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## Resilience of Eco-Industrial Parks: analysis and solutions for improvements

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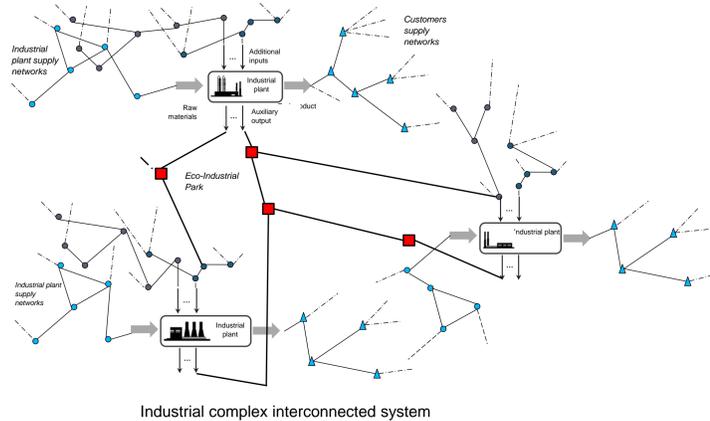
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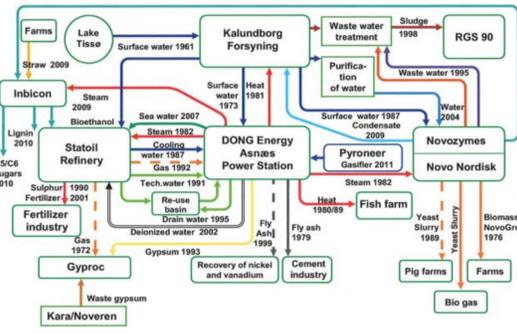
## Introduction

Eco-Industrial Park (EIP) in a complex environment of Critical Infrastructures (CIs)



Industrial complex interconnected system

An Eco-industrial Park (EIP) is a set of manufacturing and service businesses located in the same geographical area. The goal of an EIP is to enhance environmental and economic performance through the creation of Industrial Symbiosis (IS). The material and energy exchanges in an EIP and with external industrial plants, as well as information, logistics and human resources networks, make the EIP vulnerable to internal and external disruptive events due to cascading failure propagation. In this view, studying interdependencies between infrastructures which are critical for the operability of an EIP is primordial to provide solutions for risk management to enhance the resilience of an EIP to disruptive events. This study shows an application of a methodology called Input-Output Inoperability Model (IIM) allowing to analyze interdependencies between critical infrastructures (CIs), applied in the case of Kalundborg EIP.



Topology of Kalundborg Eco-Industrial Park

The identification of the relevant CIs depends on the context of the case study. The definition of CI reported by the U.S. President Commission on Critical Infrastructure Protection (PCCIP), October 1997, defines as "a network of independent, mostly privately-owned, man-made systems and processes that function collaboratively and synergistically to produce and distribute continuous flow of essential goods and services". In this view, eight critical infrastructures whose "incapacity or destruction would have a debilitating impact on our defense and economic security" were defined by this commission: telecommunications, electricity, natural gas and oil, banking and finance, transportation, water supply, government and emergency services.

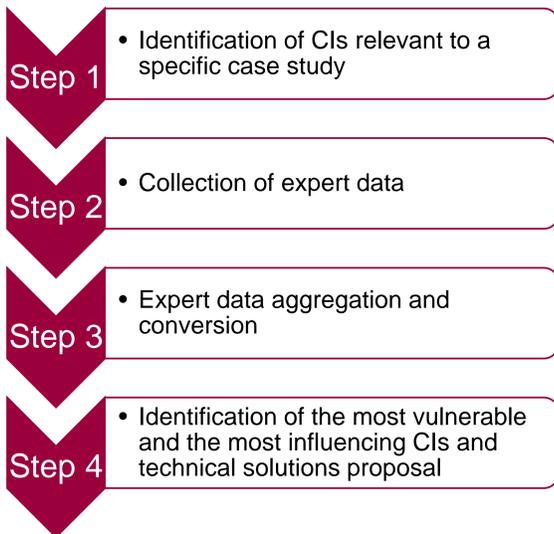
### Main challenge:

- The CIs considered in literature are the classically defined CIs evaluated mainly at global national or international levels without specific relevance to a particular case study.
- Absence of general methodology for identifying CIs relevant to a specific case study.

