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Inferring principles for sustainable development of business through analogies from ecological systems

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Abstract The literature in the field of sustainable development (SD) of businesses is piecemeal and diverse. This paper identifies and integrates principles that businesses could use for transformation towards SD. This is done through analogical reasoning from the source context of ecological systems to the target contexts of business socio-economic systems and machine/technology systems. The methodologies of systems thinking and morphological analysis supplement the analogical reasoning. Based on this, twelve principles for sustainable development of business are inferred for business managers and policy makers.

Introduction to sustainable development of business

Our world consists of islands of prosperity, viz., large businesses and wealthy governments, amidst oceans of deprivation, viz., poverty, social malaise and ecological degradation (UNGC Accenture, 2010). Our ecological footprint currently exceeds the earth's carrying capacity,[3] and continues to increase. Hence, society and businesses should pursue the path of sustainable development (SD). This paper attempts to synthesise principles for SD of businesses for use by professionals, managers and policy makers.

Sustainable development can be defined as "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs" (WCED, 1987—section 3, page 16). Sustainable development of business involves preservation and enhancement of the existing stock of resources — financial, ecological, societal, human, physical, and others — which businesses depend upon quantitatively and qualitatively,

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[3] Carrying capacity is the amount of maximum population of a given species that can be sustained in a given environment, indefinitely. This depends on human choices and natural limits in the case of human beings.

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and in the short- and long-run (Stiglitz, Sen, & Fitoussi, 2009). Sustainable development of business also involves the reduction of waste and risks in the socio-ecological context (Hanson, Finisdore, Ranganathan, & Iceland, 2010), while meeting the materialistic needs of society at appropriate prices, quality, and timeframes.

Sustainable development of business needs to be measured against the triple bottom line of people (society), planet (ecology) and profit/prosperity (economy) (Elkington, 1998). Historically, the ideologies of feudalism/traditionalism, capitalism, communism, and modernism had their own impact on the triple bottom line (Dresner, 2002). The current questions on sustainability lead to considerable speculation on the sustainable development of business in the future. Key milestones relating to voluntary initiatives for SD of business (WBCSD, 2000) since 1970 are given in Table 1.

Key works on social development of business

The literature on SD of business uses an eco-centric view or an anthropocentric view. The eco-centric view (Naess, 1992), believes that ecological systems are at the centre of all value, and that human systems are embedded in and mirror ecological systems (Capra & Pauli, 1995; Iyer, 1999; Zsolnai & Ims, 2006). The anthropocentric view places human systems above or outside ecological systems and considers it a source of all value. Ecological systems are considered to be of only instrumental, aesthetic, or utilitarian value.

Some of the key themes in eco-centric literature are

a) Sustainable communities can be built and nurtured based on ecological systems
b) Voluntary simplicity (Gandhi), small business (Schumacher) and Buddhist style economics may emerge in the future as eco-centric models of business
c) The model of human nature as selfish and asocial is a poor predictor of real human behaviour

The key principles of the eco-centric view for business are

a) De-emphasise non-essential consumer goods and emphasise production of essentials for the needy
b) Respect and restore ecological systems
c) Involve all stakeholders
d) Take part in the governance of the commons and finance it
e) Slow the economic growth rate to sustainable levels

In the anthropocentric view, SD literature is categorised as works related to the ecological bottom line and the triple bottom line perspectives. The literature related to the ecological bottom line consists of the concepts of eco-efficiency (cradle to grave approach) and eco-effectiveness (cradle to cradle approach). Eco-efficiency is achieved when goods and services satisfy human needs, increase the quality of life at competitive prices, and when environmental impacts and resource intensity are decreased to a degree that keeps them within the limits of Earth's carrying capacity (Dirk, Hausmann, Liedtke, & Weizsäcker, 2004). On the other hand, eco-effectiveness excludes the concept of waste. At the end of its life, the output of every process or product is "upcycled" separately either as a technical nutrient in the economic system or biological nutrient in the ecological system (McDonough & Braungart, 2002).

The following six principles are discussed by different authors and organisations related to SD of business from an ecological perspective (CERES, 2011; ICC, 1987; Lovins, Lovins, & Hawken, 1999; McDonough & Braungart, 2002; WBCSD, 2000)

a) Increase the productivity of natural resources
b) Reduce the quantity and toxicity of wastes
c) Increase the stock of natural capital
d) Rethink the markets with a service based business model and with less material and energy intensity Design the process and product for its lifecycle impact
e) Reduce ecological risks

From a triple bottom line perspective, SD of business necessitates the building up of social capital, apart from financial and ecological capital. The themes of triple bottom line literature are ethics, governance, transparency, relationships with suppliers, financial returns, community involvement/development, customer value, fair employment practice, and environment friendliness (Bilgin, 2009; Epstein & Roy, 2003).

Table 1 Key milestones in voluntary initiatives for sustainable development of business (WBCSD, 2000).

Year	Milestone
1975	The company 3M introduced successfully "pollution prevention pays" (3P) initiative
1986	Dow Chemicals introduced the "waste reduction always pays" (WRAP) programme
1991	World Business Council for Sustainable Development popularised the concept of eco-efficiency as a win—win solution for economy and ecology
1992	Rio Summit on SD — Business was also seen as a part of the solution, rather than as a part of the problem
1998	The concepts of eco-effectiveness and triple bottom line were popularised
2002	World Summit on Sustainable Development released top ten successes and failures since Rio meeting
2003	International Sustainable Development Communication Network strengthened to help decision makers on sustainability issues
2005	Millennium Ecosystem Assessment released, which outlined relevance of ecosystem services to business
2007	First investment negotiations forum as related to sustainability held
2008	International Standards Organisation developed the new corporate social responsibility standard
2012	In Rio+20 conference private sector also pledged finance for clean technologies in developing and under developed countries

