Eco –industrial park framework development to enhance waste management: Case study

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Abstract
The eco industrial park (EIP) concept seeks to minimise industrial pollution and resource exhaustion problems through circular economics. This study explores how the concept of eco industrial park could be implemented to a town in a developing economy to reduce the large amount of industrial waste disposed in landfills, as well improve the current unsustainable use of resources, energy and water in the case study area of Harare metropolitan. A questionnaire based survey was done to establish industrial activities and the associated waste produced by various operations. A five step anchor tenant model was used to produce a virtual eco industrial park, whose central point is based in one of the four identified distinct industrial areas, whereupon possible by product exchange and recycling patterns were generated. The resultant framework model estimated a 15-20% decrease in industrial solid waste deposited in dump sites. It was also established that the framework had to evolve over time incorporating other industries and developing new relevant by-product reuse and waste recycling technologies in line with the prevailing agricultural based economy for sustainable development.

Key words
Eco industrial; waste; by-product exchange; recycling; sustainable development

1. Introduction
The greatest challenge faced by towns in developing world, Harare included is the rapid industrialization; which is accompanied by overwhelming generation of waste which in turn is disposed in landfills (Sharma 2014). Inefficiency on the part of the municipality has resulted in uncontrolled industrial waste disposal. The greater percentage of the waste from industrial operations could be avoided through recycling materials or could be used as inputs for other manufacturing process (Ayres and Ayres 2002). Effluents, emissions, depletion of the natural eco system and exploit of resources is also a major problem as the natural resources are quickly getting used up and most of the extraction methods result in land degradation. The continuous pollution, exhaustion of resources and exploit of energy as caused by limited level of technology implemented in industrial processes as well as end of pipe waste treatment practices (Bahar et al 2016). While the increasing volume of waste constitutes a major challenge in itself, it is the growing complexity and hazardousness of the waste that is the most problematic.

2. Justification
Harare produces an average 2.5 million tons of industrial solid waste per annum. Waste collection by local authority was reported in 2007 to have dropped from 80% of total waste across different local industries in the mid-1990s to as low as 30% in 2006. Most factories do not have waste-treatment systems and drain toxic products, poisons, non-biodegradable substances and organic matter into the environment (Mushanyuri 2013). Pulp and paper mills, breweries are among the worst industrial polluters, so as are textile factories. In pulp and paper, large quantities of water are required, so a large volume of liquid waste is produced. It was also

established that, in steel manufacturing, raw materials used that include lime, iron ore and coal, which are the major polluters. Untreated industrial residues from cement and battery factories, oil and soap factories are also said to be polluting Harare's water sources. The greater percentage of the waste comes from industries and can be avoided as these are recyclable materials and can be used as inputs for other manufacturing process. The gap between waste management policy and legislation, and actual waste management practices is widening, due to ongoing capacity constraints or non-existence of waste management facilities for the different waste streams. Resolving this capacity gap will require major investments and access to technical knowhow. An integrated solid waste management is currently viewed as the only system that covers the whole spectrum of solid waste management (GTI 2014) as it covers its generation, storage, treatment, recovery and disposal with an emphasis on maximizing the use of resources efficiency.

3. Literature review

An eco-industrial park could be defined a community of manufacturing or businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues including energy, water and materials. By working together, the community of businesses would seek a collective benefit that is greater than the sum of the individual benefits each company would have realized if it optimized its individual interests (Chertow 2007). Thus an industrial eco-system would involve at least one major firm producing raw or processed materials, connected to one or more firms capable of utilizing significant portions of the major waste streams of the "anchor" industries. In turn, these would be linked to several "satellite" enterprises converting wastes into usable products. Cooperation would be facilitated by a coordination mechanism and information sharing. The interactions among businesses and natural environment; is the most critical feature required (Fleig 2000).

