Reverse – Green Virtual Enterprises and Their Breeding Environments: Closed-Loop Networks

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Abstract. Green Virtual Enterprise Breeding Environments and their Reverse-Green Virtual Enterprises, as dynamic reverse supply networks, represent a promising paradigm to face the reverse logistics and end-of-life manufacturing challenges towards closed-loop industrial processes, closed-loop supply networks and sustainable industrial development models. This paper explores different collaborative product recovery business opportunities and strategies for capturing current missed value at the end-of-lifecycle with new activities, relationships and network configurations, put forward based on the disciplines of Industrial Ecology, Collaborative Networks and Lifecycle Management.

Keywords: Collaborative Networked Organisations, Green Virtual Enterprises, Breeding Environments, Industrial Ecology, Lifecycle Management, Reverse Logistics, End-of-Life Manufacturing, Circular Economy.

1 Introduction

Nowadays, customers and authorities are starting to demand that manufacturers and service providers minimise their environmental impacts of products and services. Customer pressures will continue rising in the coming years to the extent that a new generation of *green consumers* will get more and more concern about environmental protection. Government actions encompassing new legislations and law enforcement for environmental protection will also continue eco-restructuring the way industry operates. As a result, a new industrial environmental protection *action framework* is needed to shift from the exclusive tracking of economic objectives to a consideration of ecological and social objectives as part of a *new sustainable industrial development model* [1] [2]. Hence, there is a strong necessity to combine powerful concepts like: Industrial Ecology, Collaborative Networked Organisations & Lifecycle Management [3] to shift from linear industrial processes (open systems), in where resources move through the system to become waste, to closed systems where waste can become inputs for new processes, reducing in this way the impact on the natural environment.

Industrial Ecology (IE) can be used as an eco-efficiency strategy focusing 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]. Meanwhile,

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Collaborative Networks (CNs) at intra- (e.g. eco-factory and eco-service office) and inter-organisational (e.g. green supply network) levels can support the implementation of different IE strategies by creating sustainable business units and 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 cyclic flow and sharing of resources for producing and/or delivering green products and/or services to the market [5]. Furthermore, *Lifecycle Management (LCM)* can act as an "green" product lifecycle management tool, from the product Beginning-of-Life (BOL), including its design, engineering and production, passing thru its Middle-of-Life (MOL), counting its use, service and maintenance, and End-of-Life (EOL), characterised by various scenarios such as: direct reuse/resale, product recovery by: repair, refurbishment, re-manufacturing, cannibalization and/or recycling, and waste management by: incineration or landfill [6] [7].

In this paper, a *Green Virtual Enterprise Breeding Environment (GVBE)* model will be presented as an *integrated supply network* (collaborative forward and reverse supply networks) [5], supporting closing the loop at the end-of-life of any product, and creating a cyclic flow with the highest degree of resources circulation within an industrial system (e.g. industrial symbiosis[1]) and a product lifecycle (e.g. product up-cycling[2] or down-cycling[3]). Moreover, a *GVBE operational model* compromises not only the development and delivering in a sustainable way of a new product, but also its service provisioning, product recovery and waste management during its lifecycle. As part of a *GVBE extended producer responsibility,* products will return from the end-user to undergo a product recovery operation, and thereafter will be integrated back into a forward supply network; if not possible will be safely disposed.

2 Green Virtual Enterprises and Their Breeding Environments

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* it-self is an intelligent network for competences and resources management from different green enterprises aiming to combine their green capabilities to develop triple top-line strategies[4] to create sustainable value - thru *GVEs creation* [1] [2] [5].

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[1] *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 [8].

[2] *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 [9].

[3] *Down-cycling* - is the process of converting waste materials or useless products into new materials or products of lesser quality and reduced functionality [9].

[4] *Triple top-line strategies* - promote the establishment of sustainable business requirements as initial values rather than after the fact effects (vs. triple bottom-line) [10].