From the above brief discussion, the following observations may be made

a) Current business practices are unsustainable (EIU, 2008) and require transformation (Lovins et al., 1999; UNGC Accenture, 2010)
b) Current principles of sustainability are diverse, piecemeal (Epstein & Roy, 2003), and generally address issues at lower levels of abstraction
c) The current practice emphasises the economic bottom line to the exclusion of the other two, namely ecology and society
d) The emphasis is more on reporting and branding than on developing competencies
e) Some of the principles suggested are futuristic

This paper attempts to infer and synthesise principles for SD of business on the following lines

- Using analogical reasoning with ecological systems serving as the source context
- Operating at a higher level of abstraction
- Contributing to the economic bottom line, by ensuring social and ecological sustainability

These principles have been piloted by a few businesses across the world successfully (see e.g. before reference to Table 4).

Analogical reasoning for social development of business

The various research models used in business literature are analytical models, empirical models, quasi models, analogy/metaphor models, and conjecture. Analogical reasoning is a form of inductive reasoning which involves mapping experiences from an appropriate source context, and applying the same to a target context under study (Gick & Holyoak, 1980). This works well where rigorous rational deduction and/or local search fail, or are impractical (Gavetti, Giovanni, Levinthal, & Rivkin, 2005). The field of SD of business involves novelty, complexity, rapid change, and uncertainty, making analogical reasoning a suitable approach.

In this study, the methodologies of systems thinking (Senge, 2010) and morphological analysis (Zwicky, 1969) supplement analogical reasoning to overcome its limitations (Mitleton-Kelly, 2003). Analogies are used for the purpose of explaining concepts and for suggesting principles to solve problems (Christensen & Schunn, 2007) in the context of SD of business.

The five steps of analogical reasoning are (Gavetti et al., 2005):

Step 1: Identify the characteristics of the target context that require the analogy.
Step 2: Identify possible source contexts for analogical reasoning.
Step 3: Choose the most suitable source context.
Step 4: Compare the characteristics of the source context with those of the target context to set the stage for analogical reasoning.
Step 5: Map the analogical solution from the source context to the target context.

Identification of the characteristics of the target context

The major relevant characteristics of SD of business are:

a) Businesses are systems with components, structures, processes with inputs/resources (sources), outputs (value added), and wastes (sinks), affecting their sustainability (Capra & Pauli, 1995; Senge, 2010)
b) Sustainable development of businesses is a multifaceted issue, especially in the current context of globalisation (Capra & Pauli, 1995; EIU, 2008); SD can be studied at various levels from local to global
c) The practical planning horizon of SD initiatives in business ranges from 15 to 175 years
d) Several market and non-market stakeholders affect and are affected by SD of businesses (Bilgin, 2009; Zsolnai & Ims, 2006)
e) Business policy and strategy also have a significant impact on SD of business (EIU, 2008; Prahalad, 2005). The realisation of SD is dependent on a number of principles (axioms/causes) that are applicable to the business context
f) There exist both a business case (DeSimone & Popoff, 2000) and a moral case (Dresner, 2002) for businesses to engage in SD
g) Businesses can contribute to SD through market, legal and corporate social responsibility (CSR) transactions (Mitra, 2009).

Based on the conceptual understanding of the authors, the nested relationship presented in Fig. 1 indicates that the business system is embedded in ecological systems and socio-economic systems, and in fact derives life support from these two systems. The illustrative morphological representation of the SD of business in Table 2, developed based on the conceptual understanding of the authors, indicates that the problem is complex and interconnected.

Identification of the possible source contexts

Sustainability of ecology, government, and civil society are the source contexts considered. Other meta systems (a few

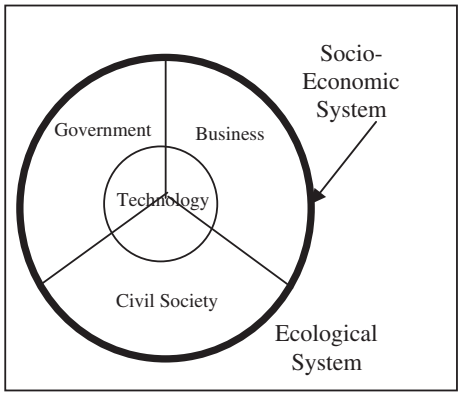

Figure 1 Ecological, socio-economic, and business systems.

Table 2 Morphological representation of sustainable development of business.

Dimensions	Options
Resource	• Natural (air, water, land, ecosystems) • Energy (renewable and non-renewable) • Materials • People • Information/knowledge • Culture • Technology • Finances
Wastes	• Unemployment/under employment • Lower productivity • Recession • Solid, liquid, gaseous, noise, light and radiation pollution • Species loss/colonisation by alien species/genetic pollution • Ill health, illiteracy • Over population • Crime, corruption • Conflict and war
Institutions	• Government • NGOs • Business • Academics • Media
Disadvantaged Group	• Non-human flora and fauna • Poor people • Women and children • Labour • Rural community • Small farmers • Indigenous community/ Specified castes • Minorities • Differentially abled • Senior citizens
Privileged Groups	• Administrators • Managers/Businessmen • Professionals • Scientists • Technologists • Religious leaders • Politicians

examples given below) are found to be inappropriate (a) universe — since a large body of conjecture exists about its functioning, (b) health, education, transportation, communication systems, which have been subsumed in government and NGOs discussed earlier, and (c) terrorist systems (for lack of similar structure and ethical reasons).

