Green Virtual Enterprises and Their Breeding Environments

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Abstract. The Industrial Ecology (IE) is a new interdisciplinary field focused on sustainable development. IE aims to the shifting of industrial processes from open-loop systems where different resources move through a system to become wastes to a closed-loop system where wastes become inputs for new processes. This paper introduces a Green Virtual Enterprise (GVE) model as an emerging sustainable manufacturing and logistics mode focused on offering, delivering and recovering green products to/from the market, under a lifecycle thinking and supported by its source network. GVEs creation is considered within a GVE breeding environment context, which acts as a long-term collaborative network aimed at offering the conditions to efficiently promote the sharing and recycling of resources such as: information, materials, water, energy and/or infrastructure with the intention of increasing economic gains and achieving sustainable development.

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

1 Introduction

The *Industrial Ecology (IE)* stands for an important strategy to promote sustainable industrial development for enterprises and their related support institutions by providing a unique collaboration opportunity, with a "business sense", to integrate ecological, economic and social considerations into the creation and operation/ evolution of new or existing industrial networks (e.g. industry clusters, industrial districts, eco-industrial parks). IE attempts to understand the potential improvement of industrial networks using an analogy between natural *ecosystems* and *industrial* systems. IE aims to the shifting of industrial production systems from open-loop systems to closed-loop systems, evolving from a linear to a cycle production approach, in order to reduce wastes and pollution and efficiently share and recycle resources within an *industrial ecosystem* towards increasing economic gains and achieving sustainable development [1].

Collaborative Networked Organisations (CNOs) represent a promising paradigm in manufacturing and service industries to help organisations to cope with the challenges of turbulent market conditions in the context of ecological, economic and social pressures on the global industry. CNOs show a high potential as drivers of sustainable industrial development by joining of complementary capabilities and capacities for creating products that are non-polluting, conserve energy and natural resources, and that are economically viable and socially rewarding for all stakeholders involved [2].

Both scientific disciplines can provide together a new interdisciplinary approach for enterprises to improve their competitive and environmental performance in terms of better managing their skills or core-competencies and resources (e.g. information, materials, energy, waste, infrastructure) to realise sustainable industrial collaborative networks and pursue new green business opportunities. In this sense, *collaboration* is presented as a challenge and at the same time as an opportunity for enterprises to re-engineer their production processes and/or networks in order to eliminate/recycle their wastes to maximise returns per unit of resource consumed, share/reduce their costs over limited natural resources (e.g. raw materials) and supporting infrastructure, and increase their business opportunities and profit by establishing long- and short-term strategic coalitions to develop new competitive advantages (e.g. green products and processes) without compromising critical resources for the future.

2 Green Virtual Enterprises and their Breeding Environments

Green Virtual Enterprise Breeding Environments (GVBEs), also known as virtual eco-industrial collaborative networks, are long-term strategic alliances of green enterprises [1] and their related support institutions aimed at offering the necessary conditions to support the rapid and fluid configuration of Green Virtual Enterprises. GVBEs, as source networks focus on traditional bases on creating an adequate environment for the establishment of cooperation agreements, common operation principles, common interoperable infrastructures, common ontologies, and mutual trust among others, with the objective of preparing their members to collaborate in potential GVEs that will be established when a green business opportunity arises or is identified by a GVBE member acting as a broker [adapted from 3] [see also 4].

On more innovative bases, GVBEs focus on bringing together a variety of green enterprises into a business ecosystem that aims to mimic the relationships between different species in a natural ecosystem and establish symbiotic mechanisms to create synergies towards an optimal production level and ecological balance in a virtual eco-industrial collaborative network. GVBEs concentrate on bringing their business ecosystems 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 or sharing of resources for producing and delivering green products with sustainable manufacturing and logistics practices through GVEs creation, and by recruiting new GVBE members (green enterprises) 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.

