Optimizing Resource Conservation Networks

From Barriers to Process Systems Engineering

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Annual Scientific Meeting
National Academy of Science and Technology, July 11-12, 2018

Kathleen B. Aviso, Ph.D.

Qualifications:

- BS ChE (UP-D), MS EnvE (DLSU) and PhD IE (DLSU)
- 95 papers in Scopus-indexed publications (2008 – present)
- *h*-index = 19 (in Scopus), 21 (in Google Scholar)
- Citations: 1177 (in Scopus), 1331 (in Google Scholar)
- Editorial board member, Process Integration and Optimization for Sustainability (Springer)
- Editorial board member, Heliyon (Elsevier)
- Associate Editor, Journal of Cleaner Production (Elsevier, IF = 5.651)
- Author of Input-Output Models for Sustainable Industrial Systems Implementation Using LINGO, Springer

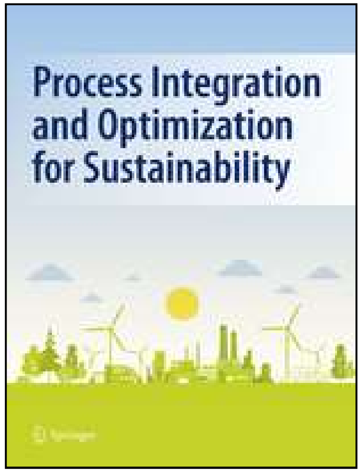
Research Interests:

- Industrial ecology (IE) (Rank 72^{nd} in the world based on Google Scholar)
- Life cycle assessment (LCA) (Rank 101^{st} in the world based on Google Scholar)
- Process systems engineering (PSE) (Rank 57^{th} in the world based on Google Scholar)
- Process Integration (Rank 28^{th} in the world based on Google Scholar)

Awards:

- Asian Scientist 100 – 2017 Edition (2017)
- NRCP Achievement Award (2016)
- Finalist of the ASEAN-US Science Prize for Women (2016)
- National Winner, CHED Republica Award (2016)
- NAST Outstanding Young Scientist (2013)
- Editorial commendation for a highly cited article in *Trans. IChemE Part B* (2012)
- Winner of NAST Talent Search for Young Scientists (2010)
- NAST Outstanding Scientific Paper (2008)

Editorial Board of Scientific Journals



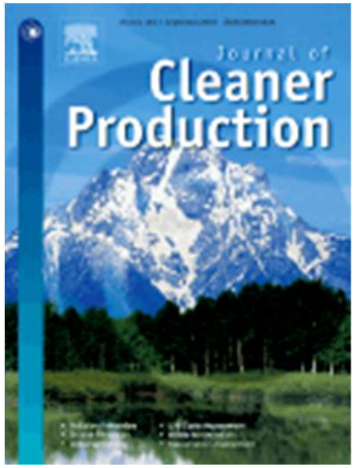
A new journal dedicated to PSE methodology and applications to enhance industrial sustainability.

(www.springer.com/engineering/production+engineering/journal/41660)

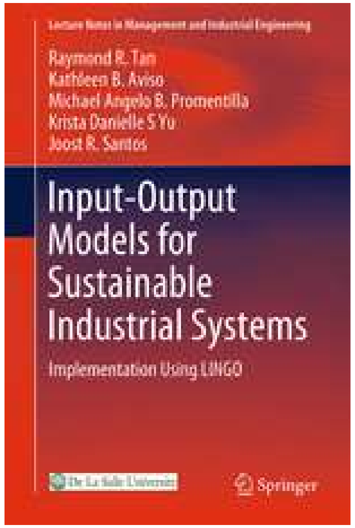
An open access journal which publishes research from various disciplines

(https://www.journals.elsevier.com/heliyon/)

Other Credentials



Associate Editor,
Journal of Cleaner Production
IF = 5.651
(https://www.journals.elsevier.com/journal-of-cleaner-production)



Lecture notes in Management and Industrial Engineering, Springer
(https://www.springer.com/gp/book/9789811318726)

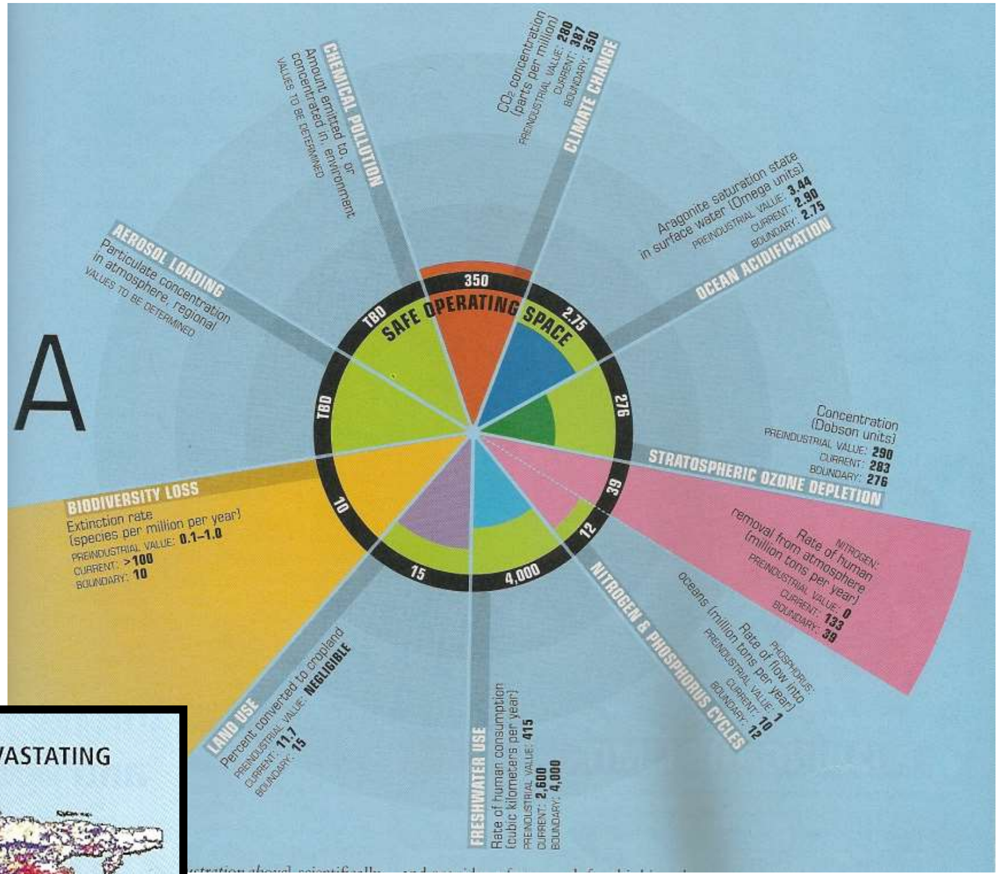
Outline of Presentation

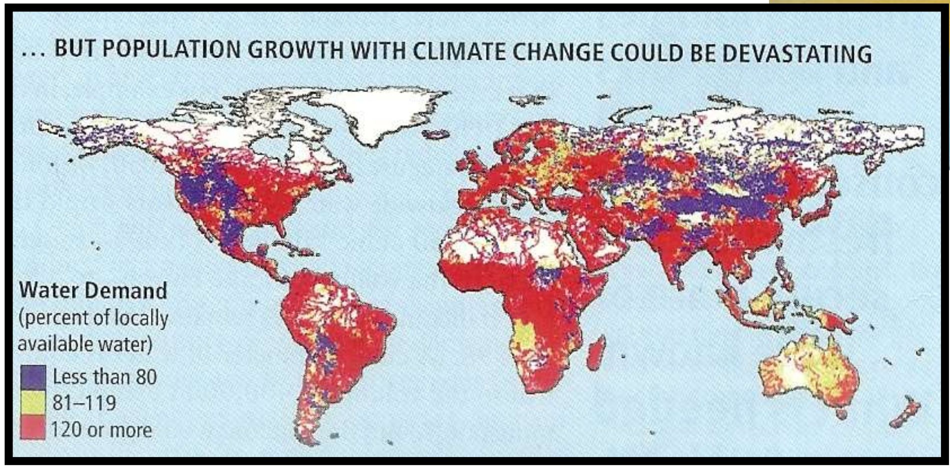
- Global Climate Scenario and Sustainability Issues
- Industrial Ecology and Industrial Symbiosis
- Resource Conservation Networks
- What is PSE?
- Areas of Application
- Conclusions and On-going Work

Introduction

- **Population** and **climate change** impact sustainability

- Different **sustainability strategies** are available





(Rockström et al., 2009)

