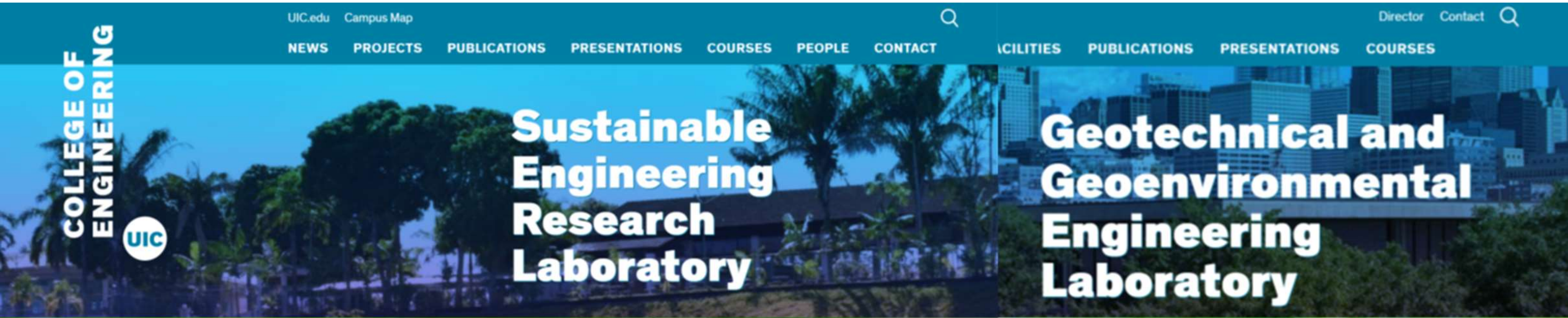

Sustainable Engineering for Climate Change Adaptation

-Integrating Sustainability in Climate Change Adaptation and Mitigation Engineering-

Krishna R. Reddy, PhD, PE, BCEE, DGE, FASCE, ENV SP
Professor of Civil & Environmental Engineering
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Geotechnical & Geoenvironmental Engineering Lab
University of Illinois, Chicago, USA

Workshop on "Integrating Climate Action in the Development Planning of Puducherry Union Territory", Puducherry, May 6, 2022

Acknowledgements

- Smitha. R, I.A.S., Secretary to Government, Department of Science, Technology & Environment, Government of Puducherry

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- Prof. S. Mohan, Vice-Chancellor, Puducherry Technological University

- Workshop Organizers (PCCC, TERI, …)

Chicago, USA

Sustainable Engineering Research Laboratory (SERL)
Geotechnical and Geoenvironmental Engineering Laboratory (GAGEL)

Directed by Prof. Krishna R. Reddy, University of Illinois at Chicago, kreddy@uic.edu

UIC

Environmental Remediation of Soils, Sediments, Groundwater and Stormwater

- In-situ remediation technologies
- Mixed and emerging contaminants
- Heterogeneous and low permeability subsurface environments
- New development or optimization of technologies:
  - Electrokinetic/electrochemical remediation
  - Air sparging/bio-sparging
  - Chemical oxidation
  - Chemical reduction by nanoparticles
  - Bioremediation/phytoremediation
  - Stabilization/solidification
  - Active and passive containment barriers
  - Integrated technologies
- Green, sustainable and resilient remediation

Waste Management and Landfill Engineering

- Beneficial use of waste and recycled materials
- Anaerobic digestion/composting
- Mechanical stability and chemical containment of landfills (coupled processes/modeling)
- Sustainable landfill liner and cover systems
- Biocovers
- Bioreactor landfills

http://gagel.lab.uic.edu/

Life Cycle Assessment and Sustainable & Resilient Engineering

- Sustainability analytics: Quantifying sustainability
  - LCA, SLCA, SSEM, QUALICS
- Sustainable engineering materials
  - Scrap tires versus sand as drainage material in landfill covers and liners
  - Biochar versus compost as landfill cover material
- Sustainable infrastructure
  - Foundations (e.g., piles versus caissons)
  - Earth-retaining systems (e.g., Reinforced cantilever retaining wall versus mechanically stabilized wall)
  - Ground improvement (e.g., lime treatment versus organic amendment)
- Sustainable waste management
  - Landfilling versus incineration
- Sustainable environmental remediation
- Resiliency framework & applications

Civil Engineering/Geotechnical Engineering

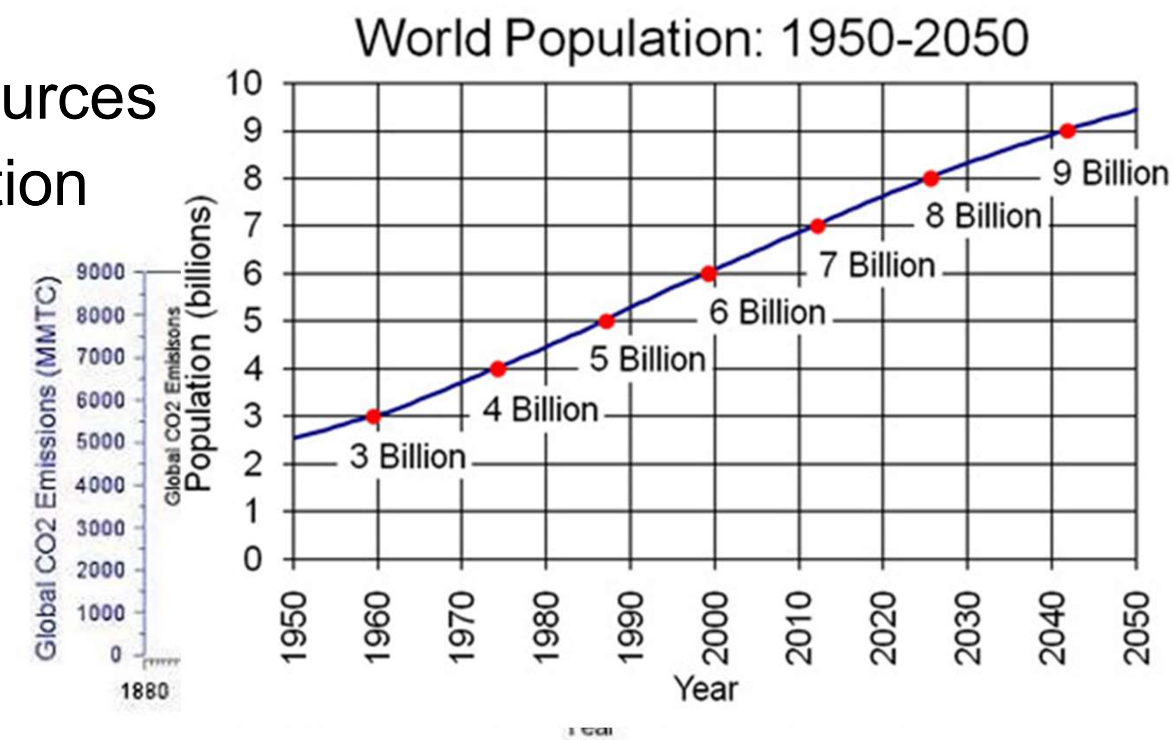
- Site investigations
- Structural foundations
- Earth-retaining structures
- Dams and levees
- Ground improvement techniques
- Geomechanics
- Geotechnical earthquake engineering

Grand Challenges in the 21st Century?

UIC

- **Global climate change and consequent extreme events (sea level rise, floods, droughts, wild fires,…)**
  - Impacts to current and future generations

- **Exploding population growth and consequent impacts**
  - Depletion of natural resources
  - Increased waste generation
  - Increased pollution
  - Damage to ecosystem
  - Loss of biodiversity
  - Urban sprawl
  - Economic disparities
  - Social injustice



Sustainable Development?

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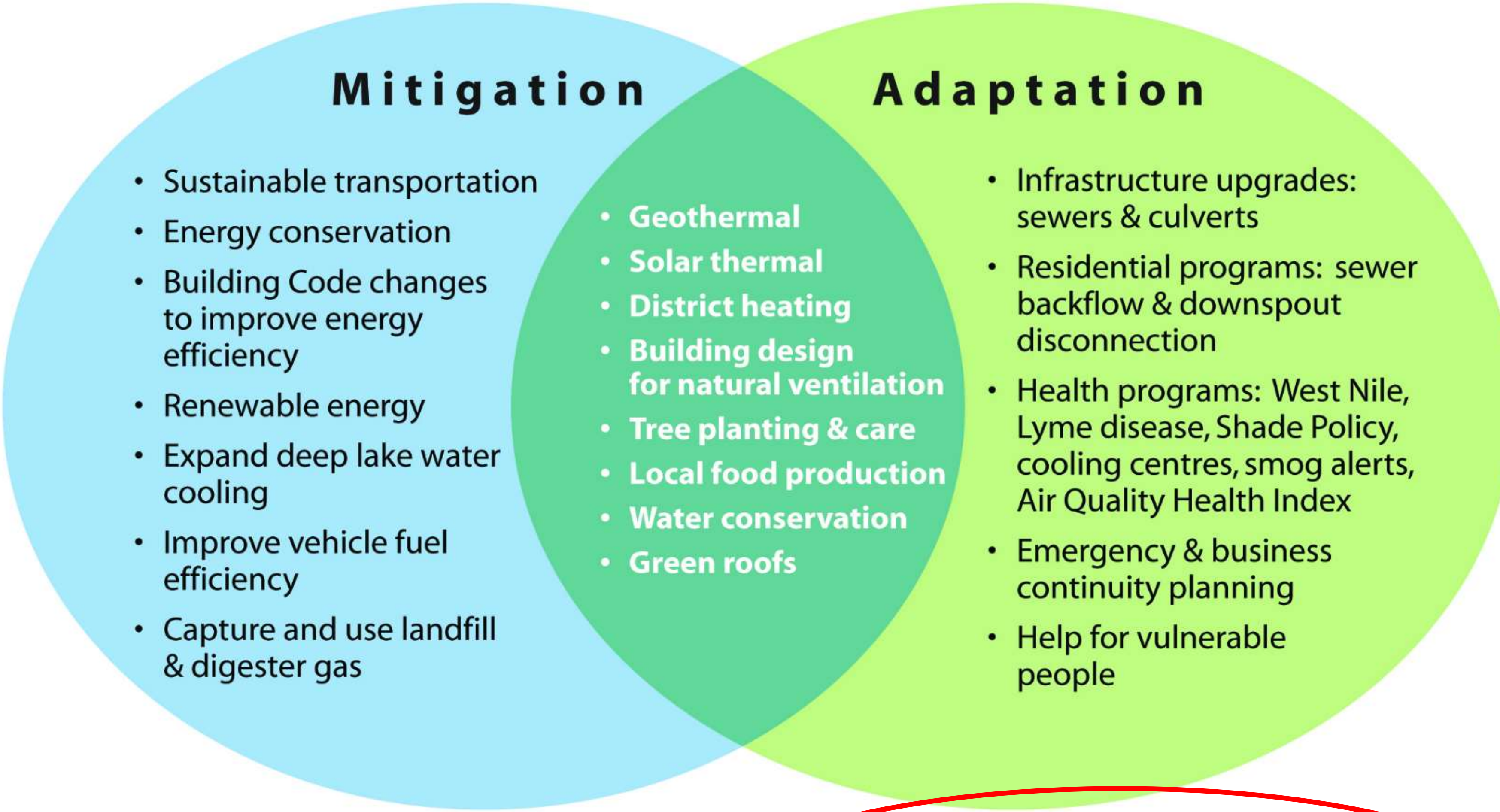
"…development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

World Commission on Environment and Development report (UN, 1987) entitled, *Our Common Future* (also known as the *Brundtland Report*)

2030 UN Sustainable Development Goals?

17 Goals with 169 Targets (All Interlinked!)

How are we going to achieve these ambitious goals?



Mitigation: the globally responsible thing to do

Actions that reduce the emissions that contribute to climate change.

Adaptation: the locally responsible thing to do

Actions that minimize or prevent the negative impacts of climate change.

Climate Impacts Are Intensifying?

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- Sustained changes in average temperatures
- Increased heavy precipitation events
- Increased coastal flooding
- Increased intensity of storm surge
- Sea level rise
- Increased wildfire severity

Coastal Erosion Due to Increased Storm Severity

Bishop (2020)

Residential Flooding Following Hurricane Harvey

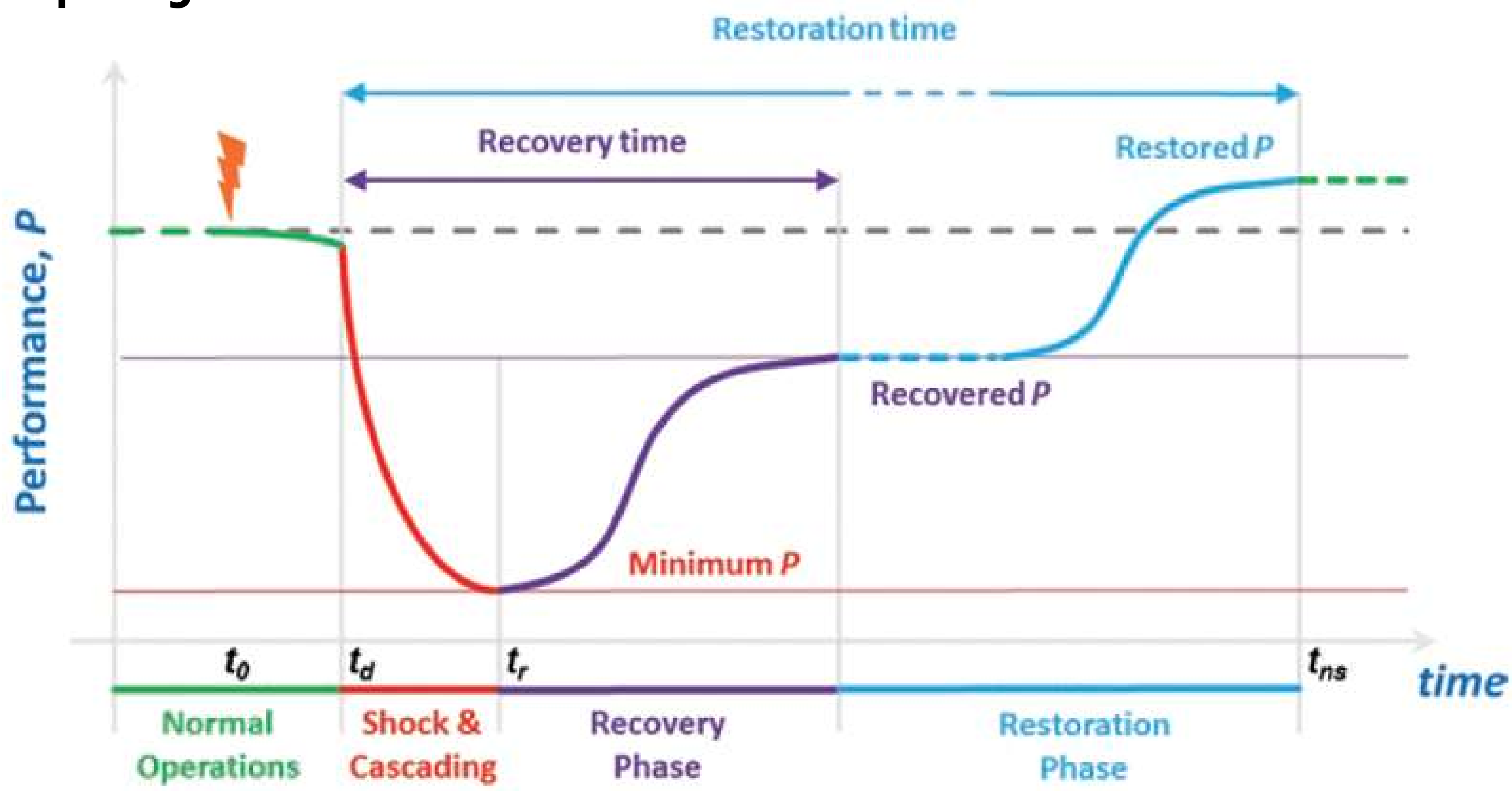
Residential flooding in the Timarron Park area of The Woodlands, TX, following Hurricane Harvey

