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Towards a Sustainable Development Maturity Model for Green Virtual Enterprise Breeding Environments

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Abstract: The following on-going research work intends to highlight the relevant contributions that Green Virtual Enterprise Breeding Environments (GVBEs) can have in the development of new sustainable industrial development models, able to address the threefold sustainability challenges of environmental protection, economic growth and social progress by means of collaborative networks and systems. Focusing on a well-integrated socio-technical strategy, the Sustainable Development Maturity Model for GVBEs proposes a new generation of [virtual] industrial eco-systems contributing to the eco-restructuring of industrial processes and systems in support of a new sustainable industrial landscape. Different eco-industrial networking strategies are explored in this direction towards a Circular Economy.

Keywords: Collaborative Networked Organisations, Green Virtual Enterprises, Breeding Environments, Industrial Ecology, Lifecycle Thinking, Cleaner Production, Sustainable Development, Maturity Model.

1. INTRODUCTION

Eco-Industrial Chains (EICs) represent a set of value activities specific to a certain series of interrelated products or services, aiming to maximise sustainable value[1] creation and capture over the entire product lifecycle based on a triple top-line[2] strategy. *EICs* aim to develop new opportunities for sustainable value creation and capture within an industrial ecosystem in where feedback cycles of resources → products → renewable resources take place in order create new forms of value; capture the value missed in under-utilised assets and resources, and material, energy and waste streams; and reducing or eliminating the value destroyed by avoiding the depletion of non-renewables, environmental damage and negative social impacts (Guo & Cui, 2010) (Short et al., 2013).

Eco-Industrial Networking (EIN) strategies support the creation of collaborative networks, based on *EICs*, between different entities [e.g. manufacturing and service businesses] to use in a more eco-efficient and effective way their core-competencies and resources by looking into opportunities for potential symbiotic and synergistic relationships and exchanges. *EIN* opportunities can be found in all sizes and types of operations, physical and virtual, in which information, materials, water, energy and/or infrastructures are utilised and/or transformed (LeBreton et al., 2004).

EIN represents an application of the principles of *Industrial Ecology (IE)*. *IE* focuses on "eco-restructuring" the industrial processes and systems towards a sustainable mode of operation 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 (Ekman et al., 2006). *IE* goal is to improve all industrial entities eco-efficiency performance by collaboratively seeking a collective benefit that is greater than the sum of the individual benefits each industrial entity would realise if it optimised its individual performance only (Lowe, 2001).

Moreover, *Lifecycle Thinking (LCT)* is an important principle of *IE*. It seeks to identify possible improvements to products, services and processes in the form of lower environmental impacts and reduced use of resources across all lifecycle stages, avoiding at all times burden shifting solutions. *LCT* involves looking at a product, service or process lifecycle generated impacts and ways to minimise these impacts. Commonly used approaches are: [a] *Environmental Lifecycle Assessment (E-LCA)* - approach that looks at environmental impacts that occur through the lifetime of a product, service or process; [b] *Lifecycle Costing (LCC)* - approach employed to have a total cost analysis of a process or a system in order to find most cost-effective means for providing a product or service; [c] *Social Lifecycle Assessment (S-LCA)* - approach applied for evaluating the social aspects of products/services, and their impact on their stakeholders, during their lifecycle; and [d] *Lifecycle Management (LCM)* - approach used to understand and analyse the lifecycle stages of products, services and processes and identify potential economic, environmental and social risks and opportunities to act upon (EC, 2011).

Another important *IE* related principle is *Cleaner Production (CP),* which encapsulates *LCT*. It refers to the continuous application of an integrated preventative environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. *CP* can be applied to the processes used in any industry, to products themselves and to various services provided in society. [a] For *processes* - *CP* results from conserving raw materials, water and energy; eliminating toxic and dangerous

[1] *Sustainable value* is the long-term shareholder value created as a scalable source of competitive advantage by embracing opportunities and managing the risks/benefits associated with their economic, environmental and social developments (Short et al., 2013).

[2] A *triple top-line strategy* establishes three simultaneous requirements for sustainable 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 (Tueth, 2010).

raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process. [b] For *products* - *CP* aims to reduce the environmental, health and safety impacts of products over their entire lifecycles, rom raw materials extraction, through manufacturing and use, to the disposal of the product. [c] For *services* - *CP* implies incorporating environmental concerns into designing and delivering services (UNEP).

Based on the above definitions and principles, is clear that pursuing a *sustainable industrial development* calls for both a more holistic perspective of the sustainability issues and a tighter collaboration among a wide rate of stakeholders as the needed industrial changes exceed the capabilities and capacities of individual entities (Camarinha-Matos et al., 2010).

In this paper, authors bring together the scientific disciplines of *Industrial Ecology* and *Collaborative Networks* in order to develop a *Sustainable Development Maturity Model (SDMM)* to help [virtual] industry clusters, and their enterprises and related support institutions, to progress towards sustainable industrial development models based-on short- and long-term eco-industrial networks aiming to increase economic gains and minimise their environmental impact.

The following on-going research work should be considered as an "exploratory research" based on a "systematic review" research design of - *Industrial Ecology* and *Collaborative Networks* - principles, frameworks and case studies, aimed to construct a 1st ver. of a *SDMM* for *GVBEs* [industry clusters].

