Green Virtual Enterprise Breeding Environments: A Sustainable Industrial Development Model for a Circular Economy

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Abstract. A Green Virtual Enterprise Breeding Environment (GVBE) is a long-term strategic alliance of green enterprises and their related support institutions aimed at offering the necessary conditions to efficiently promote the sharing and recycling of resources such as: information, materials, water, energy and/or infrastructure with the intention of achieving sustainable development in a collaborative way. A GVBE can be a three-level holistic sustainable industrial development model for achieving a Circular Economy at a micro-level with its green enterprises development, at meso-level with green virtual enterprises creation and at a macro-level with the GVBE it-self as an intelligent network for competencies and resources management from different green enterprises aiming to combine their green capabilities to develop triple top-line strategies to create sustainable value. This paper provides basic concepts and general guidelines to create sustainable industrial development models for Circular Economy based-on Collaborative Networked Organisations.

Keywords: Collaborative Networked Organisations, Circular Economy, Green Virtual Enterprises, Breeding Environments, Industrial Ecology, Industrial Symbiosis, Sustainable Industrial Development.

1 Introduction

A New Economy is emerging based on sustainable design and innovation [1] [2]. *Circular Economy (CE),* also called 'material close economy' or 'lifecycle economy', is an alternative model to the one-way model of economic activities characterised by linear flows of resources → products → wastes. *CE* aims a "sustainable economy", a closed-loop model of economic activities creating feedback cycles of resources → products → renewable resources, following the 3R principles or operating rules of reduce, reuse and recycle in the processes of production, logistics and consumption in order to achieve a sustainable industrial development. *CE* aims to meet sustainable consumption and production through (a) cleaner production, (b) industrial ecology and (c) lifecycle management / assessment, seeking to create a balance between economic development and environmental protection [2].

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Cleaner production (CP) refers to "the continuous application of an integrated, preventative environmental strategy to processes, products and services to increase eco-efficiency and reduce risks to humans and the environment". For *processes, CP* results from conserving raw materials, water and energy; eliminating toxic and dangerous raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process. For *products, CP* aims to reduce the environmental, health and safety impacts of products over their entire lifecycles, from raw materials extraction, through manufacturing and use, to the disposal of the product. For *services, CP* implies incorporating environmental concerns into designing and delivering services [3].

Industrial Ecology (IE) aims at "the shifting of industrial processes from linear (open-loop) systems, in which resource move through the system to become waste, to a closed-loop system where wastes can become inputs for new processes". *IE* focuses on eco-restructuring the industrial processes by: optimising the use of resources; closing material loops and minimising emissions; dematerialising activities; and reducing and eliminating the dependence on non-renewable sources of energy [4].

