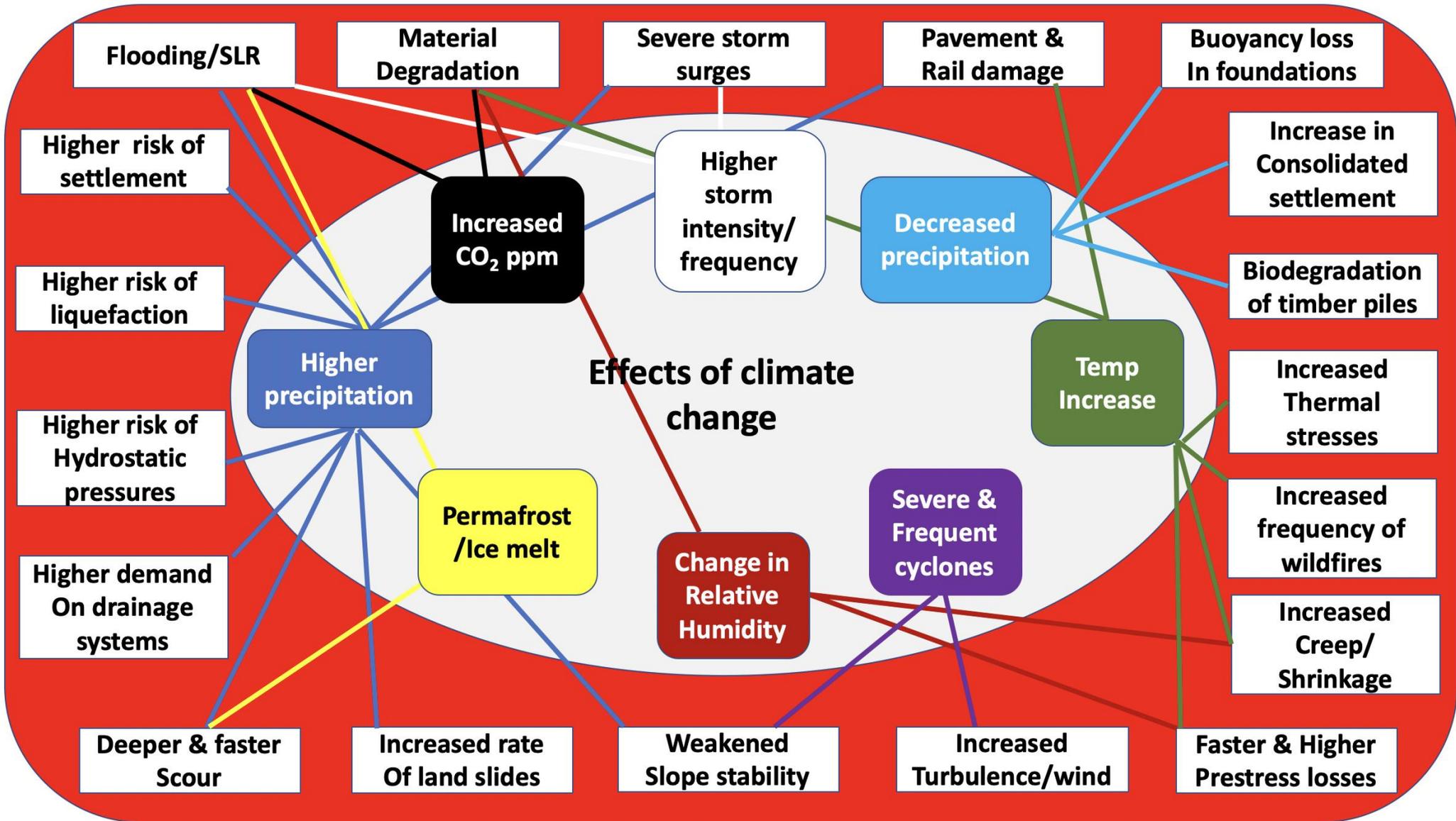
P_{cA}, P_{cBn}, P_{cCn} = Unit carbon price (₹/tCO₂e) applied to respective modules

C_r, E_r = Residual value and avoided emissions credit

r = Discount rate

n = Number of years from base year

- **Integrating** LCEC and LCCC within ILCC **enhances the transparency and accountability of infrastructure appraisal**. It provides a quantitative foundation for:
 - ✓ **Green Procurement Policies:** Establishing carbon-inclusive bid evaluation criteria.
 - ✓ **Public–Private Partnership (PPP) Models:** Incorporating carbon externalities in long-term concession assessments.
 - ✓ **Sustainable Financing:** Facilitating eligibility for green bonds and climate-aligned investments.
 - ✓ **Performance Benchmarking:** Developing project-level carbon–cost performance indicators.
- In this context, ILCC serves as an essential decision-making metric for transition towards **resource-efficient, and financially sustainable and Vision Zero infrastructure systems**.