A *Green Virtual Enterprise (GVE)* is an emerging sustainable manufacturing and logistics networked enterprise model focused on offering, delivering and recovering green products/services to/from the market, under a lifecycle thinking and supported by its source network (a *GVBE*) [1] [2] [5].

Depending on its delivering or recovering goal, a *GVE* can be tailored to become a *dynamic forward supply network* for delivering new green products (virgin or used/ recovered) to the market, or a *reverse supply network* for recovering the products sold under the *GVBE brand* (product stewardship) for service provisioning, product recovering or safe disposal [1] [2] [5].

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 to the customer with a minimal environmental impact [1] [2] [5].

In this research work, authors will focus on the case of *GVEs* as *dynamic reverse supply networks (R-GVEs)* operating as 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, refurbishment, re-manufacture, recycle or safe disposal - within a *GVBE* (see Fig. 1)[1] [2] [5].

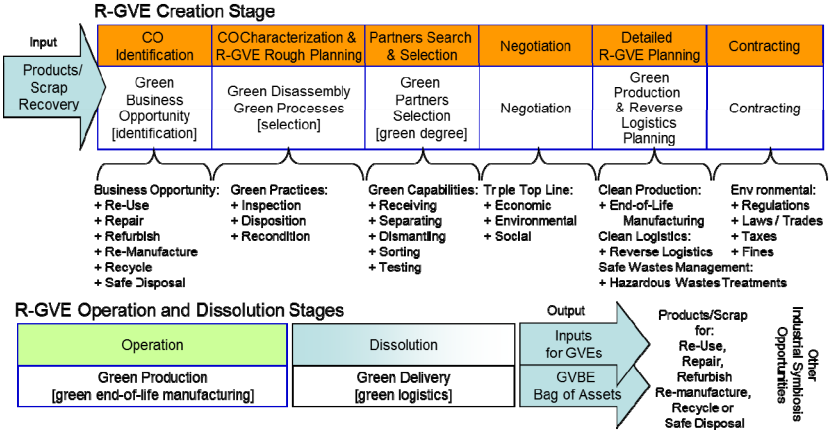

Fig. 1. Reverse Green Virtual Enterprise Lifecycle: Dynamic Reverse Supply Network

The *GVBE model potential* for closing the loop of products at their end-of-life arises from its ability to dynamically configure and launch *R-GVEs* according to a product lifecycle recovery needs and opportunities from/of the market and keep these *reverse supply networks* operational as long as these opportunities persist [1] [2] [5], suggesting a number of sustainable benefits when it comes to the uncertainties of return flows/returned products in order to recover as much of the economic and ecological value of a product, thereby reducing the ultimate quantities of waste [7].

3 Strategic Issues in Product Recovery Management and GVBEs

By analysing different *Product Recovery Management (PRM)* opportunities and their implementation challenges [7] [11], *GVBEs* represent a promising paradigm to face those challenges and overcome them towards *closed-loop industrial processes, closed-loop supply networks* and *sustainable industrial development models* [1] [2] [5].

Following sections will explore those opportunities and challenges, and propose different collaborative strategies to design *dynamic reverse supply networks,* named: *R-GVEs,* capable of managing in a sustainable way the uncertainties of return flows in a *closed-loop supply network,* and take advantage of new value creation opportunities such as: second-hand markets, improved customer service in case of defective product returns (e.g. warranties), under-utilised materials and products (e.g. up-cycling and/or down-cycling) and social-environmental responsibility (e.g. product stewardship).