Choice of source context

The following characteristics of systems have been used to evaluate the potential source contexts in this study: complexity, structure, purpose, long-term stability, flexibility, command flow, information flow, feedback, interaction, interdependence, integration, age, maturity, frame of reference, openness, input, process, output, entropy,[4] and equifinanity[5] (Morgan, 2005). Based on a comparison of these characteristics, sustainability of ecological systems derives maximum support as the source context. These reasons include:

a) Several works support the analogy of ecological systems in the context of SD of business (Benyus, 1997; Iansiti & Levien, 2004; Lovins et al., 1999; Rothschild, 2004)
b) The age of ecological systems is nearly 3.8 billion years (Benyus, 1997), whereas the human systems of government and NGOs are only 5000 and 50 years old (Mitra, 2009)
c) Ecological systems are more complex, robust, mature, and have better structures than human systems, co-evolving with all species naturally. The failure of the Biosphere-2 experiment (simulation of an ecosystem through pure human input) is testimony to the suitability of ecological systems as an analogy (Lovins et al., 1999).

The literature in the fields of biology, ecology, geography, and earth sciences is used to derive principles for SD of business from the source context. Further, literature from strategic management, industrial ecology, and SD are used to map the solution to the target context of SD of business socio-economic and machine/technology (SE and MT) systems in the following sections.

Ecological and business systems: a conceptual comparison

A comparison between the source context (ecological systems) and the target context (business SE and MT systems), in terms of their characteristics is presented in Table 3 (Capra & Pauli, 1995; Rothschild, 2004; Scale, 2010). It is evident that several characteristics of ecological systems and business SE and MT systems are equivalent, adding to the robustness of the analogy.

In the context of SD, ecological systems enjoy some merits over business SE and MT systems. These include: closed loops (Benyus, 1997), lack of need for human effort and resource inputs (Benyus, 1997), producing progeny, flexibility and adaptability (Senge, 2010), and wisdom (Lovins et al., 1999). These manifest in the form of self-organisation and self-healing, and complex interconnectedness of material, energy, and information flows as well as robustness (WRI, 2000).

Market mechanisms (Ayres & Ayres, 2002), quantum leaps in process innovation through knowledge and technology (Rothschild, 2004), short cycle times (Peltoniemi &

[4] Randomness due to lack of focus, etc., leading to loss of energy or structural order in the system, adversely affecting fulfilment of the purpose (objectives) of the system.
[5] The ability of an open system to achieve the same end states from different initial conditions and through different means.

Table 3 Equivalences among attributes/characteristics of ecological systems and business SE and MT systems (Capra & Pauli, 1995; Rothschild, 2004; Scale, 2010).

Attributes		Ecological systems	Business SE systems	Business MT systems
Units		Organism	Individuals	Devices, machines, instruments
Population — species	Groups of individuals at the same level of hierarchy	Similar devices, instruments, machines in the plant		
Community	Office	Plant		
Ecosystem	Business firm	Firm level technology infrastructure		
Biosphere	Industry/global socio-economic system	Network of industry/global technology infrastructure		
Structure		Composition, quantity, range/ gradient, food-webs	Organisation structures/ processes	Logical schema, layouts, architectures
Flows	Information	Biophysical chemical processes	Formal, informal communications	Machine language
	Materials	Biophysical chemical processes	Human transport, mobility	Materials and products through conveyors, transport, and human/animal effort
	Energy	Food and carbon cycles, solar (direct and derived)	Motivation and food	Fuels, batteries, conventional and non-conventional sources
Norms		e.g. Growth and balance	Laws, codes, ethics, and principles	Rules, operating principles, and algorithms
Environment		Celestial processes and other/ external ecosystems	Government, NGOs, other businesses, and the biosphere	Other machine systems, socio-economic system, and the biosphere
Ownership		Commonly evolved and owned by all species	Society and shareholders	Business firm
Soul (essence)		Maintaining conditions conducive for all living species	Providing materialistic need of the society	Meeting defined processing tasks through functional capabilities
Hierarchy/operational responsibility		Based on food chain with humans as the highest link	Management team at the top with the rest based on the organisation structure	Chief Technology Officer, controls (micro processor, CPU and manual) at the top
Interdependence	Synergetic	Symbiotic species	Supply chain partners and government	Equipment along a production line
	Competitive	Predator—prey, within same species	Businesses within an industry, employees at a level of hierarchy	Equipment that perform similar functions
	Parasitic	Alien species, parasitic plants, bacteria, and viruses	Rogues, criminals, and money launderers	Computer viruses and hackers
Lifecycle	Evolution	Diversity, number of members, interdependence	Human values, ecosystem's rights, knowledge, interdependence among firms	Energy efficiency, processing power, interdependence or integration, waste reduction
	Maintenance	Through inputs from sun and self-healing	Through human effort — leading to just and stronger businesses	Through human/technological routines — preventive and breakdown maintenance
	Obsolescence	Extinction	Liquidation, sell off, mergers	Decommissioning, replacement of old technologies

Vuori, 2004), free will and conscious choice (Ayres & Ayres, 2002) are the merits of business SE systems over ecological systems (Moore, 1996). Predictability, reliability and repeatability, processing speeds, and tolerance to difficult environments are some of the merits of business MT systems over ecological systems. These merits of business SE and MT systems over ecological systems may, in fact, facilitate business systems to quickly transform towards SD.

Mapping the analogical solution — inferring the principles of sustainable development of business

In this section, the principles of SD of business SE and MT systems are inferred using analogies of important sustainability principles from ecological systems. It should be noted that the mapping of analogies from ecological systems to business systems may be many to one, one to many, and many to many. The principles of SD discussed below are applicable to managers and policy makers at all levels (refer to Units and Business SE and MT systems in Table 3). It is applicable to all geographies and across all industries.