- **Durability risks**

- ✓ Accelerated degradation of superstructure
- ✓ Accelerated degradation of substructure

- **Serviceability risks**

- ✓ Heat-induced damage to bridge structures
- ✓ Risk of increased long-term deformations

- **Geotechnical risks**

- ✓ Higher Scour depths
- ✓ Higher risks of landslides and bridge slide slope failures
- ✓ Higher risk of foundation settlement
- ✓ Higher risk of soil liquefaction
- ✓ Additional loads on deep foundations that may overstress them
- ✓ Damage due to clay shrinkage and swelling

- **Increased demand risks**

- ✓ Higher wave impact on piers and abutments
- ✓ Higher risk of wind-induced loads
- ✓ Higher risk of thermally induced stresses
- ✓ Additional demand on drainage capacity
- ✓ Higher hydrostatic pressure behind bridge abutments
- ✓ Increased load on barrage bridges with control sluice gates
- ✓ Increased stresses due to the faster loss of prestressing force

- **Accidental loads risks**

- ✓ Higher chance of vessel collisions
- ✓ Higher chance of vehicle-pier collisions, vehicle accidents, and train-pier collisions

- **Extreme natural event risks**

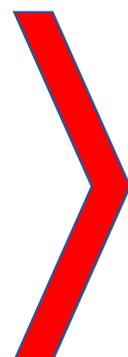
- ✓ Increase in intensity and/or frequency of floods
- ✓ Increase in intensity and/or frequency of storms
- ✓ Increase in intensity and/or frequency of wildfires

- **Operational risks**

- ✓ Frequent traffic diversion risks
- ✓ Increased risk of power shortage

Climate Change Effects

- **Changed Temp & Humidity** – Effects properties like Creep, Shrinkage, fatigue, etc.
- **Warming Seas** – affecting weather, marine life, and coasts.
- **Rainfall Shifts** – leading to floods in some areas and droughts in others.
- **Sea-Level Rise** – threatening coastal zones.
- **Extreme Flood Events** – due to intense rain and storm changes.
- **Severe Cyclones** – especially in tropical areas.
- **Snow Cover Changes** – impacting freshwater and mountain ecosystems.
- **Wildfires and Droughts** – reducing biodiversity and crop yields.
- **Secondary Seismic/Wind Risks** – from terrain destabilization.
- **Landslides and Avalanches** – in mountainous areas.



