House of sustainable waste management: an implementation framework

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Abstract: Manufacturing industries consume large amounts of natural resources as inputs to production in order to generate much lower amounts of useful products, leaving a major part of the inputs as by-products which are wastes. Waste disposal, in the present form, has significant adverse impacts on the environment as it can result in pollution of many forms. The present research critically examines the various revolutionary concepts of ‘cradle to cradle (C2C)’, ‘design for green (DfG)’, ‘triple top line’ and ‘waste is food’ as applied to industrial waste management. The exploratory study examines the prevailing practices and suggests approaches for sustainable industrial waste management. The paper proposes the ‘house of sustainable waste management’ which is a reference framework for industrial waste management which comprises three parts, ‘the hierarchy’, ‘the pillars’ and ‘the foundations’. The proposed framework is conceptual in nature and provides a direction for implementation of sustainable industrial waste management.

Keywords: cradle to cradle; C2C; design for green; DfG; hierarchy of waste; house of sustainable waste management; industrial waste management; waste management; waste is food.

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1 Introduction

From extraction to production, manufacturing industries take in large quantities of natural resources as raw material to production. Only a part of the inputs to production are converted to useful products. Even the finished goods, at the end of their useful life get converted as wastes. Waste generation happens all along the supply chain, much more than what is generated at the production plant (Ehrenfeld and Gertler, 1997). The amount of natural resources appropriated is much larger than the amount of final consumable products generated by industry. In this scenario, increased production and higher economic output will result in increased environmental harm. As nations are set to increase their manufacturing base, there is an urgent need to re-focus on the environmental impact of industrial waste and sustainable ways to manage it.

The conventional approach is to reduce industrial waste generation, then to treat the generated waste to less harmful by-products and finally dispose of the waste through landfill, incineration etc. Though these resource efficiency measures and 'end-of-pipe' actions reduce the impacts of industry on the environment, these are action plans for managing the ill effects; a strategy aimed at trying to be 'less bad', rather than being good (Braungart and McDonough, 2002). The conventional approaches to waste management do help in identifying the problems, but as strategies to reduce environmental impacts, it has limited impact. The reason for the limited effectiveness of these measures is that the total ecological footprint along the supply chain is not considered in this approach (Viswanadham and Kameshwaran, 2013).

Industrial ecology and eco-efficiency are emerging concepts which integrates sustainability principles into environmental and economic systems (Ehrenfeld and Gertler, 1997). The concept of triple bottom line (TBL) addresses the 'three pillars of sustainability' namely, ecology, economy and equity and provides these three aspects of planet, profit and people as objectives of sustainable businesses (Elkington, 2001). The cradle to cradle (C2C) approach focuses on eco-effectiveness and aims at zero emission during the entire life cycle of the product (Braungart et al., 2007). Design for green (DfG) or design for environment (DfE) addresses the environmental concerns right from the beginning at the design stage (Hauschild et al., 2004; Viswanadham and Kameshwaran, 2013). Product stewardship is a product management concept which focuses on minimising pollution and wastes throughout the life cycle of the product (Beamon, 1999; Hart, 1997; Pullman and Dillard, 2010). The triple top line (TTL) approach is a new perspective in industrial practices that seeks to enhance ecological gain while generating economic value by maximising performance in the fields of ecology (planet), equity (people) and economy (profit) (Braungart and McDonough, 2002; Braungart et al., 2007).

There are some studies existing on a framework for industrial waste management. Karamouz et al. (2006) proposed a methodology to develop a plan for management of industrial solid waste. The framework basically ranks similar industrial units based on analytic hierarchy process (AHP). Hogland and Stenis (2000) proposed a methodology for optimisation of waste management considering environmental signatures, energy utilisation and economic impacts. This study is based on case-based research and claims to be suitable for implementing integrated waste management systems. El-Haggar (2007) authored a book which presents C2C manufacturing alternatives to common traditional industries. The book attempts to provide waste management strategies with an objective of conserving natural resources and focuses on achieving 100% usage of all categories of waste.

This paper critically analyses the current concepts in industrial sustainability and waste management. Based on an exploratory study, the paper proposes a framework for sustainable industrial waste management called 'The house of industrial waste management'. The 'house' consists of three elements, namely:

1 hierarchy of sustainable waste management
2 pillars of sustainable waste management
3 foundations of sustainable waste management.

'The house of industrial waste management' can be used as a reference framework while planning and implementing industrial waste management practices.

