SUSTAINABILITY IN ENGINEERING DESIGN

(24CV306B)

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Syllabus

Module 3:

Preliminary solutions assessment, Quick scan Life Cycle Assessment (LCA) - Set-up, Goal definition and scoping, Inventory analysis, Impact assessment, Valuation, Improvement, LCA Epilogue, Evaluation of design - Stage/Gate evaluation with stakeholders, Rapid economic analysis method, Rapid social acceptance guideline, Rapid integral sustainable development assessment, Scenario set building for robustness test to future uncertainties, Red flags method for evaluation with outside stakeholders.

Preliminary solutions assessment

Preliminary Solutions Assessment is the first structured, formal evaluation process applied to conceptual design alternatives.

PSA screens concepts based on multidisciplinary sustainability principles and eliminates alternatives that fail critical thresholds.

Preliminary solutions assessment

Objectives:

- To rapidly filter out technically or environmentally infeasible alternatives.
- To identify key sustainability trade-offs at the earliest design stage.
- To enable resource-efficient design iteration by focusing only on viable concepts.
- To ensure alignment with stakeholder expectations, regulatory compliance, project constraints, and long-term environmental objectives.
- To incorporate systems thinking by evaluating interdependencies among technical, environmental, economic, and social subsystems.

Preliminary solutions assessment

Components of PSA:

A. Technical Feasibility Assessment

Evaluates whether the concept can perform its required function safely and reliably. Considerations include:

- Structural adequacy
- Hydrological/hydraulic performance
- Geotechnical stability
- System reliability
- Constructability
- Material availability
- Safety factors (conceptual-level)

Expected durability and maintenance needs

Civil engineering applications include preliminary slope stability checks, approximate flow capacity calculations, feasibility of foundation systems, and constructability analysis in constrained urban environments.

Preliminary solutions assessment

Components of PSA:

B. Environmental Feasibility Assessment

Determines whether the concept meets sustainability requirements and minimizes adverse environmental impacts.

- Assessment considers:
- Expected embodied carbon of materials
- Construction and operational emissions
- Water consumption
- Land use impacts
- Resource extraction intensity

- Biodiversity disturbance
- Pollution potential
- Waste generation
- In this phase, a Quick Scan LCA is often applied.

Preliminary solutions assessment

Components of PSA:

C. Economic Feasibility Assessment

Examines the overall economic viability. Includes:

- Preliminary capital cost estimates
- Preliminary O&M cost estimates
- Service life expectations
- Approximate lifecycle cost
- Early cost-benefit evaluation
- Basic NPV/IRR approximations
- Cost risk arising from material price fluctuations

Preliminary solutions assessment

Components of PSA:

D. Social Feasibility Assessment

Evaluates community, cultural, human-factor, and public acceptance aspects. Includes:

- User needs alignment
- Safety risks
- Accessibility
- Likelihood of community acceptance or resistance
- Compatibility with local socioeconomic conditions
- Effects on livelihood
- Public perception of project purpose and aesthetics

Preliminary solutions assessment

Components of PSA:

E. Regulatory and Policy Feasibility

Screens for:

- Environmental permits required
- Water/Air/Noise standards
- Land-use regulations
- Urban development norms
- Wetland, coastal, or forest-related restrictions
- National and regional sustainability mandates

LIFE CYCLE ASSESSMENT (LCA)

Quick Scan LCA is a simplified Life Cycle Assessment applied at conceptual design stage to compare environmental performance among alternatives.

Stages of Quick Scan LCA

- Set-up
- Goal definition and scoping
- Inventory analysis
- Impact assessment
- Valuation
- Improvement
- LCA Epilogue (Interpretation)

LIFE CYCLE ASSESSMENT (LCA)

Step 1: Set-Up

- Identify design alternatives for comparison.
- Define the purpose of Quick LCA (selection/elimination/optimization).
- Define required level of detail and acceptable approximation error.
- Select LCA datasets.
- Identify key impact categories.
- Establish boundary assumptions.
- Determine cut-off criteria for minor components (<1% mass/impact).
- Decide whether weighting will be used.
- Set-up determines scope integrity and scientific validity.

LIFE CYCLE ASSESSMENT (LCA)

Step 2: Goal Definition and Scoping

- Specifies intended application.
- Concept selection
- Environmental hot-spot identification
- Early-stage decision support
- Comparison between material alternatives
- Preliminary sustainability screening

LIFE CYCLE ASSESSMENT (LCA)

Step 2: Goal Definition and Scoping

- **Functional Unit (FU)**

  FU ensures comparability.

  examples include:

  - "M30 concrete providing 50-year durability"

- **Reference Flows**

  Amount of material/process needed to achieve FU.