These last aims are what differentiate traditional VBEs from the novel GVBEs in where collaboration targets the creation of economies of scale in a recycling and shared sustainable engineering efficiency strategy. As a result, GVBEs aim to offer their members and to the market and society a sustainable industrial development model characterised by an economic growth together with a low environmental impact in comparison with other traditional industrial development models.

[1] A *Green Enterprise* is an enterprise that strives to meet the triple bottom line by ensuring that all products, processes and manufacturing activities in its business operation address the sustainable principles: economic-equitable, environmental-viable, and social-bearable.

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 [adapted from 3].

Furthermore, 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 to the market, and on the other hand to become *dynamic reverse supply networks* for recovering the products sold under the GVBE brand (product stewardship) for direct-use, repair, re-manufacture, recycle or safe disposal (see Fig. 1).

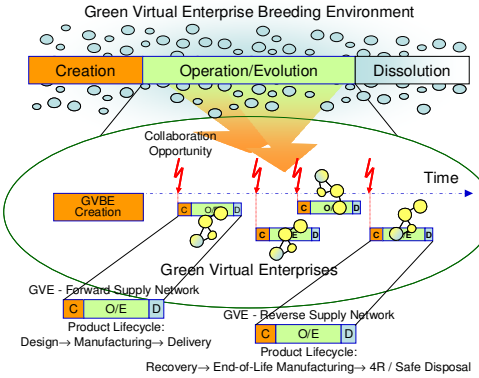

Fig. 1. GVEs creation (both modalities) within GVBE lifecycle

3 Green Virtual Enterprises Characterisation

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 and supported by their source networks. 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.

In this paper, two GVE modalities are introduced as a response to the difficulties of creating and managing integrated and stable forward & reverse supply networks, better known as closed-loop supply networks, to address the market dynamic changes (e.g. shortened product lifecycles) in a sustainable way, in where enterprises normally focus on their traditional forward supply networks and outsource their reverse supply networks to third-parties.

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.

3.1 Green Virtual Enterprises as Dynamic Forward Supply Networks

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.

GVEs lifecycle in their dynamic forward supply networks modality will go through the following stages: During its *creation,* (a) a new green business opportunity will be identified (e.g. new product developments) and will trigger the F-GVE formation; (b) the green business opportunity will be characterised in order to detail its competency requirements in terms of green design, green materials, green processes, green manufacturing, green packaging and green logistics needed to later on look for the F-GVE partners that posses these green competencies [2], and for drafting the F-GVE rough plan (e.g. work-breakdown-structure) to schedule, assign and locate activities, tasks and resources to be performed/used by the potential F-GVE partners during the F-GVE operation; (c) F-GVE partners will be searched, assessed and primarily selected from the pool of GVBE members available and in case there is a lack of competencies inside the GVBE, F-GVE partners can be recruited from outside, based on their green degree level [3] and other key performance indicators (e.g. price, delivery date, quality level, etc.) to respond to the competency requirements and constrains of the green business opportunity; (d) the selected F-GVE partners will negotiate to reach agreements and align needs with offers towards the F-GVE final configuration, following the triple bottom line sustainability principles (economic-equitable, environmental-viable, social-bearable); (e) a detailed F-GVE planning (e.g. working structure) with roles and responsibilities assigned to the F-GVE partners will be defined; and lastly (f) the F-GVE collaboration will be formalised in a contract and the F-GVE will be launched [adapted from 5] (see Fig. 2).

Furthermore, during the *operation stage,* the F-GVE most perform in an agile, green and optimal way following sustainable engineering, manufacturing and logistics principles in order to offer and deliver green products with the required quality and within the required time and cost frame needed to meet or exceed the customer expectations and environmental regulations [adapted from 6] (see Fig. 2).

Finally, during the F-GVE *dissolution,* since the F-GVE was created within a GVBE, any surplus and/or abandoned resources/scrap should be placed in the GVBE bag of assets [4] for its direct-use (re-use), repair, re-manufacture, recycle and/or safe disposal as part of the GVBE sustainable strategy, and of course the GVE product will be delivered to the customer using optimised/green logistics [adapted from 7] (see Fig. 2 & 3).