Product Recovery Opportunities and Goal-Oriented Collaborative Networks. There are eight types of product recovery/disposal options or opportunities: (1) *direct reuse/resale* when a virgin product can be second-hand used for the original purpose it was designed or a different one, without going into a product recovery operation (e.g. old clothes, old home-appliances, old toys, old furniture… are resold and/or donated - sustainability goal: waste avoidance); (2) *repair* when a durable product is fixed and/or some of its broken parts replaced to return the used product to "working order" or functional condition state (e.g. fixing a computer or replacing an auto part by a spare-part - sustainability goal: waste reduction by extending product durability); (3*) refurbishment* when all critical modules of a durable product are inspected and repaired, replaced and/or potentially upgraded to recondition the product to a specific quality level or functional state (e.g. restoring or renovating an antique, a building, a vehicle, an electronic equipment - sustainability goal: waste reduction by extending product durability); (4) *re-manufacturing* when all modules and parts of a durable product (used and new) are inspected, repaired, replaced, potentially upgraded and tested to bring the product to "as new" quality level (e.g. air condition units, heavy duty equipment, vending machines… - sustainability goal: "like-new" products for a second life); (5) *cannibalisation,* in the past three product recovery options the product identity was preserved, but in the case when a product is *cannibalised* or *selectively disassembled,* some parts of the product will be retrieved/recovered for their use in repair, refurbishment and/or re-manufacturing activities and some other part will be recycled and/or disposed (e.g. a machines boneyard as a source of spare parts inventory - sustainability goal: waste reduction by used parts reutilisation); (6) *recycling,* as opposed to previous product recovery options, when recycling a product its identity and functionality will be lost, but its component raw materials will be processed to make the same raw materials or useful degraded materials available for use into new products (e.g. glass, paper, metal, plastic, textiles… sustainability goal: consumption reduction of "fresh" raw materials), (7) *incineration,* is a disposal method for a product based on combustion or thermal treatment to convert it into heat, gas, steam or ash (e.g. sustainability goal: waste-to-energy), and (8) *landfilling,* is the last resort and less desired disposal method based on burying the waste (e.g. sustainability goal: properly designed and managed landfills) [7].

Fig. 2 depicts an integrated view of the different *PRM opportunities* and *activities* that will trigger an *R-GVE creation* with the required reverse logistics and end-of-life manufacturing capabilities and capacities to repair, refurbish, re-manufacture/ cannibalise, recycle, or safe dispose a product. Considering the uncertainties in the timing, quantity, quality, composition and location of potential returned products from customers [7], the *R-GVEs dynamic creation* within a *GVBE,* offers a great opportunity to *GVBE members* (green enterprises[5]), on the one hand to close the loop in their supply chains based on a collaborative supply chain model, and on the other hand to explore new collaboration (business) opportunities based on creating value through product recovery (e.g. creating value from waste by recycling; delivering added-value thru function not ownership by repair, refurbishment and/or re-manufacturing; encouraging sufficiency by direct-use/re-use; and maximising resources efficiency by any of the previous).

PRM opportunities call then for innovative sustainable collaborative business models, and networked green enterprises, capable of unlocking new business opportunities at the end-of-lifecycle. The *GVBE model* [1] [2] [5] is the authors response to explore new collaboration strategies for capturing current missed value at the end-of-lifecycle with new activities, relationships and network configurations.