2. BASE CONCEPTS ON GREEN VIRTUAL ENTEPRISE BREENDING ENVIRONMENTS

Green Virtual Enterprise Breeding Environments (GVBEs) are a long-term strategic alliance of *green enterprises* and their related support institutions aimed at offering the necessary conditions [e.g. human, financial, social, infrastructural and organisational] to threefold support: [a] the evolution of their member enterprises to *Green Enterprises,* [b] the rapid and fluid configuration of dynamic *Green Virtual Enterprises* as forward and reverse supply networks, and [c] the sharing and recycling of resources by means of collaboration mechanisms such as: information, materials, water, energy and/or infrastructure [services] with the intention of achieving sustainable development in a collaborative way (Romero & Molina, 2010; 2011; 2012).

2.1 Green Enterprises

A *Green Enterprise (GE)* 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 (Romero & Molina, 2010). *GVBEs* aim to develop mechanism for assessing and enhancing their member enterprises green degree level[3].

Some authors like Willard (2005) have proposed a "corporate sustainability continuum" based on a five-stage sustainability journey starting with [1] *pre-compliance* - where the enterprise ignores any notions of sustainability and flouts environmental, health, and safety regulations; [2] *compliance* - where all labour, environmental, health, and safety regulations are obey and pollution abatement equipment is installed in the enterprise; [3] *beyond compliance* - where proactive operational eco-efficiencies are pursue in the green enterprise by saving energy and reducing its associated carbon footprint, saving water, saving materials in products and packaging, and saving waste-handling costs; [4] *integrated strategy* - where the green enterprise transforms itself to a cyclic sustainable borrow-use-return business model making cleaner products, applying eco-effectiveness and lifecycle stewardship, and starts developing competitive advantages from its sustainability initiatives; and [5] *passion and purpose* - where the green enterprise consolidates its cyclic sustainable business model and starts launching eco-innovation initiatives (Willard, 2010).

Other authors have focused more on approaches and tools for improving industrial facilities sustainable performance, such as Graedel & Howard-Grenville (2005), which have introduced a toolset based on: [a] *regulatory compliance* - with emissions to air, water and soil; [b] *pollution prevention* (also termed *cleaner production*) - methods for reducing impacts and risk of impacts to employees and the environment by identifying a problem or potential problem, locating its source within the manufacturing process, and changing the source so as to reduce or eliminate the problem [e.g. process/technology modification techniques and/or good housekeeping based on routine maintenance and/or operations routines to minimise or eliminate waste]; [c] *industrial facility assessments for the lifecycle perspective* - *of products* [e.g. lifecycle stages: pre-manufacturing, manufacturing, product delivery, product use, end-of-life], - *of processes* [e.g. resource provisioning, process implementation, primary and complementary processes operation, refurbishment/recycling/disposal], and - *of facilities* [e.g. site/facility/infrastructure development, facility business activity/facility operations, facility refurbishment/transfer/ closure]; [d] *sustainability-related performance* - measures for material throughput, hazard potential, and use of materials, water and energy; and [e] *sustainability assessment* - of environmental performance and reporting responsibilities.

Furthermore, authors like Despeisse et al. (2012) have gone further by proposing a "factory ecosystem model" as reference model for *green enterprises,* focusing on resources flows to identify potential connections where the outputs of some activities could be used as the inputs elsewhere in the system rather than treated as losses or wastes leaving the system. The novelty of this *eco-factory model* is the application of *IE* at factory level and the integration of all resource flows in order to develop integrated solutions for lower resource input, higher resource productivity, fewer wastes and emissions, and lower operating cost within a factory.

GVBE administrators (Romero & Molina, 2011) play a vital role in a *GVBE and their members' sustainable development maturity progress.* As part of their management activities, *GVBE administrators* are responsible for providing general guidelines to the *GVBE members* on how assessing and enhancing their sustainable performance at intra- and inter- enterprise levels. Some mechanisms include offering incentives to promote proactive greening projects, feedback from past performance records of collaborations as opportunities for improvement, and specific green capabilities||capacities development plans.

[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 (Romero & Molina, 2010).

2.2 Green Virtual Enterprises

A *Green Virtual Enterprise (GVE)* is an emerging sustainable manufacturing and logistics networked enterprise model focused on offering, delivering and recovering green products to/from the market, under a lifecycle thinking and supported by its source network. *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 (Romero & Molina, 2010; 2011; 2012).

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 a *dynamic reverse supply networks* for recovering the products sold under the *GVBE* brand [product stewardship] for direct-use [re-use], repair, re-manufacture, recycle or safe disposal (Romero & Molina, 2010; 2011; 2012).

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-competencies and shared resources, for developing and delivering in a sustainable way new products to the customer with a minimal environmental impact - within a *GVBE* (Romero & Molina, 2010; 2011; 2012).

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-competencies and shared resources for their direct-use [re-use], repair, re-manufacture, recycle or safe disposal - within a *GVBE* (Romero & Molina, 2010; 2011; 2012; 2013).

The *GVE networked enterprise model* aims the achievement of sustainable and fully flexible supply networks based on the ability of dynamically configure forward and reverse supply networks [virtual closed-loop supply networks], according to the needs and opportunities of the market and keep them operational as long as these opportunities persist, suggesting a number of sustainable benefits, among which the following can be emphasised: [a] agility [*GVE* ability to react], [b] leanness [*GVE partners* efficiency and lowest cost-to-serve], [c] greenness [*GVE partners* green capabilities], [d] flexibility [*GVE partners* capacities integration], [e] collaboration [*GVE partners* sharing costs and risk], and [f] specialisation [*GVE partners* green core-competencies] (Romero & Molina, 2011).