Principle 1 — manage with lifecycle orientation — is discussed in detail with the following structure — (a) Abstracting the constituent sub-principles of SD from ecological systems (b) Inferring the sub-principles for SD of businesses from those of ecological systems, including the corresponding strategic perspectives and initiatives (c) Providing a business example of the application of the principle, and (d) Summarising the discussion in Table 4. Principles 2 to 12 are briefly discussed and their elaboration is left for further research.

Principle 1: manage with lifecycle orientation

In an ecosystem, in the context of sustainability, the entire lifecycle needs of most individuals in every species are provided for (Nisimura & Numata, 2001). For example, carpet beetles develop from larvae to adults in 1—3 years' time, depending on the ability of the environment to meet their lifecycle needs. Larvae hatching from eggs in the spring and early summer, often in the nests of birds, feed on natural fibres throughout their development. Eventually, they experience a dormancy period during low food supply prior to pupation into the adult stage during May to August, feeding on pollen of flowering plants. Thus, the lifecycle of the carpet beetle is adapted to the availability of required resources in its ecosystem.

Further, in ecosystems, lifecycle orientation dictates the major life history characteristics, such as age at first reproductive event, reproductive lifespan and ageing, and the number and size of offspring. This reflects different allocations of an individual's resources (i.e. time, effort, and energy expenditure) to competing life functions (Promislow & Harvey, 1990). Further, the life history characteristics dynamically change according to the population density as well as the ecosystem's stability. Genotypes with highest fitness at the dense population level have lower fitness at lower population density. An unstable environment tends to promote those organisms that produce a large number of offsprings early in life. Thus, lifecycles in an ecosystem involve tradeoffs between reproduction, growth, and survivorship (Kozlowski & Wiegert, 1986).

Another example of lifecycle orientation in an ecosystem is that the waste of one species serves as food for another (Lovins et al., 1999), or, waste equals food

Table 4 Analogy for principle 1: manage with lifecycle orientation.

Sub-principles of ecosystems sustainability	
a) Lifecycle needs of most species are provided for	
b) Self-adaptive cyclical processes of life and transformation exist across spatial and temporal scales (the panarchy model). The cycles typically consist of *exploitation* (γ phase), *conservation* (κ phase), *release* (Ω phase), and *reorganisation* (α phase). Cross scale linkages of *revolt* and *remember* exist.	
c) Lifecycle orientation dictates life history characteristics; Species in ecosystems balance and tradeoff resources (time, energy, and effort) across competing life functions (reproduction, growth, and survivorship).	
d) Waste of one species is food for another	
Sub-principles for sustainable development of business	
Business SE systems	***Business MT systems***
a) Ensure self-adaptive cyclical process of transformation towards SD	a) Ensure safe decommissioning of productive facilities, plants and other MT processes
b) Plan in the fore loop and dynamically manage the back loop, through experimenting and change management	b) Move from a linear to cyclical process in the context of energy and materials
c) Manage multiple variables but only a handful of key variables across phases; manage slow and large variables, apart from fast and small variables; use multiple leadership styles across phases	c) Design to recycle/upcycle separately as technical waste and biological waste
d) Manage social and ecological aspects during the lifecycles in addition to financial aspects	
e) Design products for lifecycle	
f) Adopt extended producer responsibility	
g) Move towards a service based business model	

Sources: Ecology: Kozlowski & Wiegert, 1986; Lovins et al., 1999; Promislow & Harvey, 1990. Businesses: Westley, 1995; Whitaker, 1987.

(McDonough & Braungart, 2002). The following cycle illustrates this process:

a) The bodies of dead animals are food for microorganisms (detritus food chain)
b) The wastes from microorganisms at the end of this process become humus for plants (grazing food chain)
c) Oxygen release, which connotes the wastes of plants during the day, serves as an input for the breathing process of animals.

Panarchy, a metaphor from ecosystems lifecycles, provides a simple framework to understand complex adaptive systems operating at various scales in space and time (Gunderson & Holling, 2002). Across the four phases of the panarchy model, ecosystems are described on the three dimensions of potential or wealth, internal connectedness or resources-species/actors networks and resilience or adaptation and survival spirit as explained in Fig. 2.

a) *Potential* (*y* axis) refers in the ecosystem context to the accumulation of biomass, nutrients, and structure (openness, density and centrality, innovations and mutations) in the system at each stage. It sets the limits to what is possible — the number and kinds of future options available. Analogously in business systems, competencies of individual businesses, skills of the workforce, technologies, institutional competencies, finances, as well as quality and quantity of soft infrastructure (cultures) and physical infrastructure constitutes the potential of the system.
b) *Connectedness* (*x* axis) in the ecosystem indicates the extent of diffusion or connectedness of internal elements (variables) through their connections and relationships (processes linking resources and species). Low connectedness in the system is an indication of diffused elements that are loosely connected. Hence, the behaviour of the system is dominated by outward relations and affected largely by outside variability. High connectedness means tight coupling among the aggregated elements, with the system's behaviour being dominated by inward relationships among the aggregate elements. The high connectedness enables mediation or control of the influence of variability of external elements (e.g. temperature regulation in warm blooded animals, which involves five different physiological mechanisms). Analogously in business systems this refers to internal connectedness of actors and components, traded and un-traded dependencies between stakeholders, units within and outside the organisation, local networks of trust, formal and informal associations, social networks, knowledge spillovers, and patterns of mobility within and from outside the network. Thus in business systems connectedness includes the idea of interaction between actors (human stakeholders with foresight and conscious choice).
c) *Resilience* (*z* axis), in ecosystems, is a measure of the system's ability to recover from unexpected and

