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INDUSTRIAL ECOLOGY A NEW PATH TO SUSTAINABILITY: AN EMPIRICAL REVIEW

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ABSTRACT

The precise understanding of the link between industrial ecology and sustainability is vitally important for a continuous environmental performance. In this study, an intensive review of industrial ecology principles, its application areas and the extent to which industrial ecology has been applied was documented. It was observed that the effective application of industrial ecology is critical for sustainability, since the industry is the main polluter of the environment. It was further inferred that, there is inadequate applicability of the industrial ecology principles by developed countries. Thus I hypothesized that, there is a great opportunity for new investment in this field considering the absence of modern means for the liquid and solid waste management. For example, improper incineration of wastes such as hospital wastes, and the electrical and electronic equipment was perceived to bring health problems in the near future. Therefore, it is time for the governments in both developed and developing countries to increase the applicability of industrial ecology, for sustainable social, economic, political and environmental performances.

Keywords: Industrial ecology, Sustainability, Environment, Resource, Materials, Energy

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1. INTRODUCTION

In recent years, implementation of industrial ecology strategies has been ever-increasing due to growth in environmental concern including depletion of natural resources and severe pollution of water, air and soil (DESPEISSE, et al. 2012; QUIJORNA, et al. 2011; THATCHER, 2013).

Industrial ecology deals with identifying all possible energy and material exchanges that allow mitigation of the resources used (e.g., materials and the environmental impacts of human activities for sustainable developments) (ECKKELMAN; CHERTOW 2009; GERBER, et al. 2013).

The industrial symbiosis is an important aspect of industrial ecology such that wastes, by-products and energy exchanges between different industries for sustainability are practiced. Industrial Ecology (IE) was established and implemented by developed countries so as to achieve satisfactory levels of sustainability. An important application of IE concept is the Eco-Industrial Estate that is defined as: The community of business seeking which improves social, economic and environmental performance via collaboration in managing environmental and resource issues (e.g., energy, water and materials) (LOWE; EVANS, 1995; PANYATHANAKUN, et al. 2013).

The applicability of IE strategies by developing or low income countries including Tanzania is at the infant stage such that much has been done for the waste management only. Many tons of industrial wastes are produced every year (MBULIGWE; KASEVA, 2006; MAGASHI, 2011), but safe waste disposal systems are lacking. For example various solid wastes (e.g., plastic bottles, the electronic and electrical equipment, metal scraps and so on), that may pose serious human health and environmental problems today or in the future are collected at the dumping sites. Some people think that we are not industrialized and thus, it is not possible to encounter serious environmental problems as the industrialized countries.

With the chemistry of action, heavy metals and chemical substances that were used to manufacture plastics and electrical and electronic products will degrade in the environment leading to pollution of water resources, soil, air and even sediment. After all the adverse effects of the industrial wastes that are resulted from improper (lack of) treatment and incineration of toxic substances will appear after several

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decades, since some of the chemicals are persistent in the environment. However, utilization of IE depends on the social, economic, environmental and political status of the specific country. Considering the differences in economic levels between developed and developing countries, what is the position of poor (i.e., low income countries) in implementation of the IE principles? To what extent can low income countries manage to implement the IE concept? Or low income countries are not affected by the current environmental problems, despite of the fact that pollution has no boarders? And so on).

These are some of the important questions that industrial ecologists need to address to achieve sustainable development goals. The applicability of IE has more to do than sustainability that is through utilization of IE principles such as zero wastes, material minimization and design for environment for conservation of natural resources of the country. With the IE and sustainability thinking, much saving of the natural resources including minerals, water, energy and other useful materials are achieved.

And this should be considered by both developed and developing countries, with the aim of ensuring sustainable developments. Much attention must be considered in its implementation as well, so as to avoid shifting the environmental impacts to other environmental media (i.e., when countries are trying to reduce freshwater scarcity for example by desalination technology, there is possibility of producing more CO_2 to the environment that might contribute greatly to greenhouse gas emissions).

Or reuse of wastes via recycling in the industrial parks, might lead into other environmental problems such as production of large quantity of defected products which have health problems to the consumers. Therefore, this study intends to present an empirical review of the existing link between IE and sustainability as well as the IE application areas.

2. DELINEATION OF SUSTAINABILITY

Human activities have contributed significantly to the degradation of natural resources and the ability of the Earth's natural resources to recover over the last 150 years (VITOUSEK 1994, THATCHER 2013, DUMONT et al. 2013).

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Many human activities including intensive agriculture and manufacturing have contributed in a large extent to the disruption of the Earths' natural nutrient recycling patterns, climatic systems and the ecological biodiversity (GRAEDEL; ALLENBY, 2004; BATES, et al. 2008). Likewise, the degradation of the environment has been linked to severe adverse effects to human health and ecosystem quality such as increased respiratory problems, body cancer, inhibition of growth and disruption of the endocrine systems as well as global warming effects that have accelerated malnutrition in many parts of the world (PIMENTEL, et al. 2007).

