Energy and Sustainability Systems and Metrics

UCC501 Sustainable Energy, Fall 2014

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Contents

- Systems analysis (SA) overview
- Risk analysis (process/engineering/finance)
- Life cycle analysis (product)
- Economic/Energy Models (industry/nation)
- Scenario Analysis
- Simulation models
  - Discrete event (process/engineering)
  - System Dynamics (firm/industry/nation)

Why do we need SA?

- There are always options and they usually have consequences
- It is not always easy to make informed decisions…
- Complexity
  - Combinatorial complexity (e.g. airline scheduling)
  - Dynamic Complexity
    - Coupling – Feedback
    - Nonlinearity
    - Path-dependence
    - Adaptation / self-organization
- Uncertainty
  - Known unknowns
  - Unknown unknowns

What makes the decision for a decision-maker?

- Gut instinct
- Scoping analysis
  - Simplified, linear, few/no feedbacks
  - Easy to understand, broad picture, clearly shows problems
- Detailed SA
  - Follows scoping for projects
  - Is the only option for large-scale complex problems

--> Be wary of all – especially SA. You never know what the analyst “forgot” - biases

Problems for Systems Analysis

- Investor: Build a power plant?
  - What type of fuel?
  - Is the price of the fuel? Is it volatile?
  - Will it be profitable? Under which conditions?
  - Will its externalities be priced in the future?
  - Will it be subsidized? If yes, will the subsidy be stable?
  - Will the demand be there?
  - What will the competitors do?
- Government: Regulate Emissions? SUVs? Tobacco?
- Firm: Fix a quality control problem in a PV production line? Reduce inventory costs in a supply chain but at the cost of increasing disruption risks?

Common characteristics of SA

<u>SA ANSWERS a question</u>

- done for its own sake is not a great idea – don't know where to stop

1. Define problem
2. Define the system
3. Identify best SA approach suited for the problem
4. Define boundaries

   Separate exogenous vs. endogenous variables
5. Define options
6. Create system map
7. Implement SA approach
   1. Verify - debug
   2. Calibrate - test against historical/real-world
   3. Validate - sell to decision makers
8. Test options
9. Make recommendations
10. Implement & Repeat as necessary

Risk Analysis

- Risk analysis involves rare incidents (accidents, mechanical failures, unanticipated market changes)
- If you cannot simulate then you can observe (uncertainty) and if not then you can extrapolate
- We want to minimize risk but it is not possible to achieve zero risk

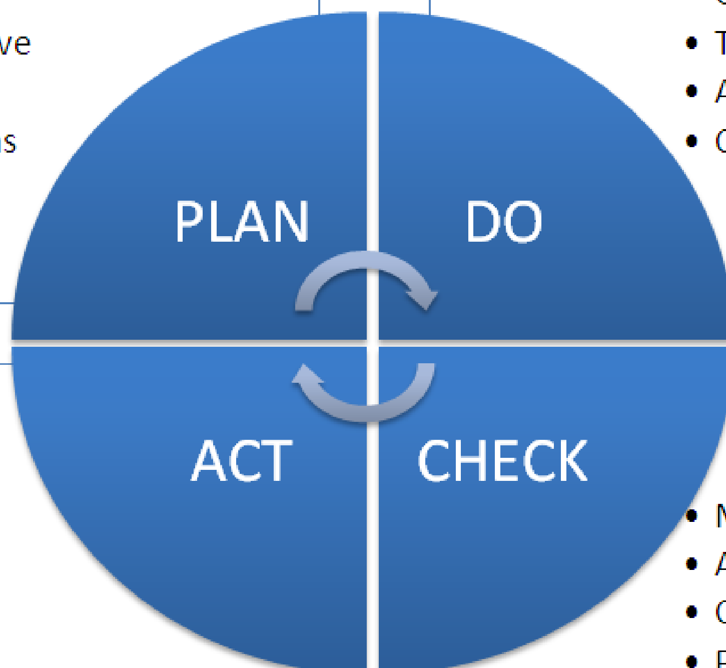
- Risk = Frequency x Consequence

- Risk mitigated design:
  - Redundancy, Robustness, Maintainability
- Techniques:
  - Event/fault tree analysis, uncertainty analysis, TQM

Continual Improvement

- Responsibility of top management
- Energy policy
- Management representative
- Energy review
- Objectives and action plans

- Implementation and realization
- Communication
- Training
- Awareness
- Operational Control