Sustainability Issues

- Climate change affects several aspects of sustainability

  Water availability

  Water scarcity

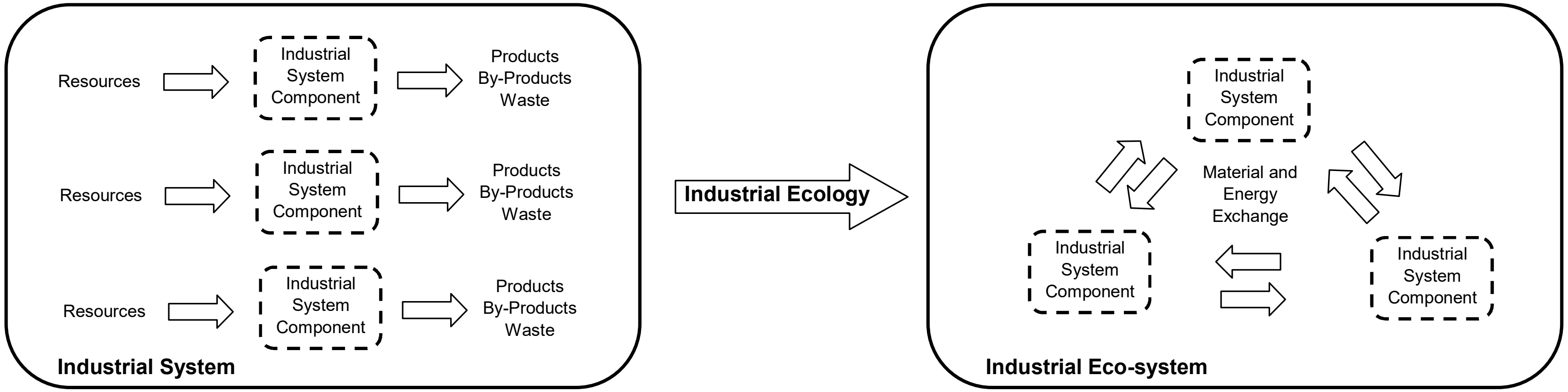
  Resource constraints

  Disease outbreaks

  More severe weather patterns

http://commons.wikimedia.org

Industrial Ecology



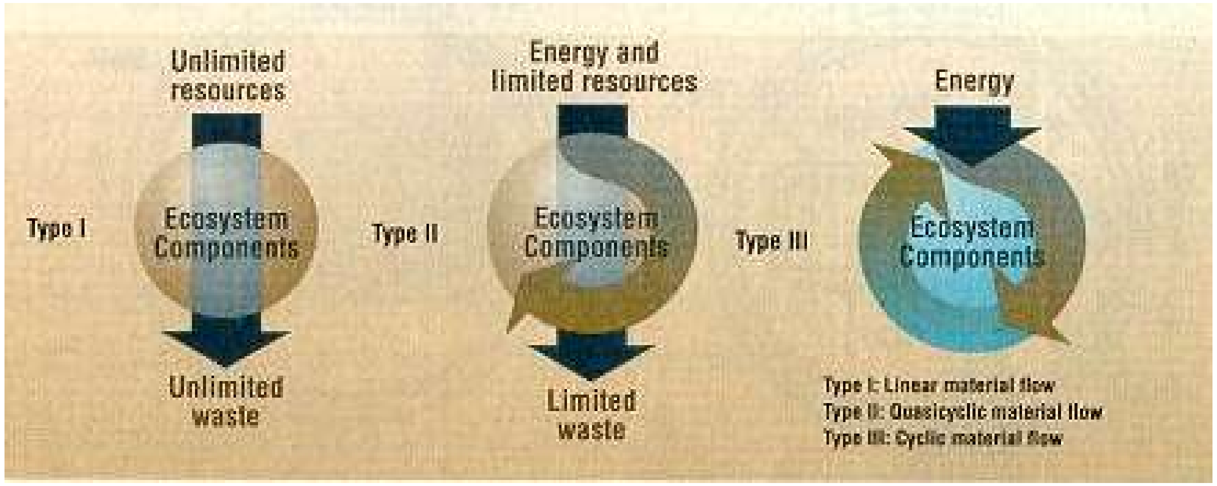
- Popularised in 1989 by Frosch and Gallopoulos
- Analogy between **the industrial system** and **natural ecosystems**
- Waste materials become inputs of another industry
- IE is a systems approach towards sustainability

(Frosch and Gallopoulos, 1989, Scientific American, 261, 94 – 102)

Industrial Symbiosis

- mimic **cyclic flows** in natural ecosystems

•from **linear** to **circular** flow of streams



(Frosch and Gallopoulos, 1989; Lowe and Evans, 1995)

Industrial Symbiosis

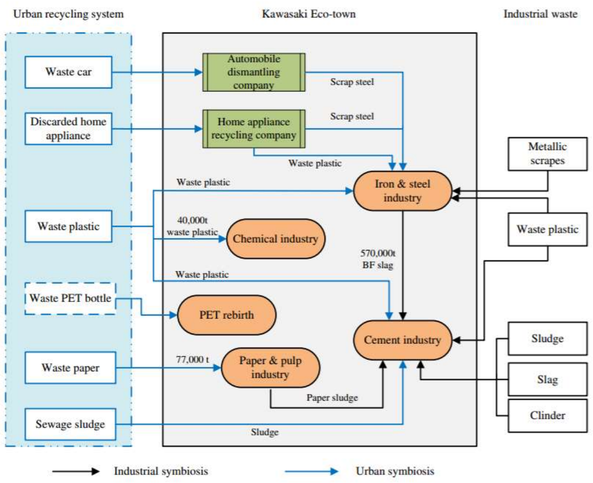
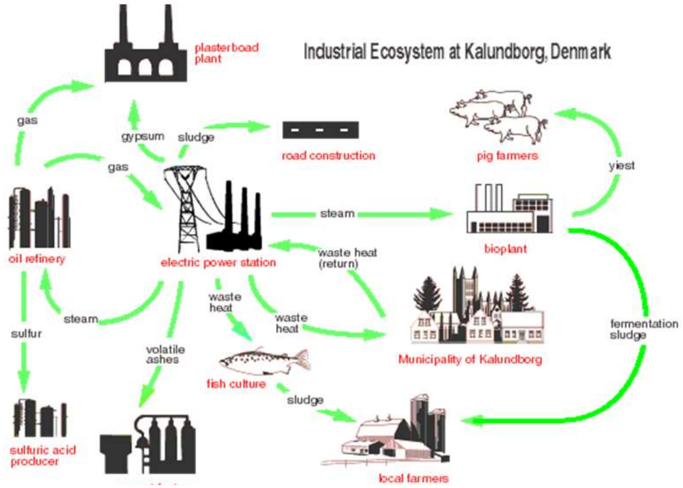
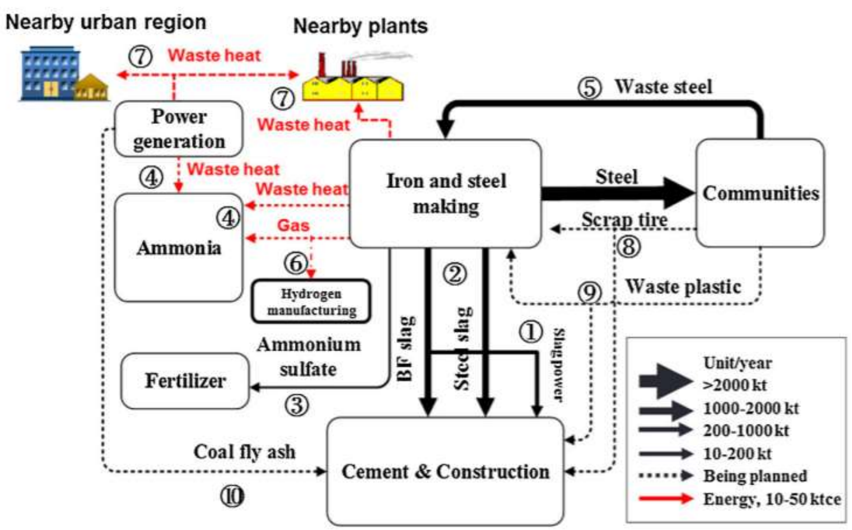


Fig. 2. Material synergy network in Kawasaki Eco-town.





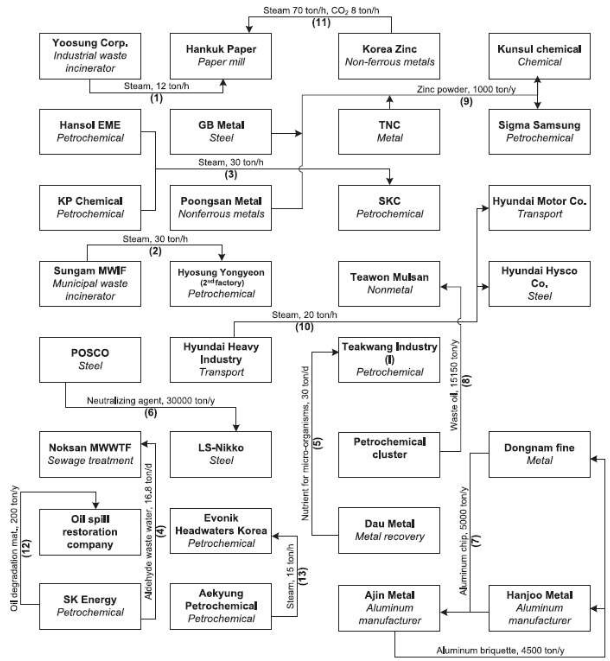
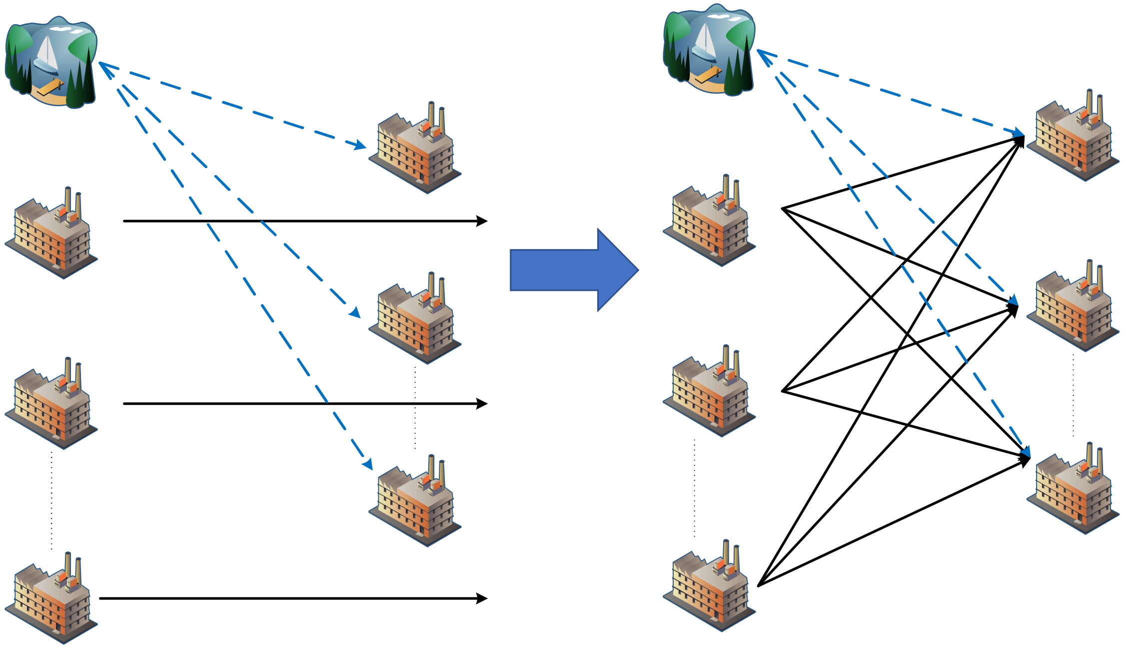