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[2] *Green competencies* are those environmentally conscious business practices and strategies such as: Design for the Environment (DFE), Product Lifecycle Management (PLM) and Lifecycle Analysis, Lean Manufacturing, Total Quality Environmental Management (TQEM), Environmental Management Systems (EMS), Green Supply Chain Management (G-SCM), Green Logistics, ISO14000 series' requirements, etc. [*Focus on Forward Supply Networks*].

[3] *Green degree level* is the outcome of using quantitative and qualitative metrics to scale and provide a meaningful evaluation of the green capabilities and capacities of an enterprise.

[4] 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.

3.2 GVE Modality: Dynamic Reverse Supply Networks

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.

GVEs lifecycle in their dynamic reverse supply networks modality will go through the following stages: During its *creation,* (a) a new green business opportunity will be identified (e.g. products or scrap recovery) and will trigger the R-GVE formation; (b) the green business opportunity will be characterised in order to detail its competency requirements in terms of direct-use (re-use), repair, re-manufacturing, recycling and/or safe disposal approaches needed for managing certain products or scrap in their end-of-life to later on look for the R-GVE partners that posses these green competencies [5], and for drafting the R-GVE rough plan to be carried-out by the potential R-GVE partners during the R-GVE operation; (c) R-GVE partners will be searched, assessed and selected based on their green degree level and other key performance indicators to respond to the competency requirements and constrains of the green business opportunity, (d) the selected R-GVE partners will negotiate to reach agreements towards the R-GVE final configuration, following the triple bottom line sustainability principles, (e) a detailed R-GVE planning with roles and responsibilities assigned to the R-GVE partners will be defined, and (f) lastly the R-GVE collaboration will be formalised in a contract and the R-GVE will be launched (see Fig. 2).

Furthermore, during the *operation stage,* the R-GVE most perform in an agile, green and optimal way following sustainable logistics, end-of-life manufacturing and safe disposal principles in order to re-use (e.g. deal with the direct-use of product components as spare parts), re-manufacture (e.g. restoring and rebuilding products), recycle (e.g. reclaim raw materials) and/or safe disposal (e.g. hazardous wastes management) of products and their scrap always respecting the environmental regulations (see Fig. 2).

Finally, during the R-GVE *dissolution,* outputs may take two paths: (a) the outputs of the end-of-life manufacturing processes that were selected for direct-use (re-use) re-manufacturing and/or recycling will be returned immediately, if possible, as inputs to active forward supply networks (F-GVEs) within the GVBE or will be placed in the GVBE bag of assets as inputs for future F-GVEs, and/or (b) those outputs selected for safe disposal may trigger a new GVE formation specialised in hazardous wastes disposal practices (see Fig. 2 & 3).

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[5] Green competencies are those environmentally conscious business practices and strategies for dealing with the end-of-life of products such as: inspection, diagnostic and recondition techniques to obtain the most value from a recovered product through a re-use (e.g. spare parts), refurbish (e.g. repair or re-manufacturing), recycling (e.g. scrap) and/or safe disposal (e.g. hazardous wastes treatments) strategy [*Focus on Reverse Supply Networks*].