- Management review
- New strategic goals
- Optimization

- Monitoring
- Analysis
- Corrective Action
- Preventive action
- Internal audit

Lifecycle Analysis

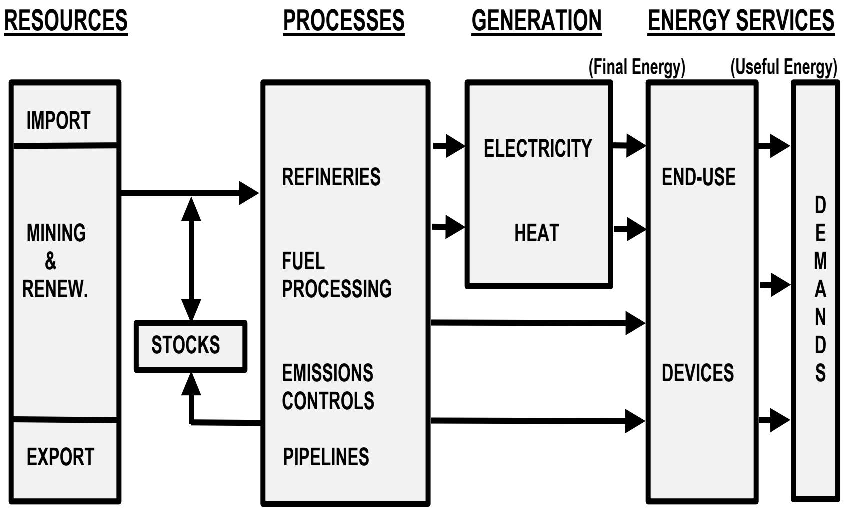
- Comprehensive cradle-to-grave analysis
- Include
  - Raw materials
  - Materials processing
  - Manufacturing
  - Distribution
  - Repair and maintenance
  - Waste disposal
  - Decommissioning

--> Can be very time/resource consuming. Use of existing databases (Simapro, GREET) makes things easier

Economic/Energy models + climate

- Bottom-up models & General Models
- Supply/Demand Equilibrium:
  - Demand Elasticity +
  - Economic Input Output Tables
  - Computable General Equilibrium Models
- Environmentally Extended I/O
- Global Circulation Models

Markal Model

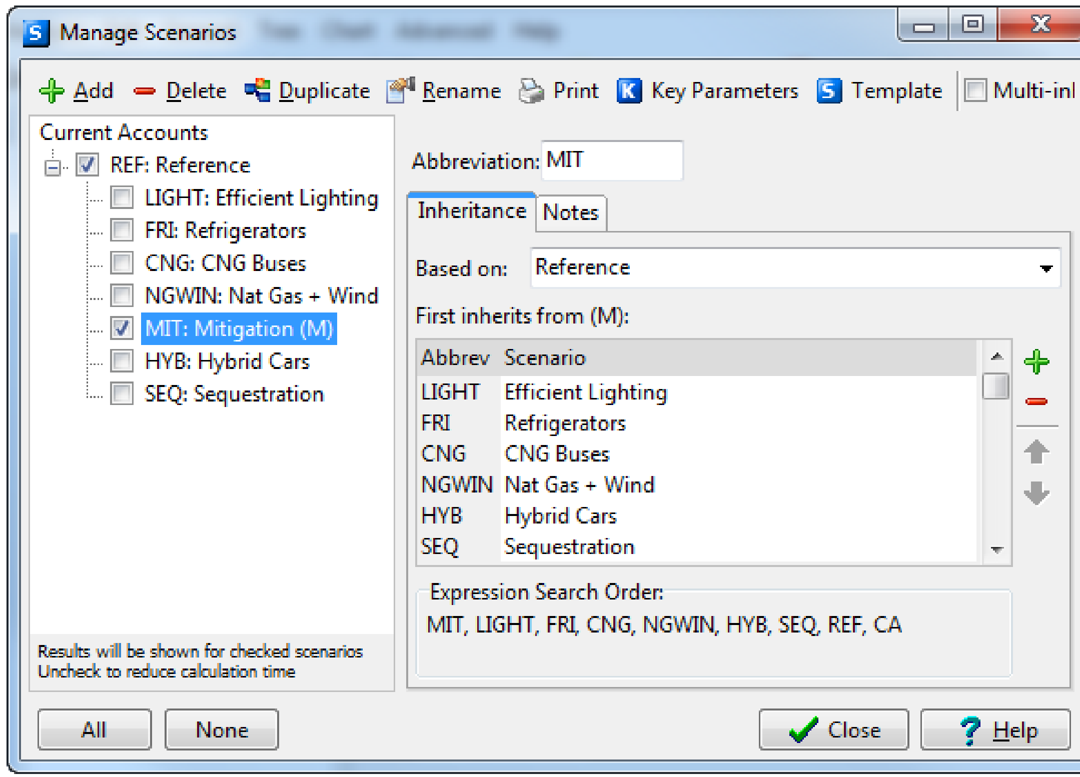


- Originally developed by IEA-ETAPS
- ***Bottom-up*** approach for modeling ***technology specific portfolios*** of the entire energy - materials flow system – synergies and feedback for economic optimization
- A ***dynamic integrated framework*** to assess ***market competition***, ***technology diffusion*** and ***emission/waste accounting***
- Facilitates Program Managers in selecting ***technology mix*** over the entire energy - materials system based on ***life cycle accounting*** and ***least cost***
- Uses ***mathematical programming*** to identify optimal mix (least cost for meeting certain constraints).
- As good as its assumptions (like all models) but extremely sensitive to costs (artifact of optimization)

Basic Info: http://www.epa.gov/nrmrl/appcd/climate_change/pdf/MARKAL_handout_final.pdf

Leap modeling and scenario analysis

- Long-range Energy Alternatives Planning: scenario analysis.
- Scenarios are self-consistent storylines of how an energy system can evolve
- Create and evaluate alternative scenarios by comparing their energy requirements, their costs and benefits and environmental impacts.
- Assess marginal policy impact as well as interactions that occur when multiple policies and measures are combined.
- E.g. "benefits of appliance efficiency standards combined with a renewable portfolio standard might be less than the sum of the benefits of the two measures considered separately."



http://www.energycommunity.org/default.asp?action=47

Simulation Analysis: Discrete Event

- Operations / Queuing Models
- Statistical observations

- Example:

Masdar Personal Rapid Transit (Mueller, 2009)

System Dynamics

- Solving hundreds of partial differential equations cannot be exciting? Right?