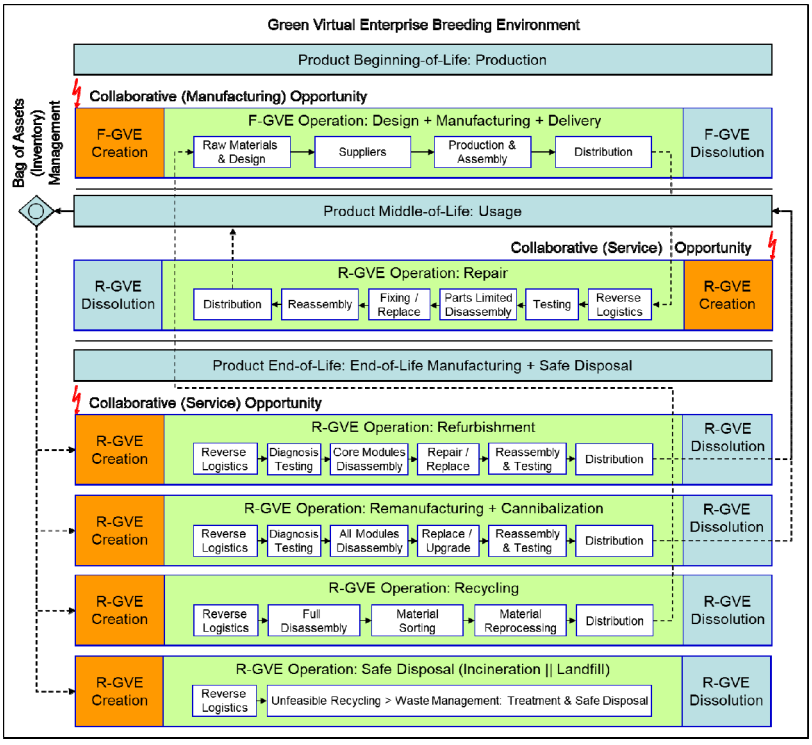

Fig. 2. Product Recovery Opportunities-driving R-GVEs Creation

[5] *Green Enterprise* - is an enterprise that strives to meet the triple bottom line by ensuring that all its activities in its business operation address the sustainable principles [1] [2] [5].

Moreover, in order to generate new solutions that capture new value at the end-of-lifecycle, green enterprises need to achieve sufficient volume and cost-efficiency, flexibility and competency in their reverse logistics and end-of-life manufacturing activities. These requirements are often drivers for inter-organisational collaboration in industry, and authors approach based on *GVBEs creation* [1] [2] [5] puts forward the conditions and environment to support green enterprises to set-up their *closed-loop supply networks* by means of collaborative business infrastructures enabling multiple coordination and cooperation mechanisms like: shared commuting, shared shipping, integrated (reverse) logistics, joint product recovery operations, information exchange, etc. to create *closed-loop business ecosystems (F-GVEs + R-GVEs).*

Centralised vs. Decentralised Reverse Supply Networks: Why Not Both? *RGVEs* focus on responding to collaborative product recovery business opportunities. Returned products or product recovery opportunities can be recovered/emerge from *forward supply networks* due to warranties and/or unsold products, from market-driven streams based on "bring-back the old and take-back the new one cheaper" promotions, and waste streams from manufacturing discarded products due to quality and/or technical issues [12]. The uncertainties in the timing and quantity of returns are clear and call for diverse *reverse supply networks* configurations with different life-spans of existence in order to cope with the uncertain life of products.

For example, in some cases "responsive and decentralised" *reverse supply networks* may be needed to deal with high-time sensitive products (e.g. electronic equipment with a short-lifecycle as a result of high-speed technology grow) where a faster response to a product recovery opportunity is needed to capture the returned value effectively at the end-of-lifecycle and fast-track move on to resale on a secondary market for: (a) *products* in case of repair or refurbishment; (b) *components* and *parts* in case of re-manufacturing and cannibalization; or (c) *raw materials* in case of recycling. In other cases, "efficient and centralised" *reverse supply networks* may be required where the sense of urgency is lower and the focus is on the design of cost-efficiency *RGVEs* (e.g. functional and long-lifecycle products like household appliances) (see Fig. 3) [13] [14]. In this sense, *GVBEs* as *breeding environments,* underline the possibility of rapidly forming a consortium of green enterprises (an *R-GVE*) triggered by a product recovery opportunity and specially tailored to the competency requirements of that opportunity (e.g. capabilities, capacities, time, cost, quality, risk) and dissolve once their mission has been accomplished [1] [2] [5].

"Efficient and centralised" *reverse supply networks* use a postpone strategy or later product differentiation in order to achieve processing economies by delaying inspection, sorting, and disposition activities until the returned products are collected at a central location. Furthermore, "responsive and decentralised" *reverse supply networks* use an early product differentiation to maximise assets recovery and fast-track returns for disposition and 5R[6] or safe disposal (see Fig. 3) [13] [14]. *GVBEs* as long-term strategic alliances of green enterprises (e.g. manufacturers and logistics providers), geographically distributed, offer the possibility of collaboratively

[6] 5R - Re-use, Repair, Refurbish, Re-manufacture, and Recycle.

managing a single or multiple bag(s) of (returned) assets[7], traditional named: shared warehouses and distribution centres, providing an agile and flexible (inventory) approach when warehousing volumes, returning times and 5R possible operations are uncertain [1] [2] [5].