Climate Change Risks

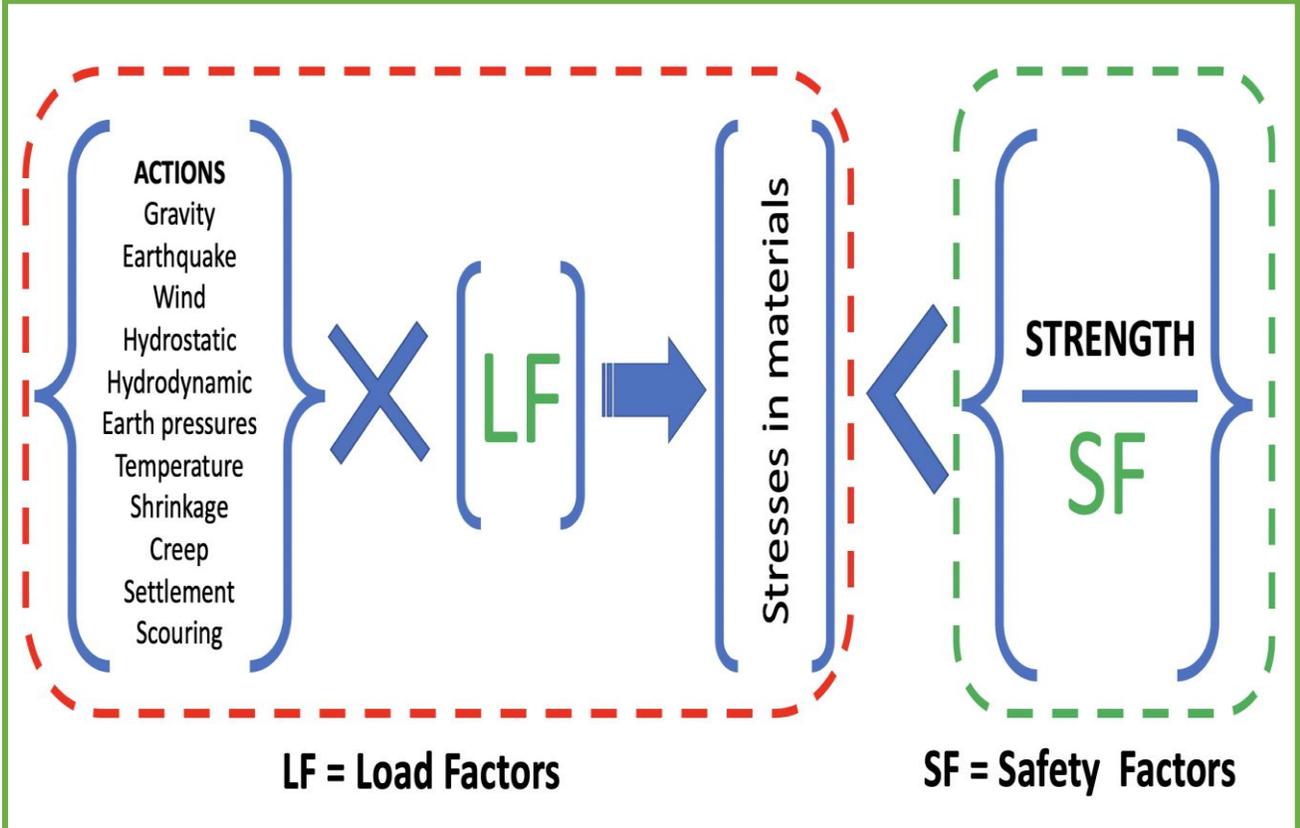
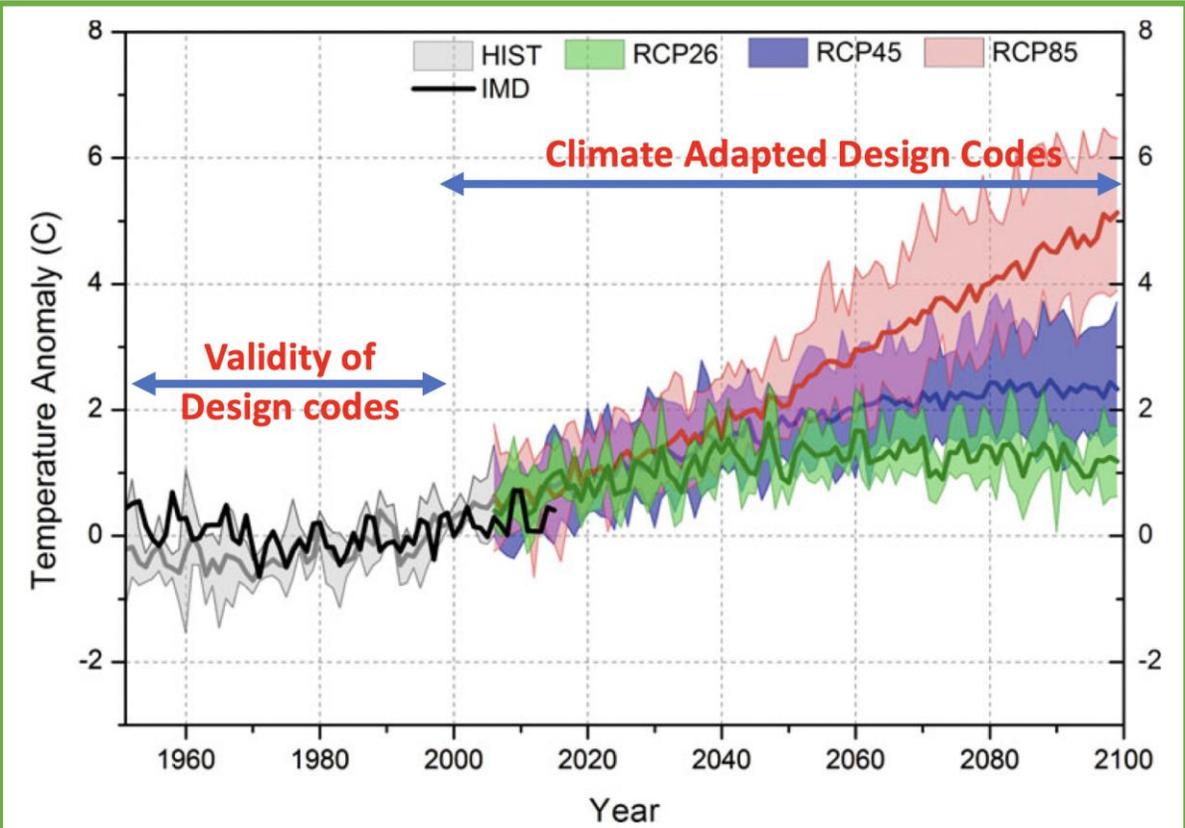
- **Material degradation**
- **Geotechnical degradation**
- **Heat-induced risks**
- **Long-term deformation**
- **Scour risks**
- **Landslides and avalanches**
- **Foundation settlement**
- **Drainage capacity overloads**
- **Wave and wind impacts**
- **Floods, cyclones, and wildfires**
- **Collisions and accidents**