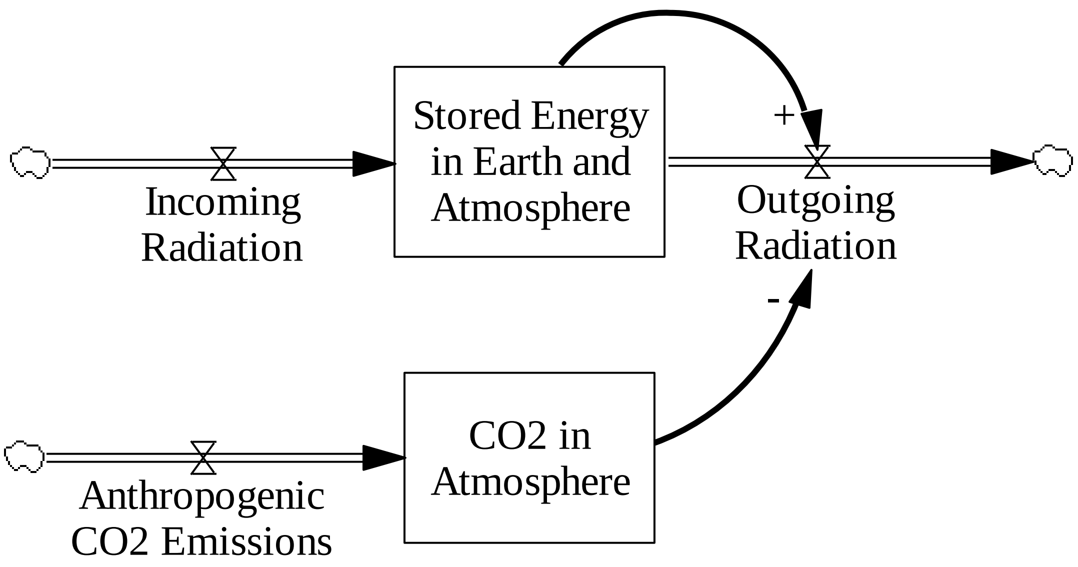
- SD allows the modeling of stocks, flows, delays and their causal connections for a large array of socio-economic phenomena

Global Warming from SD perspective

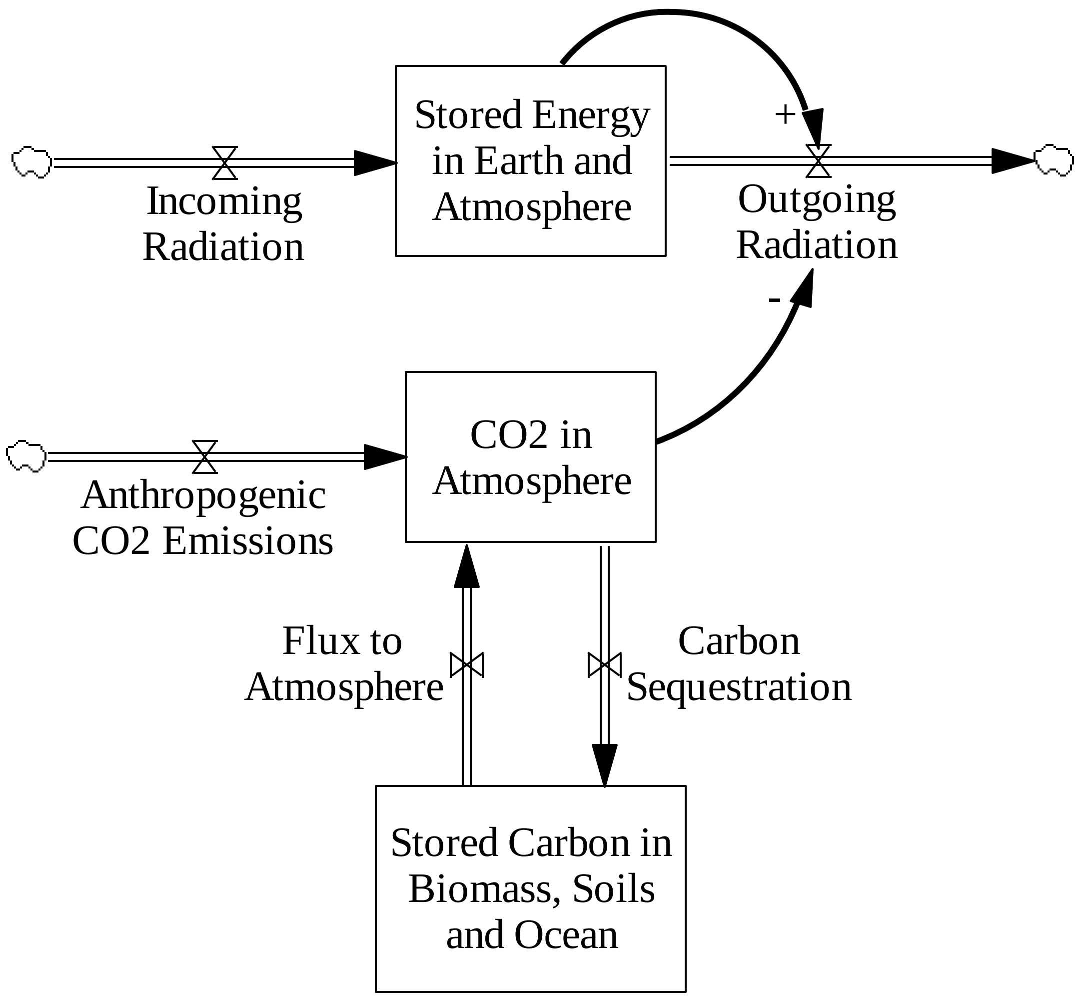
- What is the problem?
  - *Rising global mean surface temperatures.*
- Key variables (start simple)
  - Incoming solar radiation
  - Outgoing radiation
  - Global mean surface temperature
  - CO_2 emissions
  - CO_2 concentration in atmosphere