Bishop (2020)

Need Climate Adaptation (Resilience)

UIC

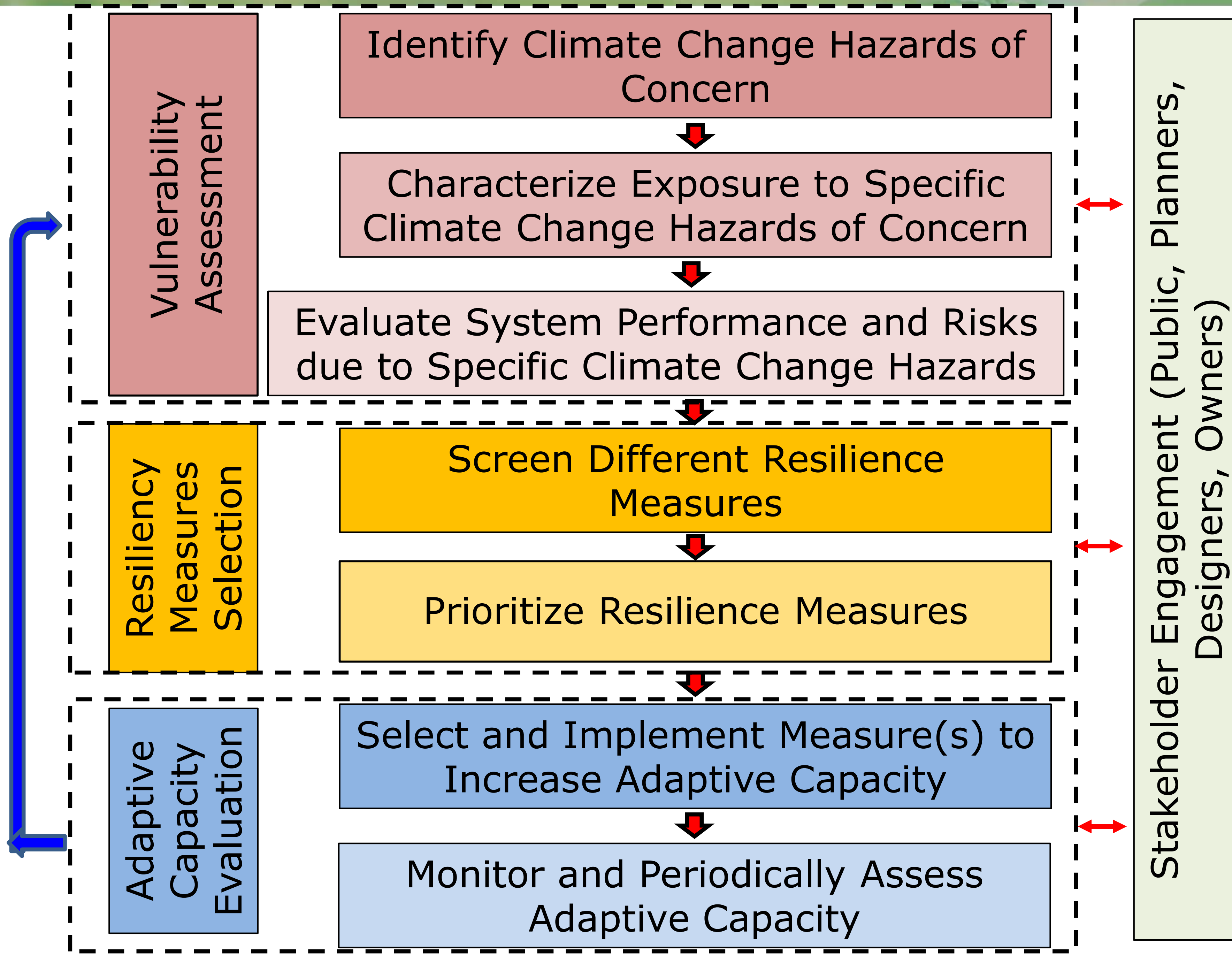
- Ability to cope, adapt, and grow in the face of foreseeable climate and extreme weather impacts that may occur over the life cycle of project



Source: Sansavini 2016

Climate Resilient Design Framework

Adaptive Management Methodology(Reddy et al. 2021)



Data Sources and Tools

- National Oceanic and Atmospheric Administration (NOAA) resources such as *Digital Coast* and *Sea Level Trends.*

- National Weather Service resources such as *National Storm Surge Hazard Maps* and *Sea, Lake, and Overland Surges from Hurricanes (SLOSH).*

- Modeling that uses predictive weather and climate data, through use of conventional software or commercially available risk assessment software for engineered systems.

- Developing site-specific maps and matrices that can aid decision-making.

Resilient Design: Building Foundation

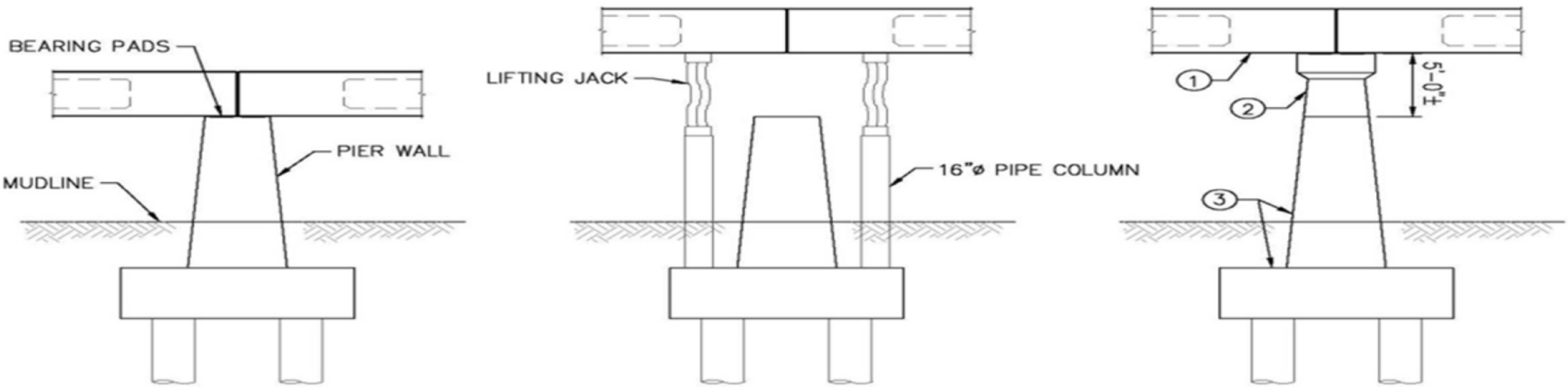
Resilient Design: Building Foundation

Resilient Design: Rail Corridor

LOSSAN (Los Angeles to San Diego) Rail Corridor follows the sea coast and crosses low-lying areas on trestles.

Resilient Design: Rail Corridor

Used Moffat and Nichol concept of precast piers and caps to allow insertion of additional pier segments if needed to adapt to flooding hazard.



Richard Dial, Bruce Smith and Gheorghe Rosca, Jr., "Evaluating Sustainability and Resilience in Infrastructure: Envision™, SANDAG and the LOSSAN Rail Corridor" Proceedings of the 2014 International Conference on Sustainable Infrastructure, American Society of Civil Engineers, pp 164-174.

Resilient Design: Landfill Cover

- Resilience of a covered landfill at the Davisville Naval Construction Battalion Center Superfund site, in Rhode Island, is strengthened by an armored base to prevent erosion.
- Intertidal wetlands and a seawall work together below the base to reduce wave energy during storm surge from the adjacent Allen Harbor.

Preferred Option: Climate Mitigation?

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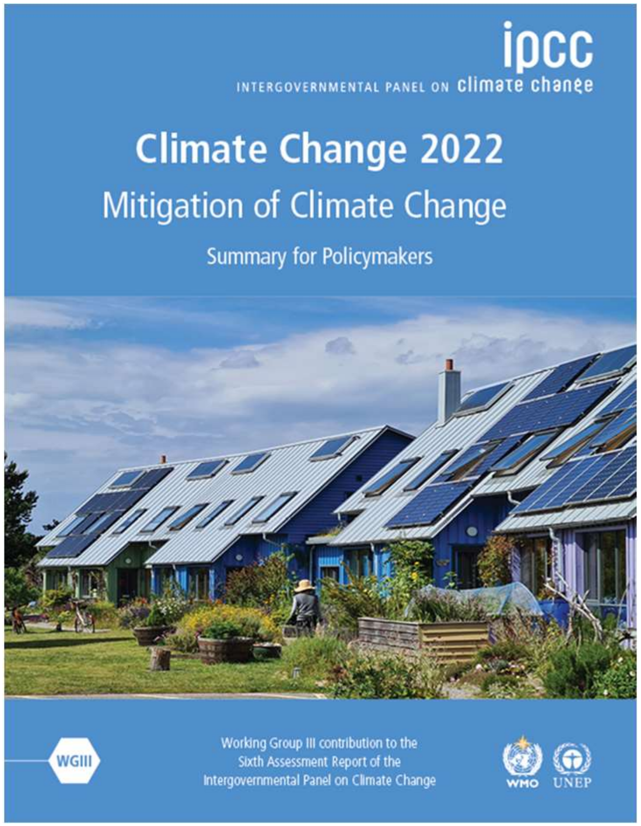
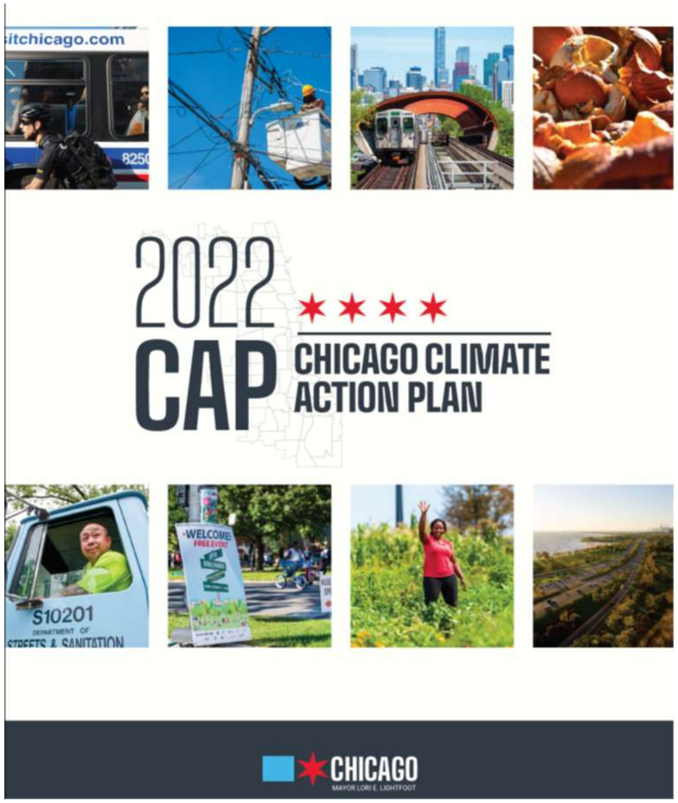
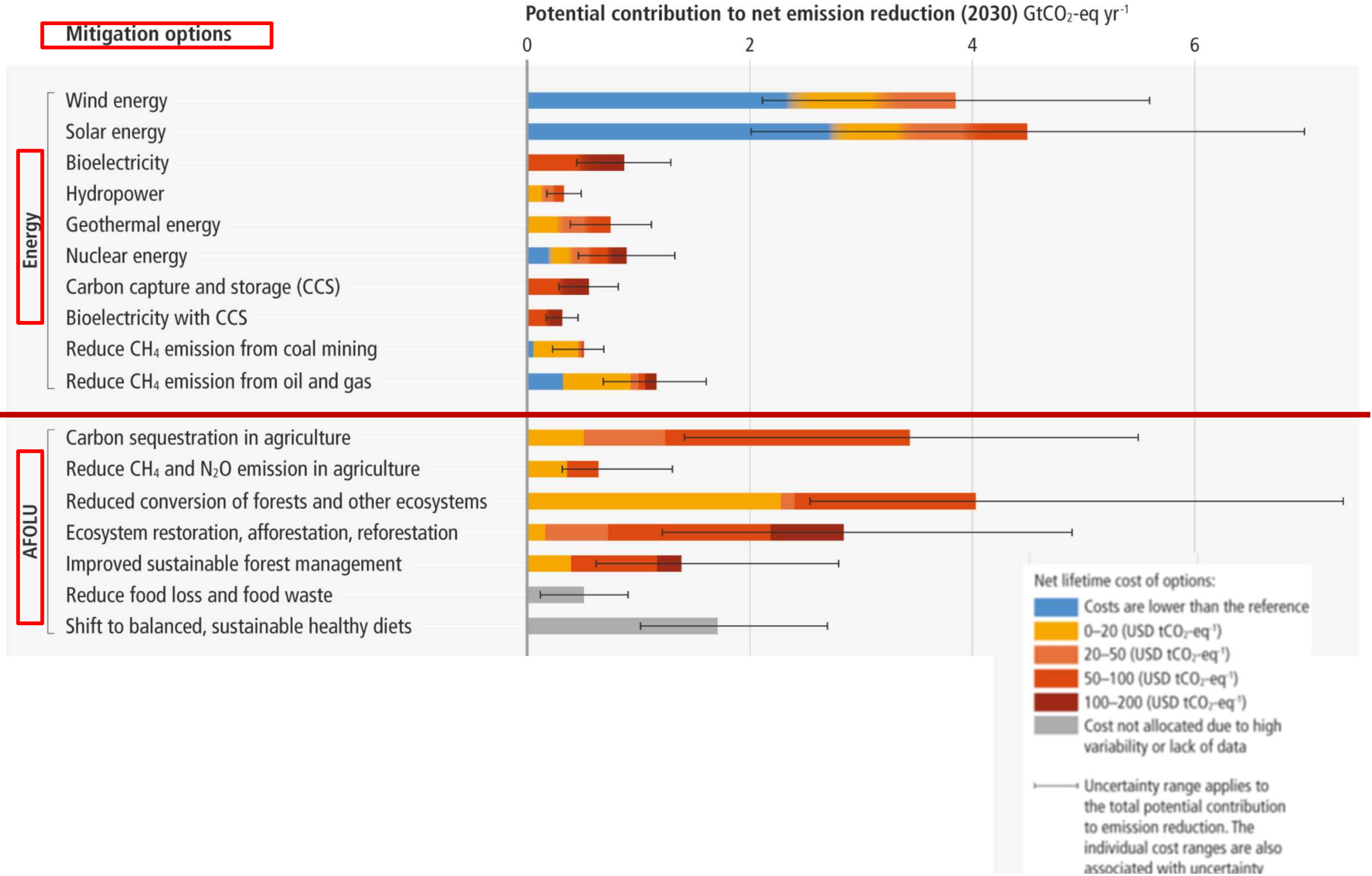
- Adaptation or resiliency options will be challenging and will be limited, if GHGs (climate change) continues to increase!