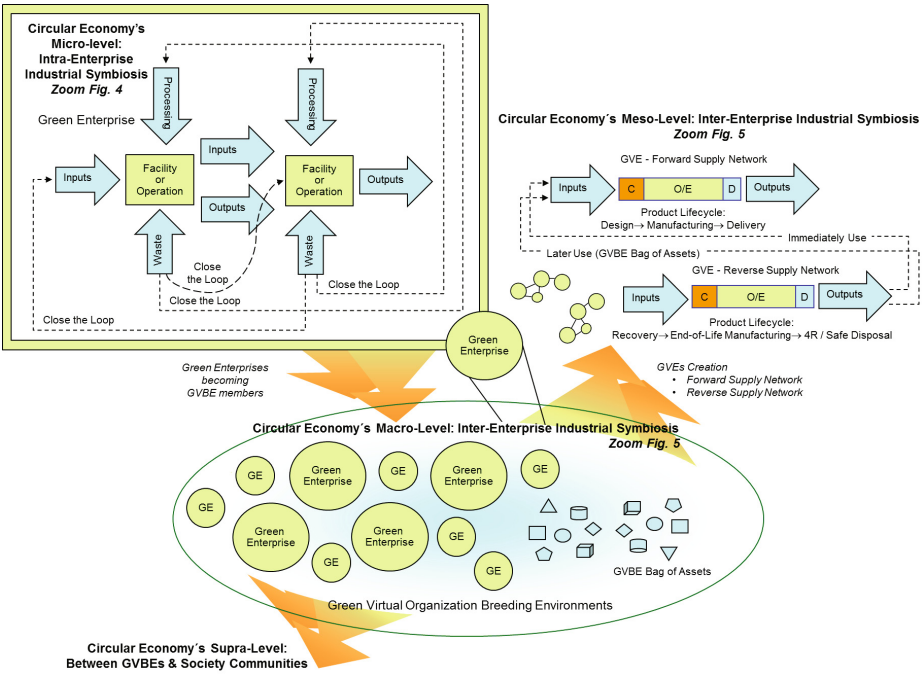

Fig. 1. GVBE Three-Level Holistic Sustainable Industrial Development Model

Lifecycle Management (LM) refers to "the process of managing the entire lifecycle of a product from its conception (imagine, specify plan, innovate), through design (define, develop, test, analyse and validate) and manufacture (make, build, procure, produce, sell and deliver) to service (use, operate, maintain, support, sustain) and

disposal (phase-out, retire, recycle, safe-disposal)", while *Lifecycle Assessment (LCA)* is "a technique to assess environmental impacts associated with all the stages of a product´s life from-cradle-to-grave, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling". *LCA* can help avoid a narrow outlook on environmental concerns by compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential impacts associated with identified inputs and releases; and interpreting the results to help to make more informed decisions [5].

A *Green Virtual Enterprise Breeding Environment (GVBE)* is a long-term strategic alliance of green enterprises and their related support institutions aimed at offering the necessary conditions to efficiently promote the sharing and recycling of resources such as: information, materials, water, energy and/or infrastructure with the intention of achieving sustainable development in a collaborative way [6] [7]. A *GVBE* can be a three-level holistic *sustainable industrial development model* (see Fig. 1) for achieving a *Circular Economy* at a *micro-level* with its green enterprises development, at *meso-level* with green virtual enterprises creation and at a *macro-level* with the *GVBE* it-self as an intelligent network for competencies and resources management from different green enterprises aiming to combine their green capabilities to develop triple top-line strategies to create sustainable value. This paper provides basic concepts and general guidelines to create *sustainable industrial development models* for *Circular Economy* based-on *Collaborative Networked Organisations.*

2 Green Enterprises: Circular Economy's Micro-level

A *Green Enterprise* is an enterprise that strives to meet the triple bottom line by ensuring that all products, processes, manufacturing and logistics activities in its business operation address the sustainable principles [6] (see Fig. 2).

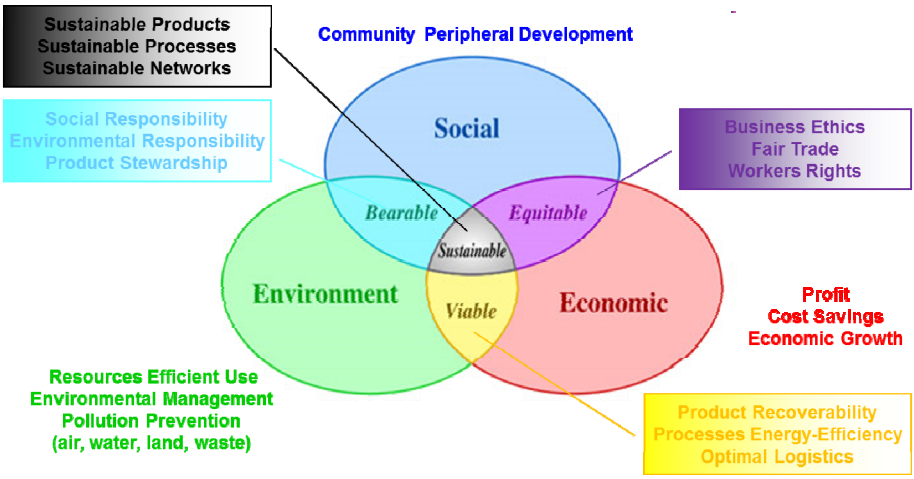

Fig. 2. Green Enterprise Operating Principles

According to the *Circular Economy* literature, the baseline of a strategy to develop a *Circular Economy* starts with the establishment of more *Green Enterprises* in the industrial landscape, representing the micro-level (small-cycle) of a *sustainable industrial development model.* Modern enterprises should then adopt "green enterprise systems" (see Fig. 3) [8] in their business operation in order to become *Green Enterprises,* continuously monitoring, analysing, re-designing and implementing a triple top-line[1] value production (for a product) or a triple top-line value offering (for a service) as conditions change and new opportunities emerge for achieving new sustainability levels. G*reen Enterprises* aim to change the way products are manufactured and the way services are provided to the customers towards a *sustainable enterprise development model* [9].