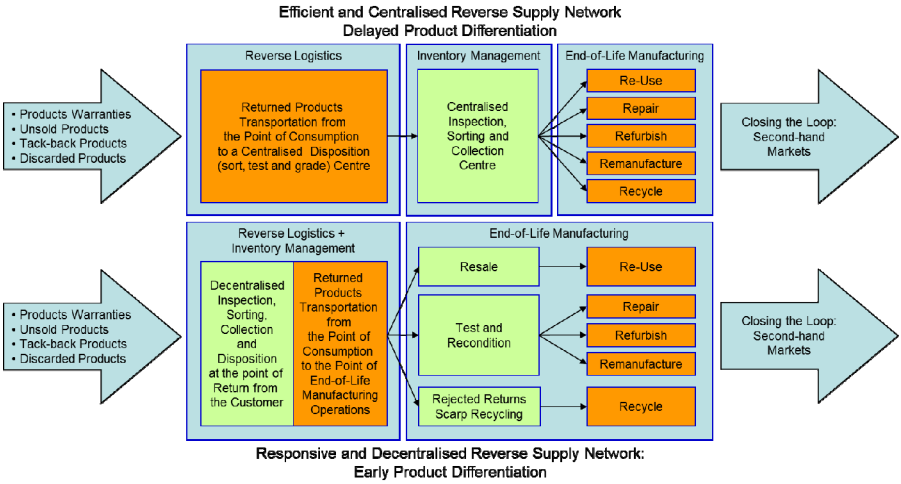

Fig. 3. Efficient-Centralised & Responsive Decentralised Reverse Supply Networks Adapted from [13] [14]

Information Management for Product Recovery Strategies and Net Design. *Reverse supply networks* or *R-GVEs* are created by a number of collaborating (legally) independent green re-manufacturers and reverse logistics providers in order to recover back products from the market. Their belonging to a long-term collaborative network such as *GVBE* offers those green enterprises the opportunity and time for developing a common ground for communication and information exchange for mutual benefit (e.g. collaborative ICT business infrastructures [see 15]). Recalling, *GVBEs* are aimed at offering the necessary conditions (e.g. human, financial, social, infrastructural and organisational) to support the rapid and fluid configuration of *F-GVEs* and *R-GVEs. GVBEs* mainly focus 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 be ready to collaborate in potential *GVEs* that will be established when a collaboration (business) opportunity arises [1] [2] [5]. In this context, *GVBEs* cooperation atmosphere and *GVBE members'* preparedness for collaboration facilitates the reduction of information asymmetries and improves the alignment of potential *R-GVE partners,* emphasizing in the dynamic creation and operation of *information-driven reverse logistics networks.*

[7] Bag of assets - is a common virtual and physical warehouse to make easier the share of tangible and intangible assets between GVBE members for different collaborative purposes [1] [2] [5].

Information management, starting from information creation to exchange and exploitation for decision-making, is vital for the process of common planning and scheduling of *R-GVE partners* activities in a *reverse supply network.* Efficient design of *R-GVEs* strongly depends on information available not only about the potential returned products but also the potential members available for joining a *dynamic reverse supply network* to tackle a product recovery opportunity.