EIP operations are based on the concepts of industrial ecology, collaborative strategies not only to include by-product synergy ("waste-to-feed" exchanges), but can also take the form of wastewater cascading, shared logistics and receiving facilities, green technology purchasing blocks, multi-partner green building retrofit, district energy systems, and local education and resource centres (Romero 2013). This is an application of a systems approach, in which designs and processes are integrated to address multiple objectives. Thus an industrial symbiosis would be present in the form of a sub-field of industrial ecology that is primarily concerned with the cyclical flow of resources through networks of industrial units as a means of cooperatively approaching environmentally sustainable industrial activity.

The virtual industrial park type is the most preferred type (Lowe et al 2016). It is a case in which industries are not necessarily co-located, but linked through exchange of waste and collaboration at different levels. These are defined according to activities and, points out virtual industrial park as another type of EIP and , the "virtual" label captures the notion that computer programs and systems may be designed to identify exchange partners, create electronic links among them, and optimize for efficient transportation of materials (Paquin 2012). An example of one such project is the Brownsville Project (USA), which takes a regional approach to exchanging materials and by-products. As currently envisioned, the project would include not only industrial facilities, but also agricultural partners and small businesses. A database of companies would be developed and analyzed to identify possible materials exchange opportunities among companies. Cost-based data was added to the database to allow a marketing plan to be developed to evaluate and recruit participants.

The top-down approach is normally used; it begins with an extended data survey and progressively focuses on a detailed analysis of the companies and processes. The following five (Tudor et al 2007) detailed steps form the logical framework for the selection of best industrial ecology (IE) strategy to improve waste management (Weitz 1996):

1. Survey of the companies: A survey is conducted of companies and production sites; and their characterization on the basis of production typologies, activities, sizes and corresponding economic sectors is done. The characterization aims at identifying the most representative companies or the activities with the highest improvement potential.

2. Data collection: Then data collection is done for energy and material consumption and the waste production of companies. This key step is necessary because the success of intended initiative heavily depends on it, as well as the availability of complete, significant, and representative data. As the detailed survey proves to be time-consuming activity, the focus is on the potential environmental problems and related key parameters, in the context of local and national priorities.

3. Analysis of processes: The productive processes for selected companies are assessed, particularly the input (raw material, water, semi-manufactured products, and energy) and output flows (wastes, scraps, air, and water emissions). This step is key in providing an informative basis to evaluate the potential for input substitution or output exchange between processes.

4. Selection of feasible IE strategies: Effort is made to identify feasible actions for industrial symbiosis where interlinked companies share sub-products, services, structures and plants. With due regard to raw materials production and waste disposal, effort is aimed at reducing resource consumption and environmental burdens in the derived network.

5. Energy and environmental assessment: The final step aims at assessing the benefits that arise from the assumed production scenarios. This will improve, from the lifecycle perspective, the companies' performances and minimize the environmental impact of products and services throughout their life cycle.

The final model generated may be a hybrid combination of the development scenarios, which considers supply chain and reverse logistics, existing organizational relationships and anchor tenant EIP model. The optimal EIP framework is achieved through use of an iterative method.