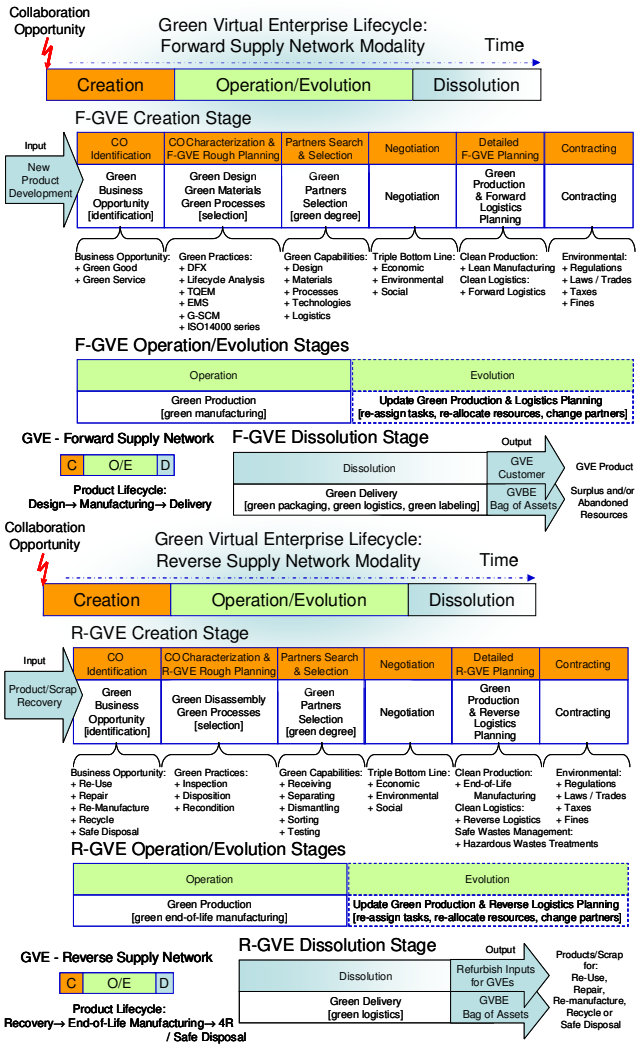

Fig. 2. GVE Modalities (top – F-GVE || bottom – R-GVE) Lifecycle, Methods & Tools

4 GVE Breeding Environments: Industrial Symbiosis

Industrial Symbiosis (IS) 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 a eco-industrial network [8]. IS systems like GVBEs, offer their members the opportunity to collaboratively optimise resources utility at efficiencies beyond those achievable by any single enterprise and at the same time open new possibilities to access/explore green business opportunities in the global marketplace that would not be possible, or would have a higher cost, if attempted individually.

In this paper, GVBEs are introduced as virtual eco-industrial collaborative networks with the capabilities and capacities to deploy innovative, cost-effective and green technologies and practices to promote sustainable industrial development through F-GVEs and R-GVEs creation, operation and dissolution. GVBEs have as their main goal becoming intelligent networks for resources management (GVBE bag of assets) in order to match GVEs inputs and outputs (match-making) to maximise resources utility towards achieving industrial symbiosis.

In Fig. 3 a generic GVBE industrial symbiosis scenario is presented, in this setting when a F-GVE is created: [a] some inputs can be collected from the GVBE bag of assets, [b] some others can be provided by running GVEs acting as green suppliers, and [c] if necessary, missing inputs within the GVBE bag of assets can be purchased outside of the virtual eco-industrial network. Furthermore, F-GVEs outputs such as surplus and/or abandoned resources: [d] will be placed in the GVBE bag of assets for its later use or [e] will be immediately incorporated as inputs for other active GVEs within the GVBE. On the other hand, in the R-GVE case, inputs may come from: [f] products/scrap recovered from GVBE inside (bag of assets warehouse) as a result of an endogenous green business opportunity (e.g. 4R[6] or safe disposal strategy) that can be announced inside the GVBE by its manager and simply GVBE members will organise to respond to it (GVE creation), or [g] products/scrap can be recovered from GVBE outside (marketplace) as an exogenous green business opportunity that can be detected by a GVBE member playing the role of a broker and GVBE members will be selected to become the R-GVE partners. Moreover, R-GVEs outputs similar to F-GVEs outputs can be [h] placed in the GVBE bag of assets for its later use or [i] can be immediately incorporated as inputs for other active GVEs within the GVBE.