Kellert (2005) and Louv (2005) contended that, the degradation of the natural environment has led to severe negative implications to the human psychological well-being and problems in human developments. Sustainability and sustainable development are well established concepts, such that they are viewed as multidisciplinary as they are composed of four interrelated components (i.e., society) (people), environment (planet), economy (profit), and technology (science) (DESPEISSE, et al. 2012).

A wide range of tools and methods have been applied to evaluate and manage the adverse effects of industrial production so as to support the integration of sustainability concepts in the corporate action plan. This among others includes the Industrial Ecology, Cleaner Production, Pollution Prevention, Design for Manufacturing (DE), Design for Manufacturing (DM) and Sustainable Manufacturing (SM) (GRAEDEL; ALLENBY, 2004).

Manufacturing systems cannot exist in isolation from other facilities which support them as they can affect sustainability in terms of the energy utilizations. Therefore, the understanding of the link between IE practices and sustainability with considerations of the human well-being is vitally important.

To date, there are several frameworks that can be used to describe sustainability such as the frameworks of the triple bottom line approach, the natural step, ecological footprint and sustainable estimation of the emissions and resource use (MARSHALL; TOFFEL, 2005). These frameworks give emphasis on the technological innovations via integration of environmental issues in the industrial products as well as the process and service designs leading to the improved business decisions.

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The strategic change of the industrial paradigm from the end of the pipe environmental management approach to a holistic approach is encouraged. Through which the balance between social, economic and environmental business goals can be achieved for sustainable development. Fiskel (2002) contended sustainable development as a new ideology introduced to restructure the existing policies of an organization and industrial manufacturing practices, to achieve both economic growth and quality of life in the future. The reason being means to deal with wastes generated from various manufacturing processes as they threaten the state of the environment.

According to the Brundtland (1987), sustainable development can be defined as the development without causing danger to the future generations in fulfilling their needs. The characterization of impact categories resulted from pollutant emission levels, unavailability or exploitation of resources and their ultimate impacts to the three areas of protection (i.e., human health, ecosystem quality and resource depletion) is critical for sustainability.

The triple bottom line approach: This is a new approach among the sustainability frameworks which use the philosophy that sustainable development could only be achieved if business development decisions made, seek for a balance between economic, social and environmental concerns (ELKINGTON, 1998).

Traditionally business organizations were focused on the profit making and leave alone social and environmental issues which resulted into severe environmental burdens such as resource depletion, global climate change, depletion of the ozone layer as well as air, soil and water pollution. It is a true fact that, the implementation of the triple bottom line approach could be enhanced by enforcement of various policies and regulations from the global, regional and local scale such as the polluter pays principle, agreement on transfer of toxic substances, carbon dioxide emission levels and the requirement to disclose environmental information.

The Natural Step: In this framework sustainable society is determined by the level of resource exploitation, accumulation of society produce, environmental degradation and ability to fulfil the current human needs (NATTRASS; ALTOMARE, 1999). Societal sustainability is perceived from a sustained improvement of the living standard of people, in terms of the education, access to safe and clean drinking

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water and sanitary services, availability of food, political stability and decrease of vulnerable diseases. However, many industries have introduced a corporate social responsibility organ so as to ensure natural step, but still the question of its success and failures remains.

The ecological Footprint: This framework concerns with an examination and evaluation of the environmental impacts resulted from a limited utilization of natural resources as well as the functioning of the ecosystem. Ecological footprint estimates the ratio of earths available for the required biological productive land area to maintain resource flow and wastes at a normal standard of living of the society (WACKERNAGEL; REES, 1996).

The key concern is to compare natural resource availability with respect to users so as to establish the environmental impacts of resource unavailability with respect to those of users. This could best be explained by the water footprint or carbon footprints, which can be avoided by the change of industrial behavior whereby water intensive production processes are replaced by less water intensive or a customer behavior change by acceptance of products that are manufactured from recycled by-products as a means to minimize the virgin material use (i.e., resource use).

The sustainable emissions and resource use: This is a four stage comprehensive rate of resource use framework (GRAEDEL; KLEE, 2002) which includes; (1) determination of the supply of available raw materials (2) estimation of materials consumption rate in the population (3) accounting of the recycled materials and the existing landfills for the estimation of consumption rate and finally, the obtained consumption rate is considered as maximum sustainable rate to benchmark the present and future resource use.

This is an optimistic approach which seeks to ensure optimal use of resources (i.e., energy, water, and materials) as well as the use of byproducts (e.g., wastes) as feedstock materials for the optimal raw materials use and continuous environmental improvements of the Earth. Indeed implementation of IE principles via a well-defined sustainability framework guarantees a continuous environmental quality of performances for the manufacturing and service industries.