4. Methodology

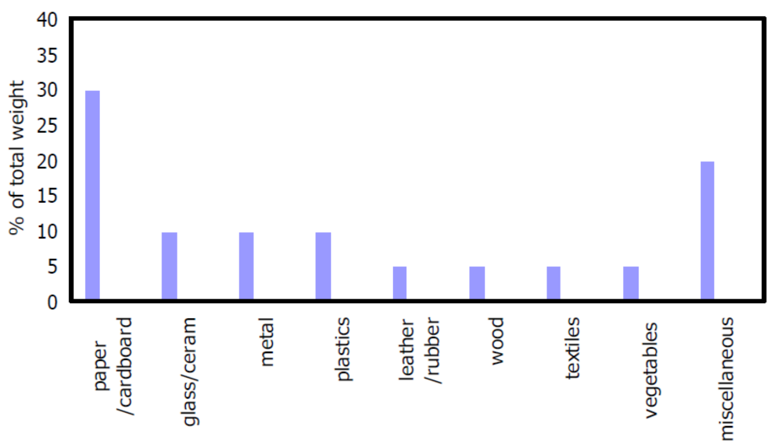
The total industrial area was zoned into four distinct adjacent industrial areas — Msasa, Graniteside, Workington and Southerton —populated by a diverse mix of more than 100 independent enterprises spanning a size range from micro scale one-person informal enterprises to large, domestically owned companies and subsidiaries of multinational corporations. A structured interview format was with managers of 35 facilities who provided annual material flow analysis data for their facilities from 2014 and information about their relationships with others in the neighborhood. Interviewees were presented with a list of names of companies and managers, and were asked a series of questions about their interactions with those on the list (a whole network approach). Common and rare products produced, waste products, by products and processes were identified. Also the dominating industries were noted. Graphs were printed to identify the traits and to easily interpret the data to allow the development of a simple prototype eco industrial park.

5. Findings and discussion

5.1 Characterization of industrial waste in Harare

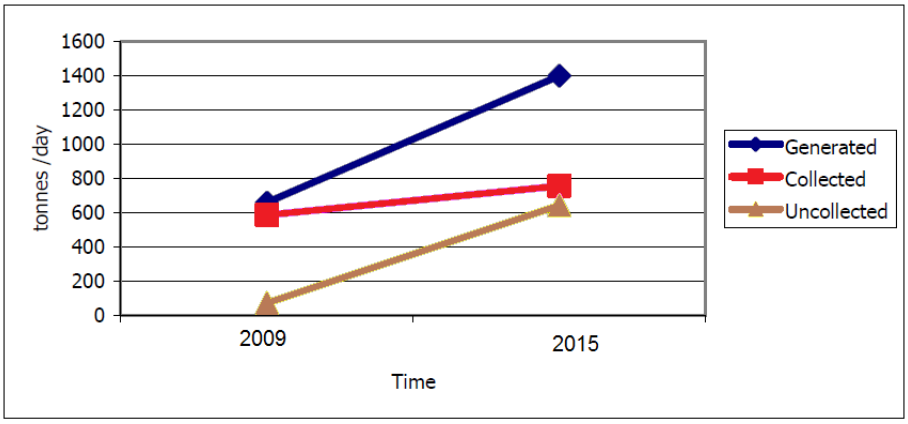
There common industrial wastes were; ash, sludge, waste oil, waste acid, waste alkali, waste plastics, waste rubber, metal scraps, waste glass and ceramics, paper scraps, wood chips, waste textiles, slag, debris, dust, discarded solid matter derived from animals, and matter resulting from the treatment of the above- mentioned industrial waste before disposal. Industrial waste is subject to the polluter pays principle (PPP), under which the entity generating the waste has responsibility for treating it. There is very little evidence of characterization and segregation of waste – hence the homogenous nature of all the waste found at non-formal disposal sites. Harare urban area continues to grow faster than the provision and expansion of infrastructure and services. Waste by category is given by Figure 1 below.

Figure 1. General composition of Harare urban waste (2009 - 2015)