Combating Climate Change Sector Action Measures

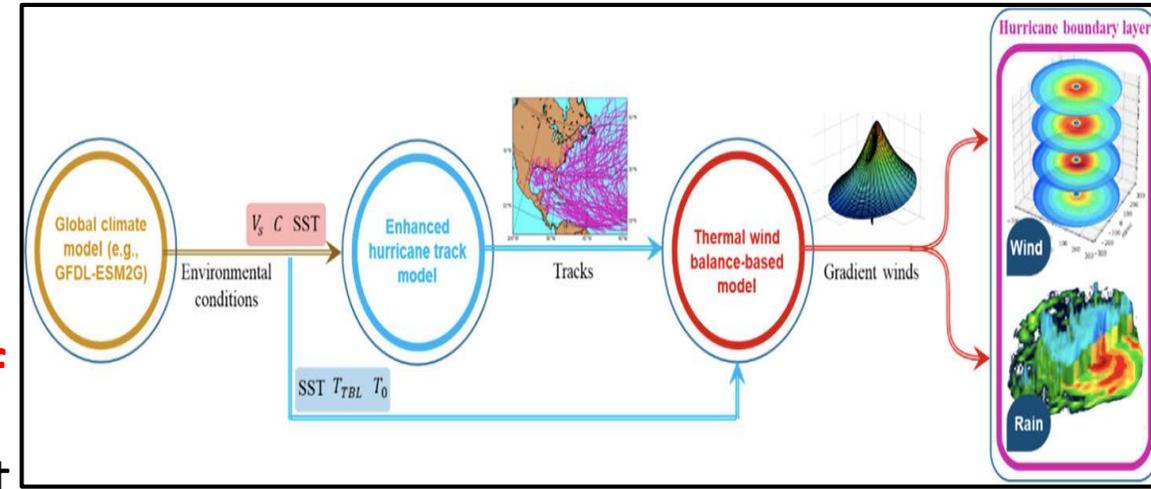
Sector	Action Measures	Expected Outcomes
Water Resources & Coastal Management	<ul style="list-style-type: none"> • Implement integrated water resource management to address both droughts and extreme rainfall. • Establish integrated coastal management strategies to address sea-level rise, inoling sustainable development and long-term adaptation frameworks. • Strengthen hydrological forecasting systems for better flood preparedness. • Enhance monitoring systems for glaciers, rivers, and weather patterns to inform timely interventions. 	<ul style="list-style-type: none"> • Reduced flood and drought impacts. • Enhanced resilience of coastal communities. • Timely and accurate water-related risk alerts. • Better regional coordination for water security.
Infrastructure & Urban Planning	<ul style="list-style-type: none"> • Upgrade and climate-proof coastal, mountain, and urban infrastructure to withstand extreme weather and geophysical hazards. • Incorporate climate resilience into urban and regional planning to reduce disaster vulnerability. • Reassess hazard zonation maps to account for glacier retreat, slope instability, and changing hazard patterns 	<ul style="list-style-type: none"> • Improved food security. • Reduced economic losses for farmers. • Enhanced livelihood resilience.
Disaster Risk Reduction & Early Warning	<ul style="list-style-type: none"> • Develop robust early warning systems for floods, cyclones, thunderstorms, landslides, and other extreme weather events 	<ul style="list-style-type: none"> • Faster and more effective disaster response. • Reduced loss of life and property.