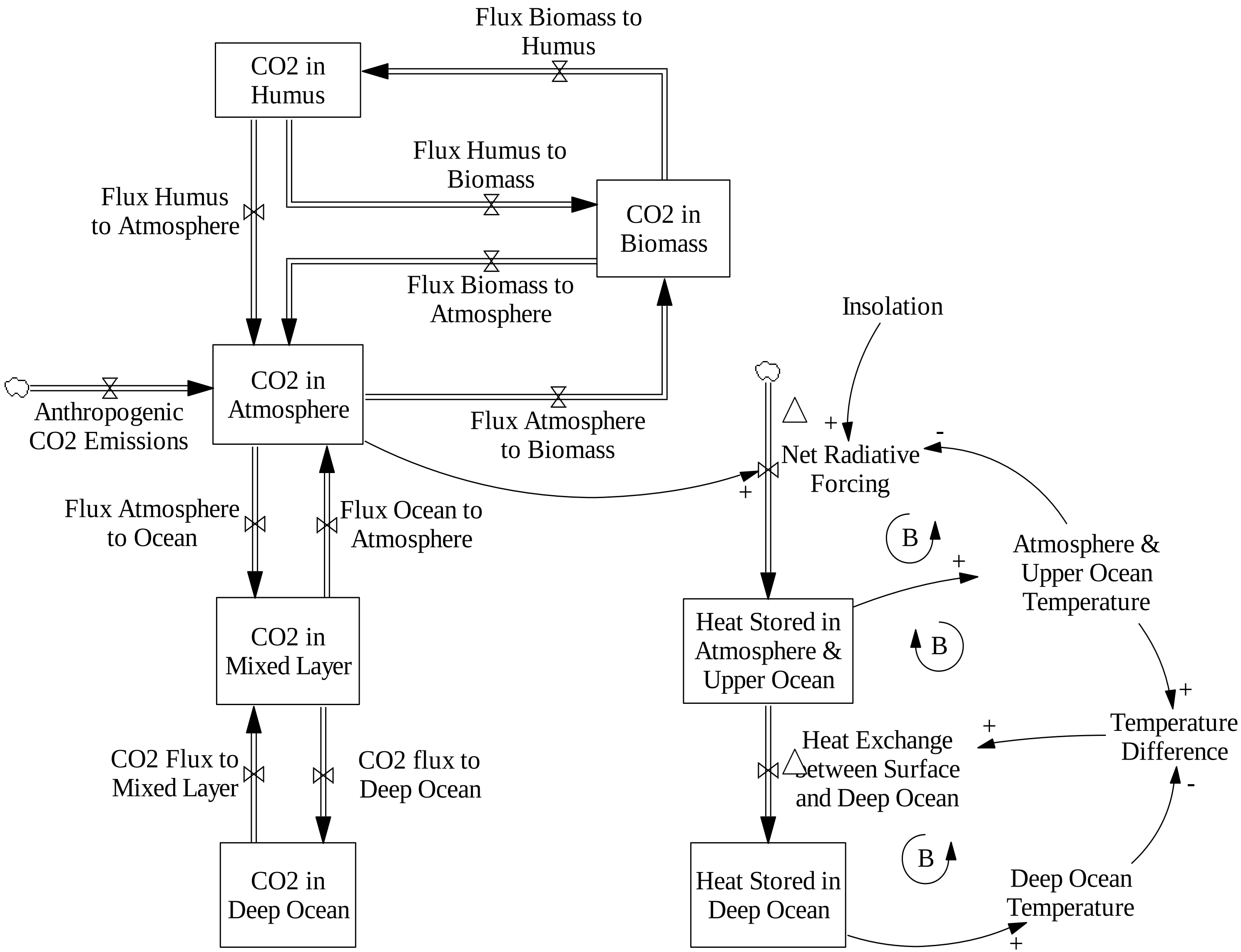
A simple energy balance

- How do you expect each variable to behave (reference mode)?