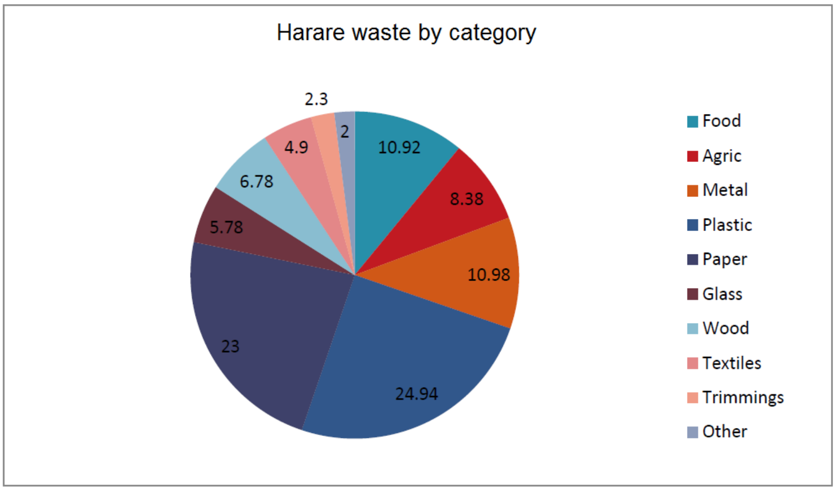
Whilst waste generation is on the increase, levels of collection are deteriorating (Figure 2). This has resulted in illegal dumping of waste. Levels of recycling and reuse in the urban areas are now very low.

Figure 2. Solid waste collection trends in Harare



The waste profiles in Harare were dominated by plastic and paper, accounting for 48.94% (almost half of all the waste generated in the city). Figure 3 shows that Harare had more plastic and paper waste. These were the most widely used materials for packaging, wrapping and carrying goods. There was very little construction activity in the city. Rubbish waste was at 15.5%, which was quite a high percentage. This was attributed to the presence of informal industries which operated mainly in the backyards. Also Figure 3 shows that more than 50% of the solid waste is biodegradable. An integrated waste management system also promotes energy recovery and greater coordination between the stakeholders and processes. An integrated waste management system also promotes energy recovery and greater coordination between the stakeholders and processes The gaps noticed were with regard to sorting and separation at source; national item-specific waste recovery, reuse & recycling schemes and programs; and statutory backing and partnerships; as well as strategies to prevent/ avoid, reduce, reuse, and recycle wastes. The potential for recycling by waste type is another possible area of research and ways to recycle a larger proportion of the waste should be sought.

Figure 3. Waste profile of Harare

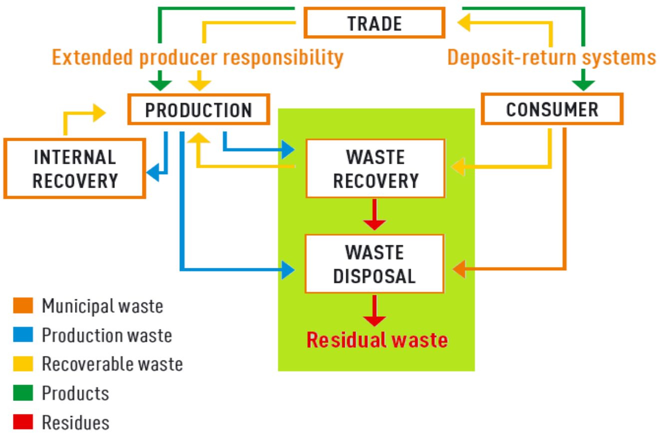


The volume of waste should be reduced as much as possible prior to disposal and the residual should be disposed of in an environmentally sound manner, preferably at landfills. The waste handling mechanisms that were used in Harare were still very traditional and did not reflect any efforts by the city council to modernize the mechanisms. There is need to access new manufacturing techniques and technologies that increase resource use efficiency.

5.2 Integrated waste management

The concept of re-use means that materials should be used again and again for as long as they can still serve the purpose for which they were made and do not pose a threat to human health and the environment. Materials recovered from the waste stream can be used in their current form, like bottles and plastic containers that are cleaned after use and then used again. Used water can be used for cleaning cars, gardening and cooling machines in industries. This cuts costs, saves time on manufacturing and reduces volumes of waste to landfills, given by the framework in Figure 4.