Sector	Action Measures	Expected Outcomes
Water Resources & Coastal Management	<ul style="list-style-type: none"> • Implement integrated water resource management to address both droughts and extreme rainfall. • Establish integrated coastal management strategies to address sea-level rise, including sustainable development and long-term adaptation frameworks. • Strengthen hydrological forecasting systems for better flood preparedness. • Enhance monitoring systems for glaciers, rivers, and weather patterns to inform timely interventions. • Foster transboundary cooperation on shared water resources, especially in glacier-fed river basins. 	<ul style="list-style-type: none"> • Reduced flood and drought impacts. • Enhanced resilience of coastal communities. • Timely and accurate water-related risk alerts. • Better regional coordination for water security.
Infrastructure & Urban Planning	<ul style="list-style-type: none"> • Upgrade and climate-proof coastal, mountain, and urban infrastructure to withstand extreme weather and geophysical hazards. • Incorporate climate resilience into urban and regional planning to reduce disaster vulnerability. • Reassess hazard zonation maps to account for glacier retreat, slope instability, and changing hazard patterns. 	<ul style="list-style-type: none"> • Reduced infrastructure damage during extreme events. • Safer urban environments. • Better land-use planning based on updated hazard risks.
Disaster Risk Reduction & Early Warning	<ul style="list-style-type: none"> • Develop robust early warning systems for floods, cyclones, thunderstorms, landslides, and other extreme weather events. • Improve disaster preparedness plans tailored to evolving climate risks. • Mainstream multi-hazard risk assessment frameworks that integrate climate projections with geomorphological and hydrological data. 	<ul style="list-style-type: none"> • Faster and more effective disaster response. • Reduced loss of life and property. • Improved long-term disaster resilience.

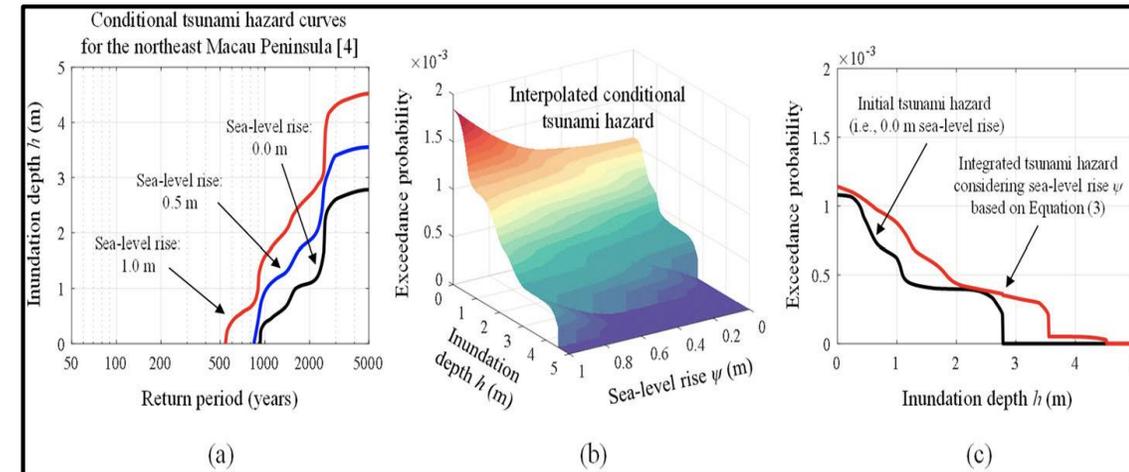


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- **Effective temperature ranges & temperature gradients** in the codes to be re calibrated.
- **The creep shrinkage effects** needs to be re calibrated on the basis of changed precipitation pattern & relative humidity.
- **The studies on corrosion, fatigue and strength of the materials** due to change in temperature, humidity, creep and shrinkage shall be carried out.
- **UB climate-dependent stochastic simulation framework for TC wind and rain hazards** shall be carried out to reassess the impacts of Wind and floods to arrive at changed cyclonic and scouring effects.
- **SLR effects** including the change in the impact of Tsunami shall be carried out.
- Special studies on the **climate change effects on earthquake** shall be instituted.
- Studies on **change in geotechnical parameters**.