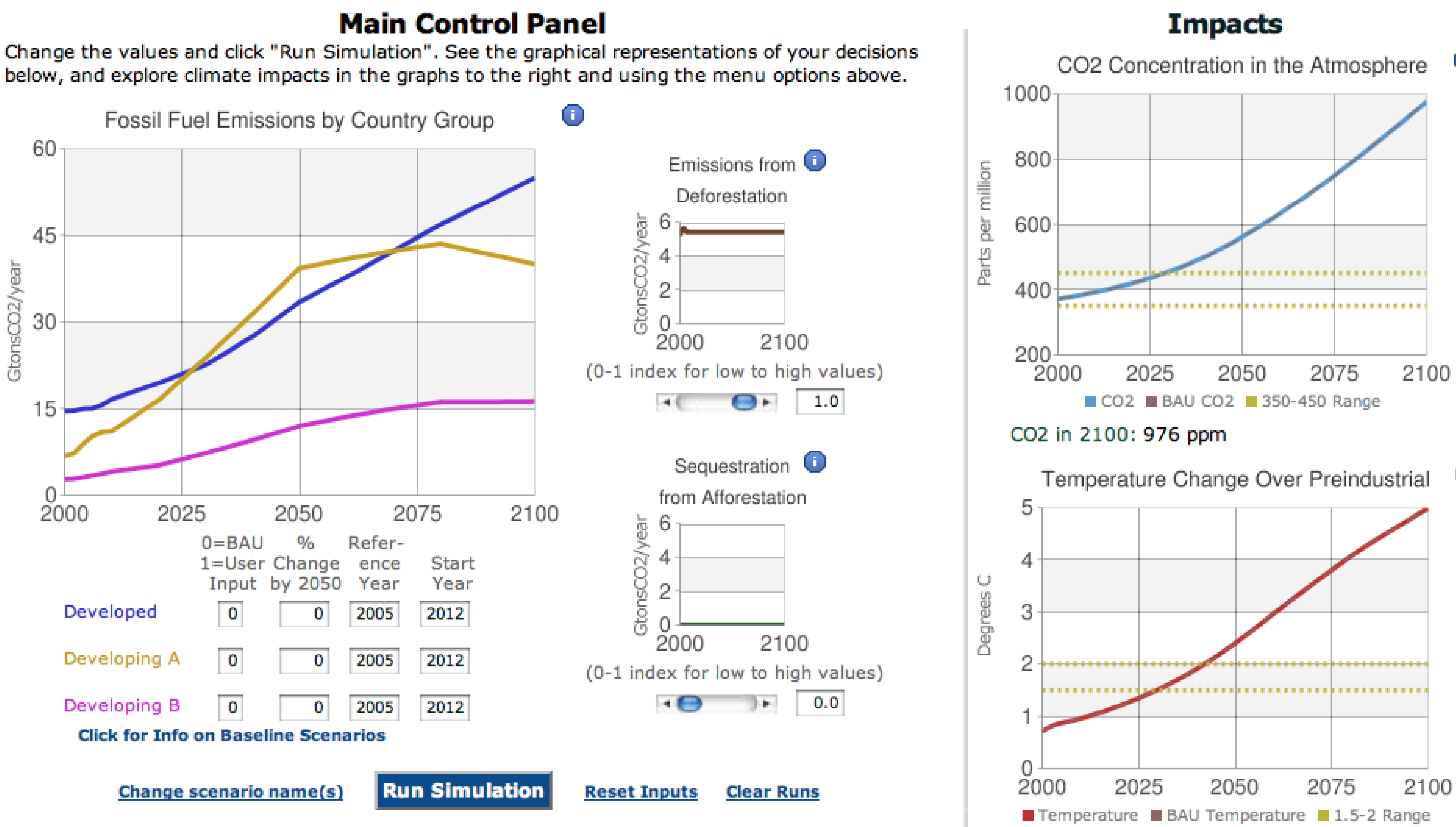
Energy and carbon balance



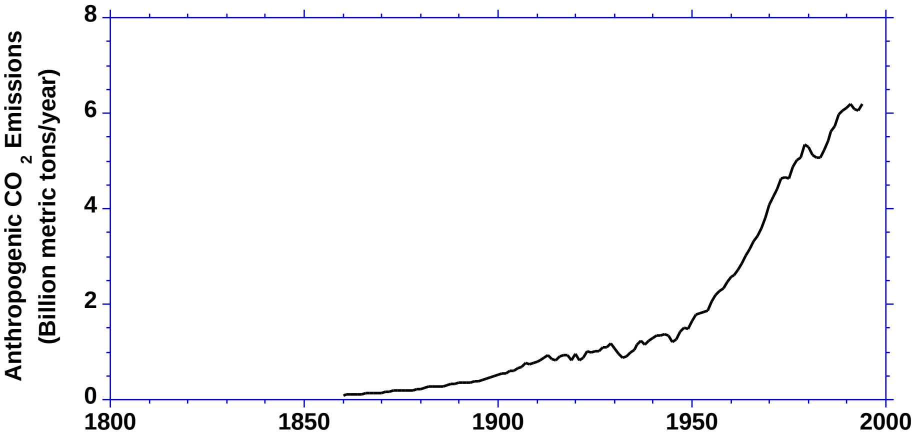

Flux Biomass to Humus
CO2 in Humus
Flux Humus to Biomass
Flux Humus to Atmosphere
CO2 in Biomass
Flux Biomass to Atmosphere
Insolation
Anthropogenic CO2 Emissions
CO2 in Atmosphere
Flux Atmosphere to Biomass
Net Radiative Forcing
Flux Atmosphere to Ocean
Flux Ocean to Atmosphere
B
Atmosphere & Upper Ocean Temperature