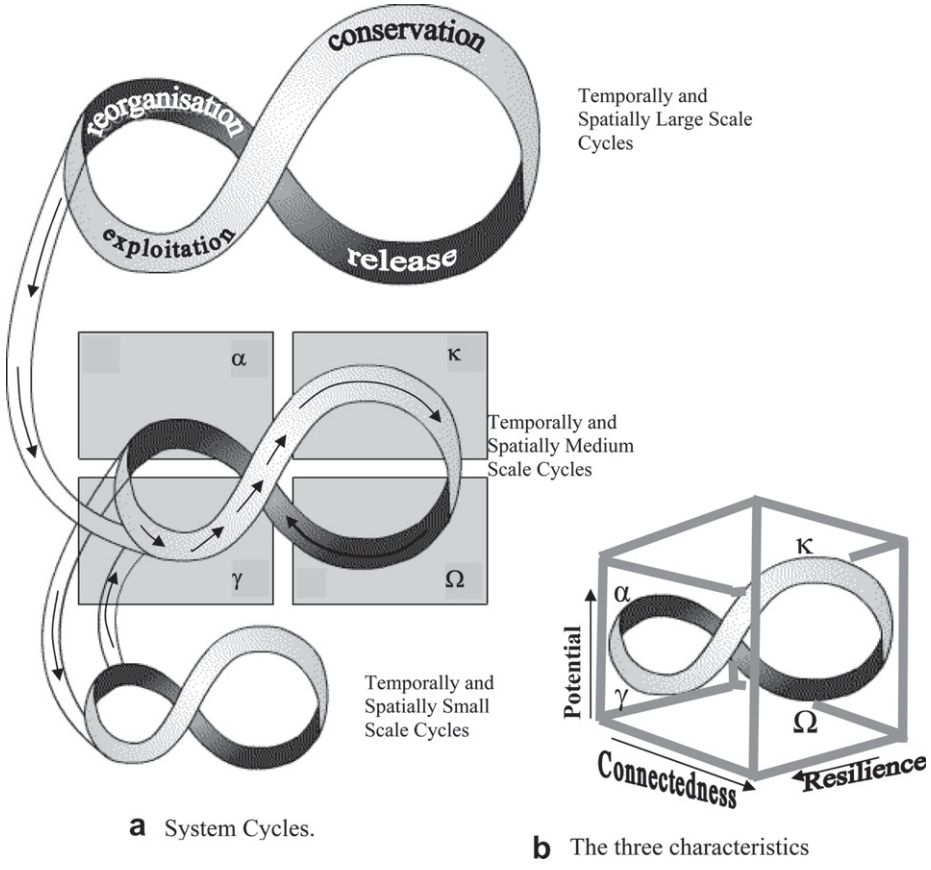

Figure 2 Panarchy model (Gunderson & Holling, 2002).

unpredictable shocks. At the stage of high resilience, the ecosystem is able to sustain itself, or recover well to a better state, from shocks without radical change to structure, function, feedback and identity. Analogously, in business systems it is the ability of an SE system to recover, to a similar or better state from unexpected or unpredictable shocks, without radical change in structure, form, function and/or identity. Thus systems with high resilience avoid collapse in response to shocks. Further, system-wide costs of failure are low when resilience is high.

It is evident that ecosystems and business systems alike go through the following four phases (Gunderson & Holling, 2002; Simmie & Martin, 2010). The cycle commences with "exploitation" (γ phase), exhibiting rapid growth. In this phase, species rapidly colonise fertile niches in the ecological system. In business systems the successful entrepreneurial organisations rapidly grow by taking advantage of the comparative advantages of the local economy.

This is followed by the "conservation" (κ phase) of maturation and rigidities. In ecological systems, biomass and nutrients are slowly accumulated and stored. In the business systems large bureaucracies slowly consolidate their market share. This leads to the vulnerabilities to external shocks in both the systems.

This is followed by the "release" (Ω phase) of creative destruction. In this phase, ecosystems and species decline and biomass/nutrients are released (e.g. through forest fire). Businesses as well as the regional economy decline and workers and CEOs get fired as a cost cutting measure during recession.

The "reorganisation" (α phase) with innovations and experimentation follows. Some resources are depleted, while others are recombined, reused, rebuilt, and acquired to "reorganise" and form a new ecosystem. Similarly new business models, institutions and comparative advantages emerge by dropping obsolete competencies, recombining, regrouping existing competencies, and adding new competencies. This leads to a new platform for the following "exploitation" (γ phase) and continuation of the cycle.

The exploitation (γ phase) and conservation (κ phase) together are called the fore loop of the cycle which maximises the ecological successions (in ecological systems) and capacity building (in business systems). The release (Ω phase) and reorganisation (α phase) together are called the back loop that maximises experimentation and innovation in both systems and facilitate transformation.

The panarchy model consists of hierarchies of "small and fast" cycles nested in "large and slow" cycles. The causation is both bottom up and top down. There are two relationships across the scales: a) The "revolt", which occurs when fast, small events or systems overwhelm large, slower ones, leading to novelty and b) The "remember", when the potential accumulated and stored in the larger, slower levels influences the reorganisation phase of a smaller, faster level and contributes to recovery and continuation of the cycle. Since minimal constraints exist in the back loop, it provides opportunities to transition to SD. In the sustainability context, the transition from conventional to sustainable organic agricultural practices has been studied in the panarchy model by Apeldoorn, Marthijn, Sonneveld, & Veldkamp (2011).

Managers are good at strategically planning in the fore loop, but are less aware of appropriate behaviour in the back loop. The acid test for managers and leaders is to be able to transition from the back loop to the next robust fore loop. Key insights to the managers from the panarchy model in this context are:

a) Dynamically manage the activities self-adaptively, and enable transformation in the back loop. Such dynamic management in the back loop includes several experiments with low cost of failure (e.g. skunkworks, which are separate entities in the organisation for experimenting with innovative ideas), which while facilitating change, involve all stakeholders and provide adequate time. Further, conservation and aggregation of critical capital (through reserves) and management of cross scale linkages is required in the back loop.
b Manage "slow and large" variables, apart from the "fast and small" variables. Manage multiple but handful of key variables.
c) Adopt different leadership styles as appropriate for the different phases and ensure depth of management to transition successfully from the back loop to the next cycle.