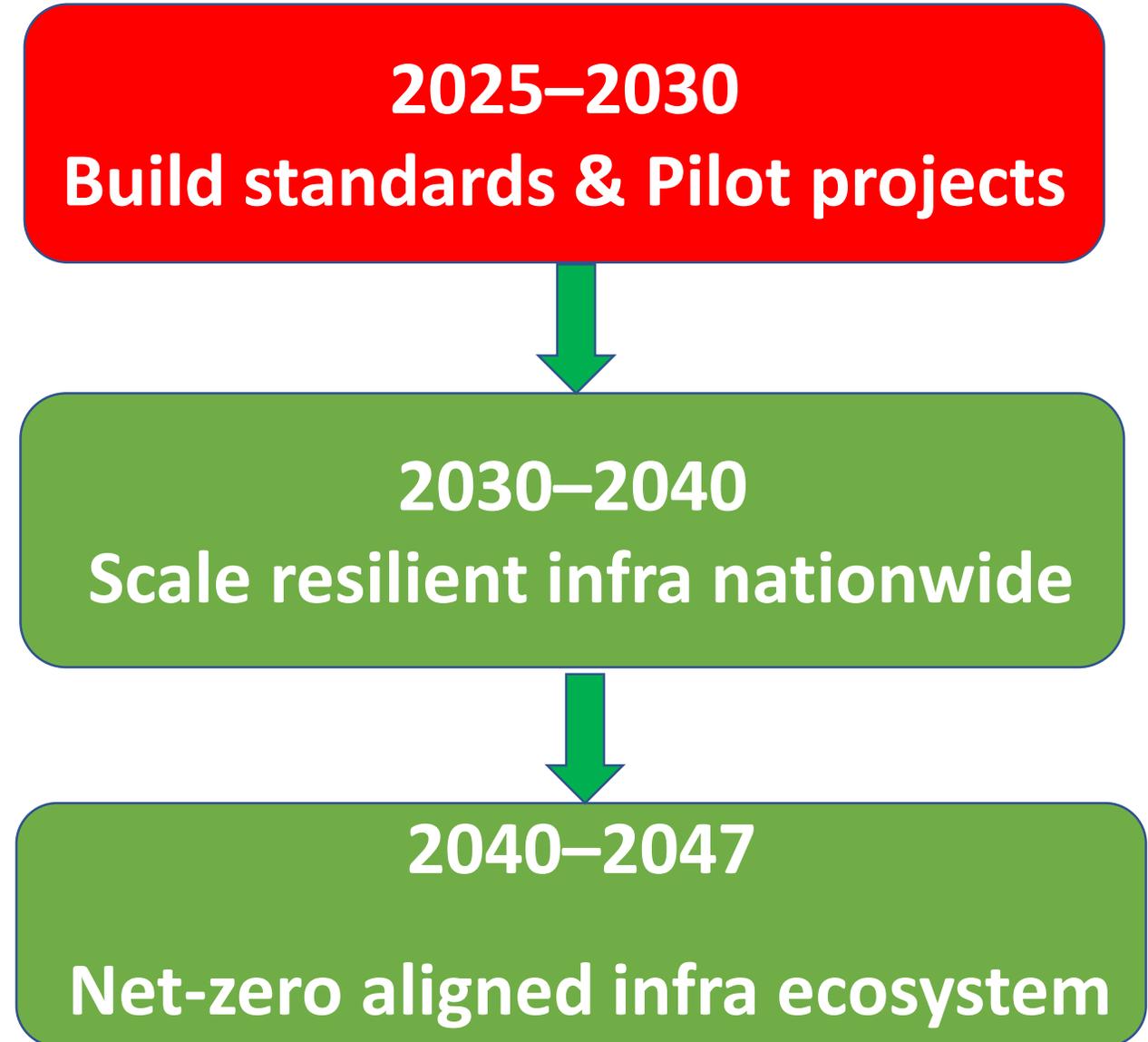
Climate-dependent stochastic simulation



Conditional tsunami hazard curves for SLR

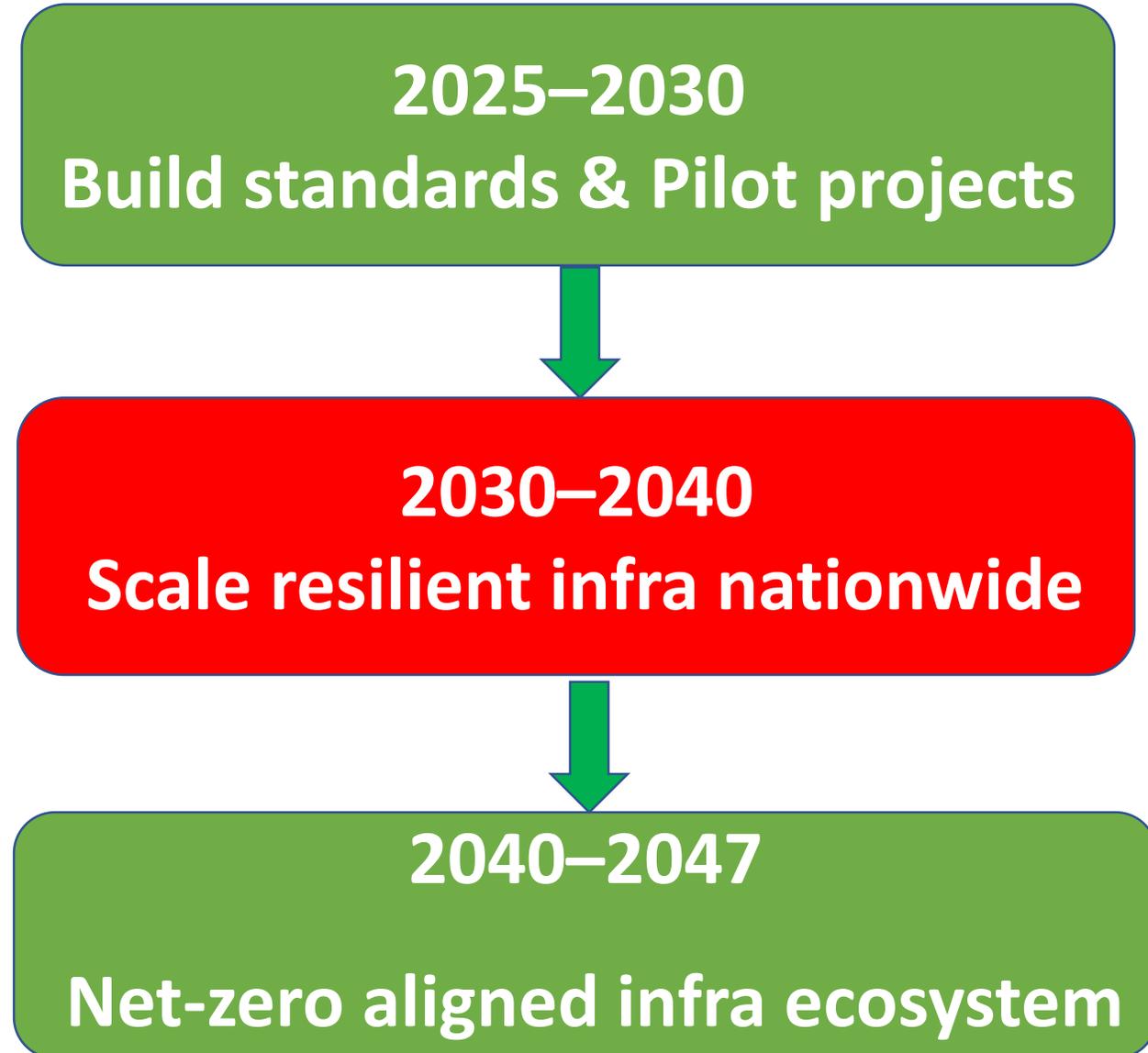
Near term: 2025–2030 (establish foundations)

1. Establish National Infrastructure Resilience Strategy and Resilience Fund (2025–26).
indiainvestmentgrid.gov.in
2. Mandate resilience screening for all NIP projects and onboard all ministries to PM GatiShakti data layers by 2026–27.
pmgatishakti.gov.in Press Information Bureau
3. Launch 10 national resilience pilot projects (one per region) — urban floodproofing, coastal mangrove belts, resilient highway corridors, power backup hubs.
4. Update IRC/BIS clauses for climate projections and initial resilience procurement rules.
5. **Make Life Cycle Impact Analysis (Integrated economic-carbon) mandatory for all procurement processes.**