Furthermore, the *GVE networked enterprise model* offers an attractive research framework for *reverse supply networks* in where the uncertainties of return flows call for responsive reverse logistics channels and flexible inverse manufacturing systems, based on dynamic capabilities, in order to deal with the complexity of collecting, inspecting, separating and re-processing end-of-life products in a sustainable way (Romero & Molina 2013).

2.3 Green Virtual Enterprise Breeding Environments

A *Green Virtual Enterprise Breeding Environment (GVBE)* represents an association [also known as a cluster] or pool of organisations that have both the potential and willingness to cooperate with each other towards "eco-industrial networks" creation [e.g. GVEs] (Romero & Molina, 2010; 2011; 2012).

GVBEs can be described as "virtual industrial eco-systems" enabling their members to work together to implement and share sustainable business practices by adhering themselves to a *sustainability continuum,* with the main goal of improving their core-competencies and resources utilisation, enhancing their industrial competitiveness, enriching their eco-innovation capabilities, and reducing their transaction costs at individual and collective levels (Romero & Molina, 2010; 2011; 2012).

GVBEs offer their *members* the opportunity to collaboratively optimise their use of resources, close material loops, minimise emissions, dematerialise activities, and reduce and eliminate the dependence on non-renewable sources of energy and raw materials beyond individual efficiency levels, and at the same time open new possibilities for creating competitive advantages based on eco-innovations and green business opportunities (Romero & Molina, 2010; 2011; 2012).

GVBEs act as long-term supporting networks underlying the nesting environments for preparing their *members* to integrate and collaboratively deploy their green capabilities and capacities through *GVEs* creation and operation for delivering green products to the market, and servicing and recovering them for providing added value after-sales services and for pursuing up- or down- cycling[4] green business opportunities (Romero & Molina, 2010; 2011; 2012).

GVBEs can also be seen as "intelligent networks" for resources management, based on their *bag of assets*[5] *management*, in order to match-make *GVEs* inputs and outputs towards a closed-loop system for material, energy and waste streams, as well as a shared infrastructure system [e.g. industrial symbiosis] (Romero & Molina, 2010; 2011; 2012).

3. TOWARDS A SUSTAINABLE DEVELOPMENT MATURITY MODEL FOR GREEN VIRTUAL ENTERPRISE BREEDING ENVIRONMENTS

Working towards the conception of a *Sustainable Development Maturity Model (SDMM)* for *GVBEs,* a *SDMM* can be viewed as a set of structured levels and stages that describe how well a set of eco-strategies [e.g. behaviours, practices and process] of a *GVBE* can reliably and sustainably produce and improve its sustainable development performance [Figure 1].

[4] *Up-cycling* - is the process of converting waste materials or useless products into new materials or products of better quality or for better environmental value, while *Down-cycling* - is the process of converting waste materials or useless products into new materials or products of lesser quality and reduced functionality (McDonough & Braungart, 2002).

[5] 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 (Romero & Molina, 2010, 2011, 2012).

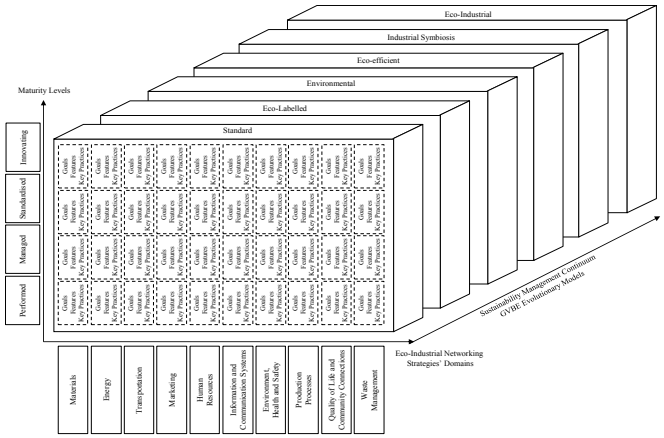

Figure 1. Sustainable Development Maturity Model for Green Virtual Enterprise Breeding Environments

Adapting the - original - *Capability Maturity Model (CMM)*[6] structure, the *SDMM* "structure" involves six aspects:

Maturity levels: A four-level process maturity continuum, here the uppermost (4th) level is a notional ideal state where eco-industrial networking strategies would be systematically managed by a combination of process optimisation and continuous process improvement [Section 3.1].

Eco-Industrial Networking (EIN) strategies' domains: An eco-industrial networking strategy domain identifies a cluster of sustainable practices that, when performed together, achieve a set of sustainability goals [Section 3.2].

Sustainability goals: The sustainability goals of an EIN strategy domain summarise the states that must exist for that eco-strategy to have been implemented in an effective and lasting way. The extent to which the sustainability goals have been accomplished is an indicator of how much capability in the *GVBE* has established at the maturity levels. The sustainability goals signify the scope, boundaries, and intent of each eco-industrial networking strategy domain [Section 3.3].

