ADB

Environment and Nature

LEARNING WEEK 2025

7–10 October 2025 | Multifunction Halls 2–3 | ADB Headquarters

THIS TRAINING IS ORGANIZED BY THE **ENVIRONMENT COMMUNITY OF PRACTICE**

Presentation

Applying Dynamic Systems Modeling for the Circular Economy

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Transforming Circular Economy Policy into Measurable Impact

"What if ADB could predict the outcomes of waste management policies before investing millions?"

SINGAPORE'S SUCCESS: National Environment Agency Zero Waste Masterplan

System dynamics modeling predicted policy outcomes, saving $600M in misdirected investments

70% Recycling Rate by 2030

$600M Investment Savings

10 yrs Landfill Life Extended

How can ADB Apply Dynamic Systems Modeling

ADB

1 Infrastructure Investment Planning & Risk Assessment

Model long-term infrastructure ROI and test investment scenarios before committing capital

ADB SECTOR APPLICATIONS:

- **URBAN** Waste-to-energy facility sizing for Manila's metro expansion (System Dynamics)
- **WATER** Wastewater treatment capacity planning under climate scenarios (Hybrid Models)
- **TRANSPORT** EV battery recycling infrastructure network design across SE Asia (Agent-Based)

2 Policy Testing & National Strategy Development

Simulate policy combinations and regulatory frameworks before implementation

ADB SECTOR APPLICATIONS:

- **ENVIRONMENT** Extended Producer Responsibility scheme impacts in Viet Nam (System Dynamics)
- **AGRICULTURE** Organic waste composting policy for rural Viet Nam (Discrete Event Simulation)
- **INDUSTRY** Industrial symbiosis incentive structures for Chinese industrial parks (Agent-Based)

3 Regional Coordination & Cross-Border Material Flows

Optimize regional circular economy strategies and predict transboundary impacts

ADB SECTOR APPLICATIONS:

- **TRADE** ASEAN plastic waste trade flows and recycling capacity gaps (System Dynamics)
- **ENERGY** Regional biogas from organic waste potential in Greater Mekong Subregion (Hybrid)
- **FINANCE** Green bond market development for circular economy projects (Agent-Based)

Understanding Dynamic Systems Modeling

Captures how circular economy elements **interact, change, and influence each other over time**.

Three Model Paradigms

A model is a simplified representation of reality—used to simulate, explain and predict.

White Box Models

Built from known relationships and theory

Basis: Mathematical equations
Strength: High interpretability
Transparency: Complete visibility

Example: Material flow equations for waste streams

Grey Box Models

Combines theory with empirical data

Basis: Hybrid approach
Strength: Balanced accuracy
Transparency: Partial visibility

Example: Predicting informal waste picker behavior in Jakarta's recycling system

Black Box Models

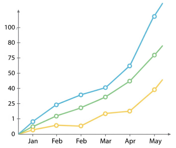
Data-driven machine learning approach

Basis: Neural networks, AI
Strength: Predictive power
Transparency: Limited visibility

Example: AI-based waste generation and leakage prediction

How They Work: Core Components

π **Mathematics**
Differential equations, probability, agent rules



Data Integration
Historical trends, stakeholder behavior, economics

Outputs
Scenarios, sensitivity analysis, policy forecasts

Modern Tools Simplify Creation

Software Platforms
Vensim, AnyLogic, Stella, Insights Maker, Simul8 etc.

Rapid Testing
Scenario exploration in hours, not months

Visual Interface
No coding required for basic models

User-Friendly
Drag and drop model building

AI & Data Analysis
Improving model accuracy

Automated model building
Elimination of many manual actions

Four Core Modeling Methods

System Dynamics (SD)

Best for: Policy-level strategic planning with feedback loops

CHARACTERISTICS:
- Aggregate modeling
- Feedback analysis
- Stock & flow structures
- Long-term (5-30 years)

ADB APPLICATIONS:

→Waste generation forecasting under GDP scenarios

→Recycling infrastructure capacity planning

Agent-Based Modeling (ABM)

Best for: Behavior-driven outcomes and heterogeneous actors

CHARACTERISTICS:
- Individual entities
- Spatial dynamics
- Emergent behavior
- Behavioral economics

ADB APPLICATIONS:

→Informal waste sector integration modeling

→Market formation for secondary materials

Discrete Event Simulation (DES)

Best for: Operational efficiency and process optimization

CHARACTERISTICS:
- Process flow modeling
- Resource utilization
- Queue analysis
- Short-medium term

ADB APPLICATIONS:

→Waste collection route optimization

→Sorting facility throughput analysis

Hybrid Models

Best for: Complex systems requiring multi-level analysis

CHARACTERISTICS:
- Combines 2+ methods
- Micro & macro dynamics
- Multi-scale integration
- Comprehensive view

ADB APPLICATIONS:

→Policy (SD) + Consumer behavior (ABM)

→Multi-sector analysis (land, water, plastic, agriculture etc.)