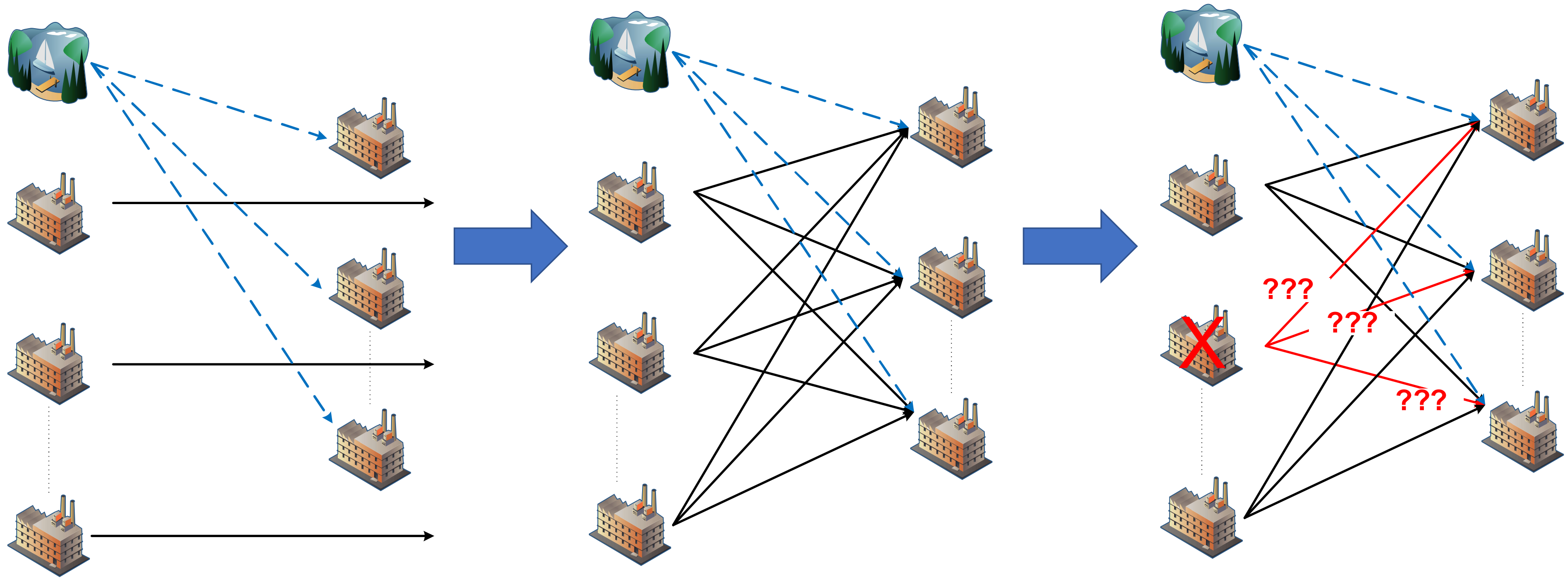
Fig. 5. Overview of symbioses developed in the Ulsan EIP (numbers within bracket along the arrows indicate the networks).

Resource Conservation Networks



- Resource conservation networks (RCN) **minimize environmental impact**
- Common utilities such as **energy and water**
- The goal is to identify the **optimal system design**

Resource Conservation Networks



- Multiple decision-makers
- Increased **interdependence**

Designing Sustainable Systems

Areas of Application

- Resource Conservation Networks
- Efficient Energy Systems
- Sustainable Supply Chains
- Disaster Analysis and Risk Management

Levels of Implementation

- Within a single plant
- Inter-plant or within an eco-industrial park
- Across a product's life cycle
- Across the supply chain
- On a regional/national level
- Inter-regional level

What is PSE?

(Stephanopoulos and Reklaitis, 2011)

Chemical Engineering Science 66 (2011) 4272–4306

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ELSEVIER

Process systems engineering: From Solvay to modern bio- and nanotechnology.
A history of development, successes and prospects for the future

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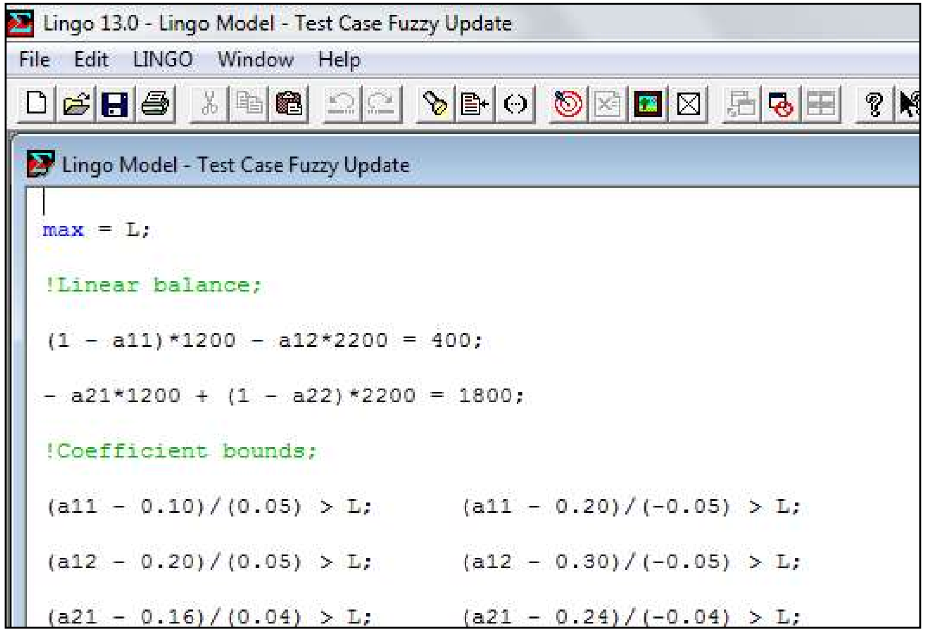
ABSTRACT

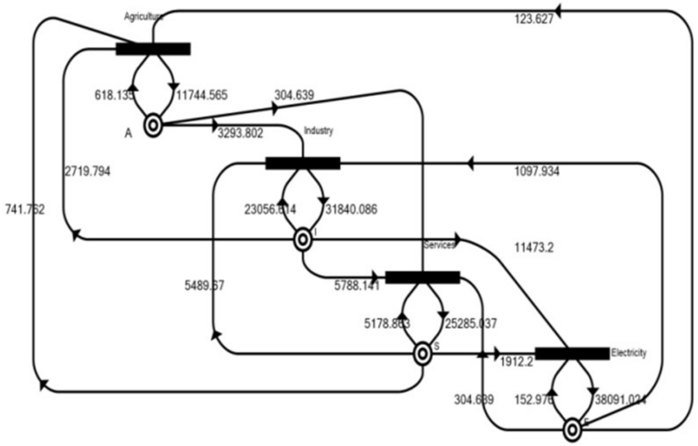
The term Process Systems Engineering (PSE) is relatively recent. It was coined about 50 years ago at the outset of the modern era of computer-aided engineering. However, the engineering of processing systems is almost as old as the beginning of the chemical industry, around the first half of the 19th century. Initially, the practice of PSE was qualitative and informal, but as time went on it was formalized in progressively increasing degrees. Today, it is solidly founded on engineering sciences and an array of systems-theoretical methodologies and computer-aided tools. This paper is not a review of the theoretical and methodological contributions by various researchers in the area of PSE. Its primary objective is to provide an overview of the history of PSE, i.e. its origin and evolution; a brief illustration of its tremendous impact in the development of modern chemical industry; its state at the turn of the 21st century; and an outline of the role it can play in addressing the societal problems that we face today such as; securing sustainable production of energy, chemicals and materials for the human wellbeing, alternative energy sources, and improving the quality of life and of our living environment. PSE has expanded significantly beyond its original scope, the continuous and batch chemical processes

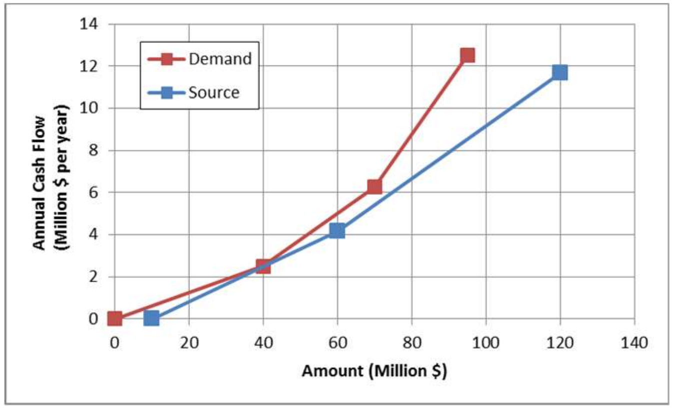
- Computational branch of chemical engineering
- Originally focused on design and operation of process plants
- Also known as "**computer-aided process engineering**" (CAPE), etc.