- We should prefer reducing GHGs that are the root cause of climate change (climate mitigation)

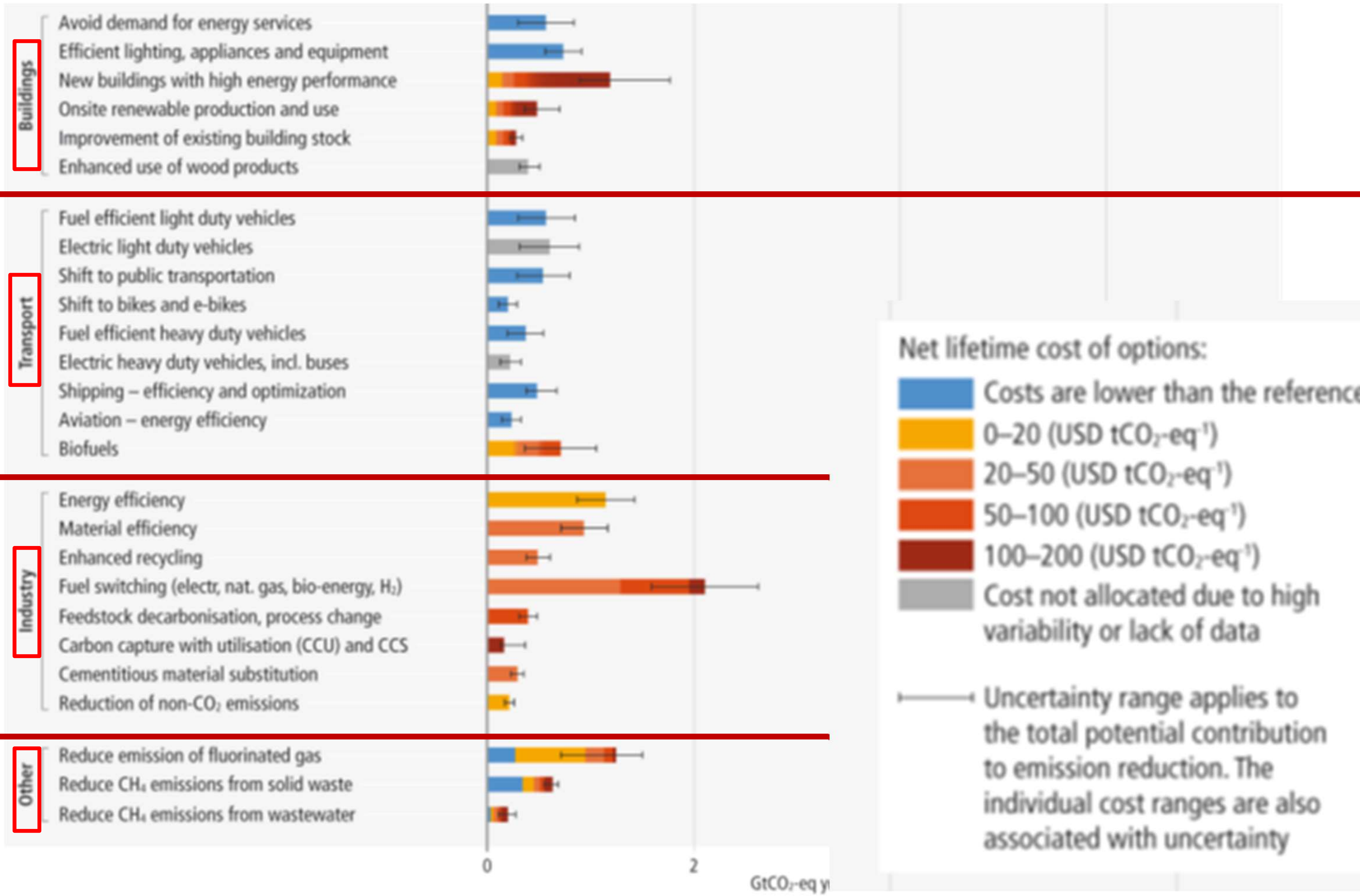




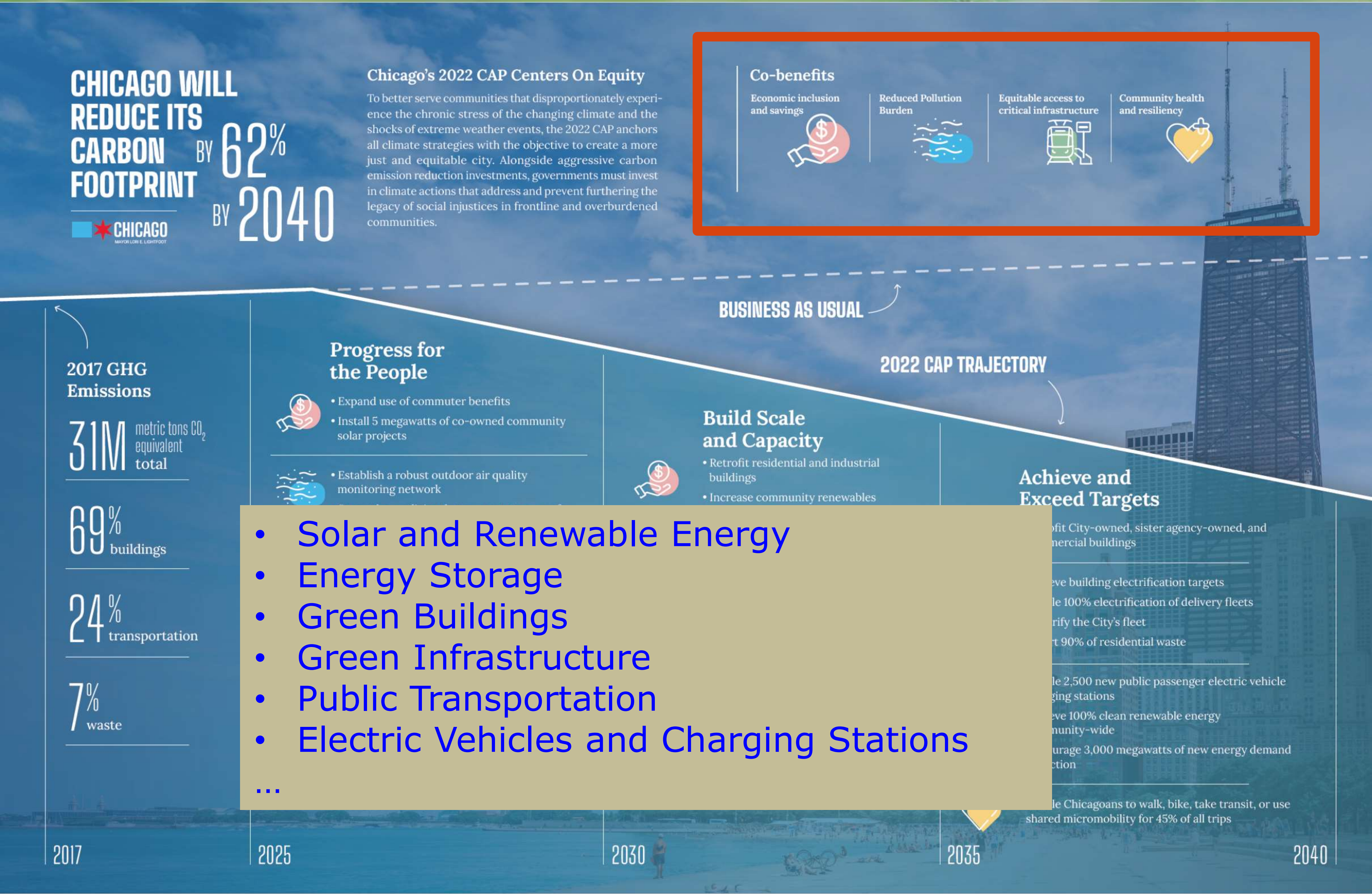
IPCC: Mitigation Options and Costs



IPCC: Mitigation Options and Costs



Chicago: 2022 Climate Action Plan (CAP)



- Solar and Renewable Energy
- Energy Storage
- Green Buildings
- Green Infrastructure
- Public Transportation
- Electric Vehicles and Charging Stations

…

Sustainability Versus Resilience

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Sustainability is the capacity for:

- Ensuring economic prosperity
- Protecting ecological resources
- Enhancing societal well being

continuity

fitness

Resilience is the capacity for:

- Overcoming unexpected crises
- Adapting to turbulent change
- Flourishing in a chaotic world

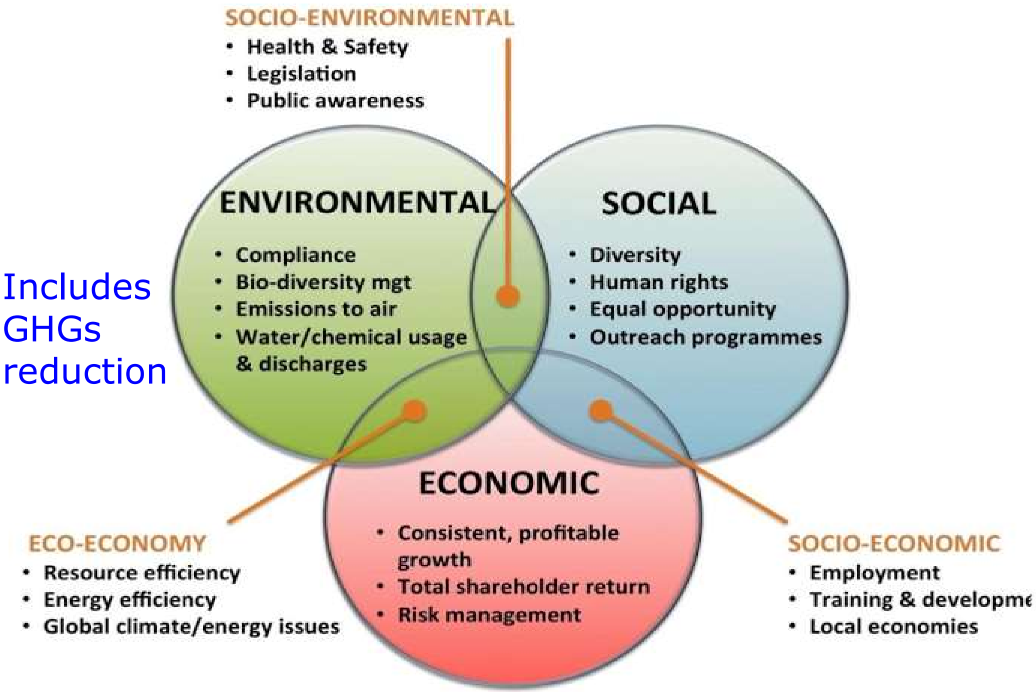
Co-Benefits: UN SDGs

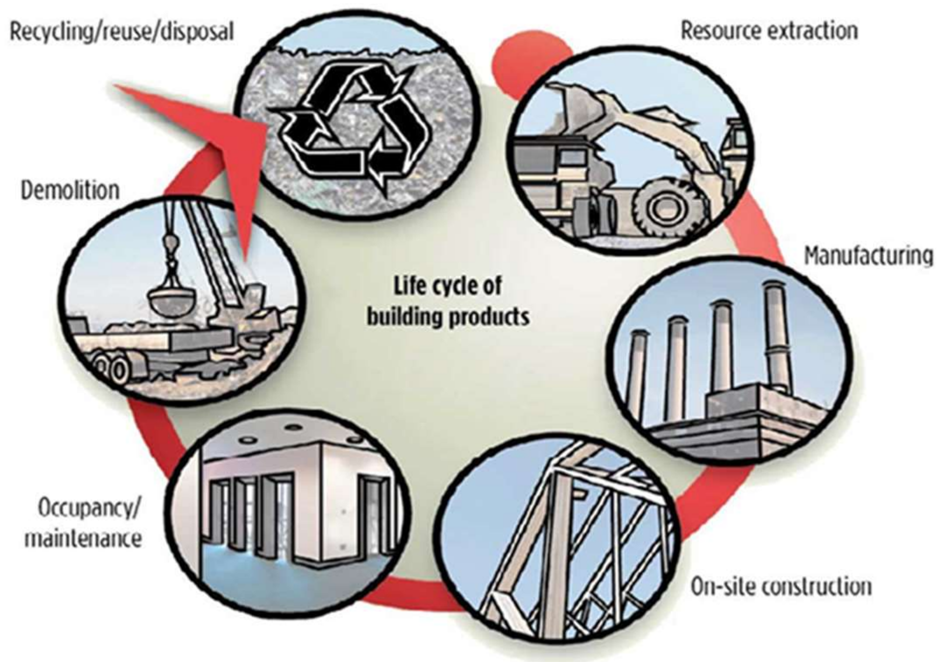
17 Goals with 169 Targets
(All Interlinked)

Integrating Sustainability?