Emerging: Digital Twins & Next-Gen Dynamic Modeling

- **Real-time Data**
  Live integration with operational data
- **Auto-updating**
  Models learn from new data
- **Live Decisions**
  Instant predictions and decision support

Case Study Implementation

Plastic Waste Management Policy Simulation – Caballero et al., 2023

Context: Urban area facing increasing plastic waste and inadequate recycling infrastructure

1 Problem Definition

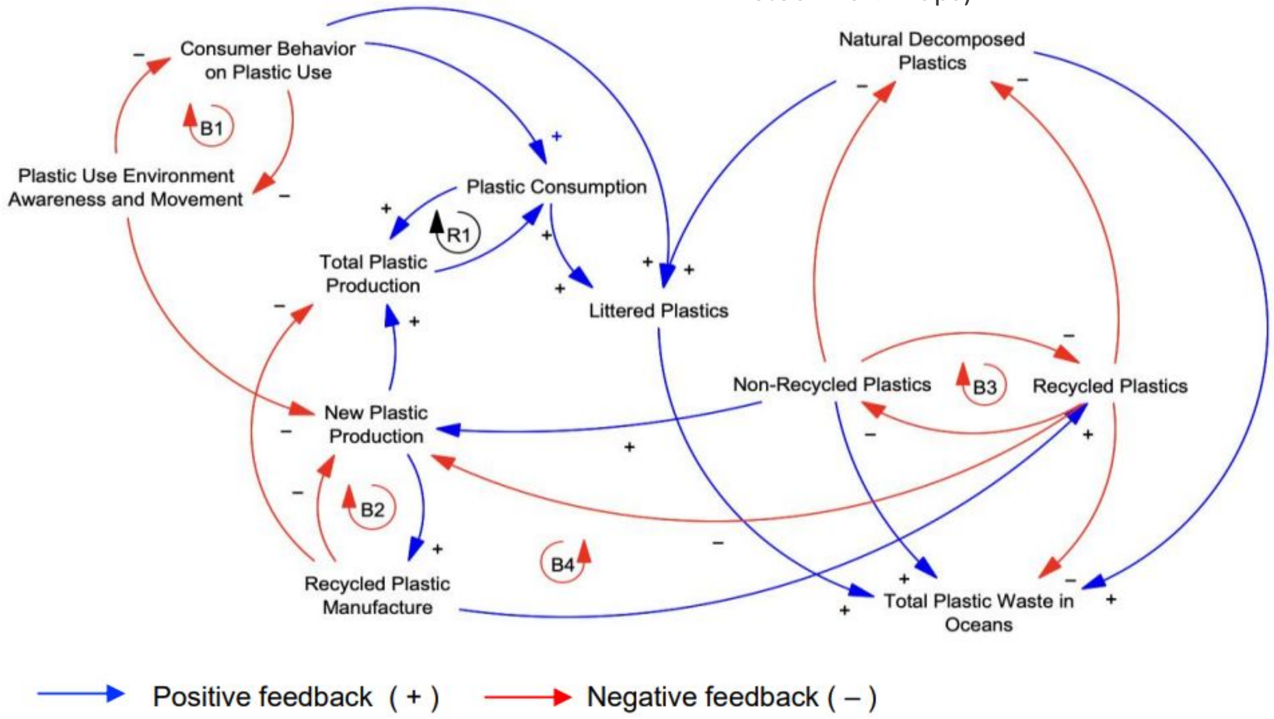
What This Entails:

- Define problem and intended purpose of study
- Identify system boundaries (what's in, what's out)
- Determine key performance indicators (KPIs)
- Engage stakeholders to understand priorities

2 Model Conceptualization

What This Entails:

- Map causal relationships and feedback loops
- Choose appropriate modeling method(s)
- Define variables, parameters, and data needs
- Create conceptual diagrams (causal loop diagrams, stock-flow maps)



Step 1: Case Study Application

Purpose of the model:

Analyzing the effectiveness of different strategies and plastic waste management policies

System Boundaries: What is the system?