Businesses are well tuned to manage the economic aspect of the triple bottom line over the lifecycle, e.g. product lifecycles, product line lifecycles, technology lifecycles, and economic long waves. However they are less tuned to manage lifecycle impacts on society or the ecology, which is a fundamental requirement of SD of businesses.

From the social and ecological standpoints, businesses need to address key lifecycle issues such as:

a) Providing for livelihoods in the vicinity of the community, when a mine or quarry is closed after its useful life
b) Protecting the health of a community from stored toxic wastes, after decommissioning a nuclear plant
c) Maintaining the eco-services to industry, while exploiting the ecosystem for input industries, especially extractive industries.

From the ecological point of view, the complexity of the processes must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition (Anastas & Zimmerman, 2003). In an individual business context, lifecycle orientation can be in the form of product design, extended producer responsibility, and meeting consumer needs through a service based business model. This would facilitate minimisation of lifecycle impacts on the ecological bottom line (Lovins et al., 1999; McDonough & Braungart, 2002).

Products designed for lifecycles are easier to use, have smaller sizes and simpler functionalities for consumers, and are more durable. They are also less resource intensive, generate less waste, and are safer to use by the consumer (Benyus, 1997). They use smaller diversity of materials and components. They have better serviceability and easier upgradability (WBCSD, 2000).

Eco-efficiency opportunities can emerge at any point in the entire lifecycle of a product/process (WBCSD, 2000). The industrial production system lifecycle has three stages: (a) the materials transformation (the industrial production of materials) (b) the industrial manufacture of products, and (c) the customer product cycle (including disposal). Extended producer responsibility (EPR) (equivalent to the detritus food chain) shows the commitment of a business firm to design for the end of product/process lifecycle. This means that an organisation is committed to take back products and decommission plants harmlessly at the end of their life. In this way, the ecological effects at the end of the product/process lifecycle are minimised and are reflected in the cost of the product. This, at the bare minimum, involves the ability to easily disassemble a product at the end of its life for recycling or ensure that the byproducts are revalourised (WBCSD, 2000). Further, a closed loop value addition cycle that recycles/upcycles wastes to inputs is preferable (McDonough & Braungart, 2002), instead of consuming virgin material and spewing out wastes (Benyus, 1997). In such a case, waste materials and energy can be reused almost continuously in a closed cycle, subject to the constraints of physics and thermodynamics. Such a redesign of business processes from linear to cyclical forms is referred to as "the natural step (Capra and Pauli (Eds.), 1995). In lifecycle orientation, "monstrous hybrid" wastes should be prevented and wastes should be amenable for separate recycling in the form of "technical waste" as nutrients for new products, or "biological waste" as a nutrient for the ecosystem (McDonough & Braungart, 2002). Examples of such practices exist even at the inter-organisation level, where wastes from one industry are broadly publicised for use by another industry, requiring such a material as input (Benyus, 1997).

A transition from current sale of product relationship to service/solution to customer relationship is also required in lifecycle orientation (Capra and Pauli (Eds.), 1995; Benyus, 1997). Increasing service intensity (DeSimone & Popoff, 2000) and a move towards a leasing based business model could facilitate this (Dirk et al., 2004). In doing so, a firm can align the goals of its business with the goals of the customer, society, and ecology (Lovins et al., 1999). This would facilitate the business and client to share a portion of the savings of resource efficiency and waste reduction.

Interface Corporation successfully used lifecycle design to increase its market share of its carpets business (between 1990 and 1998). It substituted PVC with selenium. This led to longer life, easy maintenance, less toxicity and higher raw material efficiency. It benefited from improvements in material efficiency and waste reduction using a leasing model. Such benefits were also shared with clients (Lovins et al., 1999).

Table 4 summarises the discussion relating to the principle of manage with life cycle orientation.

Lifecycle orientation is the cornerstone of all principles of ecosystems sustainability. There are other principles that pertain to each of the three dimensions of the panarchy model, viz., potential, connectedness and resilience. These support the principle of lifecycle orientation of ecosystems as well as business systems vis-à-vis their triple bottom line. The key properties pertaining to each of the three dimensions of the panarchy model serve as the basis for deriving the other principles of SD of business. (Detailed discussions on the corresponding sub-principles, strategic perspectives, and initiatives are, however, beyond the scope of this paper.)

Principles related to potential

The key properties related to potential are concerned with inputs, value, structure and knowledge pertaining to ecosystems, and hence analogically with business systems as well. Businesses should learn from nature to avoid ecological and social bankruptcy, which ultimately would end in financial bankruptcy (Dirk et al., 2004; Lovins et al., 1999; UNGC Accenture, 2010; WBCSD, 2000).

Principle 2: limit use of inputs

Processes in nature work with finite availability of resources — absolute stocks in the short run and their replenishment rate in the long-run (Scale, 2010). Further, in nature, form and function are strongly and dynamically related, and the same material performs several functions to achieve this (Benyus, 1997). Similarly, in the business context the social and ecological resources should be used at a rate that is consistent with the stock in the short run and replenishment rate in the long-run (Dirk et al., 2004). This is especially true because natural capital is increasingly becoming the limiting factor (Lovins et al., 1999).