Why PSE?

- Development of rigorous methods to **aid decision-making**







Mathematical Models as Decision-Support Tools

Follower's objective: $\max \ \lambda$

Subject to:

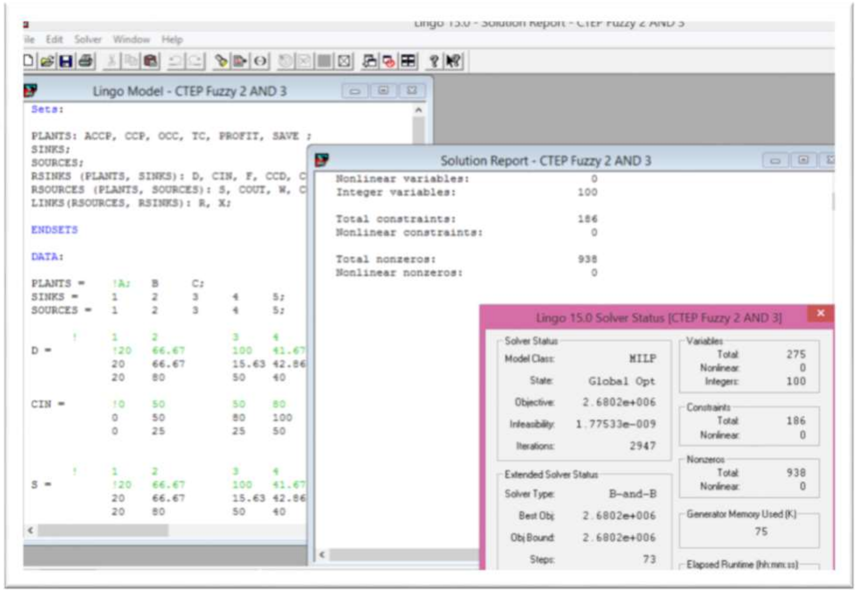
$$\lambda_i = \begin{cases} 0 & \text{if} \quad cost_i > b_i^U \\ 1 - \dfrac{TC_i - b_i^L}{b_i^U - b_i^L} & \text{if} \quad b_i^L \leq cost_i \leq b_i^U \\ 1 & \text{if} \quad cost_i < b_i^L \end{cases}$$

Level of satisfaction

$$\lambda \leq \lambda_i$$

Material balances: $\sum_j r_{ij} + W_i = S_i$ $\quad \sum_i r_{ij} + F_j = D_j$

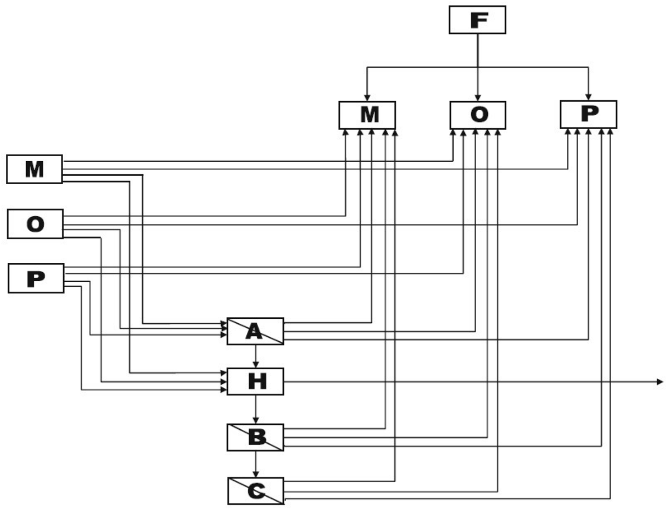
Quality constraints: $\sum_i r_{ij} c_i \leq D_j c_j$

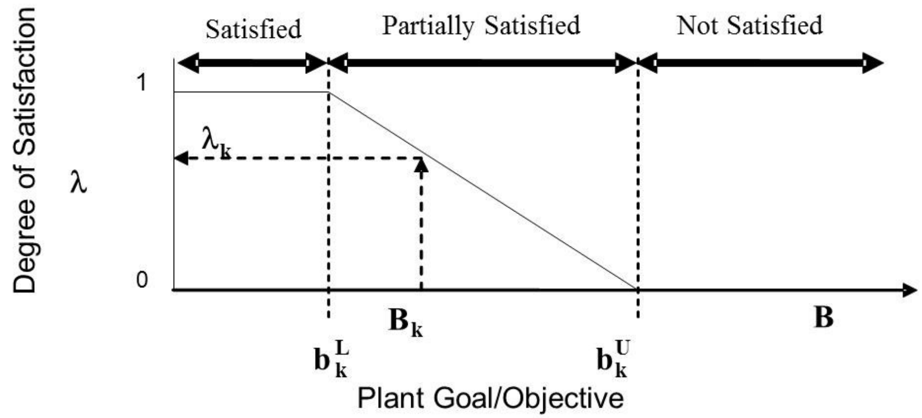


Water Exchange Networks

(Aviso et al., 2009)

- Minimize **fresh resource consumption** or **waste generation**
- Fuzzy optimization integrates **multiple objectives**
- Simultaneous consideration of objectives





Leader – Follower Strategy
(Aviso et al., 2010; Tan et al., 2011)

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Bi-level fuzzy optimization approach for water exchange in eco-industrial parks

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ABSTRACT

In order to minimize the consumption of resources and the generation of waste, eco-industrial parks (EIPs) have been designed to encourage the establishment of waste exchange networks between the plants contained within them. Considering that the participating plants have their individual fuzzy cost goals and that the park authority has the objective of minimizing total freshwater consumption in the EIP, this problem may be formulated as a bi-level
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*This article received an Editorial commendation for being a highly cited article in *Trans. IChemE Part B* (2012)
*most highly cited paper in *PSEP* in 2010

Process Safety and Environmental Protection 89 (2011) 106–111
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A note on an extended fuzzy bi-level optimization approach for water exchange in eco-industrial parks with hub topology

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[b] *Department of Electrical and Computer Engineering, The Ohio State University, 205 Dreese Lab, 2015 Neil Ave., Columbus, OH 43210-1272, USA*

ABSTRACT

In our previous paper, a fuzzy bi-level programming model was developed to determine optimal interplant water integration networks in eco-industrial parks (EIPs). This approach allowed the appropriate incentive mechanisms, in the form of fresh water and effluent fees as well as water reuse subsidies, to be optimized from the perspective of the EIP authority. This work extends the original mathematical model by modifying the role of the EIP authority to include water regeneration and redistribution via a centralized hub. The resulting fuzzy bi-level programming model may then be solved to yield a "satisficing" solution that reflects a reasonable compromise between the EIP authority's desire to minimize fresh water usage, and the participating companies' desire to minimize costs. A case study is used to illustrate the modeling approach.

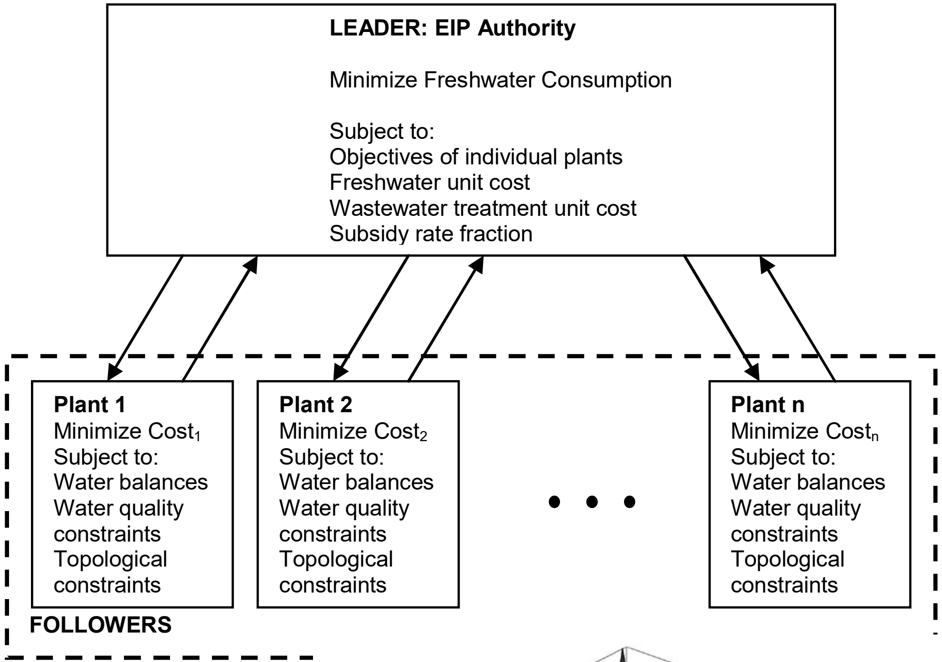
Keywords: Eco-industrial park; Interplant water network; Stackelberg game; Bi-level programming