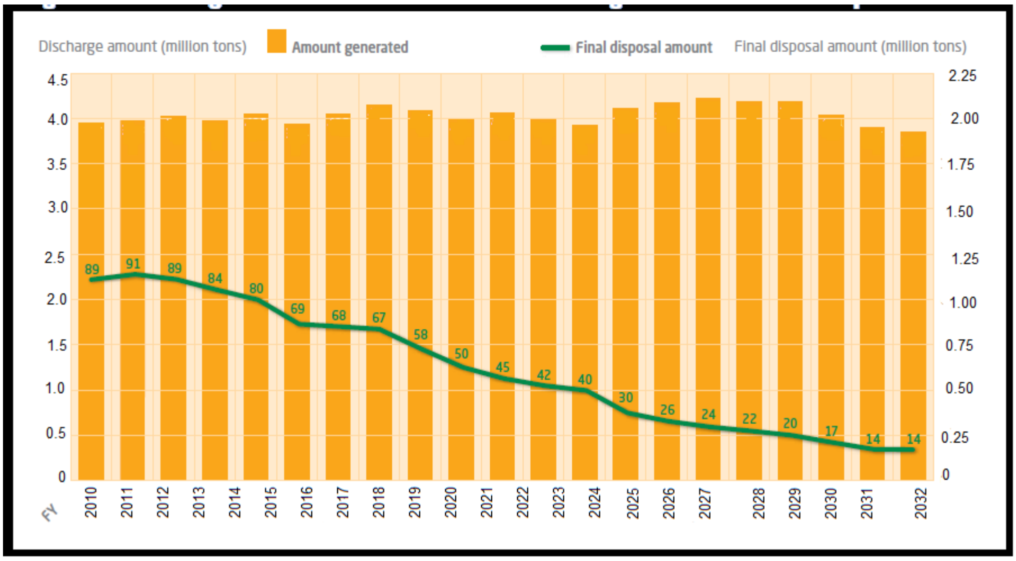
Figure 4. Guiding principle of waste policy – integral part of sustainability



It was also noted that Zimbabwe municipal by-laws for environmental offences, particularly littering, are not prohibitive. UNEP (2011) stated that the strategy is weak, as the laws are less strictly and less harshly enforced. There is also a lack of documentation on solid waste quantities.

Aggressive efforts were also needed to upgrade the quality of recycling technologies; and if waste generated was combined with dormitory towns of Chitungwiza, Norton and Ruwa; the trend of waste generation and resulting waste for disposal was estimated to be as shown in Figure 5 below. The space at the single active Pomona industrial waste landfill sites was declining and it was estimated that these sites will be full in the near future.

Figure 5. Changes in the amount of industrial waste generated and final disposal

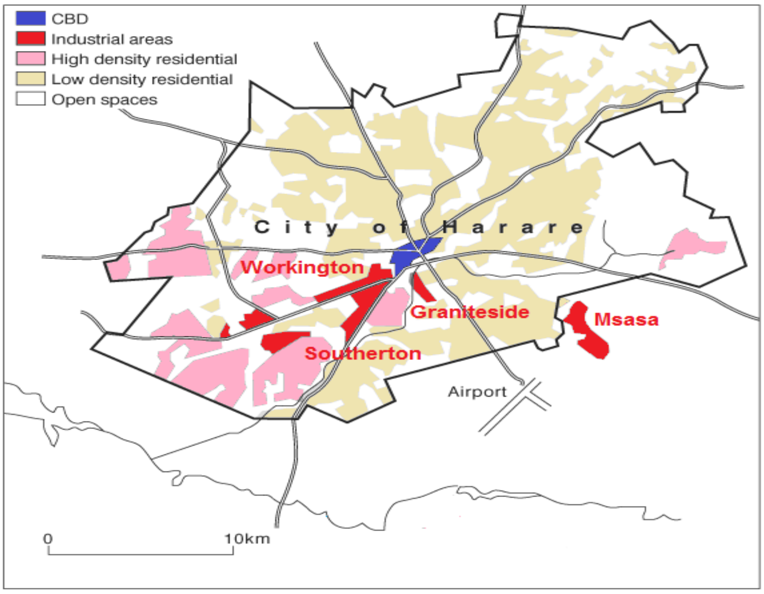


The focus could also be shifted to the recovery of energy as heat and electricity from waste, with the aim of reducing the waste to be land filled as much as possible (Figure 5). This may also result in decreased illegal dumping. There was now need for development of a virtual industrial park links various industrial area in and around the city of Harare; or making attempt to transform existing industry and community in the city by attracting new industry that is capable of using waste materials available locally.