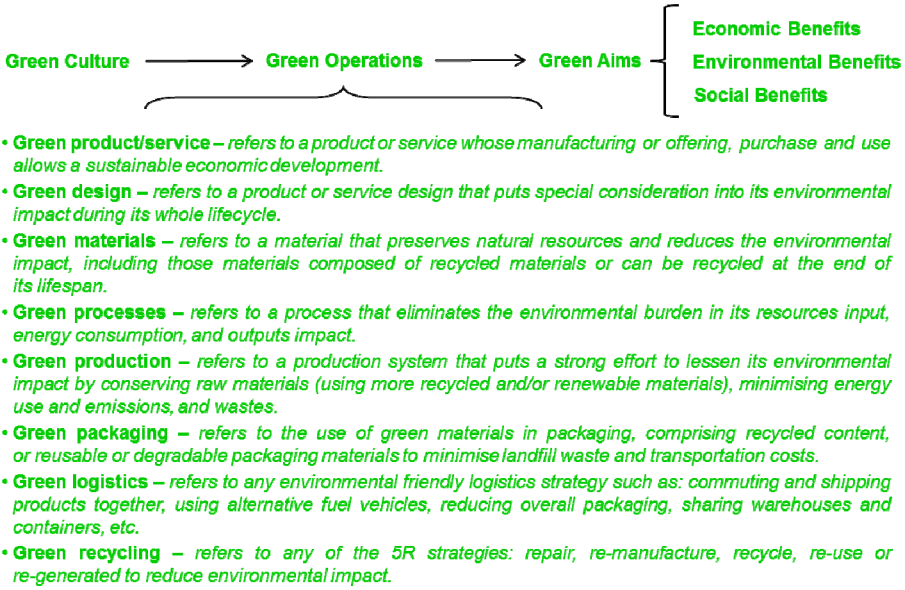

Fig. 3. Green Enterprise Systems / Technologies

Despeisse et al. [10] have proposed a "conceptual factory ecosystem model", which can be considered as a candidate to define a *Green Enterprise* reference model, focusing on resources flows to identify potential connections where outputs of some activities can be used as inputs elsewhere in the system rather than treated as losses or wastes leaving the system (e.g. industrial symbiosis[2] [11] at *intra-enterprise*

[1] A triple top-line value production or offering establishes three simultaneous requirements of sustainable business activities: financial benefits for the enterprise, natural world betterment, and social advantages for employees. Though this is sometimes called the triple bottom line, triple top line stresses the importance of initial value rather than after the fact effects [9].

[2] Industrial Symbiosis can be defined as an industrial ecology strategy, based on collaboration and synergetic possibilities, aimed at sharing/exchanging information, materials, water, energy and/or infrastructure (e.g. services) among industrial actors in order to increase economic gains and achieve sustainable development in an eco-industrial network [11].

level – see Fig. 4). This ecosystem view of a factory, an eco-factory, can be used to build cross-disciplinary models of the material, energy and waste flows linking the manufacturing operations, the supporting facilities and the surrounding buildings [10]. Furthermore, other sustainability strategies as factory level include: *at the source,* preventive measures such as product and process design and dematerialisation to reduce the intake of resources in the technosphere; *during manufacturing,* with technical and organisational measures to increase the efficiency with which resources are transformed into economically valuable products; and *at the end of product lifecycle,* with closed-loop circulation of resources with the technosphere through reuse, remanufacturing and recycling [10] [12] [13] [14] [see also 9 for Greening the Industrial Facility] .