Regarding product related information management, two strategies may be pursued: (a) a *product-centric information management strategy* based on treating a product as an "intelligent object" capable of creating (e.g. thru sensors and actuators), storing (e.g. in smart-tags) and sharing (e.g. using communication technologies) information about itself over its lifecycle [16]. In this strategy, *F-GVEs* will need to consider these product features as part of the product design and engineering in order to make the product entity the central repository and access point for its historical information, supporting in this way all information provision requirements for conducting middle- and end-of-life after-sales services and product recovery operations on the product, which will trigger the creation of different types of *GVEs* and help to characterise the collaboration opportunity in terms of its competency requirements when a product arrives to a service or recovery location [17], or (b) a *product-integration information management strategy* based on the integration of product-relevant information from multiple enterprise information systems (e.g. CAD, PDM, PLM, ERP, SCM, CRM) from all the product lifecycle stakeholders *(GVE partners)* to build a common database (e.g. knowledge repository): the *GVBE collaborative ICT business infrastructure* [15] - with the entire product historical information for data-mining it to forecast possible after-sales services and end-of-life product operations that will also launch the creation of different types of *GVEs* [17].

With respect to information on potential members of a *dynamic reverse supply networks, GVBEs integral management system* [18] offer a very complete set of information management systems covering: *GVBE members membership structure, profiling and competency information* [19], and *GVEs creation* [20] and *operation assistance information services* [21]. All these information management systems aimed at supporting the identification and characterisation of a product recovery opportunity, and a dynamic *R-GVE creation* and *operation,* including its partners search and selection, planning, set-up and operation, and dissolution management [20] [21].

Authors and [22] believe that by combining *products'* and *GVBE members' information,* better decision-making can be done to forecast and identify reprocessing lead-times for particular products, volume of returned product flows, possibilities for grouping products families (commonalities), locations of potential collection points (distribution points), waiting time for returns, volume of returns inventories in distributed locations, and availability of recovery services in order to better design *R-GVEs* and locate *GVBEs bag of assets* (shared warehouses and distribution centres).

Second-Hand Markets, Brokers and Green Consumers: Collaboration Again. *Reverse supply networks* also highlight the activity of "resale" of repaired, refurbished or re-manufactured products in second-hand markets in order to up- or down-cycle a product in a *Circular Economy* [2] [23]. Therefore, *GBVE brokers* [1], play a vital role in the identification and/or development of new collaborative product recovery business opportunities in the market. *GBVEs brokers* are perhaps the most important factor for successful and profitable *reverse supply networks* and *closed-loop supply networks.*

GBVEs brokers will be responsible for (re-)marketing the returned recovered products and negotiate with (potential) green customers thru different channels such as other re-manufactures (e.g. for product recovery cannibalisation strategies), green internet-based auctions, specialised retailers in returned products or second-hand products (e.g. outlets) among others [23]. Furthermore, *GVBE brokers* will leverage on the *GVBE sustainable industrial development model* for eco-branding and eco-marketing as well as for building a green strategic competitive advantage in a growing environmentally conscious market.

Moreover, in order to promote the acceptance of returned recovered products in the marketplace, *GVBE brokers* may promote the creation of *green consumer networks* around the *GVBE* aiming the creation and expansion of secondary markets.

Collaboration between green customers and green manufacturers is foreseen again by the authors as trend that will led the manufacturing industry to responsive (profit) actions to a growing demand for eco-friendly products, acceptance of products with recycled materials, and increasing market requirements for after-sales services and take-back programmes, stimulating the emergency of product recovery opportunities at the end-of-lifecycle: *R-GVEs creation.*

4 Conclusions and Further Research

Dynamic *R-GVEs* represent an intelligent integration of green enterprises' competences, best practices and technologies for responsive and efficient (hybrid) reverse logistics and end-of-life manufacturing activities in response to the challenges, but also emerging collaborative (business) opportunities for product recovery operations.

Future research aims the refinement and proof of concept of the *R-GVE - dynamic reverse supply network - model* introduced (a case study), and the study, development and validation of sustainable product recovery business models [24] for reducing waste, recovering value at the end-of-lifecycle, and improving profit in a *closed-loop supply network* and *Circular Economy.* The research work represents an exploratory work in progress aiming to create synergies between the *IE* and the *CNs* disciplines.

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