5.3 Potential for EIP network participation

The primary source of energy for most of the industries is electrical energy from Zimbabwe Electricity Supply Authority (ZESA). One such power plant in Harare is located in Workington area. Southerton is dominated by tobacco processing companies. All the industrial areas and major company sites are linked by an intense rail infrastructure network. The current status or setup of the industrial operations is based on the data collected for areas surrounding Harare City centre which are Msasa, Granite, Southerton and Workington industrial sites (red) as given in Figure 6.

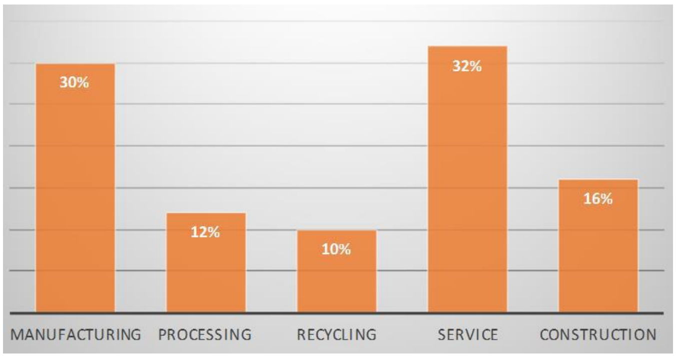
Figure 6. Map for Harare metropolitan area (*Source:* City of Harare 2014)



5.4 Industry composition

According to the questionnaires Figure 7 below shows types of industries in Harare metropolitan area.

Figure 7. Industries by type of operation



The questionnaire intended to establish the average composition of the whole area and also it intended to get also information about the environment, energy, water, traces of industrial symbiosis and recycling activities.

The summary of some of the operations and processes in Msasa and Workington are given by Table 2 and Table 2.

Table 1. Msasa companies processes and waste / by-products

Company	**Product**	**Raw Material**	**Waste /By-products**
Lafarge	Cement	Limestone	Kiln gases (CO_2), dust
Zimphos	Fertilizer	Natural gas, air/ Sulphur, coal	Chemical effluents, SO_x emissions
Feedmix	Stock feeds	Maize	Dust
GMB	Grain products, rice, mealie meal	Grain	Poor quality grain and Decayed grain
Multi-manufactures	Detergents and Cleaning accessories	Chemicals and Plastic pellets	Chemical effluents
John Hook	Metal Fabrication	Metal beams	Scrap metal
Mirable	Shoes	Leather, Soles And Glue	Leather cuts, ash, Insole board cuts
First Plastics	Rigid Plastics bottles	Plastic pellets	Damaged plastic bottles
Barzem	Repair and assembly of Earth moving machinery		Used oils and scrape metal

In Workington industrial area, waste by-products that could be shared include coal ash, slag, and metal scraps. Heavy industries, such as the metal, electricity, and petrochemical industries, were the main sources of these by-products that could be used by a wide range of industries. For example, among the six coal ash production industries, the electricity and steam industries contributed the most coal ash. Regarding the receiving industries, the material flow mapping indicated that the ready-mixed concrete, cement and other mineral product industries consumed the most coal ash.

