Nanotechnology Supply Chains: A Framework for Evaluating Their Global Implications

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Initiatives of the United Nations System

- Brundtland Report, *Our Common Future*, 1987: "Sustainable Development"
- Sustainable Development Goals (SDGs): 2015 – 2030 (17 goals)

Overview of presentation

- What I do: Scenario analysis
- Relation to the “nanotechnology supply chain”
- Life cycle assessment and input-output economic models
- Nanomaterial taxonomy
- Prototype designs for integrated water and wastewater treatment systems

Scenario analysis

- Model and database of world economy
  - Consumption, production, trade
- Several-decade timeframe
- Assumptions about
  - Demographics
  - Material standard of living
  - Technological choices
  - Availability of ecosystem goods and services

Will we be able to feed 10B people in 2050?

- Baseline assumptions
- Screened alternative scenarios for feasible solutions with low forest clearing and low rise in food prices.

Springer, N. and F. Duchin, 2014. Feeding Nine Billion People Sustainably: Conserving Land and Water through Shifting Diets and Changes in Technologies, *ES&T*, 48(8): 4444–4451.

Assumptions: Nanomaterial production technologies, penetration

- Resource and energy requirements
- Money costs and prices
- International division of labor
- International distribution of income

Explore alternative scenarios to achieve specific objectives.

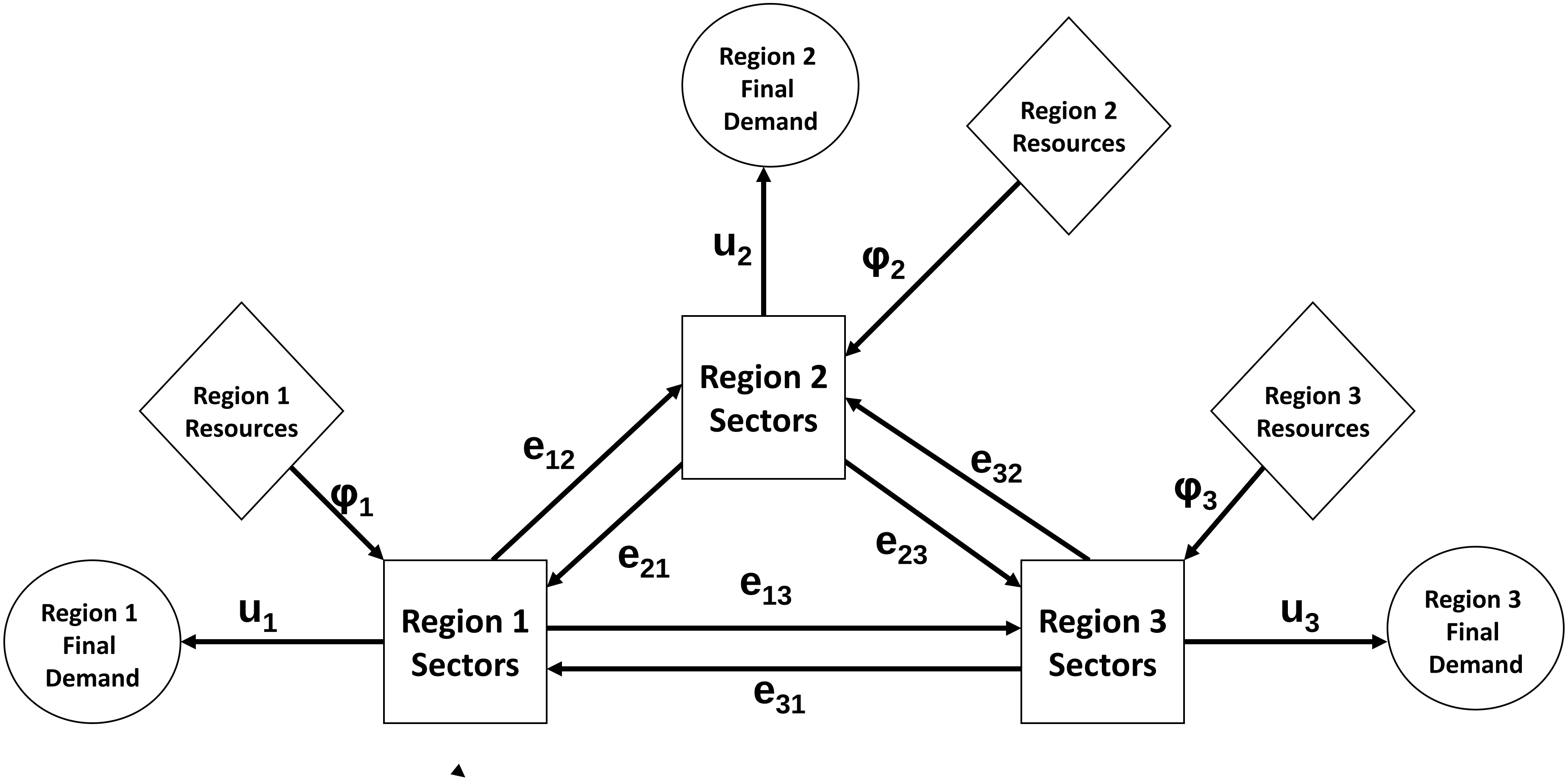
“Nanotechnology supply chain” as building block for a systemwide representation