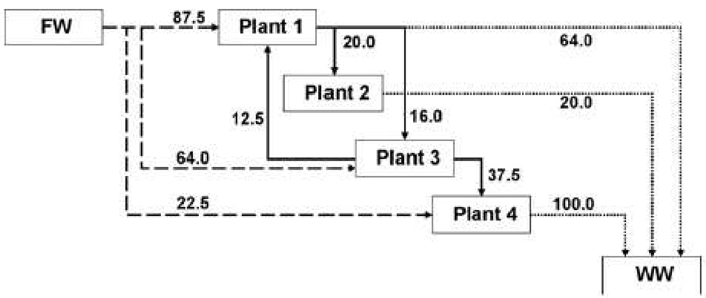
Leader-follower Strategy

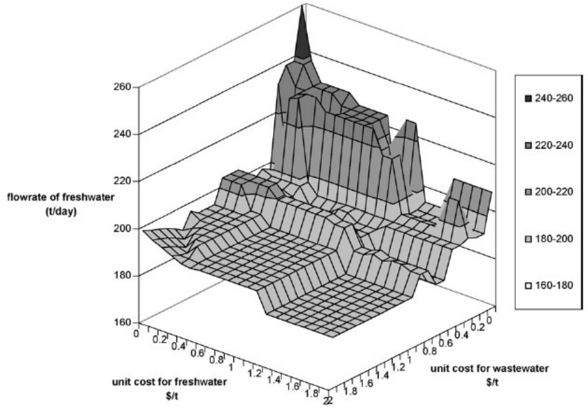
(Aviso et al., 2010)

- **Leader** influences the decision of **follower**

- Government can influence through **incentives** or **disincentives**







Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

*This article was funded by DOST-NAST

SUSTAINABLE PRODUCTION AND CONSUMPTION 7 (2016) 57–65

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Sustainable Production and Consumption

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IChemE

Analyzing barriers to implementing industrial symbiosis networks using DEMATEL

Lindley R. Bacudio[a], Michael Francis D. Benjamin[c], Ramon Christian P. Eusebio[d], Sed Anderson K. Holaysan[b], Michael Angelo B. Promentilla[b,d], Krista Danielle S. Yu[e], Kathleen B. Aviso[b,d,]*

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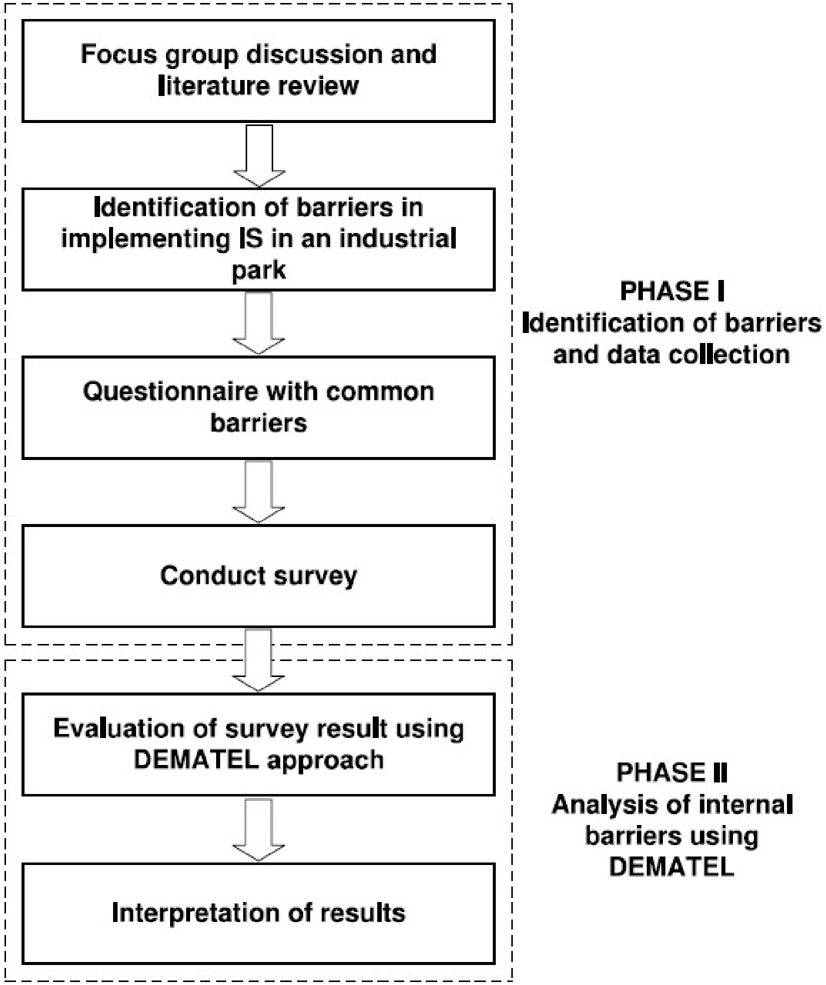
[e] *School of Economics, De La Salle University, Manila, Philippines*

Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

- Decision Making Trial and Evaluation Laboratory (**DEMATEL**)

  (Gabus and Fontela, 1972)
- A problem structuring approach
- Identifies the **cause and effect relationship**



Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

Focus Group Discussion with Industrial Park Stakeholders

Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

Main barriers identified

B1 – Lack of trust

B2 – Lack of information sharing

B3 – Lack of top management support

B4 – Lack of training

B5 – Lack of policy to incentivize initiatives

B6 – Lack of funding

B7 – Lack of technology and infrastructure readiness

B8 – Lack of institutional support

B9 – Lack of willingness to collaborate

B10 – Lack of awareness of IS concepts

Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

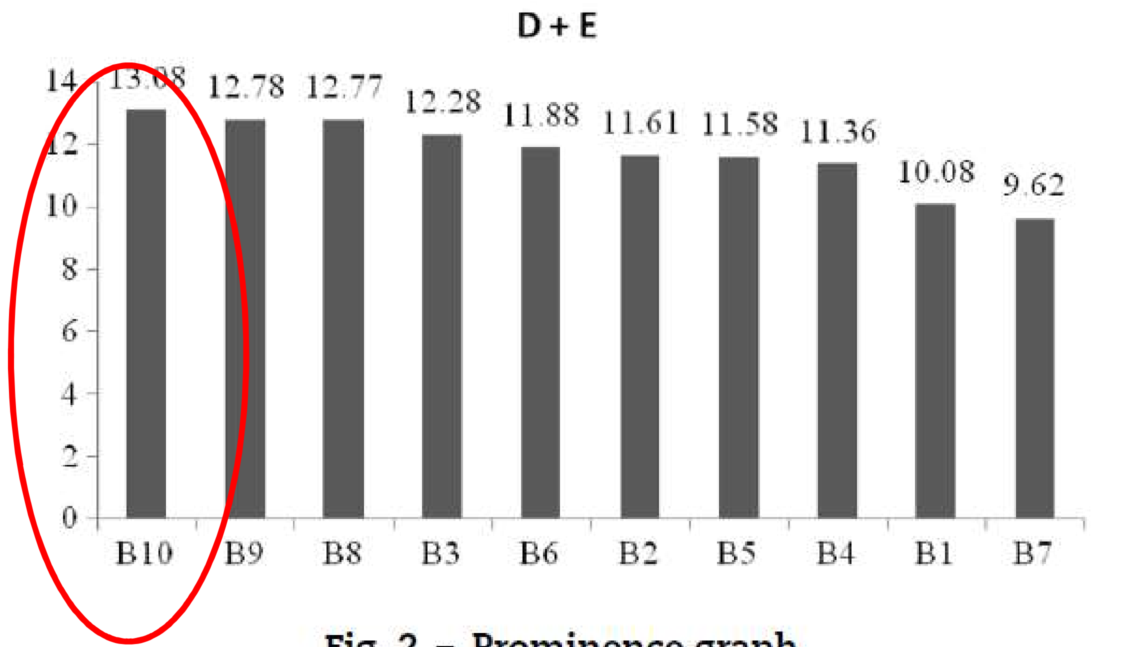


Fig. 2 – Prominence graph.