Principle 3: add value and do not deplete it

Ecocentrists believe that all life has an intrinsic value and a right to live (Singer, 1999). On the other hand, anthropocentrists estimate that the ecosystem services, to which each species contributes, are as much as the economic income of the world (Hanson et al., 2010). These services include: (i) provisioning (ii) regulating (iii) culture, and (iv) support services. Analogous to ecosystems, businesses should also ensure long-term value addition and minimal value depletion, qualitatively and quantitatively, in the following (IPCC, 2007a, b) (a) green infrastructure and their services (Groves et al., 2010; Lovins et al., 1999) (b) social and soft infrastructure, and (c) technology infrastructure (WBCSD, 2010). Minimising quantity, concentration and toxicity of waste is a way of minimising value depletion. When such depletion occurs due to their activity, businesses should offset such depletion of ecosystems (biodiversity and carbon offsets) (WBCSD, 2009).

Principle 4: strengthen the base

Typically, a healthy ecosystem is shaped like a pyramid. The more energy efficient species — primary producers (e.g. plants) — form the strong base of the food pyramid in terms of biomass (stock of energy), productivity (flow of energy), and numbers (Odum, 1971). The large, fierce animals that are least energy efficient are rare, and form the apex of the food pyramid. In the socio-economic context, those at the bottom of the pyramid (BOP), 4 billion people who earn less than $2 a day, should be made active, informed and involved consumers, employees and investors (Prahalad, 2005). If this is not achieved, we may see forced changes in wealth distribution like the French

Revolution (Huang, 2010). To avoid this, businesses should provide adequate resources to the BOP market, including senior management time. In an individual business system context, overheads (analogous to carnivores) need to be minimised, and value adding professionals (analogous to primary producers) increased to have a strong base. For this purpose, sustainability professionals should behave like value adding professionals, contributing to increased revenues, and decreased costs/risks (Lovins et al., 1999).

Principle 5: encourage learning
A species or an ecosystem, which does not learn, does not and cannot survive in the long-run (Buzzle, 2011). As an example, several species are already adapting to early signs of global warming in North America (Hendry, Farrugia, & Kinnison, 2008). Learning in ecosystems occurs best in a constant state of incremental flux in the environment (Tissier et al., 2006). Species in an ecosystem learn to adapt to changes: in a place (by change in form/timing/adaptive evolution-gene frequency), and by shift of geographical range. Similarly, businesses should learn and accumulate knowledge to adapt towards SD. A business should have future scenarios and generate adaptive portfolios in the context of SD, instead of learning by shocks (Grantham et al., 2010). Further, the current and future managers should be empowered with the latest developments in health, ecology, and SD (Dirk et al., 2004).

Principles relating to connectedness

Processing power, networks and controls are key properties related to connectedness in ecosystems. Ecosystems show that appropriate and tailored connections contribute to sustainability. Likewise, these will enable SD of Business.

Principle 6: respect and improve processing power
Inputs in excess of the processing power are harmful to ecosystems. Hence such excesses are curbed through their intriguing processes (Benyus, 1997). At the global level, economic systems are burdening ecosystems with inputs in excess of nature's processing power (e.g. carbon) (Meadows & Meadows, 2004; IPCC, 2007a, b). Attention to material and energy flow analysis through tools like lean thinking (Womack & Jones, 2003) and focussing on quality rather than quantity of throughput could help avoid an unfavourable threshold and curb unsustainable industrial metabolism (Zsolnai & Ims, 2006).

Principle 7: ensure synergy through networking
Synergy within and across ecosystems occurs through networking, where the whole (ecosystem) is more than the sum of the parts (species and non-living matter) (Lovelock, 1979). Fitness of one species depends upon the fitness of another (co-evolution). Even competing animals in nature often avoid friction and loss of energy, by avoiding unnecessary fights (Benyus, 1997). Businesses should learn to be "keystone" organisations that share value in the network, rather than those "hub landlords" that drain value (Moore, 1996). The short-term interests of businesses should be subservient to the long-term interests of society and stakeholders and ultimately the long-term interests of business. This would involve adopting a process/value chain view, instead of an intra and inter-organisation structural view. In this context, there is a need to promote close cooperation, shared values, and shared vision among stakeholders towards SD of business (Senge, 2010).

Principle 8: adopt appropriate controls
The properties of self-organisation, self-regulation and self-healing are innate in ecosystems (Peltoniemi & Vuori, 2004; Wu & David 2002). In the context of SD of business, where complexity, uncertainty, and discontinuity are involved, self-adaptive control, based on empowerment is more appropriate than top down or efficiency based, incentive driven controls. The role of top management in such situations is to ensure that constraints to SD are removed (Doppelt, 2003). Further, measurement and action are required on leading and lagging indicators of business health under the triple bottom line (Hanson et al., 2010). At the economic system level, externalities must be internalised not only through laws, incentives and markets for carbon/biodiversity, but also through self-regulation (Stringham, Miller, & Clark, 2010). Adoption of the precautionary principle (Look before you leap; Burden of proof on the initiator) is critical when introducing new technology (Dirk et al., 2004). In this context, public disclosure about performance on the social and ecological bottom line should be ensured.

Principles related to resilience

Modularity, redundancy, diversity and security are properties of resilience. Resilience ensures the ability of a system to recover from shocks and adversity and hence ensure their sustainability for ecological and business systems alike. Principles for SD of business relating to these properties are presented below.

Principle 9: design modularly
Modularity in ecosystems helps dynamic stability, enables low response time for adaptation, growth and evolution, fault tolerance, containment of toxins, easier duplication, and specialisation in the context of sustainability (Wu & David, 2002). Several communities of organisms live locally in an integrated and enduring way within a module (Benyus, 1997). Just like in nature, business systems should be designed modularly, consistent with system optimality (Lovins et al., 1999) in order to derive the above benefits in the SD context. Hence there is a need to use local cultural, economic, natural, and social resources and sell locally and be connected with the landscape (McDonough & Braungart, 2002).