- Select climate adaptation and mitigation choices considering broader <u>environmental, economic, and social dimensions based on the life cycle</u>

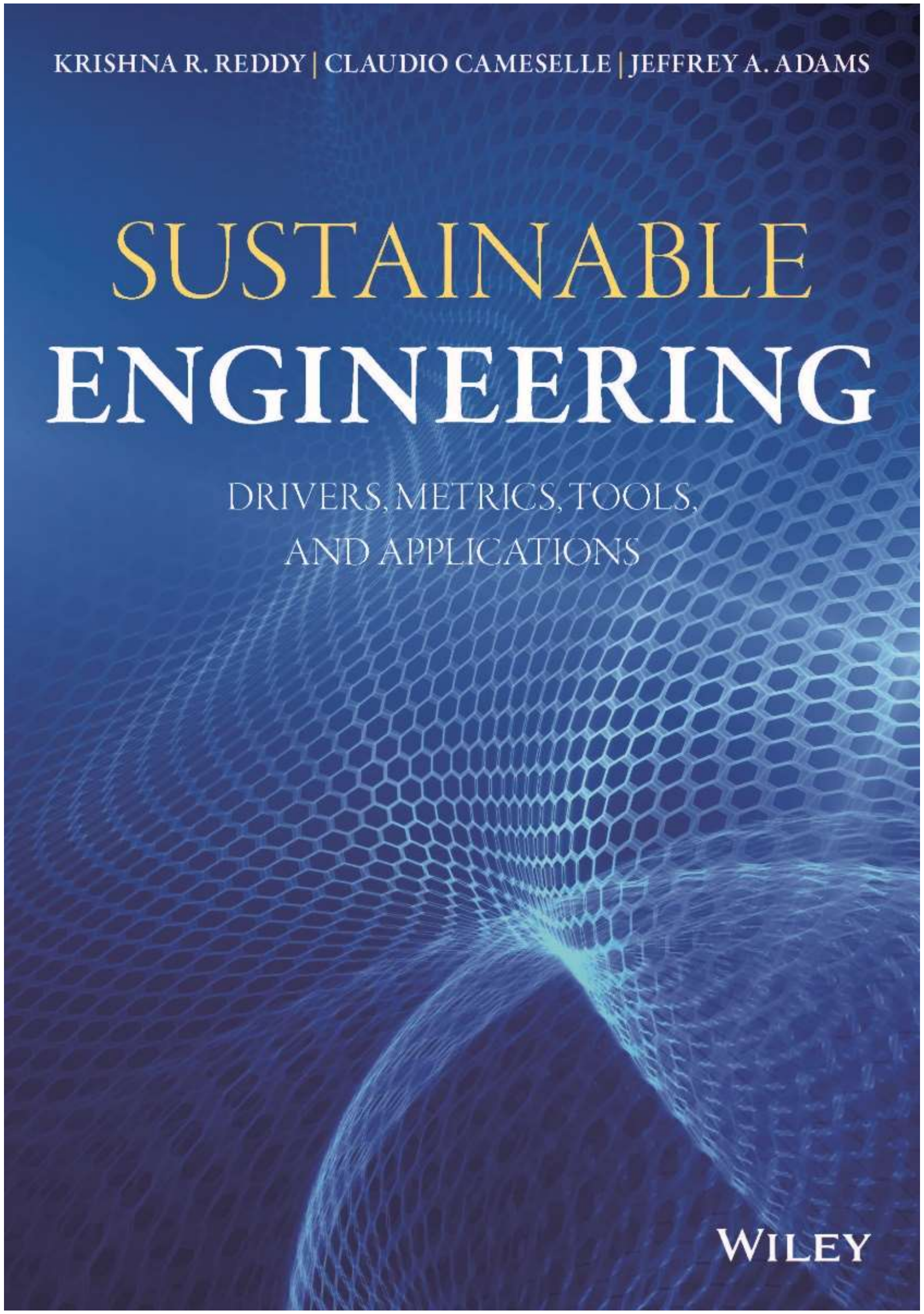
Includes GHGs reduction





Sustainable Choices: Environmentally friendly, economically viable, and socially acceptable through entire life cycle!

Useful Reference



Sustainable Engineering: Drivers, Metrics, Tools, and Applications

Krishna R. Reddy
Claudio Cameselle
Jeffrey A. Adams

ISBN: 978-1-119-49393-8

2019

John Wiley & Sons

Scale of Sustainability Projects

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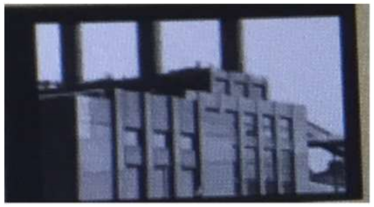
- Global Scale (e.g. Global CO_2 budgeting)

- National Scale (e.g., Energy)

- Regional Scale (e.g., Watershed)

- Business or Institutional Scale (e.g., Eco-industrial park)

- Sustainable Technologies Scale (e.g., Sustainable materials, designs, products and systems)



Integrating Sustainability:
Envision™ Rating System

UIC

64 sustainability and resilience indicators

Quality Of Life
14 Credits

WELLBEING
- QL1.1 Improve Community Quality of Life
- QL1.2 Enhance Public Health & Safety
- QL1.3 Improve Construction Safety
- QL1.4 Minimize Noise & Vibration
- QL1.5 Minimize Light Pollution
- QL1.6 Minimize Construction Impacts

MOBILITY
- QL2.1 Improve Community Mobility & Access
- QL2.2 Encourage Sustainable Transportation
- QL2.3 Improve Access & Wayfinding

COMMUNITY
- QL2.1 Advance Equity & Social Justice
- QL2.2 Preserve Historic & Cultural Resources
- QL2.3 Enhance Views & Local Character
- QL2.4 Enhance Public Space & Amenities

- QL0.0 Innovate or Exceed Credit Requirements

Leadership
12 Credits

COLLABORATION
- LD1.1 Provide Effective Leadership & Commitment
- LD1.2 Foster Collaboration & Teamwork
- LD1.3 Provide for Stakeholder Involvement
- LD1.4 Pursue Byproduct Synergies

PLANNING
- LD2.1 Establish a Sustainability Management Plan
- LD2.2 Plan for Sustainable Communities
- LD2.3 Plan for Long-Term Monitoring & Maintenance
- LD2.4 Plan for End-of-Life

ECONOMY
- LD3.1 Stimulate Economic Prosperity & Development
- LD3.2 Develop Local Skills & Capabilities
- LD3.3 Conduct a Life-Cycle Economic Evaluation

- LD0.0 Innovate or Exceed Credit Requirements

Resource Allocation
14 Credits

MATERIALS
- RA1.1 Support Sustainable Procurement Practices
- RA1.2 Use Recycled Materials
- RA1.3 Reduce Operational Waste
- RA1.4 Reduce Construction Waste
- RA1.5 Balance Earthwork On Site

ENERGY
- RA2.1 Reduce Operational Energy Consumption
- RA2.2 Reduce Construction Energy Consumption
- RA2.3 Use Renewable Energy
- RA2.4 Commission & Monitor Energy Systems

WATER
- RA3.1 Preserve Water Resources
- RA3.2 Reduce Operational Water Consumption
- RA3.3 Reduce Construction Water Consumption
- RA3.4 Monitor Water Systems

- RA0.0 Innovate or Exceed Credit Requirements

Natural World
14 Credits

SITING
- NW1.1 Preserve Sites of High Ecological Value
- NW1.2 Provide Wetland & Surface Water Buffers
- NW1.3 Preserve Prime Farmland
- NW1.4 Preserve Undeveloped Land

CONSERVATION
- NW2.1 Reclaim Brownfields
- NW2.2 Manage Stormwater
- NW2.3 Reduce Pesticide & Fertilizer Impacts
- NW2.4 Protect Surface & Groundwater Quality

ECOLOGY
- NW3.1 Enhance Functional Habitats
- NW3.2 Enhance Wetland & Surface Water Functions
- NW3.3 Maintain Floodplain Functions
- NW3.4 Control Invasive Species
- NW3.5 Protect Soil Health

- NW0.0 Innovate or Exceed Credit Requirements

Climate and Resilience
10 Credits

EMISSIONS
- CR1.1 Reduce Net Embodied Carbon
- CR1.2 Reduce Greenhouse Gas Emissions
- CR1.3 Reduce Air Pollutant Emissions

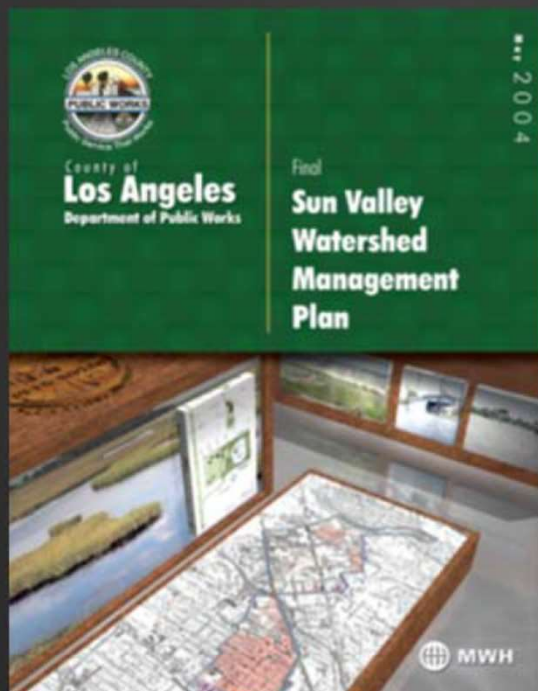
RESILIENCE
- CR2.1 Avoid Unsuitable Development
- CR2.2 Assess Climate Change Vulnerability
- CR2.3 Evaluate Risk & Resilience
- CR2.4 Establish Resilience Goals and Strategies
- CR2.5 Maximize Resilience
- CR2.6 Improve Infrastructure Integration

- CR0.0 Innovate or Exceed Credit Requirements

ENVISION™

Source: Institute for Sustainable Infrastructure (ISI)

Sun Valley Watershed Management Plan



- Flood Protection
- Water Quality
- Water Conservation
- Open Space and Recreation
- Habitat

Sun Valley Watershed Multi-Benefit Project

8 Components

- Sun Valley Park Drain and Infiltration System
- Rory M. Shaw Wetlands
- Tuxford Green
- Elmer Avenue Neighborhood Retrofit
- Elmer Avenue Paseo
- Future Valley Steam Plant
- Whitnall Powerline Easement
- Sun Valley Recycled Water Line

Hazen

Water Environment Federation
the water quality people®

Envision Application Example

Envision Application Example

SUN VALLEY PARK DRAIN AND INFILTRATION SYSTEM

Envision Award Rating Criteria

- **Quality of Life:** Enhance Public Health & Safety, Enhance Public Space
- **Leadership:** Foster Collaboration & Teamwork, Plan for Long-Term Monitoring & Maintenance
- **Resource Allocation:** Protect Fresh Water Availability
- **Natural World:** Manage Stormwater, Prevent Groundwater Contamination
- **Climate and Risk:** Prepare for Long-Term Adaptability, Prepare for Short-Term Hazards

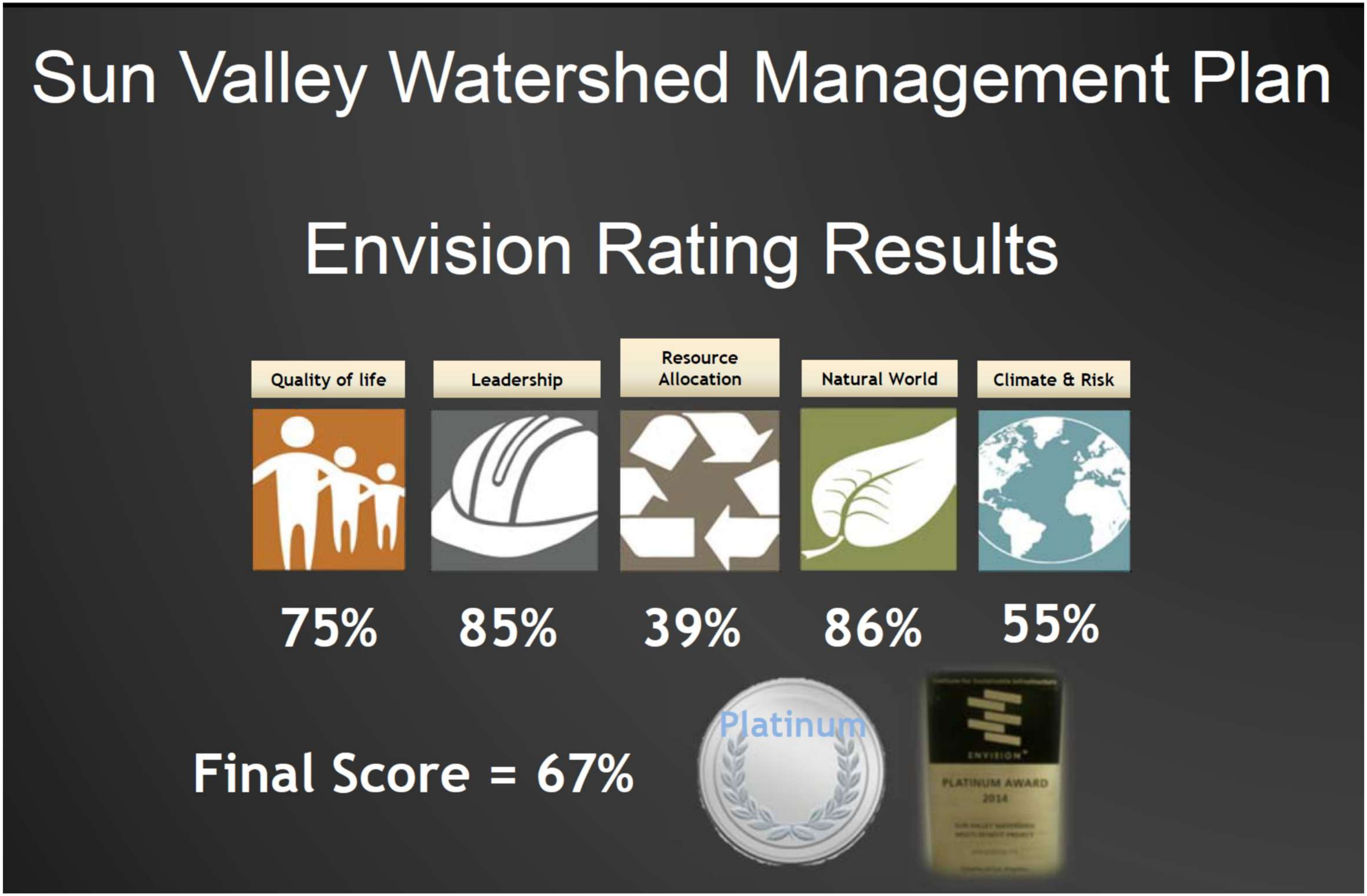
Construction of 1.7 acre infiltration chambers which are 5

Underground infiltration chambers at

Installation of water treatment system at Sun Valley Park

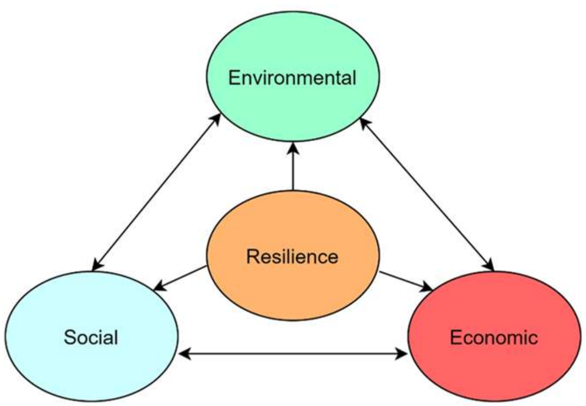
AFTER: Park space above infiltration basins at Sun Valley Park