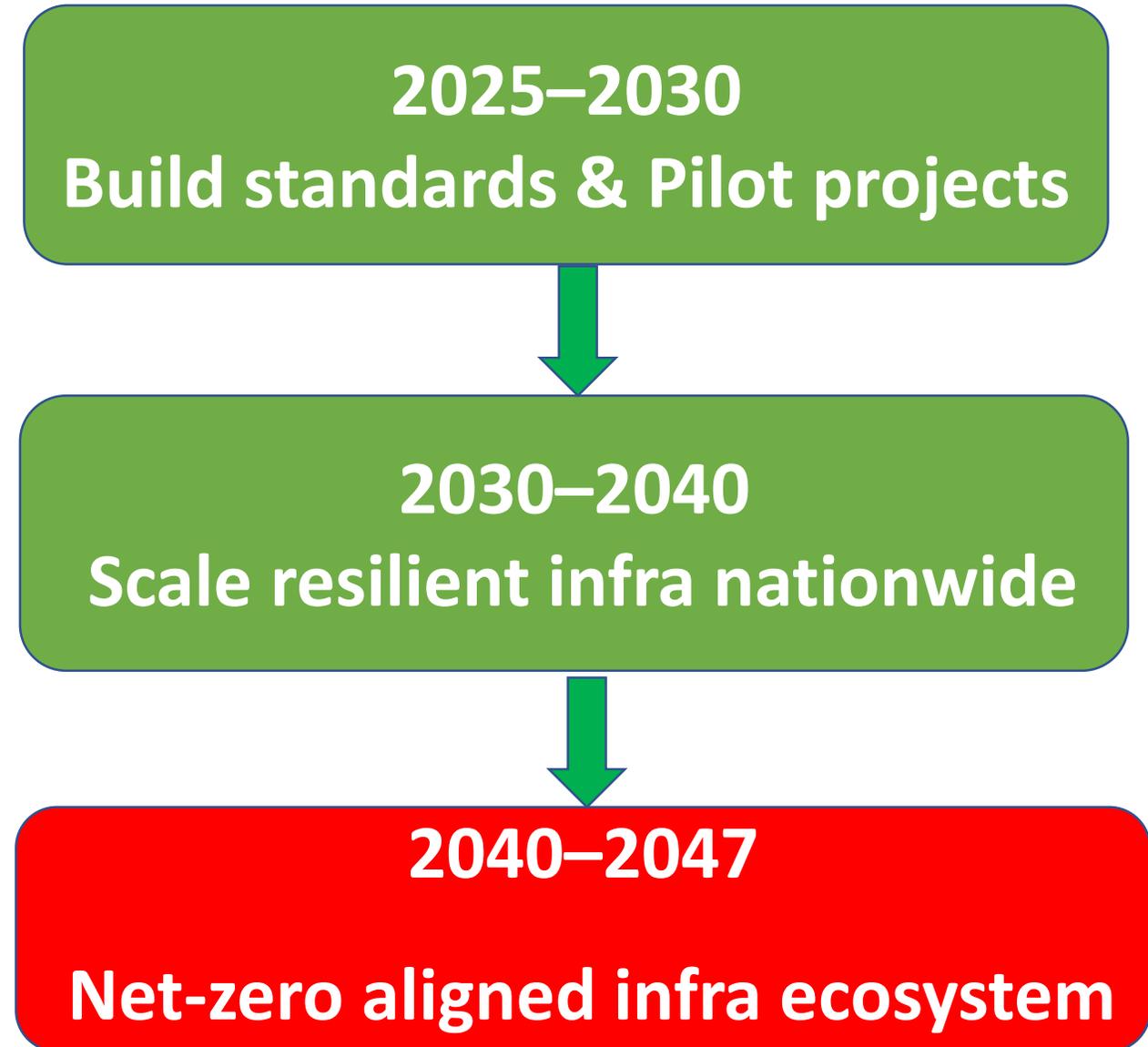
Medium term: 2030–2040 (scale & mainstream)

1. Retrofitting wave: 30–40% of critical infrastructure (ports, airports, major bridges, principal highways, water treatment plants) climate-proofed.
2. Full digital twin capability for national corridors and major city systems; sensors on most critical assets. [Geospatial World](#)
3. Private finance accounts for 25–35% of resilience investments via resilience bonds, PPPs and blended finance.



Long term: 2040–2047 (Consolidate & Achieve Vision Zero Viksit Bharat 2047)

1. 80–90% of lifeline infrastructure operates with explicit resilience ratings and life-cycle funded O&M.
2. Demonstrable reduction in annual infrastructure downtime and climate-driven economic losses (target: cut projected annual losses from major weather events by 50% relative to business-as-usual).
3. India as a regional provider of resilience technology and services (knowledge exports).



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Vision Zero is not a cost, it is an investment in
India's future

NAMASTE