Highest Prominence Value

Lack in awareness of industrial symbiosis

Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

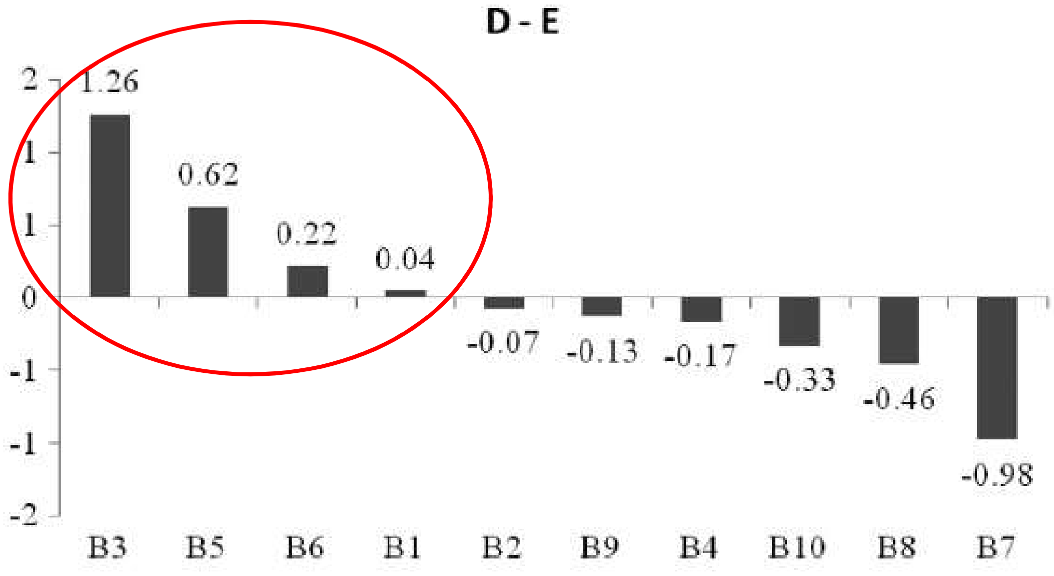


Fig. 3 – Net cause/effect graph.

Causal Barriers

B3 – Lack of top management support

B5 – Lack of policy to incentivize initiatives for Industrial Symbiosis

B1 – Lack of trust among locators

B3 – Lack of funding to promote industrial symbiosis

Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

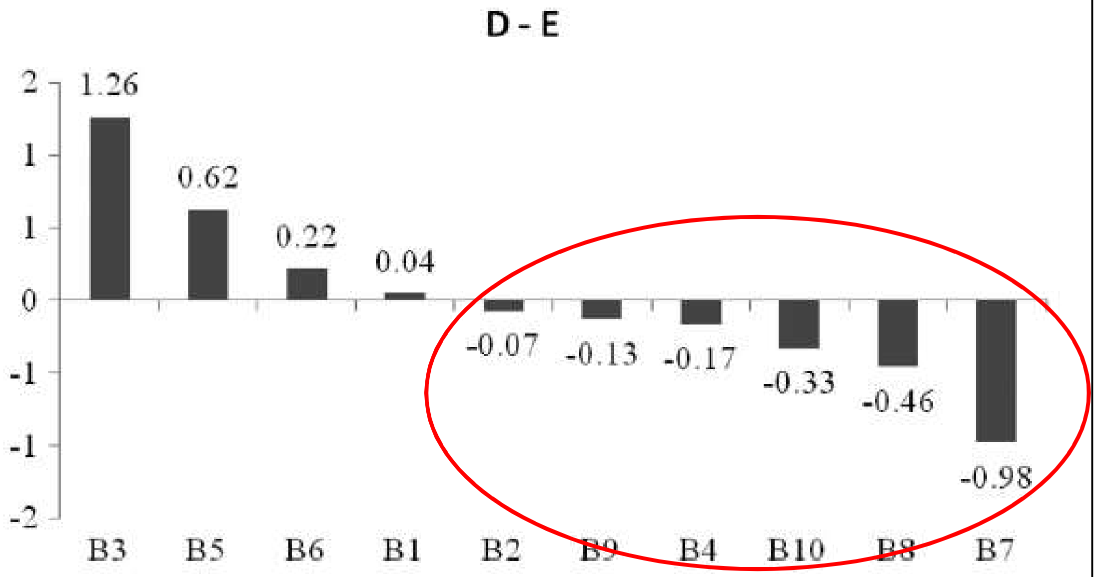


Fig. 3 – Net cause/effect graph.

Effect Factors

B2 – Lack of information sharing

B9 – Lack of willingness to collaborate

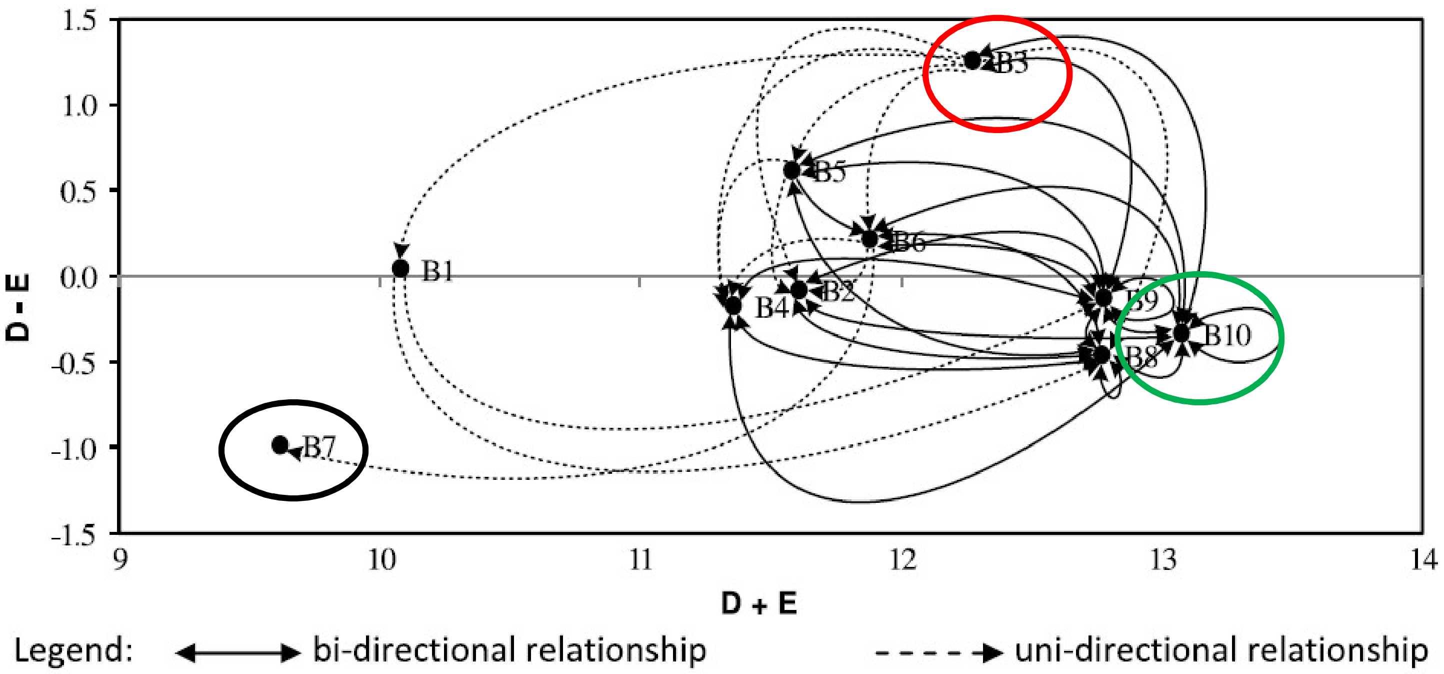
B4 – Lack of training for implementing IS

B10 – Lack of awareness of IS concepts

B8 – Lack of institutional support

B7 – Lack of technology and infrastructure

Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

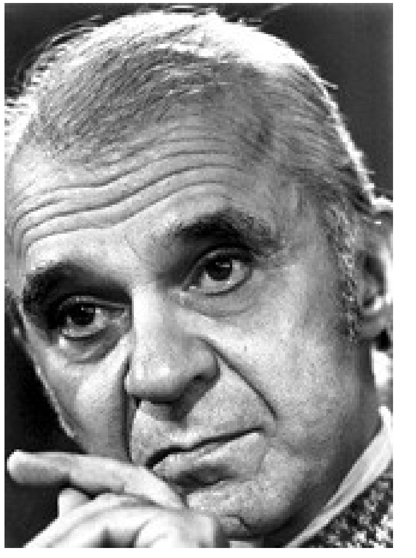


- **Top Management Support** is the most influencing factor
- **Lack of technology and infrastructure readiness** is the least influencing factor
- **Lack of awareness** is the most correlated variable

Analyzing Barriers to Industrial Symbiosis (Bacudio et al., 2016)

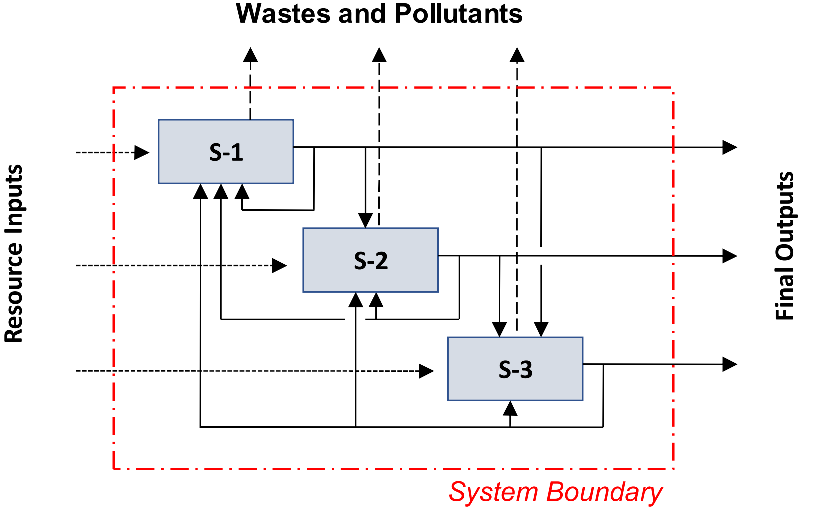
- Effect barriers may be addressed by implementing strategies on Causal barriers
- Priority on **highly correlated** (e.g. lack of awareness) and **most influencing** (e.g. top management support) factors
- Alignment of policies with IS networks