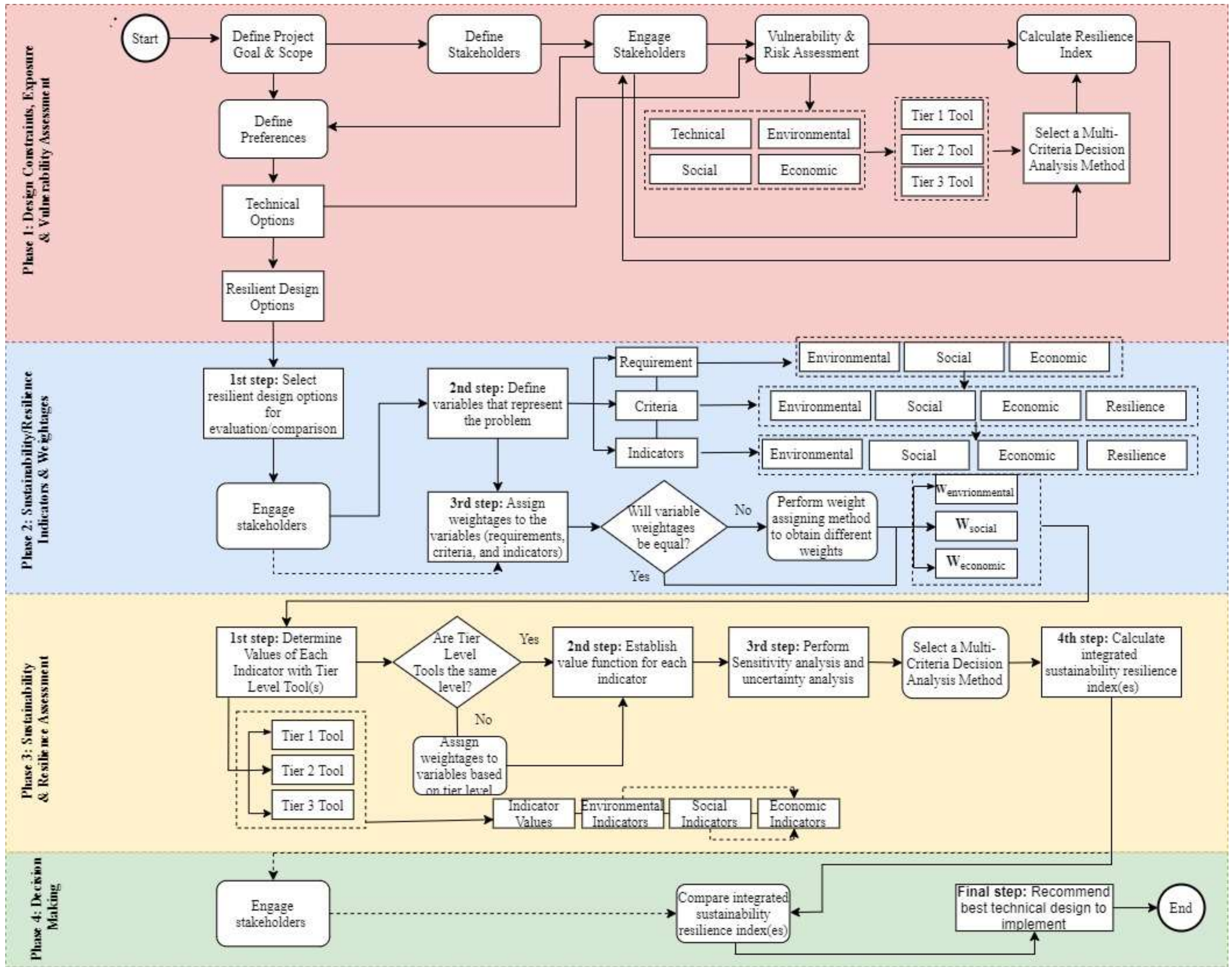
Envision Application Example



Integrating Sustainability: TQUALICSR Framework (Reddy et al. 2021)

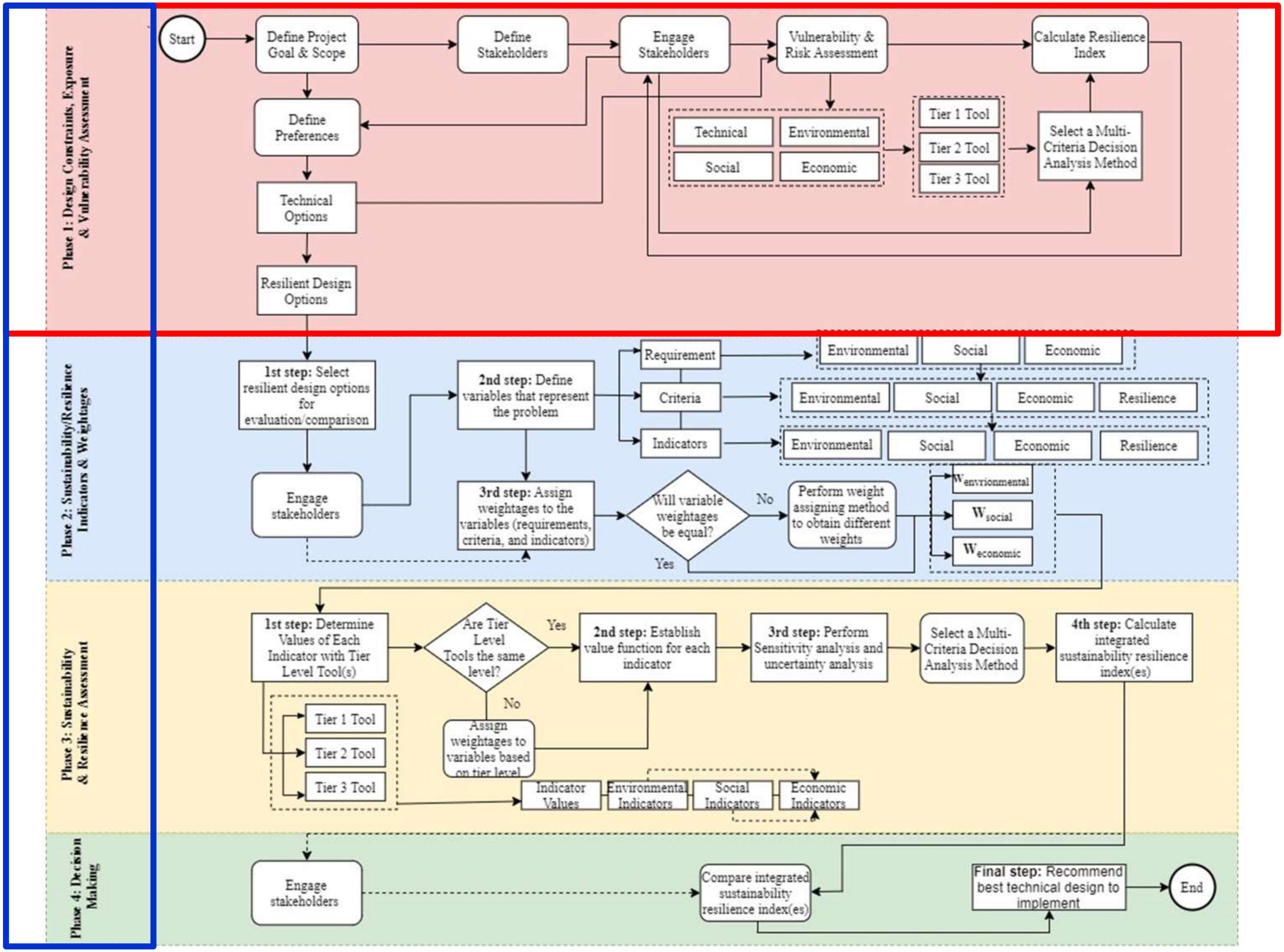
- Integration of technical, resiliency, and sustainability
- Applicability to various life cycle stages of an engineering project of any size
- Flexible, tier-based selection of tools



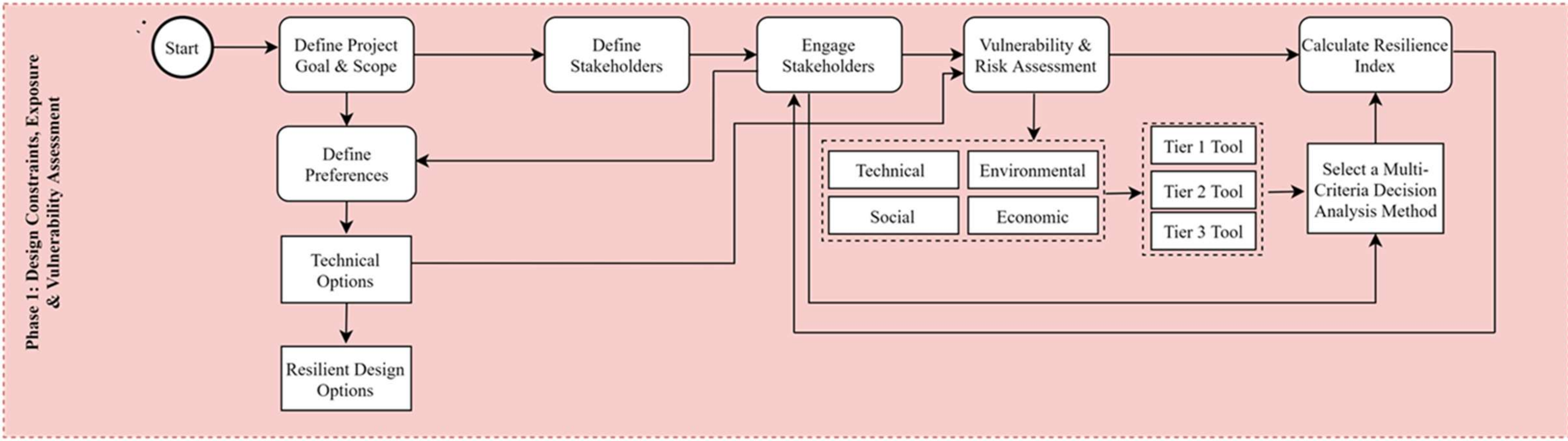


Reddy, K.R., Robles, J.R., Carneiro, S.A.V., and Chetri, J.K. (2021). **Tiered Quantitative Assessment of Life Cycle Sustainability and Resilience (TQUALICSR)**: Framework for Design of Engineering Projects, In *Advances in Sustainable Materials and Resilient Infrastructure,* Springer Nature.

TQUALICSR Framework



Phase 1: Design Constraints, Vulnerability/Risk & Resilience Index

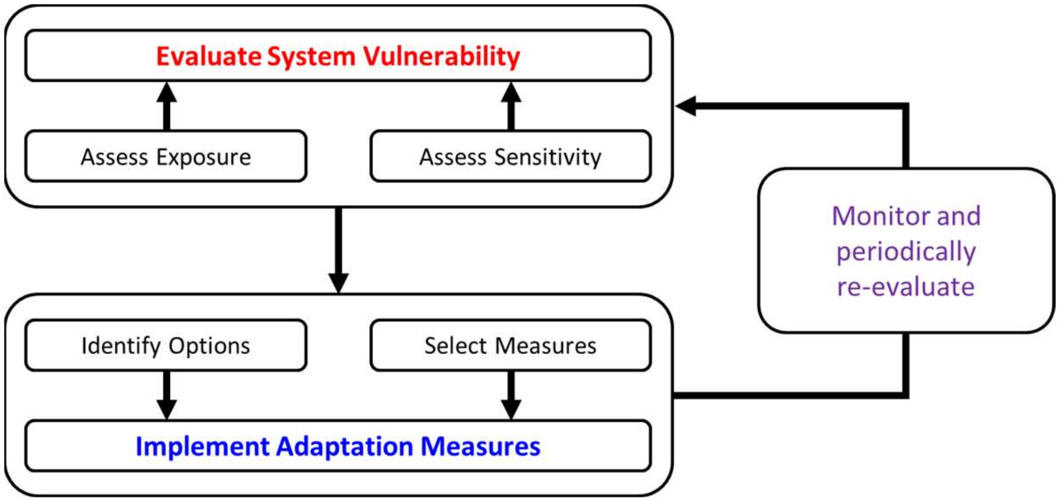


- Provides a structured flow to include more than technical considerations early in the design process
- Help identify resilience goals, constraints, and indicators in an informed manner

Phase 1

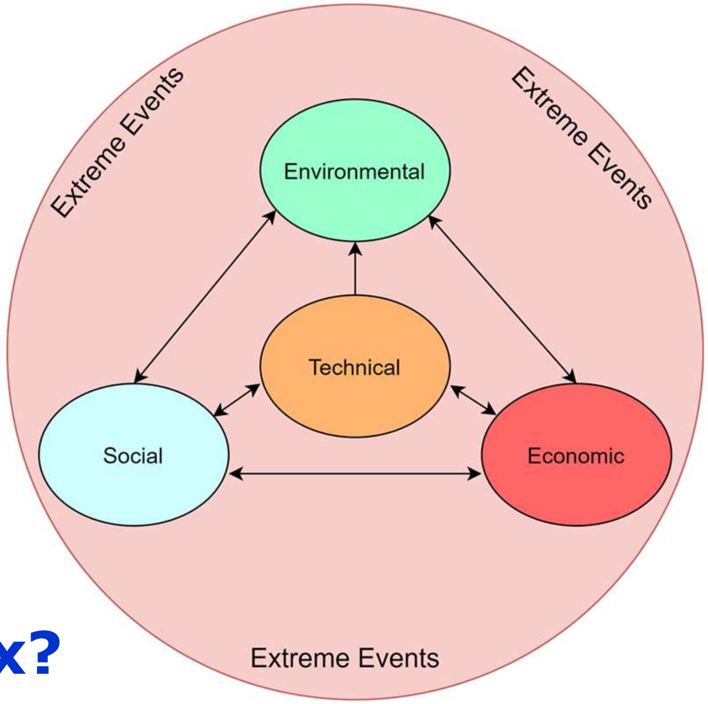
UIC

- Resilient Design Options
  - Potential technical designs based on:
  - ✓ Vulnerability/risk assessment
  - ✓ Adaptive measures



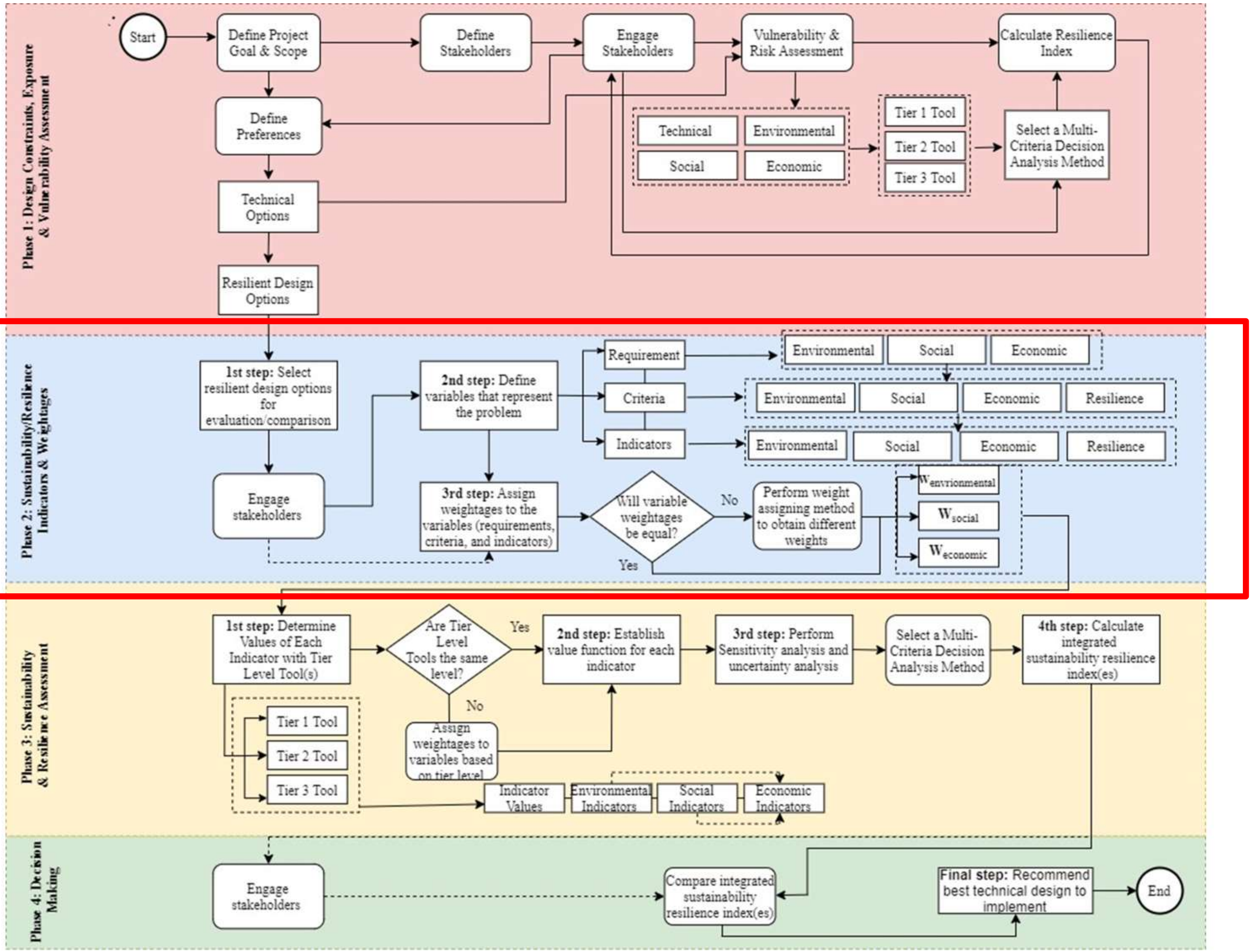
- Hazard-Resilience Indicators and Metrics
  - Technical
  - Environmental
  - Economic
  - Social

Interdependent!