Common features: Common features include practices that implement and institutionalise an eco-industrial networking strategy. There are five types of common features: *commitment to perform* [e.g. *GVBE* sustainability goals are defined], *ability to perform* [e.g. adequate *GVBE* budget and resources have been allocated to sustainability goals achievement], *activities performed* [e.g. robust programs and action plans [projects] have been put in place at the *GVBE* to achieve the sustainability goals], *measurement and analysis* [e.g. mature sustainability assessments are conducted at the *GVBE* for tracking projects progress towards goals and for discovering improvement opportunities], and *verify implementation* [e.g. *GVBE* follow-up audits are made to provide reasonable assurance that running and/or new sustainability programs and action plans [established in response to improvement opportunities] are in progress or have been successfully implemented] [Section 3.4].

Key practices: The key practices describe the elements of infrastructure and practice that contribute most effectively to the implementation and institutionalisation of the eco-strategy domain [Section 3.5].

Sustainability management continuum: The sustainability management continuum depicts six "evolutionary models" for *GVBEs* from standard [virtual] industry clusters to advanced [virtual] *eco*-industry clusters (Adapted from Ko, 2009) [Section 3.6].

GVBEs will go through the maturity levels of each evolutionary model of the sustainability management continuum, and once a *GVBE* has achieved the maturity level of "innovating" in an evolutionary model will evolve to the next one.

3.1 Maturity Levels

Following are the details of each *maturity level* meaning along the maturity continuum: [L1] *Performed* - eco-industrial networking strategies are deployed in an ad-hoc and chaotic manner. *GVBEs* EIN strategies are usually effectively but not efficiently deployed. The *GVBE* ability to plan and execute eco-industrial networking strategies needs to be improved. [L2] *Managed* - eco-industrial networking strategies become repeatable practices within the *GVBE*. [L3] *Standardised* - eco-industrial networking strategies become defined and repeatable practices. [L4] *Innovating* - existing eco-industrial networking strategies are optimised and proactive behaviour takes place towards the next *GVBE* "evolutionary model".

3.2 Eco-Industrial Networking Strategies' Domains

Based on Cohen-Rosenthal (2003) research work, authors will use and extend his proposed areas of eco-industrial networking to describe a baseline of *eco-industrial networking strategies' domains* for the conception of a *Sustainable Development Maturity Model* for *GVBEs*. In each domain, the steps [eco-practices] listed form a progression from basic eco-practices to advanced eco-practices (Cohen-Rosenthal, 2003):

Materials domain mission: to maximise resource productivity and ensure quality, safety, timeless, environmental stewardship and cost-effectiveness.

Energy domain mission: to identify means for overall energy supply, efficiency, conservation and cost-effectiveness.

Transportation domain mission: to ensure that materials and people are able to move within and outside the eco-network with highest reliability, lowest environmental loading and best cost-effectiveness.

Marketing domain mission: to expand the market recognition and revenue base of constituents and the eco-network.

Human resources domain mission: to increase the range and quality of opportunities for recruitment, career development, occupational flexibility and benefit availability.

Information and communication systems domain mission: to ensure the broadest and most efficiency use of, access to and transfer of information.

Environment, health and safety domain mission: to promote continuous improvement in all facets of environmental performance and community and employee health and safety.

Production processes domain mission: to ensure the most flexible and effective use of capital stock and production processes within and between participating tenants, leading to excellent customer satisfaction.

[6] http://cmmiinstitute.com/

Quality of life and community connections domain mission: to ensure excellent interactions between the eco-network and the surrounding in ways that enhance the community, strengthen companies and provide benefit to employees.

[NEW] Waste management domain mission: to preferably ensure the recycling and if not possible proper disposal of any waste in a safe, efficient, and ecologically sound manner.

3.3 Sustainability Goals

Setting *sustainability goals* is a fundamental requirement to progress through the "maturity levels" and "evolutionary models" of the *Sustainable Development Maturity Model* for *GVBEs.* Main reason for this is that the *GVBE* as an eco-system itself and its *members* as tenants cannot mature and evolve in an "holistic manner" towards higher sustainable levels and models until all tenants have common agreed on which/ where are that "sustainability goals" as a collective whole.

Sustainability goals will help all *GVBE members* to schedule activities, assign tasks, allocate budget, define performance indicators [KPIs] and identify risks to jointly plan, implement and evaluate *eco-industrial networking strategies.* Defining *sustainability goals* will create a performance management framework for *eco-industrial networking strategies* in order to help *GVBE administrators* to set goals and plan work, continually monitor and measure performance, and manage change [evolution] towards sustainable development.

When defining the right sustainable performance management framework for a *GVBE,* it is important to choose a shared model generally accepted by internal and external stakeholders, focus on measuring the most important elements rather everything, and report both normative data and gross totals.

Some examples: for analysis [e.g. environmental and social lifecycle assessment and lifecycle costing], for measurement [e.g. ecological footprint], for processes [e.g. environmental management systems/ISO14001].

3.4 Common Features

GVBEs as *long-term collaborative networks* aim to facilitate the engagement and interplay of multiple stakeholders needed in any effort towards sustainable development. *GVBEs* can offer a "community notion" that helps to develop at individual and collective levels *common green operating principles* [e.g. green products, green services, green design, green materials, green processes, green production, green packaging, green logistics, green recycling] that will jointly create a holistic and integrated sustainable industrial development strategy.

Furthermore, *GVBEs* stand for a new assets management logic based on mobilising and managing shared assets rather than individually owning them, providing through a *shared economy philosophy* access to resources, services and/or infrastructure beyond one to one or singular ownership possibilities; as a result increasing the effective and efficient use of physical and intangible assets, eliminating redundant assets and managing their ownership costs in a smart and collaborative way.

