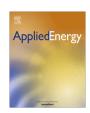
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# Design technologies for eco-industrial parks: From unit operations to processes, plants and industrial networks



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#### HIGHLIGHTS

- A four-level modelling framework is built for the EIP research.
- Advanced mathematical modelling approaches are proposed for each level of problem.
- Efficient optimisation methodologies are developed for solving EIP problems.
- Industrial symbiosis is addressed combining material, water and energy networks.

#### ARTICLE INFO

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#### ABSTRACT

The concept of eco-industrial park (EIP) has recently become the subject of a great deal of attention from industry and academic research groups. This paper proposes a series of systematic approaches for multilevel modelling and optimisation in EIPs. The novelties of this work include, (1) building a four-level modelling framework (from unit level to process level, plant level and industrial network level) for EIP research, (2) applying advanced mathematical modelling methods to describe each level operation, (3) developing efficient methodologies for solving optimisation problems at different EIP levels, (4) considering symbiotic relations amongst the three networks (material, water and energy networks) at the top EIP level with the boundary conditions of economic, social and legal requirements. For methodology demonstration, two cases at process level and industrial network level respectively are tested and solved with the developed modelling and optimisation strategies. Finally, the challenges and applications in future EIP research are also discussed, including data collection, the extension of the current networks to EIPs, and the feasibility of the proposed methodologies for complex EIP problems. The extended EIPs include the combination of material exchanges, energy systems and waste-water treatment networks. The aspects considered for future industrial ecology are carbon emission, by-product reuse, water consumption, and energy consumption. The main object of this paper is to explain the detailed model construction process and the development of optimisation approaches for a complex EIP system. In future work, this system is expected to share services, utility, and product resources amongst industrial plants to add value, reduce costs, improve environment, and consequently achieve sustainable development in a symbiosis community.

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#### 1. Introduction

Numerous aspects of eco-industrial parks (EIPs) have been widely studied over the past decades. According to Chertow [1], in an EIP system, businesses cooperate with each other and the local community to reduce waste and pollution, efficiently share

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resources (such as information, materials, water, energy, infrastructure, and natural resources), and minimise environmental impact to increase business success. Several definitions for the concept of EIP have been reported in the literature. However, a basic principle for EIP is that the total benefit (improvements to social, economic and environmental impacts) achieved by working cooperatively is higher than working as a standing alone facility [2]. Kastner et al. [3] reviewed the recent developed quantitative tools and methods identifying and cultivating industrial symbiotic exchanges in existing industrial parks to minimise overall energy