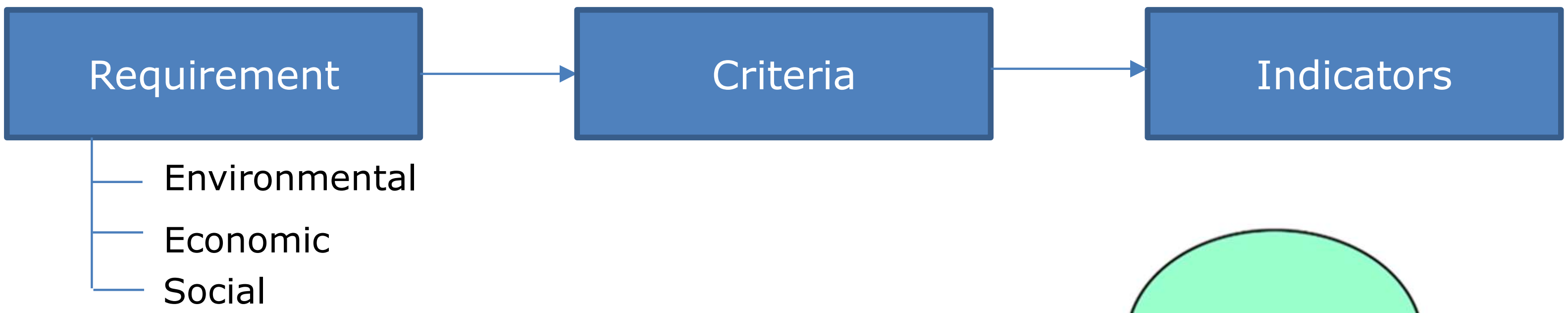
Resilience Index?

TQUALICSR Framework

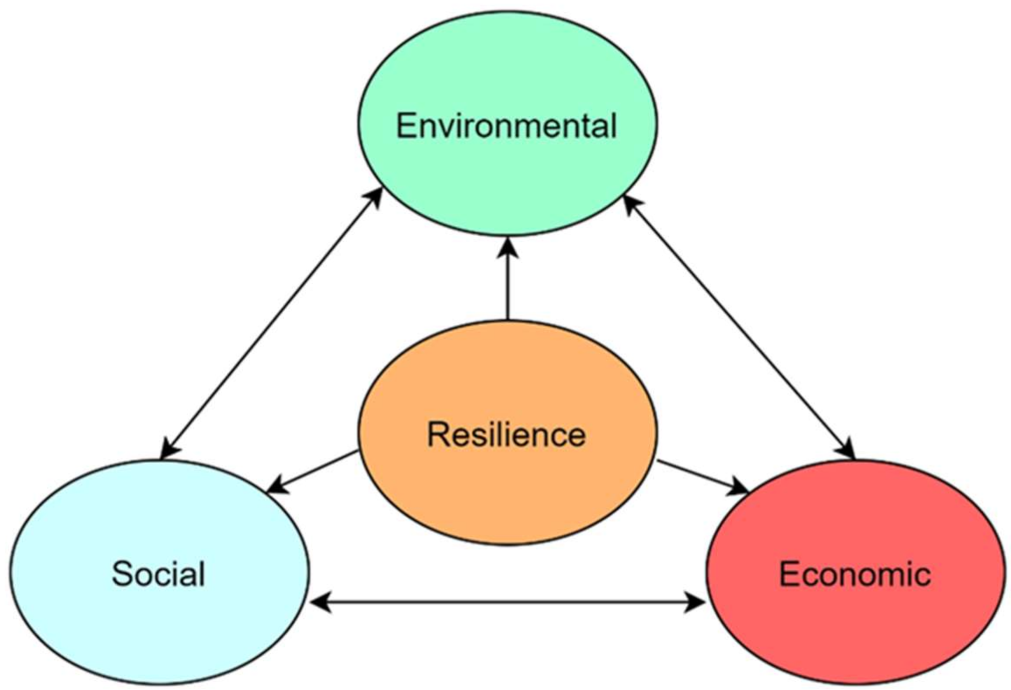


Phase 2

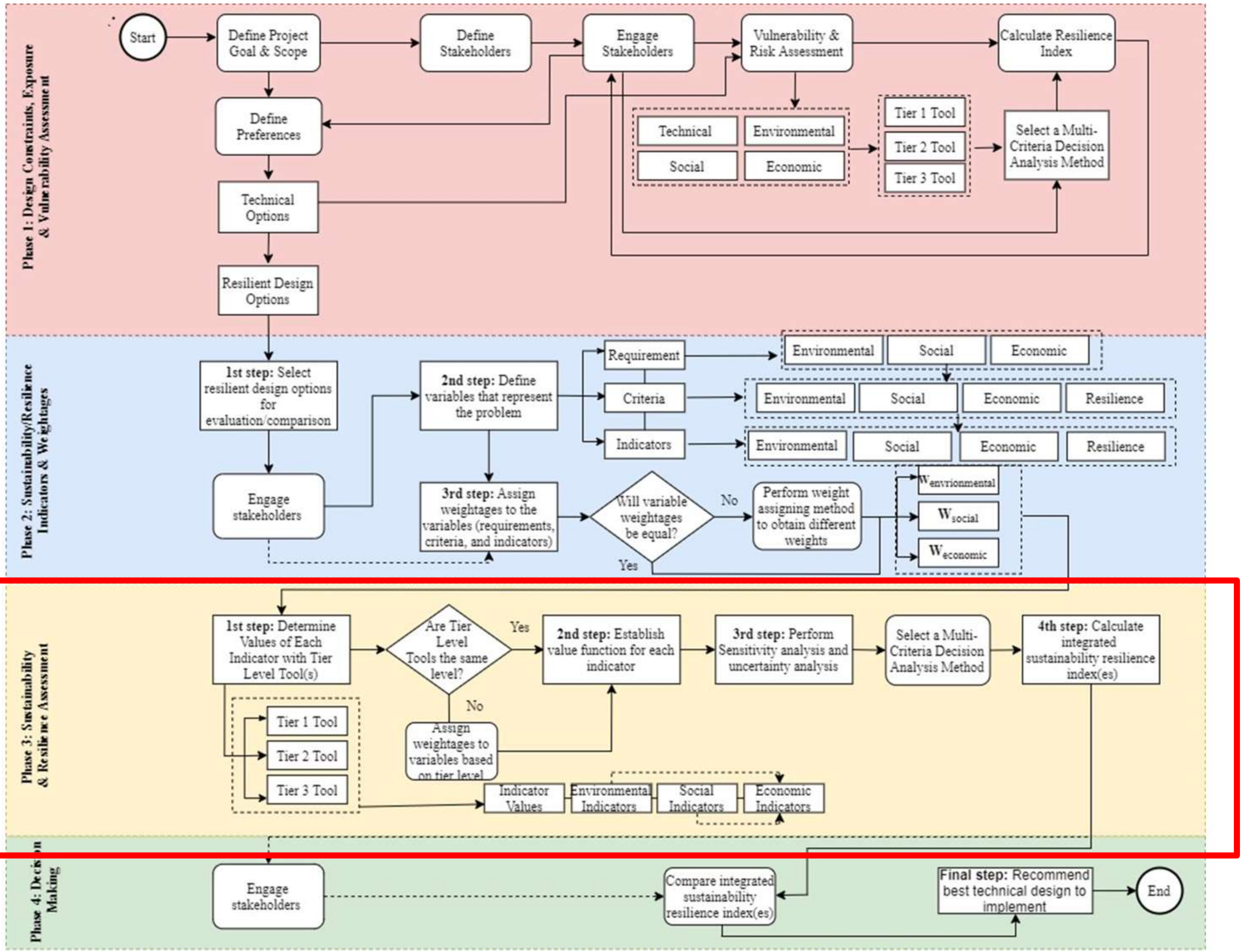
Define Qualitative and Quantitative Sustainability and Resilience Variables (Indicators)



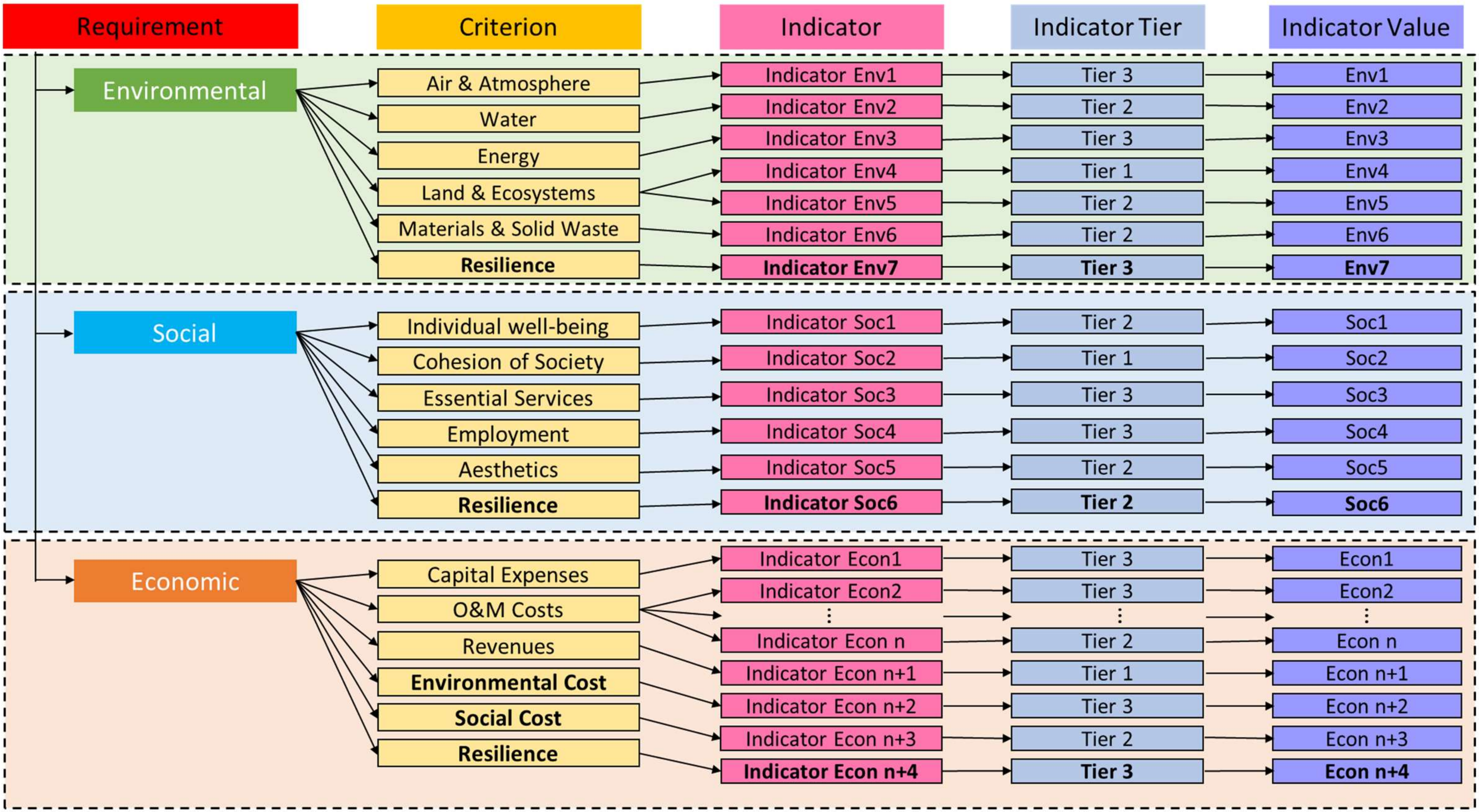
Considers **interconnections** between the three dimensions of sustainability and resilience