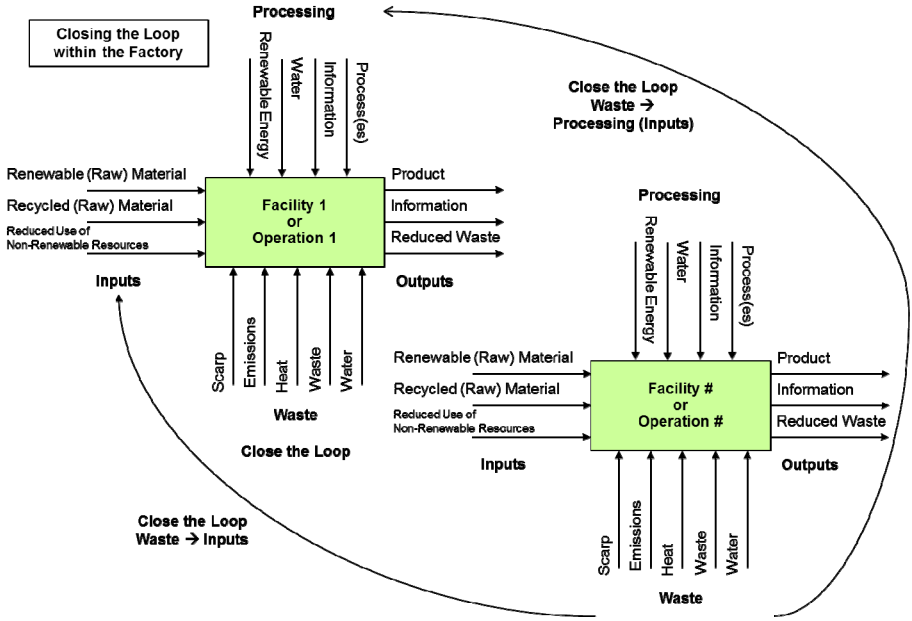

Fig. 4. Industrial Symbiosis at Intra-Enterprise Level

At the *Circular Economy's micro-level* [2], *Green Enterprises* are the access point to put pollution prevention in practice by seeking higher efficiency through cleaner production; reduce consumption of resources and emissions of pollutants and waste; reuse resources; and recycle by-products [15].

Within a *GVBE*, a *Green Enterprise,* as a *GVBE member,* will be able to develop "collaboratively" new green capabilities and capacities in order to re-engineer its "individual" production and distribution processes towards eliminating/recycling its wastes to maximise returns per unit of resource consumed, sharing/reducing its costs over limited natural resources (e.g. raw materials) and supporting infrastructure (e.g. logistics), and increase its green business opportunities and profit by establishing long- and short-term strategic coalitions to develop new competitive advantages (e.g.

green products, services and processes) without compromising critical resources for the future [6] [7].

Moreover, a *GVBE* can offer its *members* the "collaboration opportunity" to share lessons learned (knowledge) and other kind of tangible and intangible assets towards developing new technologies and standards in regards to the minimisation of pollution and the reuse, recycling, conversion and safe-disposal of waste, and new lifecycle frameworks to optimise the use of water, energy and materials at *intra-enterprise level* in order to minimise environmental impact.

3 Green Virtual Enterprises: Circular Economy's Meso-Level

Green Virtual Enterprises (GVEs) are short-term and dynamic coalitions of green enterprises, that may be tailored within a *GVBE,* to respond to a single collaboration opportunity, through integrating the green technology (skills or core-competencies and resources) required to meet or exceed the quality, time and cost frames expected by the customer with a low ecological footprint, and that dissolve once their mission/ goal has been accomplished, and whose cooperation is supported through computer networks. *GVEs* represent an emerging sustainable manufacturing and logistics mode focused on offering, delivering and recovering green products to/from the market, under a lifecycle thinking. *GVEs* focus on adopting lean-agile manufacturing and other sustainable engineering and logistics principles in order to enhance production, reduce wastes and improve their management, decrease energy consumption, achieve logistics efficiency and consequently reduce production and logistics costs and environmental impact [6] [7].

GVEs as goal-oriented collaborative networks can be designed within a *GVBE* with two different aims, on the one hand to become *dynamic forward supply networks* for delivering new green products/services to the market, and on the other hand to become *dynamic reverse supply networks* for recovering the products sold under the *GVBE* brand (e.g. product stewardship) for direct-use, repair, re-manufacture, recycle or safe-disposal. The two *GVE modalities* proposed will be crafted within a *GVBE* in where *Green Enterprises* will be prepared and ready to participate in *dynamic forward and reverse supply networks* created according to the needs and opportunities of the market, and remain operational as long as these opportunities persist, offering in this way an assertive approach towards the market dynamicity and true sustainability [6] [7].