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| short-sea shipping CO <sub>2</sub> emission for transporting per material amount per distance  short-sea shipping transportation cost per material amount and distance  truck transportation cost per material amount and distance  ctax carbon tax  cwpt transportation cost per material amount and distance for short-sea pipelines  disa <sub>s</sub> distance between source r and demand d drtr <sub>r,d</sub> distance between source r and demand d ds with short-sea pipelines  icwpt installation cost per distance for installing land pipelines  icwpt interest factor of the project lifetime installation cost per distance for installing short-sea pipelines  ify prices of source r sold in the local market ipr <sub>r</sub> prices of source r sold in the local market ipr <sub>r</sub> maximum exponent of input parameters in a reformatted surrogate model (Eq. (3))  K maximum exponent of input parameters in a reformatted surrogate model (Eq. (3))  k maximum exportation cost per material amount and distance transportation cost per material transported to demand d with short-sea pipelines  total amount of material transported from source r ricr <sub>r</sub> total amount of material transported from source rs transported from source r ricr <sub>r</sub> total amount of material transported from source rs transported from source rs transported from source rs transported from source r stransported from source r ricr <sub>r</sub> d with trucks total amount of material transported from source r total amount of material transported from source r transporting source rs total amount of material transported tode mand d with trucks total material purchasing cost in a material metwork transportation cost for transporting source rs to demand ds with short-sea ships  total amount of material transported tode for transporting source rs total material purchasing cost in a material ransported tode mand ds witc <sub>rs,ds</sub> total material purchasing cost in a material ransported to demand ds witc <sub>rs,ds</sub> total material transported to demand ds witc <sub>rs,ds</sub> total material transported to demand ds witc <sub>rs,ds</sub> total material purchasing c                              | clpt          | transportation cost per material amount and distance       |                        | short-sea ships  |  |
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| csst short-sea shipping transportation cost per material amount and distance  ct truck transportation cost per material amount and distance  ctax carbon tax  cwpt transportation cost per material amount and distance for short-sea pipelines  dja total amount of material transported to demand d distance between source r and demand ds drtr,d dwtrs,ds sea distance between source rs and demand ds dwtrs,ds sea distance between source rs and demand ds drt distance between source rs and demand ds drt distance between source rs and demand ds flo mean value of f(x) in an HDMR surrogate model (Eqs. (1) and (2))  icwpt installation cost per distance for installing land pipelines  ify interest factor of the project lifetime ipr prices of source r sold in the local market ipr, prices of source r sold in the local market ipr, prices of source r sold in the local market k exponent of x <sub>i</sub> in a reformatted surrogate model (Eq. (3))  K maximum exponent of input parameters in a reformatted surrogate model (Eq. (3))  ricat carbon tax transportation cost for transporting source r to demand d with trucks total material purchasing cost in a material network total material purchasing cost for transporting source rs to demand ds with short-sea pipelines  wtc <sub>rs,ds</sub> transportation cost for transporting source rs to demand ds with short-sea pipelines  wtc <sub>rs,ds</sub> transportation cost for transporting source rs to demand ds with short-sea pipelines  wtc <sub>rs,ds</sub> transportation cost for transporting source rs to demand ds with short-sea pipelines  transportation cost for transporting source rs to demand ds with short-sea pipelines  wtc <sub>rs,ds</sub> transportation cost for transporting source rs to demand ds with short-sea pipelines  transportation cost for transporting source rs to demand ds with short-sea pipelines  transportation cost for transporting source rs to demand ds with short-sea pipelines  transportation cost for transporting source rs to demand ds with short-sea pipelines  transportation cost for transported to demand ds with short-sea   |               |  | $ri_r$                 | total amount of material transported from source r   |  |
| ct truck transportation cost per material amount and distance  ctax carbon tax  cwpt transportation cost per material amount and distance  for short-sea pipelines  dja total amount of material transported to demand d djs <sub>ds</sub> total amount of material transported to demand d dtr <sub>r,d</sub> distance between source r and demand d sea distance between source r and demand d dwtr <sub>s,ds</sub> sea distance between source r and demand d mean value of f(x) in an HDMR surrogate model (Eqs. (1) and (2))  iclpt installation cost per distance for installing land pipelines itcwpt installation cost per distance for installing short-sea pipelines ify interest factor of the project lifetime ip <sub>r</sub> prices of source r sold in the local market ip <sub>s</sub> prices of source r sold in the local market k exponent of x <sub>i</sub> in a reformatted surrogate model (Eq. (3))  K maximum exponent of input parameters in a reformatted surrogate model (Eq. (3))  d with trucks total material transportation CO <sub>2</sub> emission in a material network  total material purchasing cost in a material network  wtcr <sub>s,ds</sub> transportation cost for transporting source rs to demand ds with short-sea pipelines  transportation cost for transporting source rs to demand ds with short-sea hipportation cost for transporting source rs to demand ds with short-sea hipportation cost for transporting source rs to demand ds with short-sea hipportation cost for transporting source rs to demand ds with short-sea hipportation cost for transporting source rs to demand ds with short-sea hipportation cost for transporting source rs to demand ds with short-sea hipportation cost for transporting source rs to demand ds with short-sea hipportation cost for transporting source rs to demand ds with short-sea hipportation cost for transportation cost for transported to demand ds with short-sea hipportation cost for installing h  | csst          | short-sea shipping transportation cost per material        |                        |  |  |
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| K maximum exponent of input parameters in a reformat-<br>ted surrogate model (Eq. (3)) $wt_{rs,ds}$ pipelines; otherwise, it is 0<br>1 if source rs is transported to demand ds with short-sea  |               |  |                        |  |  |
|   |               | maximum exponent of input parameters in a reformat-        | wpt <sub>rs,ds</sub>   | pipelines; otherwise, it is 0  |  |
|   | M             |  | $wt_{rs,ds}$           |  |  |

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