CO2 in Mixed Layer
Heat Stored in Atmosphere & Upper Ocean
B
Temperature Difference
CO2 Flux to Mixed Layer
CO2 flux to Deep Ocean
Heat Exchange between Surface and Deep Ocean
B
CO2 in Deep Ocean
Heat Stored in Deep Ocean
Deep Ocean Temperature

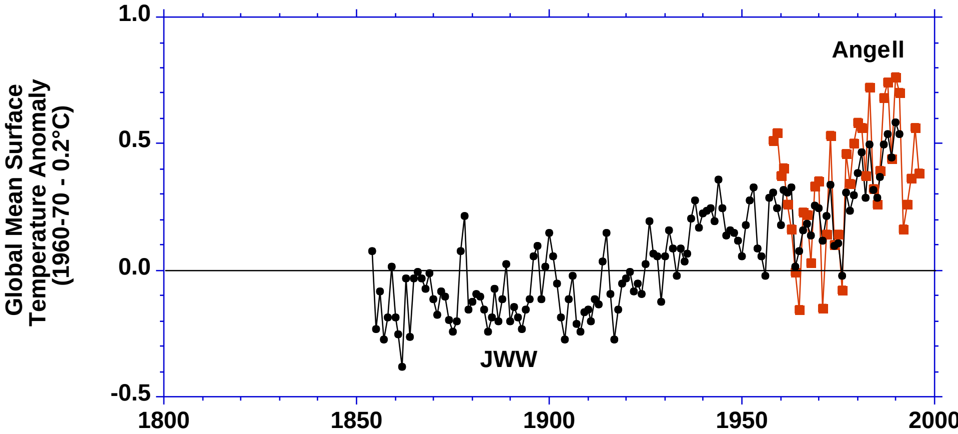
Climate Economy Simulation: C-ROADS

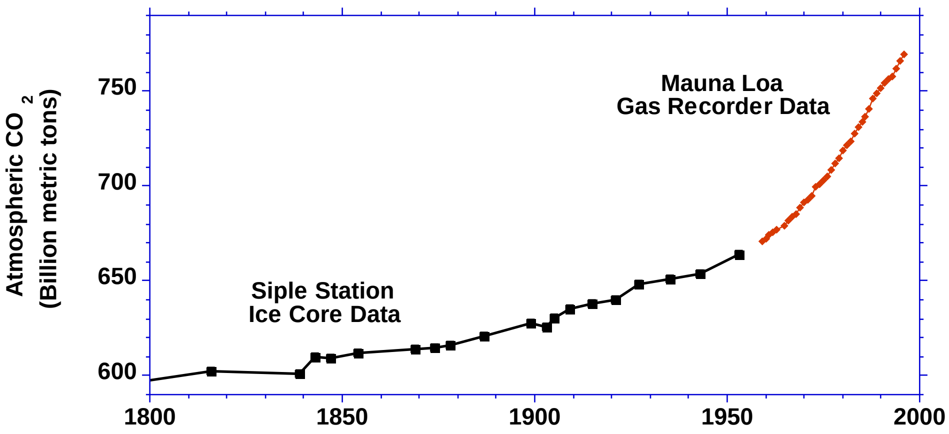
http://climateinteractive.org/simulations/c-learn/simulation