NM nanomaterials ➔ NIP nano-Intermediate products ➔ NFP final products with embodied nanomaterials

NM → NIP → NFP

Generalize to account for:

- Conventional resources and products
- Network, not a chain
- Technologies employed
- Geographies of production, consumption
- Association with multiple attributes
  - Physical quantities
  - Money values (dual of material flows)
  - Health, safety and environmental implications



Simplified supply network for a 3-region economy

Network-based framework for analyzing alternative scenarios in the global economy requires:

- Database
- Models
- Network analysis applied to model outcomes

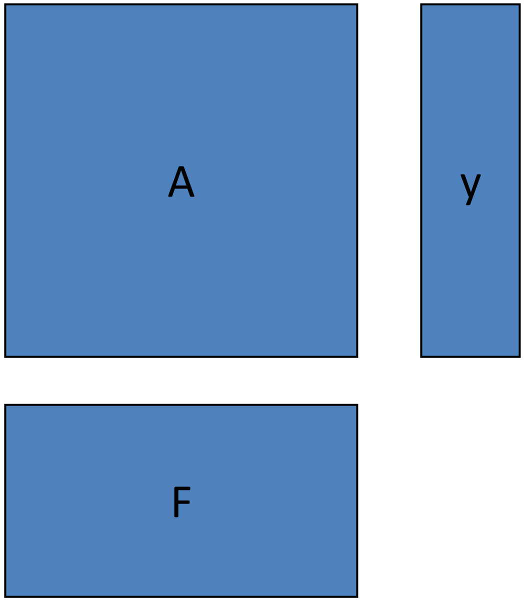
Nano-database does not exist, but important components are available:

- Industrial ecology and Life-Cycle Assessment (LCA)
- Input-output economics and meso-level databases and models
- 20 years experience integrating LCA and input-output models
- Deeper collaboration between LCA and IO

World IO Databases and Models

- First world input-output database and world model 1970s (Leontief, UN)
- National IO databases compiled periodically from censuses and surveys in most countries
- Today several detailed world IO databases, family of world IO models

Basic IO database and model for one region



$x = (I - A)^{-1}y$ Iconic input-output model

$f = Fx = F(I - A)^{-1}y$ associates resources (f) with final demand (y)

WTM Quantity Model (primal)

$$\min Z = \sum_{\mathbf{i}} \boldsymbol{\pi}_{\mathbf{i}}^{T} \mathbf{F}_{\mathbf{i}} \mathbf{x}_{\mathbf{i}}$$

$$\sum_{\mathbf{i}} (\mathbf{I} - \mathbf{A}_{\mathbf{i}}) \mathbf{x}_{\mathbf{i}} = \sum_{\mathbf{i}} \mathbf{y}_{\mathbf{i}}$$

$$\mathbf{F}_{\mathbf{i}} \mathbf{x}_{\mathbf{i}} \leq \mathbf{f}_{\mathbf{i}}$$

$$\mathbf{x}_{\mathbf{i}} \geq \mathbf{0} \ \forall \ i$$

Solves for x_i, p, and r_i

WTM Price Model (dual)

$$\max W = \sum_{\mathbf{i}} (\mathbf{y}_{\mathbf{i}}^T \mathbf{p} - \mathbf{f}_i^T \mathbf{r}_{\mathbf{i}})$$

$$(\mathbf{I} - \mathbf{A}_{\mathbf{i}})^T \mathbf{p} \le \mathbf{F}_i^T (\mathbf{r}_{\mathbf{i}} + \rho_{\mathbf{i}}) \ \forall i$$

$$\mathbf{p} \ge \mathbf{0}, \ \mathbf{r}_{\mathbf{i}} \ge \mathbf{0} \ \forall i$$

What is needed to use this framework to analyze scenarios about the diffusion of nanotechnologies throughout the global economy?

Analytic requirement: nanotechnology taxonomy

- Expand Standard Industrial Classifications to distinguish nanomaterials as products
- Quantify their production technologies (inputs per unit of output, as in LCA)
- Distinguish conventional primary resource inputs for nanomaterial production

Taxonomies and data development

- Service sectors, automation in 1970s
- “Environmentally-extended” input-output databases in 1990s
- World input-output databases in 2000s

Baseline nanotech scenario outcomes

- Global resource and energy requirements
- Contrast conventional materials and products
- Track products upstream to embodied inputs by source region (e.g., in case of illness outbreak)
- Track nanomaterials produced in selected regions downstream to embodiment in final goods.

Sustainable Development Goal #6: Assuring universal access to safe drinking water and "improved sanitation services."

I. Cazcarro, C. Lopez-Morales, and F. Duchin, "Global Economic Costs of the Need to Treat Polluted Water"

- Costs greater by > 1 trillion USD than if water endowments were maintained at higher quality
- Costs increase steeply with further degradation

What about using nanotechnology-based water and wastewater treatment systems?

My recommendation: Complement the global SDG rollout with…

Global Design Prototypes for Integrated Systems for Water and Wastewater Treatment

- Global collaborative effort to produce designs for distinct kinds of settings
- Parallel research agenda on associated risks
- Singapore water management: example of *strategic, whole-system perspective guiding design AND implementation*

Key features

- Civil society initiative, mutually reinforcing UN SDGs
- Focus on a concrete and strategic application
- Prioritize societal concerns and goals and new public-private business models
- Evaluate options with integrated LCA/Input-Output models.

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