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However, one might be interested on the extent to which manufacturing industries especially in developing countries have managed to implement either of the sustainability frameworks? It is obvious the answer shall be to a lower extent and in some countries might be no implementation at all. The expected answers indicate a sign of severe environmental problems in the future and the achievement of the millennium development goals is a mere dream. Usually, it is only through research and developments that precise answers to the questions could be obtained. Hence, under the eye of IE, this area needs more basic research to unveil the truth, for the environmental sustainability.

3. THE CONTEXT OF INDUSTRIAL ECOLOGY (IE)

The idea of industrial ecology emerged from the pioneering work of Robert Ayres and his Co-workers on the examination of materials and energy flows in various systems ranging from the river basins to the whole economies by early 1970s (EHRENFELD, 2002). That examination of the energy and materials has invented the flow of energy and food within the ecological systems based on industrial metabolism. At the same time, the research and planning groups where studying how to make the Japanese less dependent on the materials that were used in the production process by using the name “industrial ecology” in their official titles (WATANABE, 1972).

The legitimacy of industrial ecology was strengthened by the inaugural meeting of the newly formed international society for industrial ecology in Noordwijkerhout, the Netherlands November 2001 in which 300 delegates from 29 countries attended (EHRENFELD, 2002). IE concerns with the study of natural resource production and environmental impacts resulted from the industrial processes or consumer products, their production and the consumption systems (BERKEL, et al. 2009).

Therefore, industrial symbiosis and metabolism are key categories of IE. While the former concerns with the resource exchange between firms, the latter is more concerned with the resource use within firms (i.e., industrial operation in a closed loop) under the philosophy of no waste (i.e., zero emissions).

Fiksel (2002) perceived IE as the holistic framework for guiding transformation of industrial systems from a linear model to a closed loop model that resembles the

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cyclical flow of ecosystems. This includes resource use optimization by industrial systems through industrial metabolism and efficient use of the materials, energy, water and by-products via industrial metabolism.

This framework of IE seeks to achieve the multidimensional objectives of social, economic and environmental concerns for the sustainable development. White (1994) defined industrial ecology as the study of the flows of materials or energy in the industry, and the effects of these flows on environment, that influence greatly the economic, political, and social factors. This definition reflects the reality that the goal of IE is to expand the framework of industrial system and consider it in a wide perspective.

Involves thinking beyond ending up with quality products and business profits to the consideration of the environmental impacts of the production processes to the human health, and future condition of the resources. Graedel and Allenby (1995) defined IE as the science of sustainability. Whereby IE is viewed in an industrial perspective, as a practical approach which involves studying of the industrial systems to create scientific methods for the optimization of resource use, characterize environmental impacts and develop remedial measures to deal with, for greener development.

Industrial ecology is a newly emerging profession which involves an intensive examination and evaluation of natural ecosystem behavior to create scientific approaches for sustainable development (QUIJORNA, et al., 2011). With a key focus on resource use optimization through technological innovations of the existing industrial systems to accommodate reprocessing of by-products (wastes) and offer efficient use of materials and energy.

Chertow and Lombardi (2005) argued resource sharing among co-located firms to be a strategic approach for ensuring continuous industrial operation by a steady flow of materials, energy and water in resource scarce regions. Despite of the economic benefits of the process it amounts into the environmental conservation via efficient use of non-renewable resources and use of by-products (i.e., wastes) as feedstock materials by other firms.

3.1. Practical applications of IE

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The applicability of IE principles by manufacturing systems will be sustainable if it has successful impacts on the social, economic and environmental performances. To date IE has been applied in many social – economic activities such as manufacturing industries, animal farming, intensive agriculture as well as in the music theatres (e.g., quantification of carbon footprint in the music industry) and so on (GRAEDEL; ALLENBY, 2004, DUMONT, et al. 2013).

The application of industrial ecology as a sustainability tool can be viewed from the waelz process. Waelz process is a chemistry of action technological process used to recover volatile metals from an electric arc furnace dust, in which dusts are heated at temperatures 1100 to 1200 centigrade (QUIJORNA, et al., 2011).

Waelz slag generated from the process (i.e., by-products) are used in civil engineering works as a filter (dust) in roads, sports ground or dykes construction sites. Also waelz slag can be incorporated with the construction materials for bricks, tiles and pavers. The method ensures optimal utilization of virgin materials and continuous improvement through use of byproduct (e.g., waelz slag) as substitute materials for bricks making and dust remover in the construction sites.

According to Hermann et al., (2007) use of biotechnology showed savings of more than 100% of non-renewable fossil fuels and green-house gas emissions. The consumption of fossil fuels was minimized by alternative use of biofuels obtained in the process of producing bulk chemicals from biomass (e.g., biotechnology). This brought a significant effect to the resolution of current and future environmental concerns such as climate change and depletion of vital resources.