Drivers and response

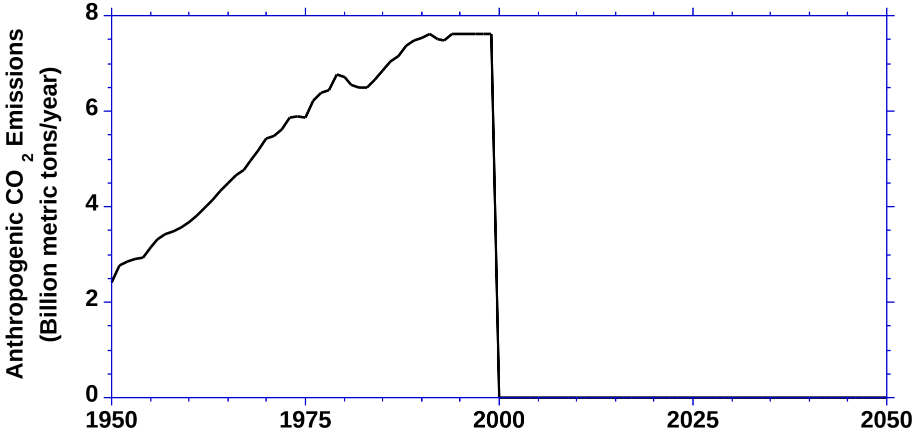


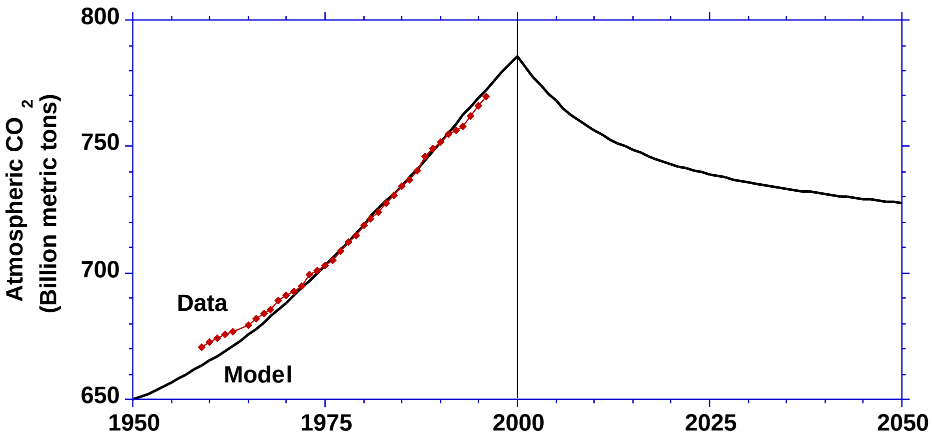




*Source*s: Data from the Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory. Emissions: Keeling (1997). CO_2 in atmosphere: Siple Station ice core data (Neftel et al. 1994). Mauna Loa gas recorder data (Keeling et al. 1997) Global mean surface temperature anomaly: Jones, Wigley and Wright (1997) and Angell (1997); rescaled.

Delays cause significant system inertia





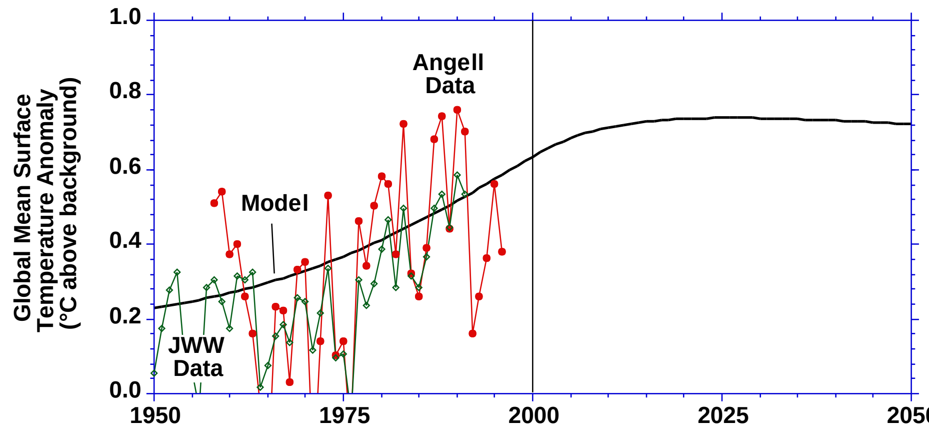
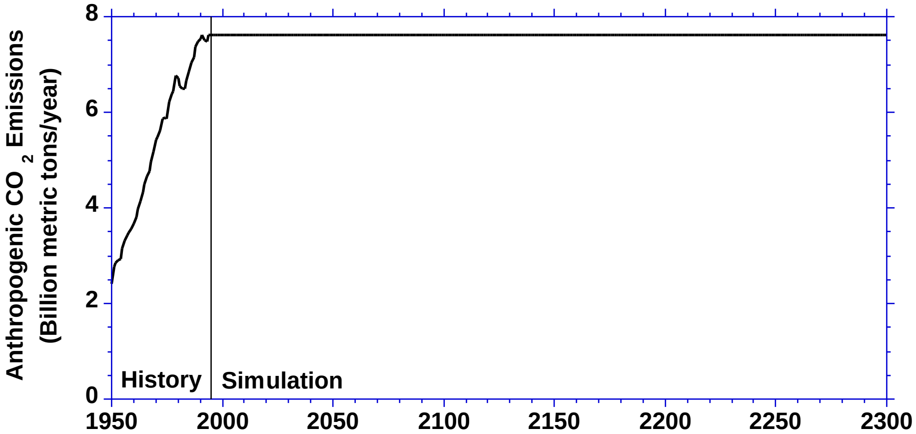
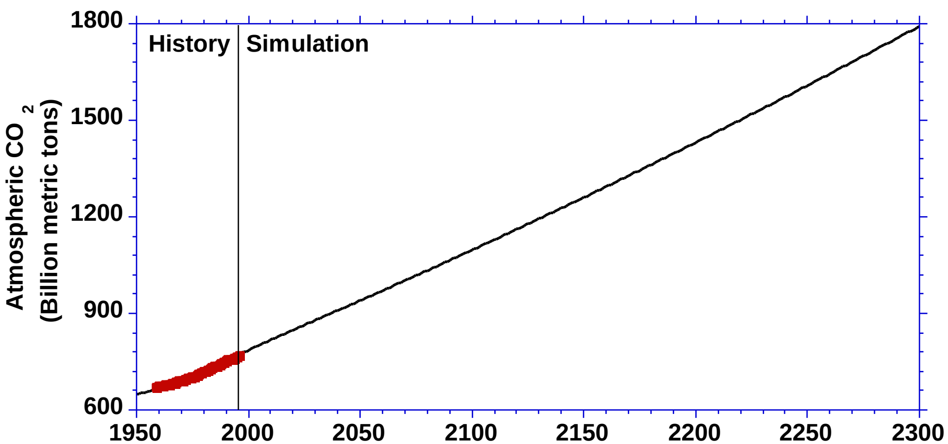