Table 2. Workington companies processes and waste / by-products

Company	**Product**	**Raw Material**	**Waste /By-products**
Windmill	Fertilizer	Phosphates	Dust Gypsum Waste water
ZFC	Fertilizer	Phosphates	Dust Gypsum Waste water
Turnall	Corrugated sheets Tiles Sewer pipes	Asbestos dust	Breakages Waste water
CAFCA	Cables	Plastic pellets Copper wire	Waste plastics Waste metals
National Foods Milling	Stock feed Mealie meal	Maize Rice	Meal dust
Tobacco Processing Zimbabwe	Processed tobacco	Raw tobacco	Tobacco dust and stems
Gold Star sugars	Sugar	Raw sugar	Molasses and slag Waste water
Dairibord P/L	Packaged milk Yorghut Beverages	Milk Packaging	Milk solid slag Waste water Steam
Unilever P/L	Detergents	Animal fats	Phosphorus compounds Waste water
Cottco	Ginned cotton		Waste cotton
Colcom P/L	-Meat -Processed foods	Live pigs	-Offals -Animal waste
ZESA Thermal Plant	Electrical power	Coal Water Lubricants	Slag coal dust Fly ash

5.5 Generation of virtual EIP

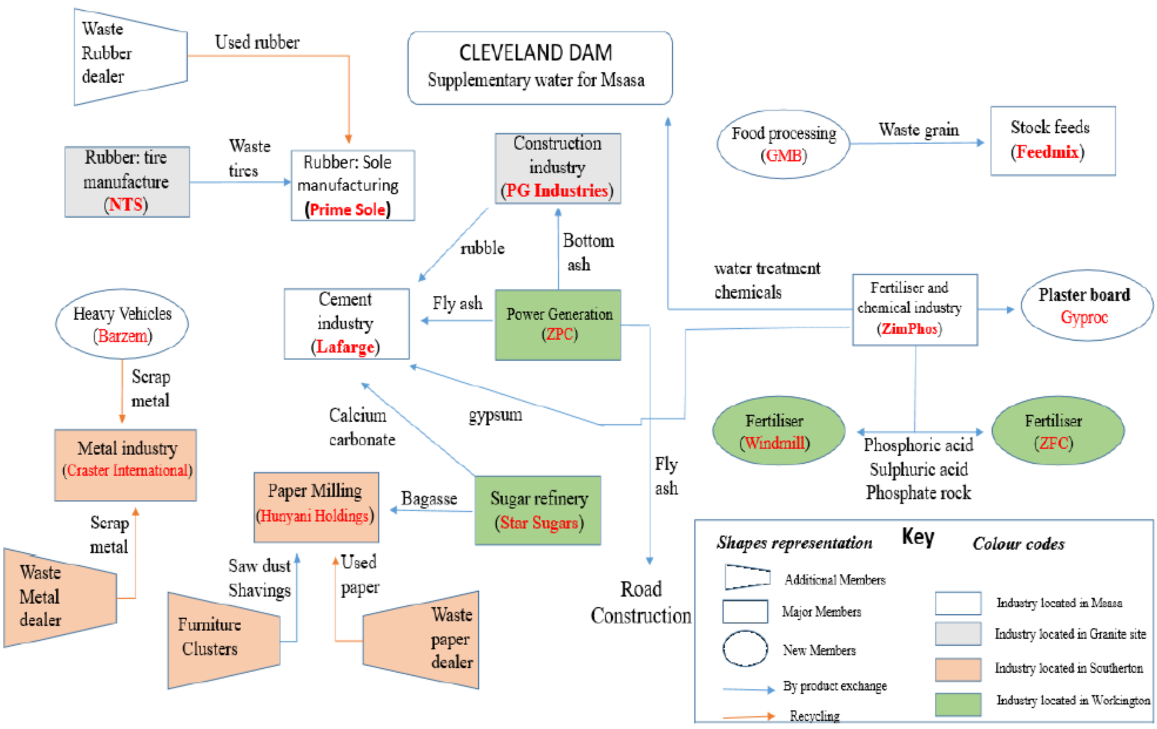
The prototype model was generated and made up of companies that were already present in the four industrial areas. Each industrial site was evaluated against each of the suggested base points with a possible weight given for each in Table 3. Thus the site was chosen for the prototype and the potential symbiotic relationships where accordingly identified.