GVBEs provide a *joint vision* for common green operating principles, shared resources and collaborative infrastructures that will enable their members to share risks, resources, responsibilities and rewards in order to increase efficiency, expand capacity, reduce waste, enhance green image and increase sustainable value.

3.5 Key Practices

GVBEs key practices represent all smart mechanisms applied to aggregate and/or merge the unique core-competencies and resources, and *common features,* available at the breeding environment to achieve *sustainability goals.* These *best practices* are adaptive mechanisms rather than fixed processes fostering incremental and radical innovations to deliver increasing levels of eco-efficiency until a sustainable [virtual] industrial eco-system can be fully established.

Some examples for *green key practices* are: Design for the Environment (DFE), Green Procurement, Green Marketing, Green Product Lifecycle Management (G-PLM), Lifecycle Thinking, Lean Manufacturing, Total Quality Environmental Management (TQEM), Environmental Management Systems (EMS), Green Supply Chain Management (G-SCM), Green [Collaborative] Logistics, ISO9000 family of standards related to quality management, ISO14000 family of standards related to environmental management, ISO26000 guidelines for social responsibility, ISO50001 specification for energy management, Waste Hierarchy Management, Safe Disposal, etc.

3.6 Sustainability Management Continuum

By adapting Ko's (2009) environmental management continuum for industrial parks, a *sustainability management continuum* was defined as a systematic approach for incorporating higher sustainability functions [strategies, features and practices] into a *GVBE.* Following definitions provide a formal description for each of the six "evolutionary models" established for the *GVBEs sustainability continuum:*

Standard VBE - An association of enterprises and their related support institutions operating in a common business sector or reduced number of sectors that collaborate with each other in order to increase general competitiveness.

Eco-labelled GVBE - An association of enterprises and their related support institutions recognised for their enhanced environmental practices by eco-standards like ISO 14000 and eco-labels such as PALME (Programme d'Actions Labelise pour la Maitrise de l'Environment) for industrial parks.

Environmental GVBE - An association of (early stage) green enterprises and their related support institutions manufacturing and/or offering environmental responsible products, services and/or technologies to the market/society.

Eco-efficient GVBE - An association of [intermediate] green enterprises and their related support institutions working to reduce resources intensity [material, energy and water], control pollution [quantity and toxicity of all emissions and wastes] and minimise collective waste outputs [e.g. lean philosophy: transport, inventory, motion, waiting, over-production, over-processing, defects, etc.].

Industrial Symbiosis GVBE - An association of [advanced] green enterprises and their related support institutions optimising the use of resources, closing material loops and minimising emission, dematerialising activities, and reducing and eliminating the dependence on non-renewable sources of energy.

Eco-Industrial GVBE - An association of [advanced] green enterprises and their related support institutions creating green collaborative benefits such as: exploring emerging green markets, increasing 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, shared commuting and shipping, alternative green packing, integrated green logistics, common enviro-mental information systems, green production technology sharing and integration, etc. As well as guaranteeing a balanced membership of producers, scavengers and decomposers creating industrial symbiosis opportunities for sharing and recycling resources such as: information, materials, water, energy and/or infrastructure.

4. GVBEs EVOLUTIONARY MODELS AND THEIR ECO-INDUSTRIAL NETWORKING STRATEGIES

Following sections will navigate through the *GVBE sustainable management continuum,* providing a comprehensive overview of each of its possible *evolutionary models,* and recommending *eco-industrial networking strategies* [goals, features and key practices] for each one. These models have been constructed based on a "systemic review" of frameworks and case studies.

4.1 Standard VBE

A *standard VBE* represents the first evolutionary model for a virtual industry cluster (VIC) towards a sustainable industrial development model. *Standard VBEs* address sustainability in an indirect way by means of cooperation variables that may have a positive effect on the three sustainability dimensions as a secondary impact. Table 1 introduces some [secondary] eco-industrial networking (EIN) strategies for *standard VBEs.*

Table 1. EIN Strategies in Standard VBE

Domain	Goal/Features	Key Practice
Materials	- Low impact materials. - Green chemistry. - Better negotiation power.	- Use of non-restricted materials. - Use of materials that come from a sustainable managed source. - Responsible materials suppliers. - Common materials buying.
Energy	- Energy awareness.	- Energy consumption measurement.
Transportation	- Reduce overall logistics costs.	- Logistics costs optimisation.
Marketing	- Lobbying and market influence.	- Co-branding. - Co-marketing.
Human Resources	- Law compliance [labour].	- Labour regulations.
I & C Systems	- Information exchange.	- Electronic documents sharing.
Environmental, Health and Safety	- Accident prevention. - Emergency response.	- Preparedness for reactive actions.
Production Processes	- Law compliance [traditional manufacturing].	- Pollution control and abatement equipment.
Quality of Life and Community	- Basic neighbour practices.	- Neighbour relationship management.
Waste Management	- Law compliance [waste and emissions outputs].	- Safe treatment and disposal.

Hence, *standard VBEs* work in the implementation of essential abatement technologies as end-of-pipe solutions for traditional pollution control [capture and treatment], dealing in this way with compliance of conventional environmental regulations.