Figure 7-8 Global temperature rises well after TGHG emissions fall to zero. Simulated emissions fall to zero in 2000. Mean surface temperature continues to rise for roughly 20 years.

***Source*: Fiddaman (1997) in Sterman, 2001.**

Stabilizing emissions





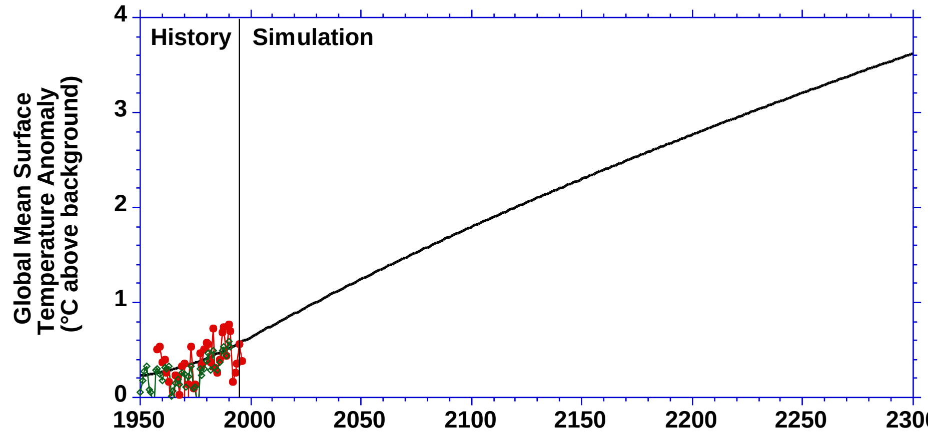


Figure 7-10 Stabilizing GHG emissions does not stabilize the climate.

***Source*: Fiddaman (1997) in Sterman, 2001.**

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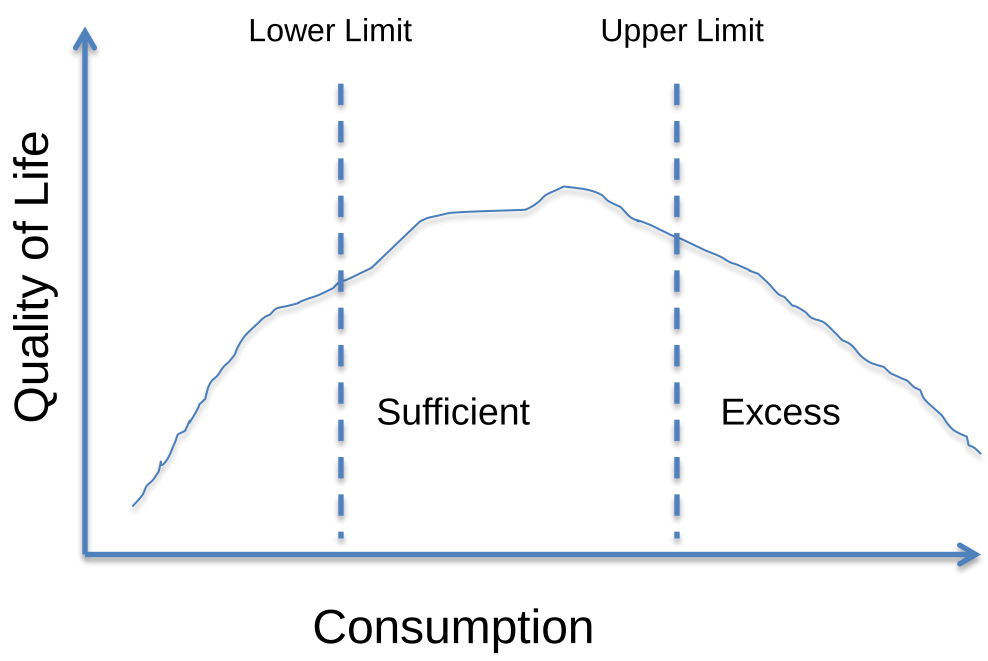
Drivers of societal change

- Technological change
- Substitution of alternatives
- Policy and regulatory requirements
- Changes in consumer preferences

  - Market barriers
  - Overcoming inertia

Drivers of societal change

Thring's sufficiency concept:



Principles of Sustainable Development

1. Clarity
2. Holistic perspective
3. Essential elements
4. Adequate scope
5. Practical focus
6. Openness
7. Effective communication
8. Broad participation
9. Ongoing assessment
10. Institutional capacity

Questions/Comments?