GVEs as *dynamic forward supply networks (F-GVEs)* are temporary alliances of green enterprises that come together in order to better respond the market demands through the most efficient use of their complementary skills or core-competences and shared resources, for developing and delivering in a sustainable way new products (goods and services) to the customer with a minimal environmental impact [6] [7].

GVEs as *dynamic reverse supply networks (R-GVEs)* are temporary alliances of green enterprises that come together in order to better respond a business opportunity based on a sustainable reverse logistics and end-of-life manufacturing approach for recovering products, parts, subassemblies and/or scrap through the most efficient use of their complementary skills or core-competences and shared resources for their

direct-use (re-use), repair, re-manufacture, recycle or safe disposal - within a GVBE [6] [7].

At the *Circular Economy's meso-level* [2], *GVEs* will help to respond to emerging interdependence opportunities and potential synergies between *GVBE members'* participating with their "individual" production and distribution processes (see Fig. 4) as *GVE partners* in temporary eco-value networks (the *GVEs*), so the waste and surplus of downstream operations within the *GVEs lifecycle* (creation, operation/ evolution and dissolution), through a certain degree of technical processing, return to the upstream operations of other *GVEs* and/or *GVBE members* within the *GVBE* in order to close the loop (see Fig. 5).

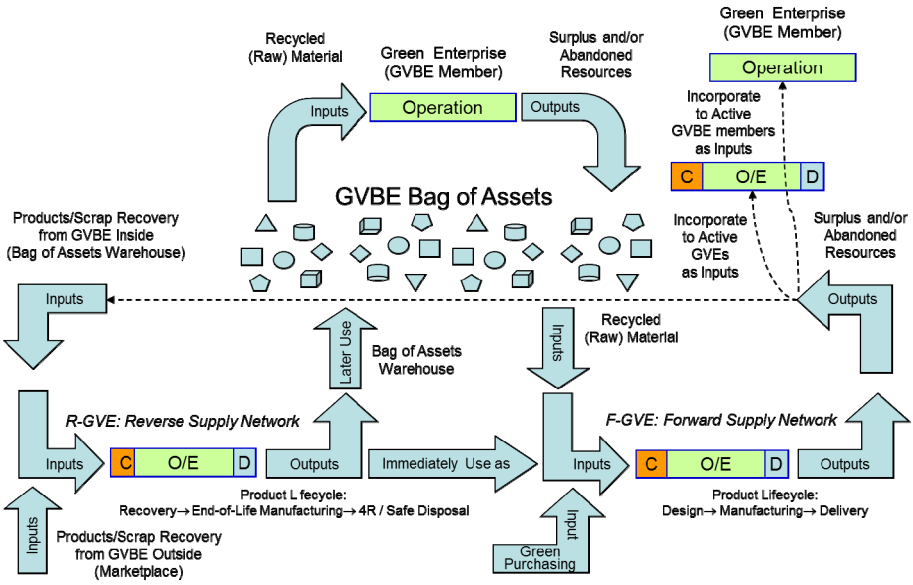

Fig. 5. Industrial Symbiosis at Inter-Enterprise Level

In this sense, industrial symbiosis opportunities at *inter-enterprise level* will take place within the *GVEs lifecycle* and also within the *GVBE members* individual business operations, including opportunities in where some inputs for a *GVBE member* as an individual entity and/or a *GVE* as a group entity can be collected from the waste and surplus of downstream operations of other businesses (the *GVBE members* and the running *GVEs*) in real-time and/or from the waste and surplus and/or abandoned resources stored by the *GVBE members* and *GVEs* after their dissolution in the *GVBE* bag of assets[3] [6] [15] [16].

Moreover, *R-GVEs* will support the logistics to share, reuse and recycle all potential resources (e.g. information, materials, water, energy and/or infrastructure)

[3] A GVBE bag of assets is a common virtual and physical warehouse to make easier the share of tangible and intangible assets between the GVBE members for different purposes [6] [7].

within the *GVBE*, so that resources will circulate fully thought the GVEs' "collaborative" production and distribution processes. Hence, *GVEs* will advocate, as a shared common operating principle of their GVE partners, to establish an industrial ecology pattern aiming to reduce resources input, extend productions lifecycle and renewable resources from scraps [6] [15] [16].