2 A paradigm shift: industrial waste management

The proponents of the industrial revolution considered the natural resources inexhaustible and nature was viewed as something to be tamed and utilised for the benefit of mankind (McDonough and Braungart, 1998). There has been a significant shift to this approach in the recent years after the realisation that the natural resources have limits. Today, many leading industrialists and researchers have begun to realise that traditional ways of doing businesses may not be sustainable over the long term and there can be alternate ways to treat environmental concerns in a better, responsible way. In the book titled Green Recovery, Andrew S. Winson (2009) states: "Climate change regulations are coming and will change business forever. The attack on emissions will affect every aspect of society, from how we power our lives and travel to how businesses source, make, distribute, and sell goods. When governments and markets 'price' carbon, the cost of everything changes, sometimes by a significant margin."

It was predicted two decades back that changes in environmental priorities will be bringing a new industrial revolution (Berry and Rondinelli, 1998). The focus of business organisations on profit and growth is getting replaced to sustainability where the business priorities are different. In many organisations, environmental concerns and its compliance are becoming the second bottom line and are part of their competitive strategies (Hassini et al., 2012). The drivers of these new sustainability initiatives are the pressures from Government regulations, customer expectations for equity and environmental friendliness, employee expectations, societal pressure like NGOs and competitors (Dyllick and Hockerts, 2002; Epstein and Roy, 2001). There is also a realisation emerging among the stakeholders of businesses that business performance and environmental quality are related. Studies show that firms that adopt proactive environmental management approaches are tending to be more efficient and competitive (Berry and Rondinelli, 1998). There is also an expanding market for business solutions that address environmental issues specifically industrial waste management and disposal. Companies have started accepting their responsibility towards doing no harm to the environment (Hart, 1995). All these points to a radical change in business approach and a paradigm shift in the life cycle management of products.

3 The concept of waste

Management experts were debating on the concept of waste since the beginning of industrial revolution (Koskela et al., 2012). As early as in 1913, F W Taylor argued that wastages caused by human inefficiencies are much more than material wastes due to processes (Formoso et al., 2002). Henry Ford in 1927 said that cost of material depends on the human work that has been put on them, and therefore, human work efficiency should be the focus of waste prevention (Formoso et al., 2002). Anastas and Zimmerman (2003) argued that the concept of waste is to be seen from a human perspective. They argue that no material is a waste, but it is just that the dealing personnel finds no use for the material due to their lack of imagination or lack of technology to use that material. According to the above reasoning, waste is that which is unable to be exploited for the owner's benefit with the available processes and systems (Anastas and Zimmerman, 2003). Another appropriate definition of waste is given by Pongrácz and Pohjola (2004) as: "Waste is a man-made thing that has no purpose; or is not able to perform with respect to its purpose." The European Union Waste Framework Directive defines waste as a "Waste is any substance or object which the holder discards or intends to discard" (Williams, 2005). Williams (2005) elaborated to specify and classify types of wastes and methods to dispose of them. There are multiple dimensions of industrial waste management; generation and management of wastes not only have an environmental impact but also consume money, effort and time for its handling and disposal (Ehrenfeld and Gertler, 1997).

There are many classifications of wastes. One classification is to distinguish waste between direct and indirect wastes (Formoso et al., 2002). Direct wastes are those wastes which are of no use and required to be disposed of. In the case of indirect wastes, physical loss of material and material disposal are not involved, however, the loss of money, effort, or time is involved. Wastage due to over design is an instance of indirect waste; for example, the weight and size of a component produced are more than what is essentially required. There are also other types of wastes due to accidents, perishability of materials, production of goods that do not meet user's needs, products that failed to reach their target (example: fertiliser washed away by rains), theft and vandalism etc. (Pongrácz and Pohjola, 2004).

According to the lean manufacturing approach, Toyota's president, Fugio Cho defines waste as "anything other than the minimum amount of equipment, materials, parts, and workers which are essential to production." Based on this definition, seven types of operational wastes are identified in lean manufacturing approach (Bergmiller, 2006; Formoso et al., 2002). The approach to such operational waste reduction is elaborately discussed in the literature and widely practiced in industry which is not the focus of this study. The focus of this paper is industrial waste reduction.

4 The hierarchy of industrial waste management

The European Union National Waste Strategy of Member States has developed the concept of the 'hierarchy of waste management' to prioritise waste disposal methods. The objective of this directive is that it encouraged waste reduction through various means followed by re-use and recovery as next preferred options. Waste disposal is the least desirable option (Williams, 2005). El-Haggar (2007) also proposed a hierarchy of waste management based on C2C approach. A schematic version of the waste hierarchy proposed by Williams, similar to EU strategy is shown in Figure 1 (Williams, 2005).