TQUALICSR Framework



Phase 3: Integrated Sustainability Resilience Assessment



Phase 3

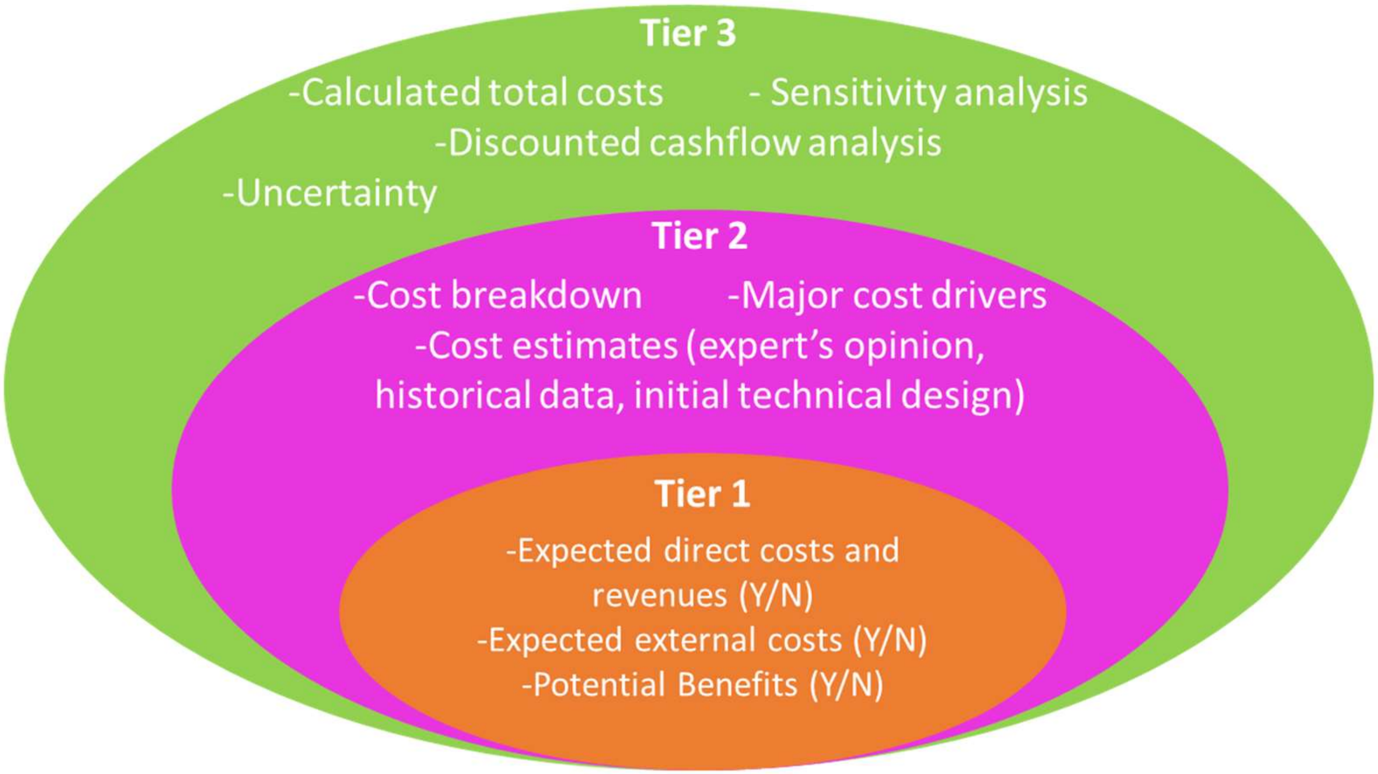
Quantify Sustainability Indicators

- Qualitative or Quantitative
- Need flexible approach
- How to quantify indicators numerically?
- Proposed use of tiered tools
  - Tier 1: Qualitative (BMPs)
  - Tier 2: Semi-quantitative (Ratings)
  - Tier 3: Quantitative

Tiered Assessment: Advantages

- Considers the amount and type of data, information, and tools **available to the user**
- Rankings based on the degree of **quantitative nature**, **time required**, and **accuracy** involved

Economic Indictors and Metrics



Phase 3

Calculate Sustainable Resilience Index (SRI)

- Derived based on Multi-Criteria Decision Analysis results
- Normalized indicator values obtained from the value function (V_{ind}) are multiplied by their respective weights (W_{ind}) assigned in Phase 2

$$V_{cri} = \sum W_{ind} \times V_{ind}$$

$$V_{req} = \sum W_{cri} \times V_{cri}$$

$$V_{final}(SRI) = \sum W_{req} \times V_{req}$$

Phase 4: Decision Making

- Participatory and comprehensive review of the designs before a choice is selected
- Multiple stakeholders' views are recommended to be considered
- Analysis of the calculated integrated sustainability resilience indicators
- The "best" option may be subjected to external project considerations:
    - Budget restrictions
    - Social acceptance
    - Stakeholders' preference

Case Study: UIC Geothermal System

- UIC has geothermal heating and cooling system inside Grant, Lincoln, and Douglas Halls.
- Goal: 50% savings in energy consumption and almost zero carbon emissions.
- Constant indoor temperature of 73 degrees runs throughout the year.

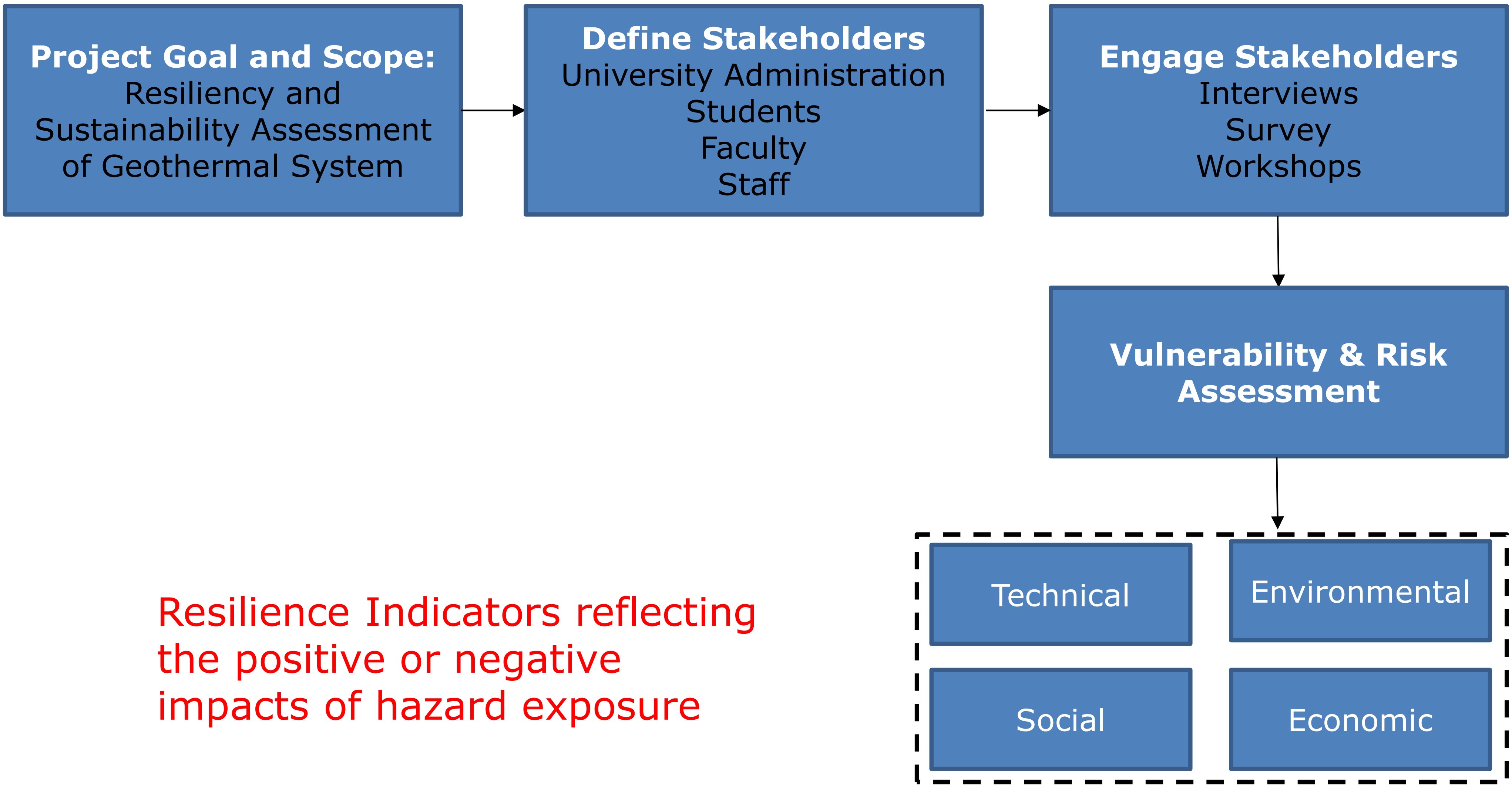
Conventional Heating and Cooling System

- Conventional system includes a direct electric heating and cooling or burned fossil fuels to convert to heat or oil HVAC (Heating, Ventilation, and Air Conditioning) systems.

- Compared to geothermal system, conventional system tends to consume more fossil fuel

TQUALICSR Framework Application

Phase I: Design Constraints, Vulnerability and Risk Assessment & Resilience Indicators



Resilience Indicators reflecting the positive or negative impacts of hazard exposure

Phase 1: Resilience Indicators & Metrics

UIC

Hazard Exposure: Extreme Heat

Criteria	W criteria - %	Indicators	W indicator - %	Indicator value	
				Conventional	Geothermal
Technical	25	Not meeting the energy demand	33	2	3
		Equipment malfunction	33	3	4
		Damage to equipment/infrastructure/utilities	33	4	2
Environmental	25	Air circulation issues	50	2	4
		Sanitation/Water supply	50	3	2
Social	25	Occupant discomfort	33.33	4	3
		Negative effect on student learning	33.33	4	3
		Negative health issues	33.33	1	3
Economic	25	Emergency/Backup energy supply	50	3	4
		Emergency repairs	50	4	3

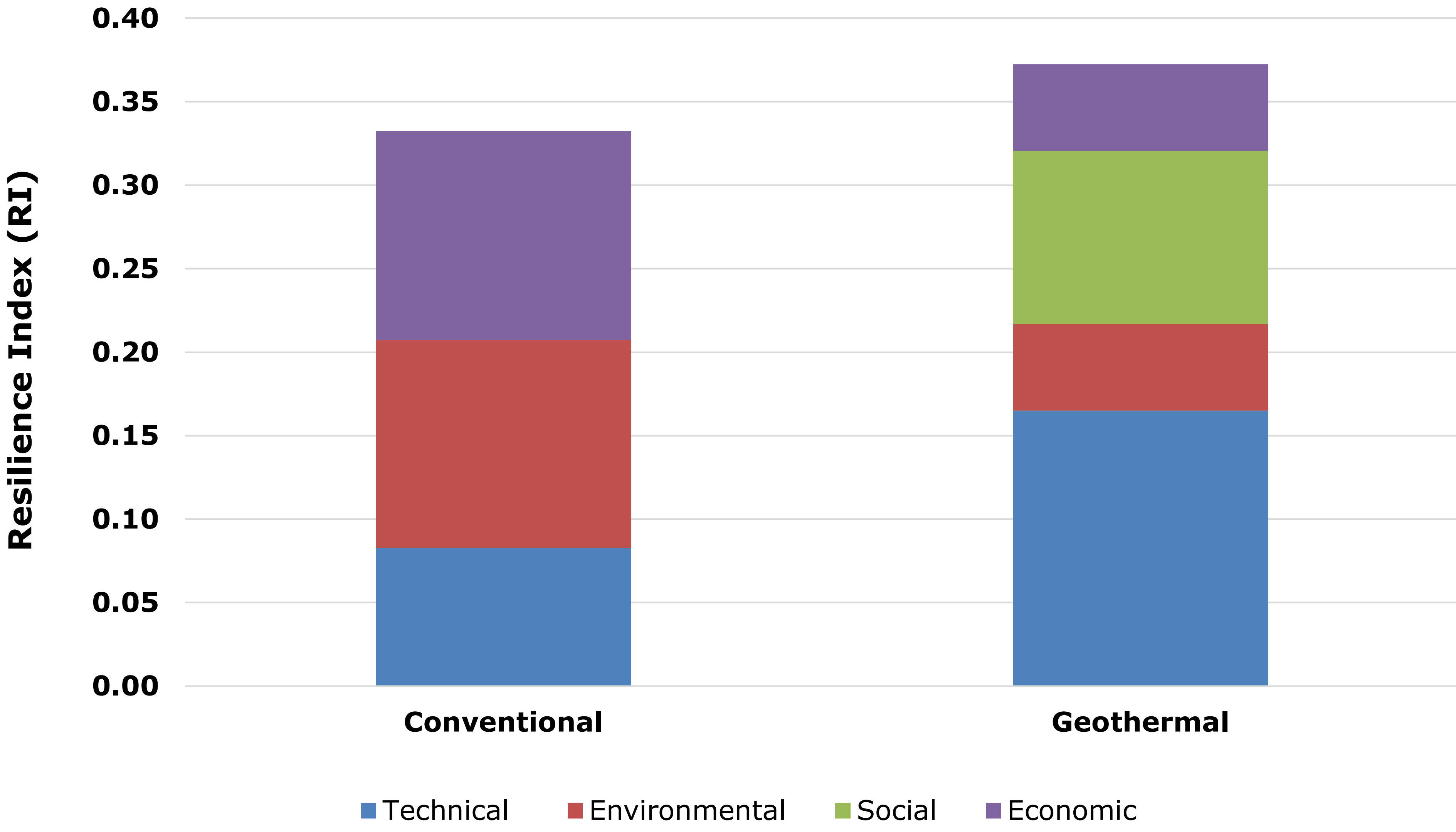
Requirement	W requirement - %	Criteria	W criteria - %	Indicators	W indicator - %	Indicator value		Tendency	X_{min}	X_{max}
						Conventional	Geothermal			
Resilience	100.00	Technical	25	Not meeting the energy demand	33	2	3	Decrease	2	3
				Equipment malfunction	33	3	4	Decrease	3	4
				Damage to equipment/infrastructure/utilities	33	4	2	Decrease	2	4
		Environmental	25	Air circulation issues	50	2	4	Decrease	2	4
				Sanitation/Water supply	50	3	2	Decrease	2	3
		Social	25	Occupant discomfort	33.33	4	3	Decrease	3	4
				Negative effect on student learning	33.33	4	3	Decrease	3	4
				Negative health issues	33.33	1	3	Decrease	1	3
		Economic	25	Emergency/Backup energy supply	50	3	4	Decrease	3	4
				Emergency repairs	50	4	3	Decrease	3	4

Indicators	Value Indicator		alue Indicator * Windicato		V criteria		V criteria * W criteria		V requirement		V final = V requirement * W requirement	
	Conventional	Geothermal	Conventional	Geothermal	Conventional	Geothermal	Conventional	Geothermal	Conventional	Geothermal	Conventional	Geothermal
Not meeting the energy demand	1.00	0.00	0.33	0.00	0.66	0.33	0.17	0.08	0.50	0.33	0.50	0.33
Equipment malfunction	1.00	0.00	0.33	0.00								
Damage to equipment/infrastructure/utilities	0.00	1.00	0.00	0.33								
Air circulation issues	1.00	0.00	0.50	0.00	0.50	0.50	0.13	0.13				
Sanitation/Water supply	0.00	1.00	0.00	0.50								
Occupant discomfort	0.00	0.42	0.00	0.14	0.33	0.28	0.08	0.07				
Negative effect on student learning	0.00	0.42	0.00	0.14								
Negative health issues	1.00	0.00	0.33	0.00								
Emergency/Backup energy supply	1.00	0.00	0.50	0.00	0.50	0.21	0.13	0.05				
Emergency repairs	0.00	0.42	0.00	0.21								