4 GVE Breeding Environments: Circular Economy's Macro-level

Green Virtual Enterprise Breeding Environments (GVBEs) have as their main goal becoming intelligent networks for competencies and resources management in order to match *GVEs* inputs and outputs (match-making) to maximise resources utility towards achieving industrial symbiosis at *inter-enterprise level* (see Fig. 4). *GVBEs* concentrate on bringing their business eco-systems as close as possible to being a closed-loop system by keeping a close interaction of material, energy, information and technology among their members towards a near complete recycle and sharing of resources for producing and delivering green products with sustainable manufacturing and logistics practices through *GVEs* creation, and by recruiting new *GVBE members* that can enhance the network capabilities and capacities to grasp new green business opportunities in time and taking into account environmental impact and resources utility. Furthermore, *GVBEs* at *intra-enterprise level* aim to enhance their members' green degree level by providing incentives to share and implement best practices that can reduce natural resources consumption, improve approaches for sustainable business operations, reduce (raw) materials costs, reduce treatment and disposal costs, etc. to meet economic gains by saving money and protecting the environment.

At the *Circular Economy's macro-level* [2], *GVBEs* aim to create synergies between enterprises and industrial networks for a more efficient and ecological use of materials, energy and other resources. *GVBEs* ultimate goal is to promote a "sustainable management" culture that oversees the sharing of information, services, utilities, by-products, and other resources among or within enterprises in order to add value, reduce costs, and improve performance in terms of sustainability [6] [15] [16].

5 Discussion: Collaborative Networks for a Sustainable World

Authors have introduced a *sustainable industrial development model* for a *Circular Economy* - the *GVBE model* - based on the *Collaborative Networked Organisations* and *Industrial Ecology paradigms.* The paper proposes a bottom-up approach towards *Sustainable Development* and *Circular Economy* following a "sustainable islands approach" [17]. The basic assumption of this approach is that development towards sustainability and closed-loop systems can be introduced in a more effective and efficient way to an enterprise, a value network and/or a business eco-system by starting from the achievement of small sustainable entities (e.g. green facilities or operations → green enterprises) and then building block to larger ones (e.g. → GVEs and their GVBEs) through different collaboration mechanisms [17] [18].

Moreover, the *sustainable islands approach* [17] has been used in this research work as an assisting mean and roadmap to increase *industrial symbiosis* and *collaboration activities* at *intra-* and *inter-enterprise levels* to develop in a hierarchical way a *sustainable industrial development model:* the *GVBE.* Furthermore, the strategy is to create islands of sustainability at *intra-* and *inter-enterprise levels* and then increase eco-networking activities to interconnect the sustainable entities (e.g. facilities → enterprises → networks) within a business eco-system to create a true *sustainable industrial development model* for a *Circular Economy.* Therefore, the *GVBE model strategy* is to reach sustainability in a business eco-system by starting from an *intra-enterprise level* and then move up to diverse *inter-enterprise levels* by promoting on a lower hierarchical level *Green Enterprises* creation and operation [6] [8] [10], which will allow to increase efficiency and hazardous substitution in the micro-system, and at a higher hierarchical level *GVEs* and their *GVBEs* creation and operation [6] [7] that will help to optimise the macro-system in an interactive way with the creation of *F-GVEs* and *R-GVEs,* and the recruiting, integration and enhancing of new *GVBE members* capabilities and capacities for developing triple top-line strategies to create sustainable value [17].

6 Conclusions and Further Research

"Eco-industrial networking" is rapidly becoming an important tool for enterprises to improve their competitiveness in a collaboratively and sustainable way [1] [2] [15] [16]. Different eco-industrial networking projects can be already found around the World, for some relevant case studies in America, Europe and Asia [please read 19].

This paper continues the exploration of potential synergies between *Industrial Ecology* [4] and *Collaborative Networked Organisations* [1] scientific disciplines to achieve more *sustainable industrial development models.* The final aim of this research work is to explore holistic and systemic strategies for seeking integrated solutions at both *intra-* and *inter-enterprise levels* for lowering resources input, enhancing resources productivity, reducing wastes and emissions, and lowering operating costs within an enterprise and between industrial networks based-on *(Sustainable) Collaborative Networked Organisations* models.

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