### Main objective:

- Propose an evaluation methodology using filtering criteria to define CIs relevant to the specific case and test it on the case study of Kalundborg EIP

## Input-Output Inoperability Model (IIM)

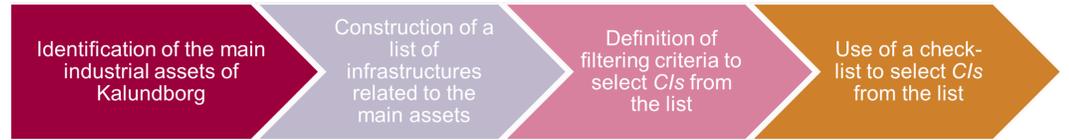


IIM flowchart

## Application of IIM on the Kalundborg EIP

The IIM methodology, used to analyze interdependencies between identified CIs, is based on the following steps:

### Step 1: Identification of CIs relevant to a specific case study of Kalundborg



Proposal of filtering criteria:

Criterion	Definition
Supplying	An interruption or reduction of products/services delivered by an infrastructure may affect the supplying of resources required for the normal functioning of other infrastructure.
Production	An interruption or reduction of products/services delivered by an infrastructure may affect the production of the other infrastructure.
Transport	An interruption or reduction of products/services delivered by an infrastructure may affect the transport of resources required for the normal functioning of the other infrastructure.
Distribution	An interruption or reduction of products/services delivered by an infrastructure may affect the distribution of final products/services delivered by the other infrastructure to the final customers.
Health and safety	An interruption or reduction of products/services delivered by an infrastructure may affect the health or safety of operators working in the other infrastructure.
Security	An interruption or reduction of products/services delivered by an infrastructure may affect the security of equipment/operators of the other infrastructure.
Economy	An interruption or reduction of products/services delivered by an infrastructure may affect the economic situation of the other infrastructure.

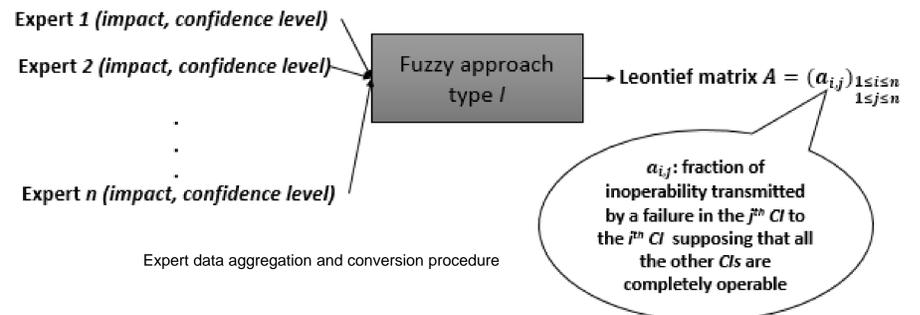
44 CIs related to Kalundborg EIP, including main EIP actors, networks utilities and products, logistics infrastructures, information and human resource networks, have been identified.

### Step 2: Expert data collection

Experts with different expertise levels are asked to give an evaluation of the impact of an outage in resources delivered by other CIs of the system of study on his own infrastructure. The impact is evaluated with a confidence level.

### Step 3: Expert data aggregation and conversion

Expert data are aggregated and converted into numerical values by using the Fuzzy approach type I. This approach takes as inputs the impact evaluation, the confidence level and the expertise level of each expert and convert them into numerical



Expert data aggregation and conversion procedure

### Step 4: Identification of the most vulnerable and the most influencing CIs and technical solutions proposal

- The dependency index  $I_d^i$  of the  $i^{th}$  CI  $\rightarrow I_d^i = \frac{\sum_{1 \leq j \leq n} a_{ij}}{n-1}$
- The influence gain  $I_g^j$  of the  $j^{th}$  CI  $\rightarrow I_g^j = \frac{\sum_{1 \leq i \leq n} a_{ij}}{n-1}$

Dependency Index	Influence Gain
Statoil Refinery (0,0099)	Industrial control system (0,0264)
Novo Nordisk (0,0097)	Electricity network (0,0247)
Novozymes (0,0096)	Human Resources (0,0201)

### Possible technical solutions to consider for Kalundborg EIP resiliency improvement:

- Solution 1:** Storage of lignin fuel, bioethanol and water in Statoil Refinery.
- Solution 2:** Effective maintenance strategies to prevent the industrial control system from failures.

## Conclusions

- Structured and systematic IIM-based methodology for:
  - identifying relevant and most vulnerable CIs for EIP analysis
  - exploring solutions for improved EIP resilience
- Future work:**
  - Extension of the methodology to include economic factors
  - Application to extended case study