Table 3. Relevant baseline points for EIP sites

Baseline point	**Possible weight**	**Msasa**	**Granite**	**Workington**	**Southerton**
Land availability	30	25	18	16	15
Anchor members	15	10	8	12	11
Possible symbiosis relationships	15	9	9.5	12	12
Infrastructure capacity	10	7	7	8	8.5
Access to market	10	7.5	8	7.5	8
Natural resources availability	5	7	7	7	7
Labor force	5	3	2	4	5
Industrial resource flow	5	3	3	3	4
Total	**100**	**71.5**	**62.5**	**65.5**	**70.5**

Using this selection system, Msasa came out as the best central site for the virtual industrial park growth (Figure 8) to other neighbouring three site which all fall within 25km radius to each other.

Figure 8. Msasa eco industrial network



Lafarge would receive gypsum from Zimphos and fly ash from Harare thermal power plant and part of municipal waste for incineration in the kiln, the overall effect is a decrease in percentage of waste disposed in Pomona. Gyproc also uses the gypsum from the Zimphos dumps, in manufacturing of plaster boards and this reduces mainly the ground water pollution in Msasa caused by the effect of the gypsum dams. The road construction industry also use the remaining fly ash from Harare power plant to improve of the road quality as fly ash contributes to the properties of the hardened concrete through hydraulic activity. Consolidation of information was challenging, as a result each industrial area was treated as a site with individual companies within it. This was a more practical simplification as the four industrial areas fall within a 25km radius; and all the sites and major companies are linked with an intense network of railway lines.

6. Recommendations

Many developing countries' economies are characterized by a huge informal sector with millions of small and individual enterprises (SMEs) in place of the large factories that are seen in industrialized countries. The collective consumption of materials, and the resultant problems, EIP framework for Harare Metropolitan of pollution and waste in this informal sector is larger than in the formal sector. Thus, there will be particular need for considerable adaptation measures to EIP-concepts, when trying to apply it to a region characterized by such a situation. For practical purposes, a virtual EIP type was opted for, to establish networking of firms across the four sites as they all fall within a 25km radius to each other. The intense rail network linking the sites and to even firm level favored this anchor tenant model for ease of by-products and waste exchange movements.It is recommended to establish EIP development centers, recycling and recovery technologies; as well as instituting regulatory legislative framework at national level to enforce mandatory environmental networking across all industries to promote economic growth in the country. The possibility exists, however, of further expanding IS connections among the companies operating in Harare industrial metropolitan. This could only be achieved through gradual realization of possible industrial symbiosis networking over time in the proposed EIP; this could be achieved through appropriate technical advances to bring about industrial symbiosis or resource synergy to comply with environmental regulation. And all this requires government endorsement and approval for waste or by-product utilization. It can be argued that industrial symbiosis is a sustainable approach to economic development, one upon which future generations can rely. It is a fact that, while much has been written, there have been few ground breakings for actual parks. It would be true to suggest that, at present, we are at the earliest stages of industrial symbiosis and that the model of the full-blown industrial ecosystem provided by the industrial district in Kalundborg, Denmark (Chertow 2000), should not be viewed as the alpha and omega for eco-industrial parks.

7. Conclusion

In this study, effort was made to identify companies with potential to be part of the EIP, with operation briefs as well as material substitution and pollution prevention strategies that could be implemented. A virtual clustering framework was done for symbiosis consideration. Msasa industrial area was given as a potential central site due the availability of land for further expansion to accommodate new symbiosis companies as they come on board. Two major operations at cement, and phosphate industries, presented opportunities for fly ash as alternative input material (from thermal power station) and supplier of chemicals to downstream industries respectively. The evolution of industrial parks into ecosystems is still at a very early stage. It should be understood from this study that industrial ecology is still in its infancy, and one of the most interesting facets of its development is that theory and practice are evolving together at the same time.

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Biography

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