Utilization of industrial ecology by government and industries can be viewed from the case of Kalundborg industrial park, Denmark. Kalundborg involves resource sharing between oil refinery, power station, gypsum board facility, and pharmaceutical companies that shares surface water, waste water, steam and fuel, and variety of byproducts which becomes feed materials to other company in the network. Resource sharing in the Kalundborg industrial park reported saving as follows: ground water saving (2.1 million m^3/year), surface water saving (1.2 million m^3/year), natural gypsum (200,000tpy) and oil saving of 20,000tonnes/year (CHERTOW; LOMBARDI, 2005).

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Recycling and reuse of industrial byproducts showed both economic (i.e., reduced operating costs) and environmental (i.e., use of by-products to save other purpose) benefits an indication for sustainability. Industrial use of byproducts (i.e., wastes) as materials for production process in Pennsylvania indicated energy saving and reduction in emissions of gaseous elements (ECKELMAN; CHERTOW, 2009).

The distribution of primary energy saving of (13pajoule), emission reductions of CO_2 of (0.9 million metric tons, eq), SO_2 (4300 tons eq) and NO_x (4200 tons) of emissions from the residual wastes were achieved. Savings was resulted from the fact that processing of secondary materials need less energy for processing as well as processing of secondary materials generates lower gaseous elements.

Inspite of the benefits, yet the process is challenged by capability of the existing facilities to cope with the generation rate of wastes in Pennsylvania. Thus, it is more appropriate to opt for a proactive technological approach whose goal is to reduce emissions from the resource extraction, production, during use and disposal.

Policy and legal frameworks of the country has vital role in successful implementation of industrial ecology ideology by industries and governments. This is evidenced by introduction of basic law for recycling based society in Japan of the year 2000. The law intended to improve resource productivity to 40% by 2010, whereby 40% of feedstock materials used for production processes must be recycled materials (BERKEL, et al., 2009).

Therefore, lack of government support and enforcement of environmental laws, implementation of industrial ecology will still remain inadequate due to costs accompanied with its implementation. Industrial ecology is accompanied with technological innovations which might increase companies operating costs to ensure standard skill level of staffs, quality of raw materials, machines and equipment. This obviously makes company owners reluctant on its implementation, unless government policies and laws intervene for the sake of majority.

Despites of the economic, social and environmental benefits from use of industrial ecology as a sustainability tool, yet shortfalls were reported for example carmakers in Japan, Europe and Korea. According to the European Commission report of 1999; European carmakers agreed to reduce CO_2 emission of passenger cars to 140 grams per kilometer by 2008, and 2009 for Asian carmakers. This

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reduction was approximated to be 2% of CO_2 emissions instead achieved to reduce CO_2 emissions to 1.2% (BETTS, et al. 2005).

However, it showed advancements in reduction of air pollution which would result into higher costs if one can quantify, looking at its impacts to human health and other ecosystem species. It is a true fact that most of the developing countries around the world have not implemented the IE principles to a large extent due to inadequate finance, lack of technology, lack of goodwill to implement, and poor infrastructure to support greener technologies (i.e., industrial symbiosis and the like).

However, it is helpful to start implementation of the principles through stages (i.e., adoption of the frameworks (models) even at a lowest level) so that they can be improved further in the future rather than not implementing them at al. Moreover, other greener production aspects needs consideration of environmental issues in the industry's strategic plans (i.e., implementation of IE principles should be treated as a strategic issue by organization and not as an *ad hoc*. This will be achieved by effective use of the corporate industrial ecology tool box, whereby the design for manufacture, life cycle assessments, industrial parks and symbiosis are practiced with the aim of resource minimization and zero waste.

4. CONCLUSION

A comprehensive review of the link between IE ecology and sustainability has been established in this study. The application of IE principles was seen to be practiced by developed or industrialized countries through industrial symbiosis and establishment of industrial parks. Whereby, less has been done by developing countries including Tanzania due to inadequate investment such that safe incineration of industrial wastes is lacking and opt for landfill type of solid waste disposal.

Thus, I argue that this is a new area of investment, by application of IE strategies in which wastes are used as virgin materials leading to conservation of natural resources (e.g. energy, freshwater and minerals). Despite of the minimum resources used via utilization of the IE principles it will also results into sustainable environmental performances of our industries.

Likewise, industrial sustainability will be achieved through effective implementation of IE concepts. Hence, it is the responsibility of the governments and

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industries to introduce and enforce policies or regulations that aim at social, economic and environmental sustainability. With the industries operating according to the laws and regulations in place, this will create sustainable business growth, the improved living standard of people, and environmental conditions.

Moreover, more researches are required to quantify the extent to which IE principles are applied, and estimate possible human health and environmental risks in the future.

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