Input-Output Analysis



- Wassily Leontief received the *Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1973*

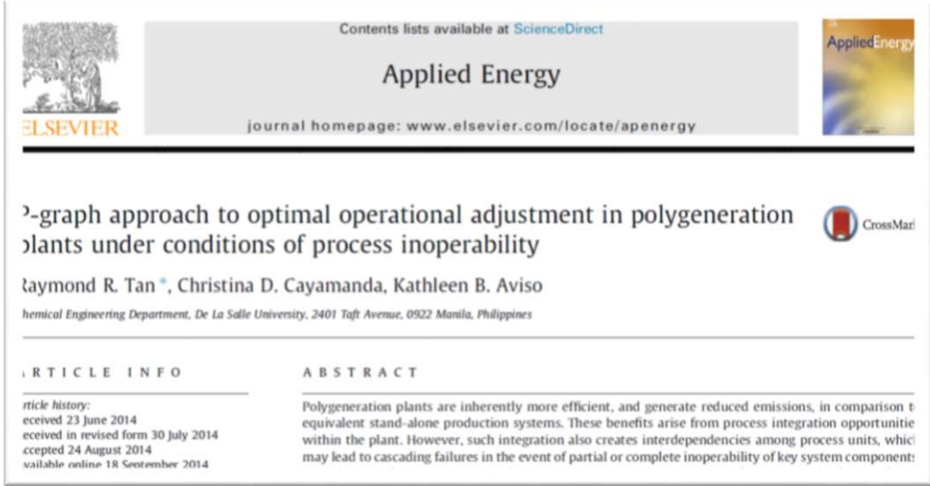
- IO provides a framework for **interdependent systems**



Efficient Energy Systems

(Tan et al., 2014)

- Design of **more efficient** energy systems



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ELSEVIER

P-graph approach to optimal operational adjustment in polygeneration plants under conditions of process inoperability

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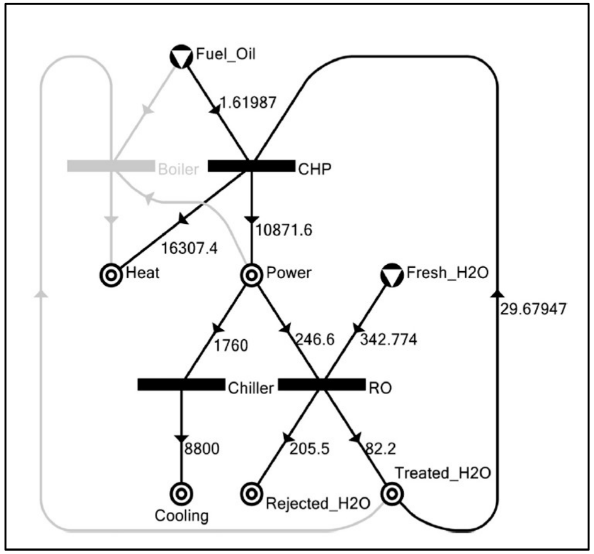
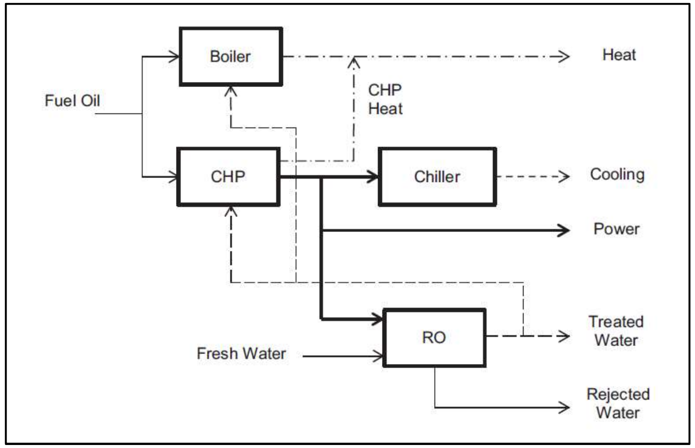
ABSTRACT

Polygeneration plants are inherently more efficient, and generate reduced emissions, in comparison to equivalent stand-alone production systems. These benefits arise from process integration opportunities within the plant. However, such integration also creates interdependencies among process units, which may lead to cascading failures in the event of partial or complete inoperability of key system components





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Designing Under Uncertainty

(Aviso, 2014; Sy et al., 2016)

- Establish more **robust networks**

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Target-oriented robust optimization of polygeneration systems under uncertainty

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[c] Mechanical Engineering Department, De

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ELSEVIER

IChemE

Design of robust water exchange networks for eco-industrial symbiosis

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Designing Under Uncertainty

(Aviso and Tan, 2018)

Energy 154 (2018) 258–268

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ELSEVIER

Fuzzy P-graph for optimal synthesis of cogeneration and trigeneration systems

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Cogener... systems... more ef... nities fo...

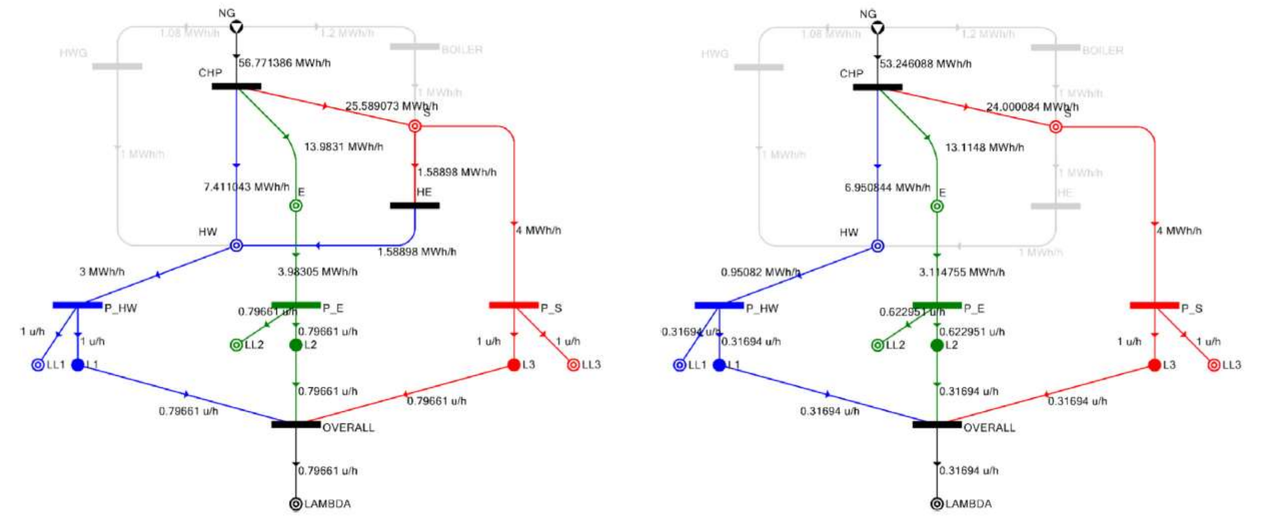

Fig. 7. Solution structure 1 for case study 1 (λ = 0.80).

Fig. 9. Solution structure 3 for case study 1 (λ = 0.32).

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National Academy of Science and Technology, July 11-12, 2018

Enterprise Wide IO Models

(Tan et al., 2016)

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A fuzzy linear programming enterprise input–output model for optimal crisis operations in industrial complexes

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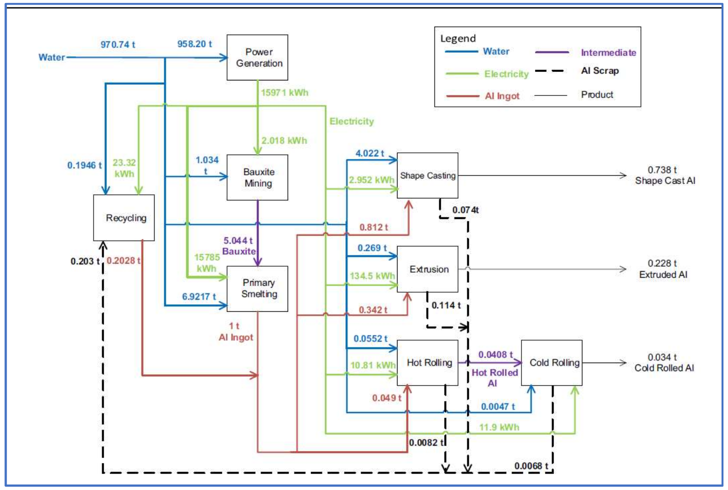
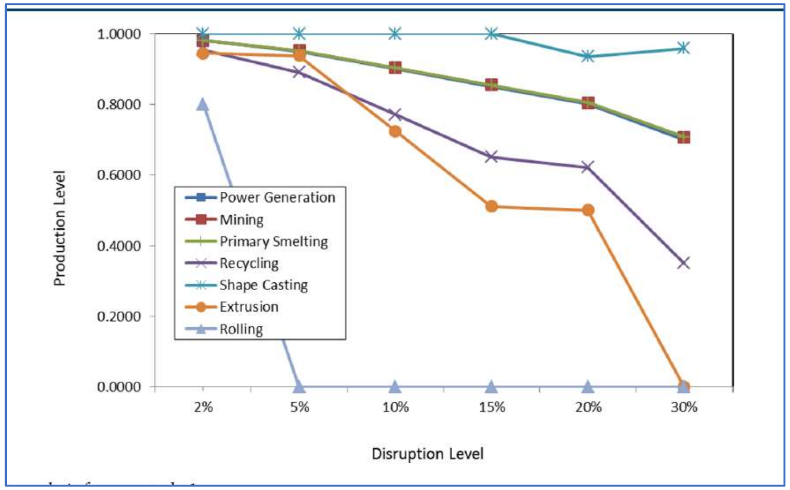
- **Sustainable supply chains**
- Allocation of resources to **minimize the impact of the disruption**