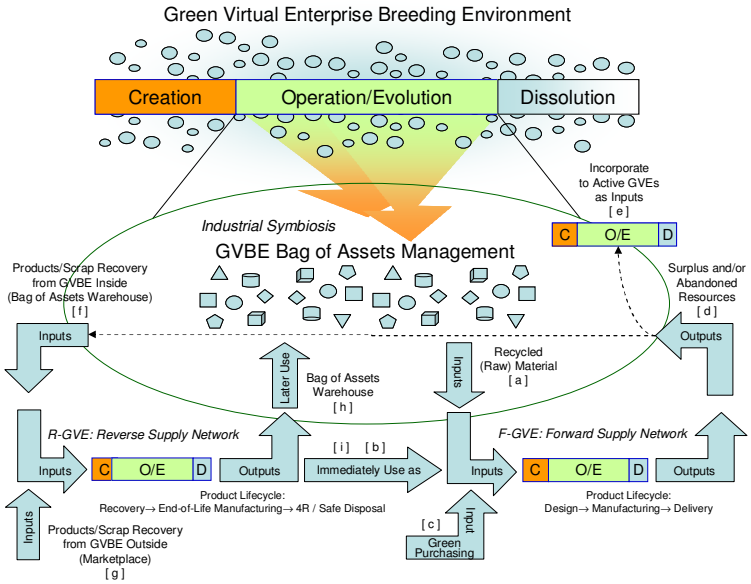

Fig. 3. GVBE Industrial Symbiosis

[6] 4R strategy stands for repair, re-manufacture, recycle and re-use green strategies.

In general, GVBEs industrial symbiosis and other collaboration strategies can increase green enterprises' competitive and environmental performance by becoming GVBE members and participating in GVEs. Some industrial symbiosis benefits/ reasons for green enterprises to join a GVBE can be to 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. While some collaboration benefits for green enterprises in a "business sense" can be to access/explore emerging green markets, increase activities/profit in a sustainable way, copying with market green trends and environmental regulations, joint purchasing (better negotiation power), joint promotion (eco-branding/marketing), social and environmental responsibility prestige/reputation, sustainable innovation as differentiator, among others; and in a more "technical sense", GVBEs collaboration benefits offer possibilities for shared commuting and shipping, alternative (green) packing, integrated (green) logistics, common environmental information systems, (green) production technology sharing and integration, etc. [see 2] [see 9].

5 Discussion & Reflexions

In the past, some eco-industrial collaborative models (e.g. eco-industry clusters/parks) bounded to their geographical proximity have improved their members competitive and environmental performance through different collaboration strategies (e.g. industrial symbiosis), which have resulted in economic benefits for the enterprises and their support institutions, and in environmental care and social welfare for their localities.

Nevertheless, with the advances in information and communication technologies and new environmental-friendly transportation vehicles/systems (e.g. hybrids), novel *virtual* eco-industrial collaborative models [10] such as the GVEs and their GVBEs are gradually emerging in the global industrial landscape, making (green) enterprises step beyond their geographical regions in order to access new complementary green competencies, and market and symbiosis opportunities. As such, nowadays eco-industrial collaborative models do not have to be bounded anymore by their members' geographical closeness and can use collaborative business infrastructures [11] playing the intermediary role as the enablers of interoperation among enterprises to support their coordination and cooperation mechanisms (e.g. design, manufacturing, logistics, warehousing) towards sustainable operations and therefore development.

Geographical proximity vs. virtuality can be a debate for the eco-industry clusters establishment; however researchers and industrial practitioners have to consider that "it is possible", as proved by the *Collaborative Networks* scientific discipline, for not physically co-located enterprises to create economies of scale and cost effective support for information, materials, water and/or energy exchanges across distance using collaborative logistics networks [12] and collaborative business ICT infrastructures [11] [see also 13].

As any strategy for an eco-industry cluster establishment, traditional eco-industry clusters (e.g. eco-industrial parks) vs. virtual eco-industry clusters (e.g. GVBEs) have their advantages and disadvantages and these tradeoffs are briefly depicted in Table 1.