MCDA

Resilience Index

Phase 1: Resilience Index

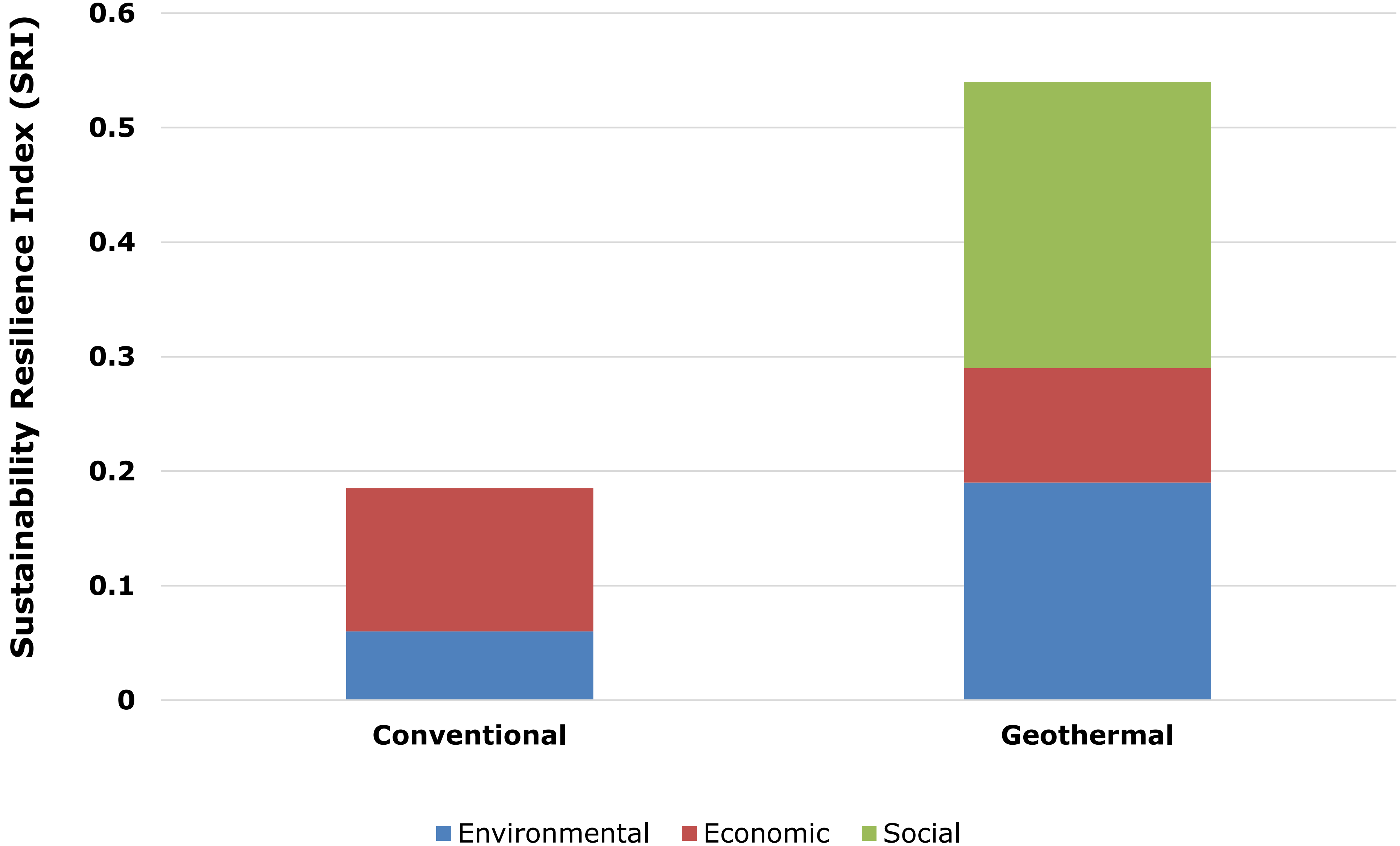


Based on this assessment, the technical design can be modified to make the system more resilient!

Phase 2: Sustainability Indicators and Weightages

Requirement	Weightage (Wrequirement - %)	Criteria	W criteria - %	Indicators	W indicador - %
Environmental	25%	Air	25%	Global Warming (kg CO2 eq)	17%
				Ozone depletion (kg CFC-11 eq)	17%
				Smog Formation (kg O3 eq)	17%
				Carcinogens (CTUh)	17%
				Non Carcinogens (CTUh)	17%
				Respitatory Effects (kg PM2.5 eq)	17%
		Water Usage & Imapacts	25%	Acidification (kg SO2 eq)	50%
				Eutrophication (kg N eq)	50%
		Land & Ecosystems	25%	Natural resource/Fossil Fuel depletion (MJ surplus)	50%
				Ecotoxicity	50%
		Resilience	25%	Release of harmful chemicals under breakdown	50%
				Reduced access to the system	50%
Economic	25%	Direct Cost	50%	Raw Materials (USD)	33%
				Transportation (USD)	33%
				Labor (USD)	33%
		Indirect Costs	20%	Stepwise Monetisation (USD)	100%
		Social Costs	20%	Social Cost of CO_2	100%
		Resilience	10%	Financial Security	100%
Social	25%	Public Survey	30%	Social-Individual	25%
				Social-Institutional	25%
				Social-Economic	25%
				Social-Environmental	25%
		Group SSEM	50%	Social-Individual	25%
				Social-Institutional	25%
				Social-Economic	25%
				Social-Environmental	25%
		Resilience	20%	Assistance to individuals	50%
				Access to alternative power	50%

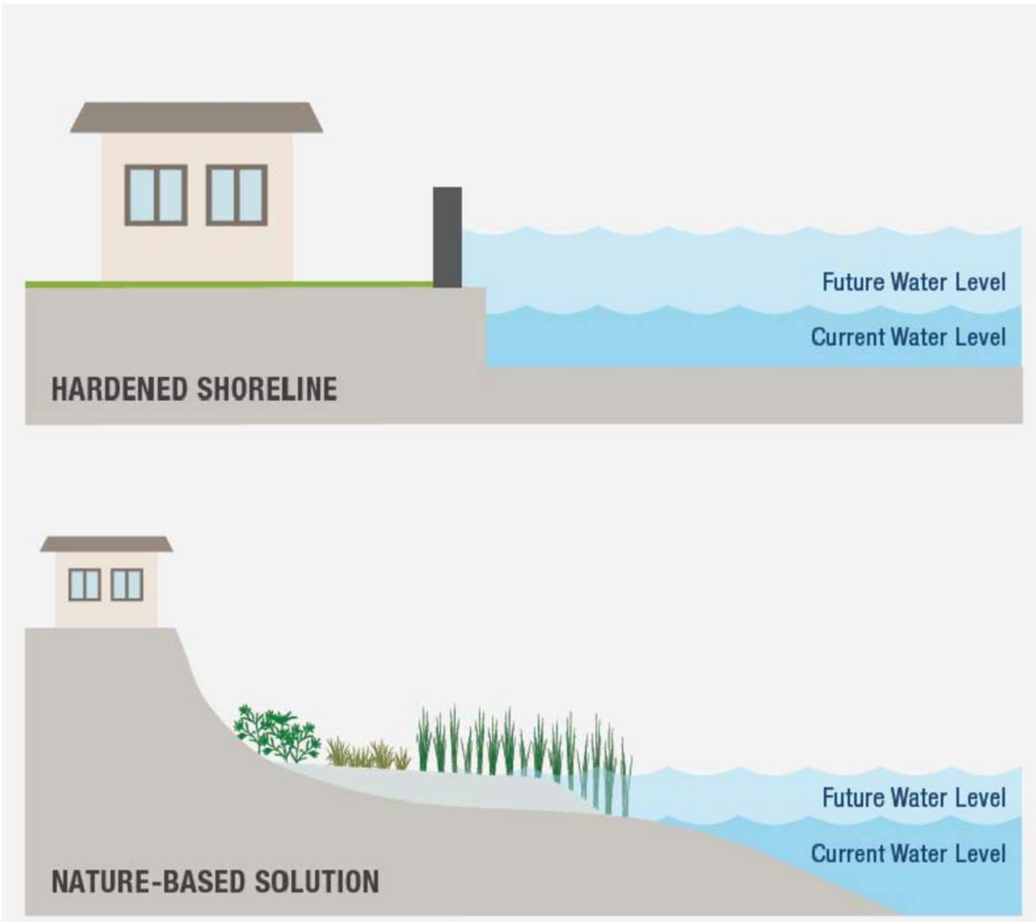
Phase 3: Sustainable Resiliency Index



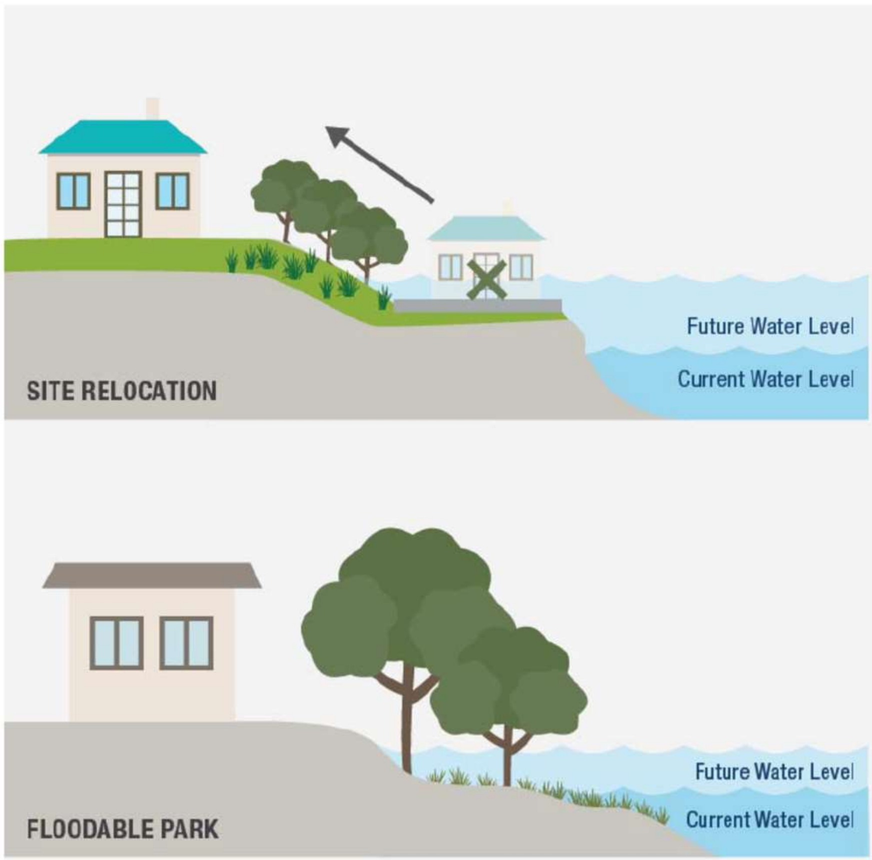
Phase 4: Decision Making

- Budget restrictions?
- Social acceptance?
- Stakeholders' preference?

Resilient and Sustainable Design: Flood/Surge Protection

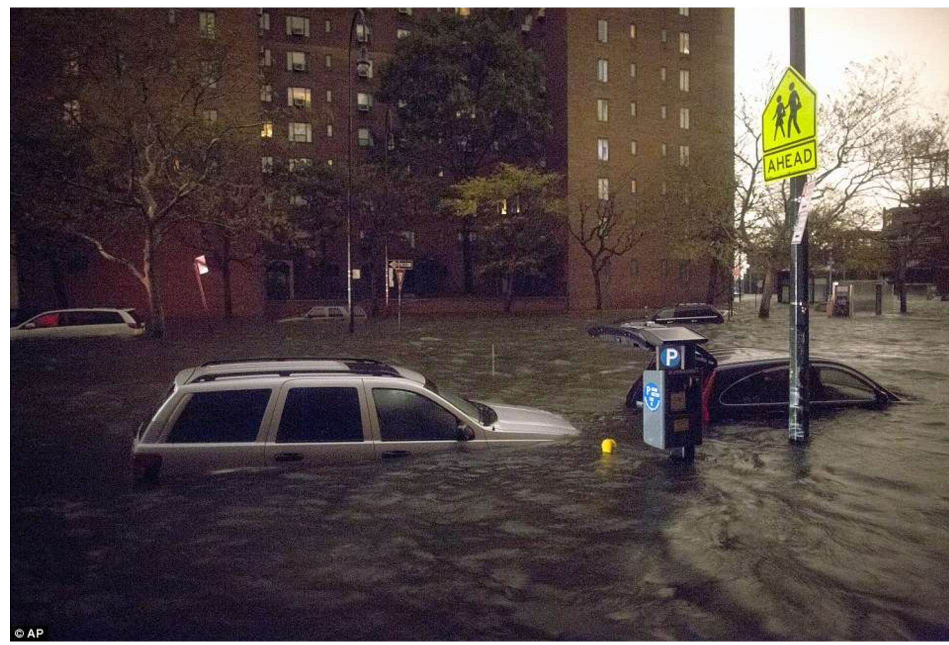


Resilient and Sustainable Design: Flood/Surge Protection



NYC Parks Design and Planning for Flood Resiliency

Hurricane Sandy (2012): New York



Resilient and Sustainable Design

Resilient and Sustainable Design

Resilient and Sustainable Design

Resilient and Sustainable Design

NY Hunter's Point South Park to Address Rising Tides

Green Infrastructure Tackling Floods

ABC Waters Site in Singapore (ABC=Active, Beautiful, and Clean)

Sponge Cities

Water Park with Stormwater Storage

New innovative water square combines leisure and storm water storage in Rotterdam, the Netherlands

Take-Home Messages

- To cope with the negative impacts of climate change, climate adaptation (resiliency) options should be recommended based on adaptive management methodology (non-stationarity? Uncertainty? Unknown Unknowns?)
- In the long-run, climate mitigation (control of greenhouse gas emissions) options are needed to minimize/prevent climate change hazards. Select options that are impactful and can provide co-benefits!
- Consider sustainability (broader environmental, economic and social issues) in selecting climate adaptation and mitigation options (to promote sustainable development)
- Use integrated resilience and sustainability assessment tools (e.g., Envision, TQUALICSR) that provide structured approach to develop optimal solutions!
- Promote nature-based engineering solutions that have potential to be both resilient and sustainable!

Contact/Additional Information

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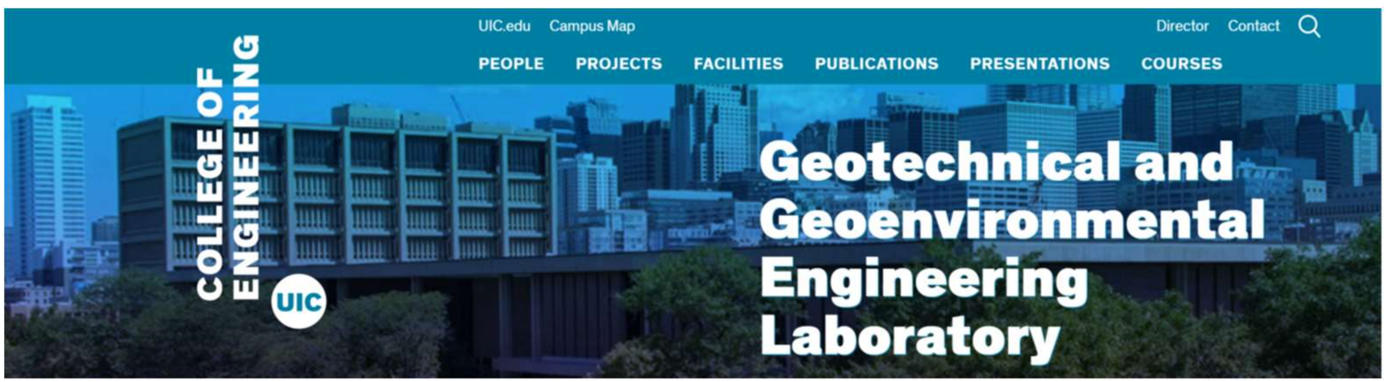

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THANK YOU

QUESTIONS ?