- **System Boundaries**

  - **Cradle-to-Gate**: extraction → production
  - **Cradle-to-Site**: includes transport
  - **Cradle-to-Grave**: includes use-life + disposal
  - **Cradle-to-Cradle**: includes recycling

LIFE CYCLE ASSESSMENT (LCA)

Step 2: Goal Definition and Scoping

- **Cut-off Rules**

  Exclude minor flows (<1% of mass or energy).

- **Impact Categories Selected**
  - GWP (CO_2-eq)
  - Energy use
  - Water footprint
  - Resource depletion
- **Data Quality Requirements**
  - Geographical appropriateness
  - Technological specificity

LIFE CYCLE ASSESSMENT (LCA)

Step 3: Inventory Analysis (LCI)

LCI Inputs

- Raw material consumption
- Fuel use (diesel, petrol, grid electricity)
- Water consumption
- Chemical usage
- Machinery use (operating hours)
- Land occupation
- Transport distances

LIFE CYCLE ASSESSMENT (LCA)

Step 3: Inventory Analysis (LCI)

LCI Outputs

- Atmospheric emissions: CO_2, CH_4, NOx, SOx, PM10
- Water pollutants: COD, BOD, nutrients
- Waste: solid, hazardous, construction debris
- Noise emissions
- Heat
- Leachates

Data Sources

- Industry-average databases
- National carbon factor databases
- IPCC Guidelines
- GHG Protocol
- Academic literature
- Inventory forms the basis for environmental quantification.

LIFE CYCLE ASSESSMENT (LCA)

Step 4: Impact Assessment (LCIA)

Major Impact Categories

- Climate Change (GWP100)
- Ozone Depletion
- Human Toxicity
- Ecotoxicity (terrestrial, aquatic)
- Acidification
- Resource Depletion
- Water Scarcity
- Land Use Impact
- Mineral/Fossil Fuel Depletion

LIFE CYCLE ASSESSMENT (LCA)

Step 5: Valuation (Weighting + Normalization)

Normalization

- Convert impacts into dimensionless form

Weighting

- Climate: 40%
- Water: 30%
- Resources: 20%
- Toxicity: 10%

Aggregation

- Single score obtained:

  Sustainability Index = Σ ($Normalized_i \times Weight_i$)

- Used for ranking alternatives.

LIFE CYCLE ASSESSMENT (LCA)

Step 6: Improvement Assessment

Improvement Measures

- Replace cement with GGBS/Fly ash
- Use recycled aggregates
- Reduce materials through structural optimization
- Use renewable energy during construction
- Minimize transport distances
- Improvement must align with project constraints.

LIFE CYCLE ASSESSMENT (LCA)

Step 7: LCA Epilogue (Interpretation)

- Significant impact contributors
- Comparison summary
- Sensitivity analysis
- Uncertainty analysis
- Limitations
- Final recommendations

STAGE/GATE EVALUATION (STAKEHOLDER GOVERNANCE FRAMEWORK)

Stage/Gate is a system of phased project progress involving multi-stakeholder decision checkpoints.

Gate Structure

Gate	Requirement	Decision
G1	Concept alternatives + preliminary screening	Go / Redesign / Reject
G2	Preliminary design + PSA + Quick LCA	Go / Revise
G3	Detailed design + refined LCA + cost modelling	Go / Conditional Go
G4	Pilot/prototype review	Go / Rework
G5	Final approval	Go for implementation

STAGE/GATE EVALUATION

Stakeholders

- Project engineers
- Environmental specialists
- Regulatory authorities
- Community representatives
- Financial agencies
- NGOs
- Design consultants

RAPID ECONOMIC ANALYSIS

Purpose

Rapid economic analysis filters economically unviable alternatives before detailed cost modelling.

Components

A. Capex Estimation

- Material cost
- Earthwork
- Construction machinery
- Labour
- Equipment

RAPID ECONOMIC ANALYSIS

Components

B. Opex Estimation

- Annual maintenance
- Energy consumption
- Replacement cycles
- Staff salaries

C. Simple Lifecycle Cost (LCC)

- $LCC \approx Capex + \Sigma\,(Opex \times Discount\ Factor)$

RAPID ECONOMIC ANALYSIS

Components

D. Economic Indicators

- Payback period
- Cost–benefit ratio
- Simplified NPV
- Approx. IRR

RAPID SOCIAL ACCEPTANCE GUIDELINE

Dimensions of Social Acceptance

1. Safety
2. Health and wellbeing
3. Accessibility and universal design
4. Cultural compatibility
5. Visual/aesthetic impact
6. Community willingness
7. Displacement risk
8. Gender and age inclusiveness

RAPID INTEGRAL SUSTAINABLE DEVELOPMENT ASSESSMENT

Dimensions Evaluated

- Technical
- Environmental
- Economic
- Social
- Policy alignment
- Resilience

Evaluation Method

- Score each criterion (1–5 or 1–7).
- Multiply by weights.
- Plot on Radar Chart.
- Compute composite sustainability index.