Table 1. Traditional Eco-Industry Clusters vs. Virtual Eco-Industry Clusters

Eco-Industrial Parks (EIPs)	GVE Breeding Environments (GVBEs)
Involve a strong investment and high environmental impact with a physical location construction and/or the re-development of an exiting one.	Do not involve an investment in a physical location construction, but require a moderate investment in a collaborative business ICT infrastructure, which represents a lower environmental impact.
EIPs most suitable members need to be collocated in a certain geographic location in order to participate in the industrial symbiosis and other collaboration opportunities, incurring in the costs associated and environmental impact to re-setup a green enterprise in a new location. Also potential EIP members will be limited to geography proximity.	GVBEs most suitable members do not need to be collocated in the same place to participate in the industrial symbiosis and other collaboration opportunities, just need to create virtual linkages supported by computer networks without any geographic barriers that could limit the best green enterprises recruitment scope.
Recruiting new EIP members in order to enhance the eco-industrial park capabilities and capacities can be extremely difficult because of the green enterprise reallocation.	Recruiting new GVBE members in order to enhance the breeding environment capabilities and capacities can be very easy thanks to a GVBE membership management system.
In an EIP more materials, water, energy and/or other waste exchanges seem to be possible in comparison to GVBEs, but this exchanges as well as enterprises skills and resources sharing are limited to the ones available in the geographical proximity.	In a GVBE perhaps less materials, water, energy and/or other waste exchanges seem to be possible because of geographic distance, but more enterprises skills and resources sharing can take place by being able to have a large number of GVBE members.

6 Emerging Eco-Industry Clusters: Typology & Examples

As discussed in the previous section, geographical proximity vs. virtuality can offer different advantages and disadvantages towards traditional and/or virtual eco-industry clusters establishment. Nevertheless, as depicted in Fig. 4, different models for eco-industry clusters exist, from traditional eco-industrial parks with enterprises located at the same site to geographically distributed enterprises creating virtual linkages, in opposition to co-location, to form virtual eco-industry clusters. Each of these sustainable industrial development models or combinations of them are characterised by different activities and uses, including green manufacturing (e.g. producing green products), closed-loop manufacturing (e.g. zero-emissions), by-product exchange (e.g. using by-products rather than disposing them as wastes), renewable energy, resource recovery (e.g. 4R strategy), green infrastructure (e.g. landscaping), green building design, cleaner production, pollution prevention, energy efficiency, and partnerships between green enterprises and their related support institutions [14].

Fig. 4. Eco-Industry Clusters Typology [14]

Most famous and first eco-industrial park, which has been the reference model for today's eco-industry clusters, is *Industrial Symbiosis* at Kalundborg, Denmark, where different industrial firms have been working together for more than 30 years exchanging waste materials and energy, and sharing resources [8]. Moreover, the first virtual eco-industry cluster was established at *Brownsville, Texas* (1996) as a regional approach to exchange materials and by-products across the USA-Mexican boarder [14],

which has been followed by other virtual initiatives such as the *Karlsruhe* virtual eco-industrial park (1998), where different enterprises exchange organic and mineral by-products, share information and focus on dematerialisation chains, and the *Bioenergie und Rohstoffzentrum Dormagen* virtual eco-industrial park (1999), where companies focus on by-product exchanges and energy cascades, information sharing and extended collaboration with universities and public entities, both at Germany [15].

Nowadays, different eco-industrial park projects can be found around the World, for some relevant case studies in America, Europe and Asia [see 15].

7 Conclusions & Further Research

The materialisation of a potential synergy between IE and CNOs scientific disciplines requires a further research on understanding these possible synergies and underlying principles for better GVEs and their GVBEs creation and management as sustainable industrial collaborative networks. Nevertheless, significant progress is already available in terms of conceptual frameworks and models [3] [4], methods and processes [13], and software tools and systems [5] [6] in CNOs scientific discipline, and perhaps is just a matter of bringing from IE scientific discipline the sustainability element as a main driving force behind the future success of sustainable collaborative networks.

Future looks for more "green" enterprises and sustainable industrial development models, and the proposed approach based on GVEs and their GVBEs appears to be well-suited to cope with emerging socio-economic and environmental challenges of the global industrial landscape.

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