4.2 Eco-labelled GVBE

An *Eco-labelled GVBE* represents the second evolutionary model of the sustainable management continuum for VICs. *Eco-labelled GVBEs* represent a new form of regulation for VICs, which is voluntary nature, but imposes a compliance with a set of practices or minimal requirements, established by shareholder bodies, for sustainability or reduction of harm to the environment. *Eco-labels* exist for many schemes broadening quality, social, ethical, safety and environmental issues at products, manufacturing processes, manufacturing systems, and industrial chains/networks/clusters [e.g. Eco-label Index- www.ecolabelindex.com]. Table 2 introduces some EIN strategies for e*co-labelled GVBEs.*

Table 2. EIN Strategies in Eco-Labelled GVBEs

Domain	Goal/Features	Key Practice
Materials	- Avoid toxic materials. - Non-toxic materials.	- Toxic materials substitution. - Zero toxic materials. - Certified materials suppliers.
Energy	- Energy reduction focuses on eco-standards/labels.	- Energy consumption management and control [auditing].
Transportation	- Reduce logistics footprint.	- Low emission vehicles. - Electric vehicles.
Marketing	- Basic green marketing strategies.	- Green design. - Eco-labelled products.
Human Resources	- Attractive working place.	- Great place to work® recognition.
I & C Systems	- Loosely systems integration.	- Basic systems integration.
Environmental, Health and Safety	- Reduce environmental impact and ecological footprint targeting eco-standards.	- Waste minimisation. - Emissions minimisation.
Production Processes	- Lean manufacturing.	- Operational efficiency. - Pollution prevention.
Quality of Life and Community	- Advanced neighbour practices.	- Monitoring surroundings and site air quality and noise.
Waste Management	- Waste management plans.	- Waste and emissions control.

Moreover, *eco-labelled GVBEs* aim to modify their products and production-logistics methods and to introduce pollution prevention technologies to prevent and/or substantially reduce their environmental impacts [footprint], as a "green marketing" strategy directed at environmental conscious consumers and intended to show the *GVBE* market environmental responsibility.

4.3 Environmental GVBE

The third evolutionary model of the sustainable management continuum for VICs it is represented by the *environmental GVBE model.* It aims to achieve the extremely demanding environmental manufacturing and logistics regulations and standards by incorporating different environmental aspects into products and manufacturing and logistics operations, including an environmental performance evaluation, audits and controls to manage environmental protection and handling environmental issues.

Table 3. EIN Strategies in Environmental GVBEs

Domain	Goal/Features	Key Practice
Materials	- Recycled materials.	- Down-cycling materials. - Green materials suppliers.
Energy	- [Renewable] energy sources balance.	- Use of alternative energy sources.
Transportation	- Shared transportation. - Shared inventories.	- Shared commuting. - Shared shipping. - Shared warehousing.
Marketing	- Intermediate green marketing strategies.	- Targeting green consumers. - Accessing green markets. - Creating green markets.
Human Resources	- Work-life balance.	- Wellness programmes.
I & C Systems	- Full systems integration.	- Integration principles.
Environmental, Health and Safety	- Design for environment.	- Design for X guidelines.
Production Processes	- Clean production.	- Scrap reduction and re-use. - Low embodied energy processes.
Quality of Life and Community	- Social responsibility. - Environmental responsibility.	- Community programmes. - Bio-diversity protection.
Waste Management	-Take-back management.	- Resources stewardship.

In order to achieve an "environmental -friendly behaviour", *Environmental GVBEs* possess a clearly defined area of environmental responsibility, a framework for setting-up and reviewing environmental objectives, and a public policy of continuous improvement on environmental matters.

4.4 Eco-Efficient GVBE

On the way to a sustainable industrial development model for VICs, an *eco-efficient GVBE* represents the fourth evolutionary model of the sustainable management continuum. *Eco-efficient GVBEs* go deep-in the ratio of environmental impacts and economic value created and shared with society.

Table 4. EIN Strategies in Eco-Efficient GVBEs

Domain	Goal/Features	Key Practice
Materials	- Recycled materials.	- Up-cycling materials. - Green materials suppliers.
Energy	- Energy eco-efficiency.	- Energy saving technologies.
Transportation	- Integrated logistics.	- Cohesive packaging, handling, storage and transportation [PHS&T] solutions.
Marketing	- Intermediate green marketing strategies.	- Joint green promotions [advertising, trade-shows, etc.].
Human Resources	- Common needs.	- Payroll. - Recruiting. - Performance record. - Scheduling. - Training/Learning management. - Benefits administration.
I & C Systems	- Systems interoperability.	- Interoperability principles.
Environmental, Health and Safety	- Design for environment. - Design to cost.	- Design for X guidelines.
Production Processes	- Sustainable manufacturing	- Green production design.
Quality of Life and Community	- Green buildings/facilities.	- Green infrastructure.
Waste Management	- Waste as input-resource.	- Waste hierarchy strategic management.

Furthermore, *eco-efficient GVBEs* focus on the adoption of more "cost-effective" pollution prevention technologies and significant changes to industrial processes and product designs in order to achieve maximum efficiency of waste treatment, products production and services delivery.

4.5 Industrial Symbiosis GVBE

The fifth evolutionary model of the sustainable management continuum is represented by the *industrial symbiosis GVBE model.* This sustainable industrial development model stands too for the first contribution of the *Circular Economy,* also called: "material close economy" or "lifecycle economy", to a closed-loop || zero waste-emissions eco-industrial model, where industrial activities create quasi-cyclic and/or cyclic feedback flows through an eco-industrial system to reduce the need for external resources input and waste output till achieving self-sufficiency with closed-loop circulation of resources.