- Plastic generation
- Collection systems
- Sorting facilities
- Recycling processes
- Landfilling

Step 2: Case Study Application

Method selected: System Dynamics (SD)

Rationale: Policy focus, aggregate flows, long-term trends, feedback effects

Key variables:

Stocks: Total plastic waste, Plastic production

Flows: new plastics rate, recycling rate, natural decomposed plastics rate etc.

Variables to define the interrelationships of the system: non-recycled plastics, plastic use environment awareness, littered plastics

Case Study Implementation

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3 Model Construction

What This Entails:

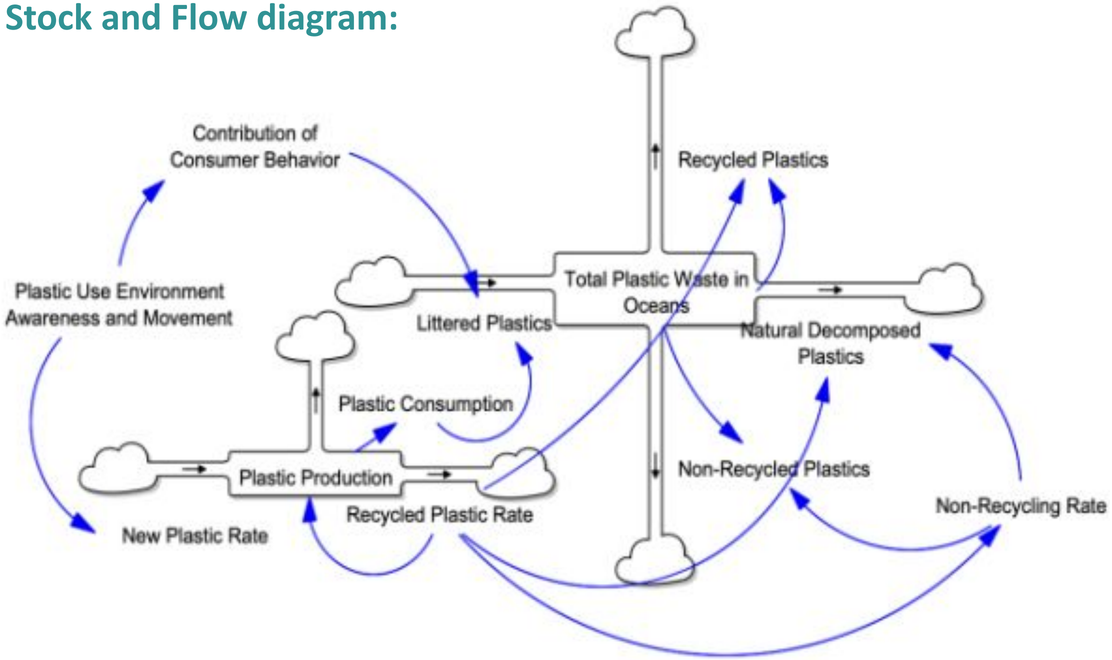
- Translate conceptual model to formal equations
- Build model in chosen software
- Set initial conditions and parameter values
- Establish time horizon and simulation steps

4 Verification & Validation

What This Entails:

- Check model logic correctly implemented
- Ensure model accurately represents real system
- Test extreme conditions
- Sensitivity analysis

Stock and Flow diagram:



Step 3: Case Study Application

From conceptual model (CLD) to formal equations:

S&F diagram automatically by the **Vensim modeling software** → User assigns mathematical relationships between the variable

Model's Equations:

Recycling rate = Collection Rate × Sorting Efficiency

d(Plastic in Landfill)/dt = Waste to Landfill – Decomposition

Initial conditions and parameter values:

Historical data on plastics from 1950 (Our World in Data (Ritchie & Roser, 2022)

Step 4: Case Study Application

Checking model logic ⇒ expert review

Ensure model accurately represents real system
Base run of Vensim coherent and corresponding to historical data

Sensitivity analysis
Variation of influencing parameters showed coherent outputs in magnitude

Case Study Implementation

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5 Model application & Scenario analysis

What This Entails:

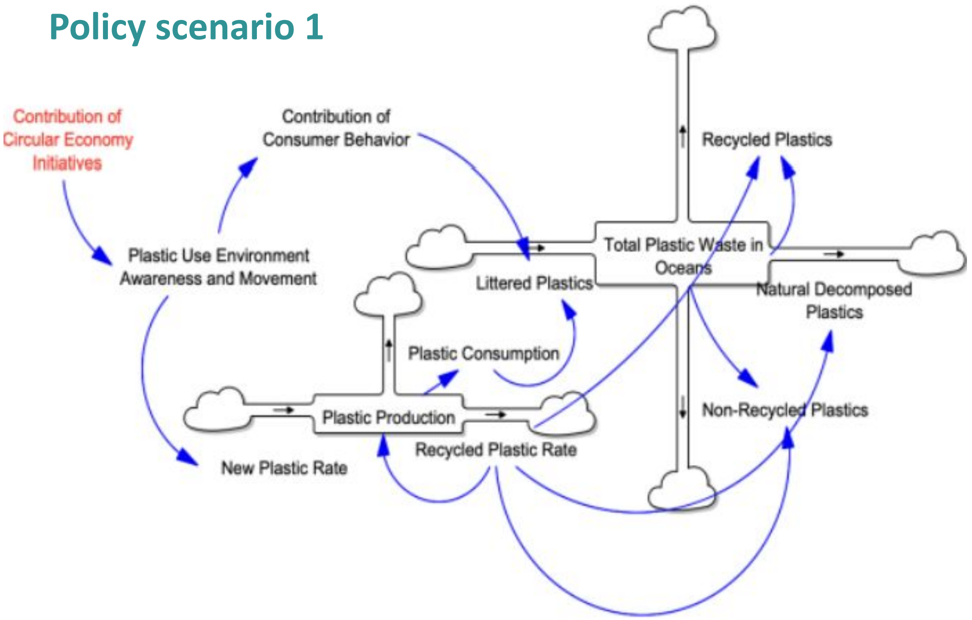
- Design policy scenarios to test
- Run simulations for each scenario
- Analyze outputs and compare alternatives

6 Evolution & Reconfiguration

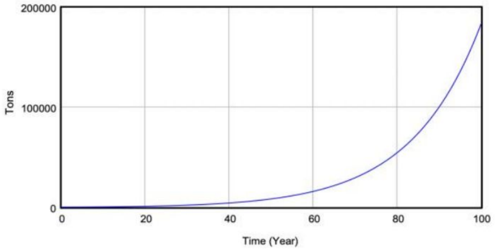
What This Entails:

- Monitor real-world implementation vs simulation
- Update model with new data
- Refine parameters on new outcomes
- Improve with ABM and Hybrid Models

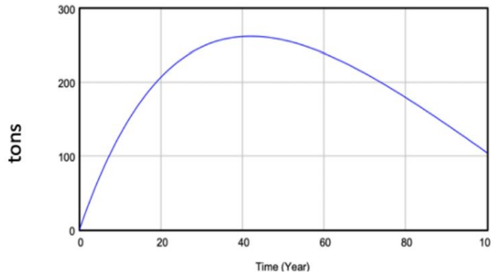
Policy scenario 1



Baseline



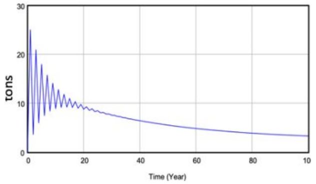
CE initiatives for Increased Awareness

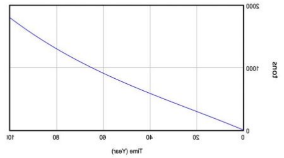


Step 5: Case Study Application

Policy Scenarios tested:

→ Reformed plastic production policy
→ Increase of plastic litter cleanup activities
→ Policy circular economy initiatives (capacity-building)





Analyze outputs and compare:

Simulations show a decrease in plastic production with an increased effectiveness for upstream actions

Step 6: Case Study Application

Monitor real-world implementation
Following results to update the model based on real situation

Refine parameters on new outcomes
Reiterative process to improve model, data quality etc.

Improving model
Study suggests impact of awareness needs to be studied more ⇒ ABM models to study emergent behaviour and use insights for current model

Unlocking Computational Modeling Potential at ADB

Who	Project Managers	Loan Officers	Operational Teams	Evaluation officers
When	Project Design	Loan Approval	Project Implementation	Monitoring & Adaptation
How	Build models templates for new projects	Simulate loan impact based on CE criteria	Continued improvement of models for better effectiveness	Use to evaluate impact of project

Dynamic Systems Modeling—Next Steps

Prepare simple pilot test for existing project → Capacity Building of a small team → Model Construction on specific process/ project → Analyze Results → Scale

THANK YOU!