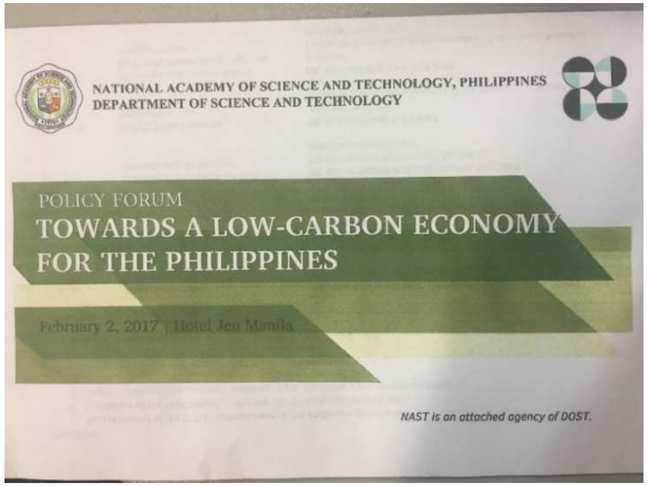


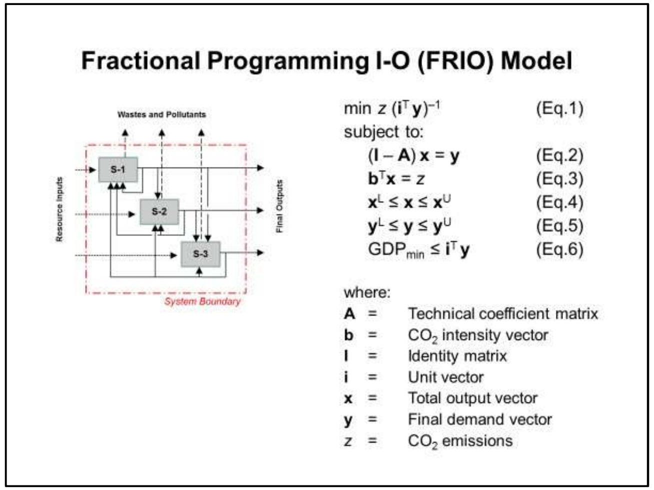


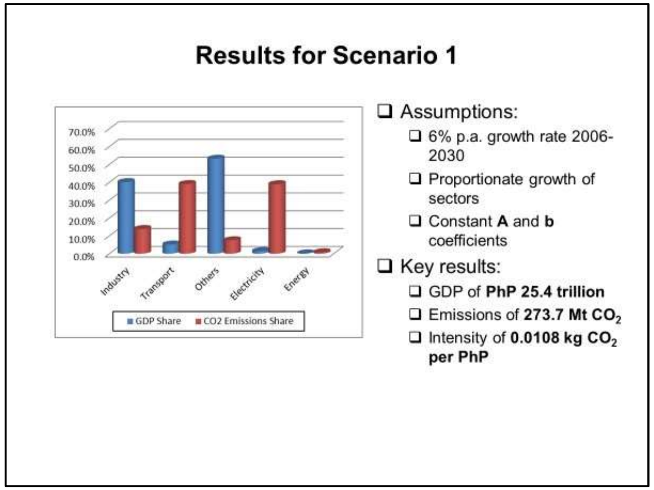
Setting National Environmental Targets

(NAST Policy Forum, 2017; Cayamanda et al., 2017)

- NAST policy forum for a **low carbon economy**
- Targets for carbon dioxide emission reductions with economic growth







Disaster Analysis and Risk Management (Aviso et al., 2015)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P-graph approach for GDP-optimal allocation of resources, commodities and capital in economic systems under climate change-induced crisis conditions

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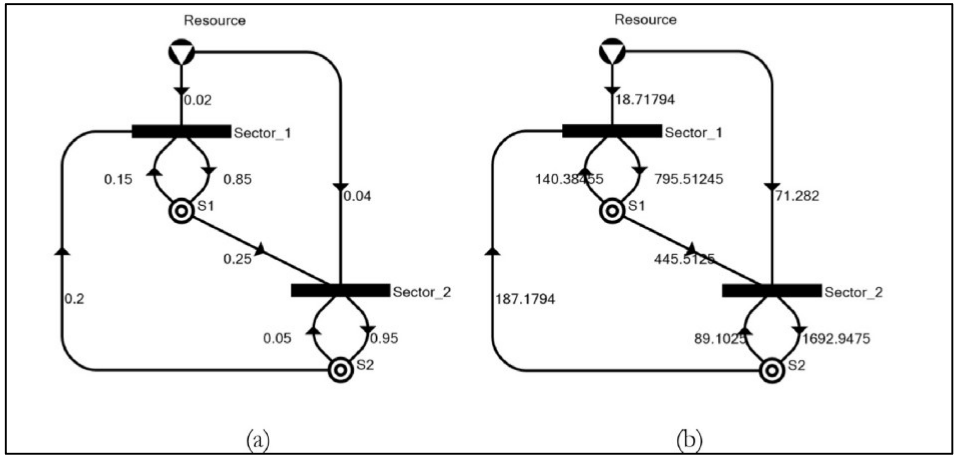

- Impact of climate change on system operations
- Reduced availability of resources

Web-based Tool

www.disaster-realm.net

- **Web-based decision support tool** for simulating the impact of disasters
- Considers sector **inoperability** and **economic loss** resulting from a disruption
- Provides insights for **decision-making**

Conclusions

- The design of sustainable systems can be achieved by **analyzing potential barriers**
- Mathematical models can be developed to identify strategies **to improve the sustainability** of industrial processes
- Models should capture the **interdependence**
- **Optimization** at various levels of the industrial system
- Alignment of policies with IS concepts should be done

On-going Work

- Development of models for other energy, industrial systems, resource conservation networks

  (e.g. hybrid renewable energy systems)
- Focus on the interplay of the **food-energy-water** (FEW) nexus
- Impact of global value chains on local industrial systems
- Applications in the promotion of **Circular Economy**

Acknowledgement

- Department of Science and Technology - National Academy of Science and Technology
- Commission on Higher Education


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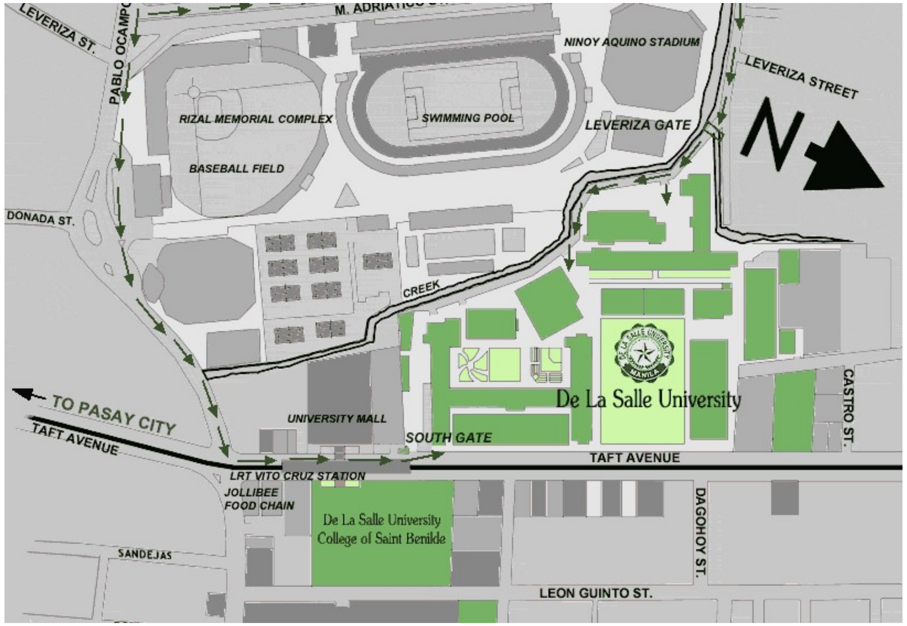
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LEVERIZA GATE
BASEBALL FIELD
N
DONADA ST.
CREEK
TO PASAY CITY
TAFT AVENUE
UNIVERSITY MALL
SOUTH GATE
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LRT VITO CRUZ STATION
JOLLIBEE
FOOD CHAIN
De La Salle University
College of Saint Benilde
DAGOHOY ST.
SANDEJAS
LEON GUINTO ST.


Research Focus
Energy and Environmental Systems Research Group
The development of mathematical models to optimize the planning, design and operations of industrial systems with special emphasis on energy efficiency and environmental footprint reduction
(Rockstrom et al., 2009)

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Photo by Martin San Diego

Thank you

Questions and Comments are Welcome

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