SCENARIO SET BUILDING FOR ROBUSTNESS

Purpose

- To evaluate performance under uncertain future conditions.

Types of Scenarios

1. **Climatic**
   - Rainfall intensity variations
   - Temperature rise
   - Extreme weather events
2. **Demographic**
   - Population growth
   - Water demand changes

SCENARIO SET BUILDING FOR ROBUSTNESS

Types of Scenarios

3. **Technological**
   - Automation
   - New materials
   - Renewable energy systems
4. **Economic**
   - Inflation
   - Fuel price variation
   - Material shortages
5. **Regulatory**
   - Stricter environmental laws
   - Land-use policy changes

RAPID INTEGRAL SUSTAINABLE DEVELOPMENT ASSESSMENT

Scenario Analysis Techniques

1. Monte Carlo simulations
2. Sensitivity analysis
3. Stress testing
4. Uncertainty quantification
5. Probabilistic modelling

RED FLAGS METHOD

- The Red Flags method identifies critical “non-negotiable’ issues that may terminate a design alternative.

Types of Red Flags

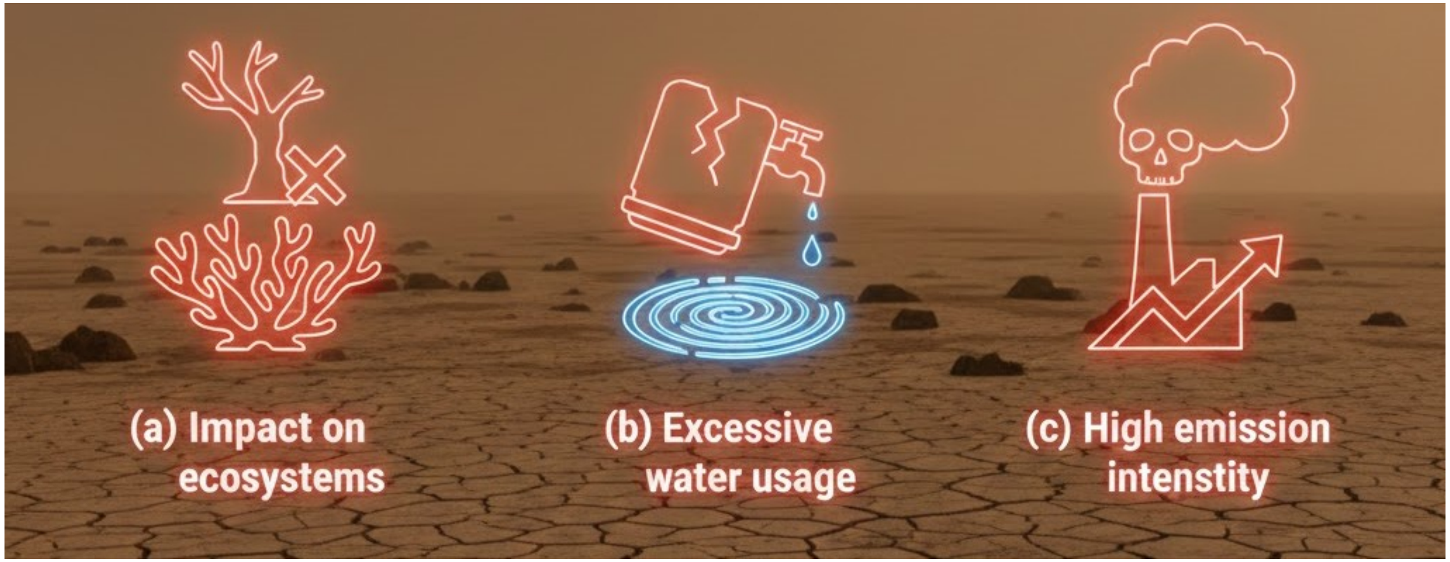
1. **Environmental Red Flags**
2. **Social Red Flags**
3. **Economic Red Flags**

RED FLAGS METHOD

Types of Red Flags

1. Environmental Red Flags

- Impact on protected ecosystems
- Excessive water usage
- High emission intensity



RED FLAGS METHOD

Types of Red Flags

2. Social Red Flags

- Community displacement
- Strong public opposition
- High accident risk

RED FLAGS METHOD

Types of Red Flags

3. Economic Red Flags

- Capex beyond funding capacity
- Unsustainable operational cost
- High vulnerability to market fluctuations
- Alternatives with multiple red flags are eliminated.