Table 5. EIN Strategies in Industrial Symbiosis GVBEs

Domain	Goal/Features	Key Practice
Materials	- Sustainable materials.	- Infinitely recycled/renewable materials. - Sustainable materials suppliers.
Energy	- Energy cascading.	- Quasi-cyclic energy flows.
Transportation	- Common logistics. - Reverse logistics.	- Synchronise logistics operations. - Closed-loop supply chains.
Marketing	- Advanced green marketing strategies.	- Marketing recyclable products. - Eco-consumption promotion.
Human Resources	- Collaborative teams. - Concurrent teams.	- Functional teams. - Lightweight teams. - Heavyweight teams. - Autonomous teams. - Virtual teams.
I & C Systems	- Shared systems.	- Groupware.
Environmental, Health and Safety	- Design for environment. - Design for recycling. - Design to cost.	- Design for X guidelines.
Production Processes	- Closed-loop manufacturing.	- Common green equipment. - Reuse, re-manufacture, and recycle.
Quality of Life and Community	- Neighbours as stakeholders. - Shared value.	- Involvement in regional planning.
Waste Management	- Closed materials loops.	- By-products exchanges.

Hence, an *industrial symbiosis GVBE* embodies the paradigm shift from a linear industrial model to a new integrated and cyclic industrial eco-system optimising systematically all kind of resources flows [e.g. information, materials, water, energy, infrastructure, etc.] through intra- and inter- green enterprises eco-industrial chains and networks.

4.6 Eco-Industrial GVBE

Sixth and last evolutionary model for VICs in the sustainable management continuum is represented by the *eco-industrial GVBEs.* This advanced sustainable industrial development model focuses on "eco-innovations", meaning all forms of innovation activities at products, services, processes, systems and business models resulting in or aimed at significantly improving in a holistic way [lifecycle thinking] environmental protection, economic growth and social progress by means of collaboration.

Table 6. EIN Strategies in Eco-Industrial GVBEs

Domain	Goal/Features	Key Practice
Materials	- Dematerialisation.	- Reduction in the quantity of sustainable materials required.
Energy	- Energy harvesting and recovery.	- Cyclic energy flows [co-generation].
Transportation	- Logistics innovations.	- Green packaging. - Reusable pallets and containers. - Shipment tracking and tracing. - Vehicles diagnosis and monitoring. - Vehicles routeing and scheduling. - Proof of delivery [e-signatures].
Marketing	- Advanced green marketing strategies.	- Joint green products ventures. - Service substitution [product-service systems].
Human Resources	- Flexible work.	- Flexible work hours. - Flexible work locations. - Flexible work arrangements.
I & C Systems	- Joint systems.	- Collaborative ICT-Infrastructures.
Environmental, Health and Safety	- Sustainable designs.	- Shared environmental information - Joint regulatory permits.
Production Processes	- Green technology transfer.	- Green technology sharing and integration.
Quality of Life and Community	- Green landscaping.	- Infrastructure bio-mimicry.
Waste Management	- Creation of new materials market.	- Blue economy.

Finally, *eco-industrial GVBEs* aim to create and promote new forms of "radical innovation based sustainable development", rather than previous models more aimed at evolving based on "incremental innovations" as a continuous improvement process for achieving sustainable development.

5. MAKING A BUSINESS SENSE FOR MORE MATURE SUSTAINABLE INDUSTRIAL DEVELOPMENT MODELS

According to Lüdeke-Freund (2010) a *sustainable business model* seeks to create balanced social, environmental and economic value through integrating *sustainability* more fully into its business model and value proposition(s). As a result, promoting the adoption of new sustainable corporate and/or industrial development models requires new reference business model architectures for sustainability and business modelling tools for making a - "good business sense" - for sustainable development [e.g. Short et al. (2012) - sustainable business models archetypes; Bocken et al. (2013) - a value mapping tool for sustainable business modelling]. Not surprisingly main encouragement to adopt new sustainable corporate and/or industrial development models will always come from economic benefits that can help enterprises and industries to justify their investments for "greening" their industrial facilities and supply networks, and in second place from government actions encompassing new legislations and law enforcement for environmental protection (Scott et al., 2001).

The proposed *SDMM* for *GVBEs* aims to point-out some EIN strategies with potential to unlock new forms of value creation.

6. CONCLUSIONS & FURTHER RESEARCH

Developing a [virtual] industrial eco-system is a continuous improvement process, at intra- and inter-enterprise levels, calling not only for a gradual adjustment process, but also a dynamic process according to market demand [e.g. green collaboration opportunities] and technical changes [e.g. eco-innovation] to adjust partners and develop new supply and demand relationships [e.g.F- & R-GVEs] (Guo & Xie, 2012). In this sense, Green Virtual Enterprises and their Breeding Environments offer an harmonic model for the integration, interoperability and networking of different "eco-industrial strategies" to reduce the natural resources consumption, negative environmental impact, reduce pollution, conserve resources and protect ecological environment, and achieve, at the same time, economic and social sustainable development.