Principle 10: ensure redundancy
Species redundancy facilitates ecosystem resilience (redundancy hypothesis) (Walker, 1992). Redundancy in ecosystems exists in inputs, processes, structures, and functions to cushion against uncertainty (Wu & David, 2002). Similarly, redundancy in business ensures higher reliability, agility, investment in future, and risk taking (DeMarco, 2001). This might be even at the expense of lower efficiency, higher time consumption, and messy

organisational structures and processes. Thus there is a need to ensure adequate redundancy in stock, flow, structure, and institutions for normal conditions for business. Redundancy in essential goods and services also assists the local community to tide over difficult situations like disasters (Tierney, 2002).

Principle 11: facilitate diversity

Diversity as in the coral polyp, is a sign of healthy ecosystems (Power & Jerjian, 2001). Any perturbation in the environment has different effects within and across species, contributing to resilience (portfolio effect) (Elmqvist, 2003). On the other hand, monocultures and overspecialisation (e.g. conventional agriculture) are more vulnerable to pest attacks and even ecosystem collapse. At the global economic system level, the dominant individual gain-centred economic logic and the liberal democracy with a welfare state are mono-cultural artifacts of today. Operations of such artifacts have brought down the great civilisations of the past (Scale, 2010). In an individual business context, social diversity of human resource stimulates creativity and ability to respond to change (Zsolnai & Ims, 2006). In a business MT system context, use of (minimal number of) diverse set of local materials and energy leads to less waste, more natural resource efficiency, and resilience.

Principle 12: provide security

In the context of sustainability, the building blocks of an ecosystem do exhibit some natural security features. The security mechanisms may be direct or indirect, innate or acquired, natural or artificial, and active or passive (Heil, 2010). These protect all levels of the ecosystem from forces attempting to destroy them. Security threats to businesses can be to human resources, physical assets, and/or information assets, that need to be protected (Bode, Akane, & Andre, 2010). These mechanisms may be at the levels of policy, technology, and architecture. While designing security measures, there is a need to minimise downside risk and take advantage of the upside. At the economic system level, there is a security imperative to strive for a future of intense cooperation to proactively address common natural and social resources challenges as well as economic inequity challenges (Barry, 2007).

The simple take-away from our current understanding of ecological systems are: (a) species in nature meet their needs without depleting from and in fact adding to ecosystems (b) survivors are those species which meet their needs without compromising the welfare of their and other's offsprings for 10,000 generations (Benyus, 1997; Lovins et al., 1999). Above discussions on the principles of SD of business are illustrated in the Indian context in the next section.

Principles of sustainable development of business: Indian examples

From time immemorial associations of traders (guilds) have been involved in SD related activities in India (Mitra, 2009). These include protection of vulnerable sections of societies and preservation of natural resources such as ponds and forests. Some of the examples of the application of the principles of SD in the Indian context in the modern era are discussed below. (The sequence numbers below refer to the principle numbers discussed earlier.)

Principle 3: ITC Bhadrachalam, a paper mill, reduced its toxicity of waste by moving to a chlorine free process (Down to Earth, 2004).

Principle 4: The Sakthi project of Hindustan Unilever and the micro—finance activities of ICICI bank are successful pilots of targetting the bottom of the pyramid (Prahalad, 2005).

Principle 8: Unilever's efforts to measure and reduce green house gas emission in its supply chain through appropriate tools (WBCSD, 2009).

Principle 9: The local sourcing and sale of agriculture produce by Pune farmers market (PFM, 2010).

Principle 10: Safety and security of nuclear energy facilities, including redundant sensors and controls (Hashemian, 2006).

Principle 11: Employee diversity in Infosys (Infosys, 2012).

While many more examples exist for the application of the principles of SD in India, the above examples illustrate that these principles are relevant in the Indian context also.

Summary, scope for future research, and conclusion

The principle of lifecycle orientation has been discussed in detail and the corresponding sub-principles have been stated in the context of ecological systems sustainability. The sub-principles for sustainability of business SE and MT systems have been inferred using analogical reasoning. Eleven other principles for SD of business, supporting the principle of lifecycle orientation, have been briefly discussed. They are conceptually classified using the three constituent dimensions, viz., potential, connectedness, and resilience, of the panarchy model. The exact prioratisation of these principles in a business organisation will depend upon the context. The context will significantly depend upon the impacts of the organisation on the triple bottom line as well as stakeholder expectations.

The inferred principles are based on conceptual understanding from ecological systems, and instances of SD initiatives of businesses. These require qualitative and quantitative empirical evaluation on a larger scale and in the Indian context. Further, while the principle of lifecycle orientation is the cornerstone of all principles, the other 11 principles supporting lifecycle orientation may not be collectively exhaustive. The conceptual classification of these 11 principles along the three dimensions needs empirical validation. A classification of a principle on a dimension may not be water tight, and a principle may, in fact, affect other dimensions. These constitute the limitations of this work.

Future research based on this paper could include:

a) Scaling these 12 principles, providing weights for them under the three dimensions, and developing a systems dynamics, data envelopment analysis (DEA) or multi criteria decision model for an Indian business or economy. Such a model can measure the impacts of these principles on the triple bottom line or an intermediate variable like innovation towards SD.

b) Creation of a dependency framework with the morphological elements discussed earlier (Table 2), on the triple bottom line, to aid in point (a) above.

However, these 12 principles for SD of business are practical, implementable, and have been piloted in several organisations successfully as briefly discussed. These principles can be mutually reinforcing (e.g. control, security and learning) and occasionally contradicting (e.g. limited use of inputs and redundancy).

Lack of social/ecological sustainability in organisations entails the risk of modern business firms becoming the dinosaurs of tomorrow. Modern businesses may then be replaced by more sustainable forms of organisations that meet society's materialistic needs. The principles and discussions in this paper would help organisations wishing to pursue the path of SD to synthesise their ideas and ensure their longevity.

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