"Collaboration" - is the key towards an optimum [virtual] industrial eco-system, where green enterprises [eco-factories and eco-service offices] explore internally how to best utilise all sort of resources to green their facilities, and contribute with their green core-competencies and technologies to create eco-industrial chains [GVEs] that collectively [GVBE] create a *Circular Economy*. By means of collaboration in short and long-term collaborative networks, optimisation can be achieved at micro-, meso- and macro- systems and achieve in this way sustainable systemic change in the industrial landscape.

Further research aims to continue the validation and enriching of the proposed *Sustainable Development Maturity Model* for *GVBEs* and to increase understanding about the attractiveness of its adoption from a business perspective [e.g. ROI] towards a sustainability-driven competitive advantage.

REFERENCES

Bocken, N.M.P; Short, S.; Rana, P. and Evans, S. (2013). "A Value Mapping Tool for Sustainable Business Modelling", Journal: Corporate Governance, Vol. 13 Issue 5, pp. 482-497.

Camarinha-Matos, L.M.; Afsarmanesh, H. and Boucher, X. (2010). "The Role of Collaborative Networks in Sustainability", IFIP AICT, Vol. 336, pp. 1-16.

Cohen-Rosenthal, E. (2003). "A Walk on the Human Side of Industrial Ecology", Eco-Industrial Strategies: Unleashing Synergy between Economic Development and the Environment, Part 1, Chapter 3, pp. 51-66.

Cohen-Rosenthal, E. (2003). "Management of Eco-Industrial Parks, Networks and Companies", Eco-Industrial Strategies: Unleashing Synergy between Economic Development and the Environment, Part 3, Chapter 11, pp. 163-185.

Despeisse, M.; Ball, P.D.; Evans, S. and Levers, A. (2012). "Industrial Ecology at Factory Level - A Conceptual Model", Journal of Cleaner Production 31(1), pp. 30-39.

Erkman, S. and Ramaswamy, R. (2006). "Industrial Ecology: An Introduction", Industrial Ecology and Spaces of Innovation, pp. 28-42.

European Commission (EC) (2011). "Lifecycle Thinking" http://lct.jrc.ec.europa.eu/glossary?search_letter=l

Graedel, T.E. and Howard-Grenville, J.A. (2005). "Greening the Industrial Facility: Perspectives, Approaches, and Tools", Springer New York.

Guo, J. and Cui, W. (2010). "Research on the Stability of Eco-Industry Chains", International Journal of Business and Management 5(11), pp. 152-155.

Guo, J. and Xie, N. (2012). "Research on the Construction of Eco-Industrial Clusters", Elixir International Journal Production Management, Vol. 48, pp. 9245-9248.

Ko, Suk-Chan (2009). "Eco-Industrial Park (EIP) Initiatives towards Green Growth: Lessons from Korean Experience", UNESCO-WTA International Training Workshop Report - Proceedings, Daejeon, Korea.

LeBreton, W.; Casavant, T. and Cote, R. (2004). "Small-Scale Eco-Industrial Networking: Inter-Organisational Collaboration to Yield System Wide Benefits in Communities", Journal: Progress in Industrial Ecology, Vol. 1, No.4, pp. 432-453.

Lowe, E. (2001). "Handbook for Development of Eco-Industrial Parks", Indigo Development, http://indigodev.com/

Lüdeke-Freund, F. (2010), "Towards a Conceptual Framework of 'Business Models for Sustainability", Knowledge Collaboration & Learning for Sustainable Innovation, Delft, The Netherlands.

McDonough, W. and Braungart, M. (2002). "Cradle to Cradle: Remaking the Way We Make Things", North Point Press, pp. 56-57.

Romero, D. and Molina, A. (2010). "Green Virtual Enterprises and their Breeding Environments", IFIP AICT, Vol. 336, pp. 25-35.

Romero, D. and Molina, A. (2011). "Green Virtual Enterprises Breeding Environment Reference Framework", IFIP AICT, Vol. 362, pp. 545-555.

Romero, D. and Molina, A. (2012). "Green Virtual Enterprise Breeding Environments: A Sustainable Industrial Development Model for a Circular Economy", IFIP AICT, Vol. 380, pp. 427-436.

Romero, D. and Molina, A. (2013). "Reverse - Green Virtual Enterprises and Their Breeding Environments: Closed-Loop Networks", IFIP AICT, Vol. 408, pp. 589-598.

Scott, J.A.; Christensen, I.; Krishnamohan, K. and Gabric, A. (2001), "Concepts and Methodologies to Help Promote Industrial Ecology", Handbook of Environmentally Conscious Manufacturing, pp. 27-56.

Short, S.W.; Bocken, N.M.P.; Rana, P. and Evans, S. (2012). "Business Model Innovation for Embedding Sustainability: A Practice-Based Approach Introducing Business Model Archetypes", 10th Global Conference on Sustainable Manufacturing, Istanbul, Turkey.

Short, S.W.; Rana, P.; Bocken, N.M.P. and Evans, S. (2013). "Embedding Sustainability in Business Modelling through Multi-stakeholder Value", IFIP AICT, Part I, Vol. 397, pp. 175-183.

Tueth, M. (2010). "Fundamentals of Sustainable Business: A Guide to the Next 100 years". Hackensack: World Scientific Publishing Co.

United Nations Environment Program (UNEP). Definition of "Cleaner Production". http://www.unep.org/

Willard, B. (2005). "Next Sustainability Wave: Building Boardroom Buy-In". Gabriola Island, BC, Canada: New Society Publishers.