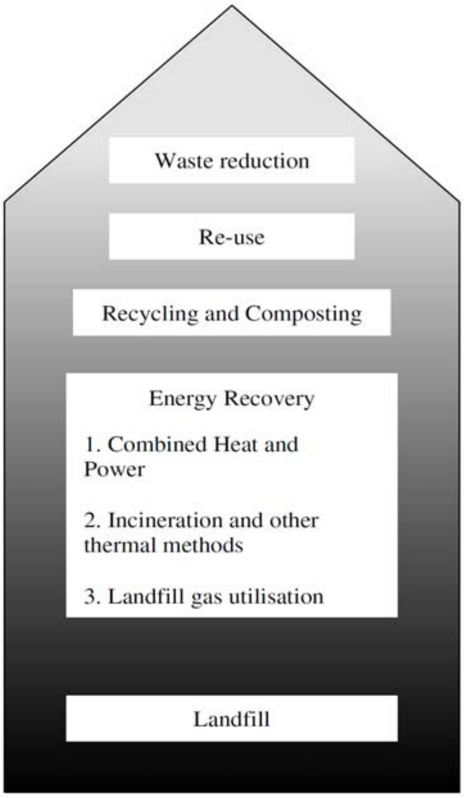
The present study analysed various waste management options with special emphasis to TBL and eco-efficiency of businesses and proposes a revised and modified hierarchy of waste management. The focus of the waste strategy is guided by the principles of sustainable development. This implies that waste management is not limited to recycle it, but also to look at innovative ways to reduce the amount of any wastages that is created anywhere along the supply chain (Linton et al., 2007).

The proposed hierarchy of waste management is shown in Figure. 2. Waste prevention tops the preference followed by waste minimisation, re-use and reclamation whereas landfill is the least preferred option. The hierarchy is derived based on three conditions of TBL, namely, environmental, economic and societal considerations. The justification for this proposal of the hierarchy of waste management is given in the succeeding paragraphs.

Waste prevention focuses on elimination of waste before it is generated. Activities, processes and techniques that reduces, avoids and eliminates waste at its source is defined as waste prevention (Williams, 2005). Waste prevention normally happens within the bounds of the manufacturing unit. Value analysis (also called value engineering), a systematic approach, while improving 'value' of the product, also addresses the issue of waste reduction at design stage (Miles, 1972). Waste minimisation is similar to waste prevention. Waste minimisation and waste prevention are better approaches to environmental protection compared to minimising of wastes at the end of the pipeline (Zamorano et al., 2011).

Re-use and reclamation is using the product in its initial form even after its expected life time by way of cleaning, repairing, reclamation, overhauling etc. A very effective reduction in environmental impact of a product can be made by product re-use and re-manufacture in which the geometrical form of the product is retained (Nnorom and Osibanjo, 2010). This approach is, in a way, akin to the higher order of 'waste prevention' as the product is still not converted to waste. A product, by-product or residual product does not constitute waste if it is destined for direct re-use in a further process in its existing form (Pongrácz and Pohjola, 2004). There is a business prospective on re-use and reclamation whereby the value of the product is extended midlife. Re-use and reclamation can be applicable to the entire product, some of its modules (sub-assemblies), or individual components.

Figure 1 Hierarchy of waste management

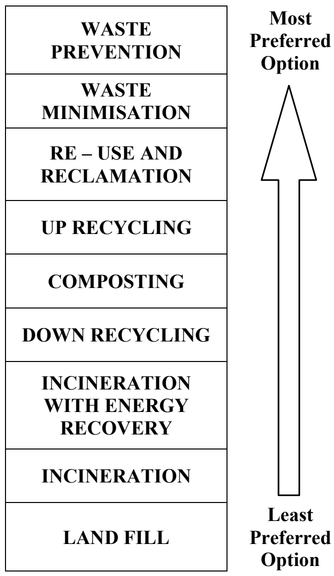


Source: Adapted from Williams (2005)

In up-recycling or up-cycling, old product material is given more value, not less. It is aimed at converting waste components (material) into fresh products or materials with better quality and improved value while providing minimum adverse environmental impact. Up-recycling reduces the consumption of fresh raw material which in turn results in reduced pollution and waste generation (Braungart and McDonough, 2002; Lodder et al., 2014). Right material selection during product design stage plays a critical part in up-recycling. However, in the hierarchy of waste management, up-cycling is placed below re-use and reclamation because a product is disassembled to its basic materials and then re-processed to be used in new products. In addition, in a product consisting of many materials, all material components may not be up-recyclable. Most metals are examples of up-recyclable materials.

The nature's method of recycling is composting. The organic and biodegradable fraction of the waste is decomposed to stable products such as manure for plants and soil conditioners through composting. Using biodegradable material as raw material, proper segregation of such waste material and a good mechanism for composting are the ways to environmental friendly waste management through composting. Composting is ‘food for nature’ and thus reduces overall entropy whereas down-recycling for industrial use do not reduce entropy but usually increases it. Hence down-recycling is placed below composting in the hierarchy of waste management.

Figure 2 Proposed hierarchy of waste management



Energy recovery from waste incineration and using of landfill gases as fuel are other options of waste management. However, both the above options are less desirable due to their impact on environment. Landfill is the least preferred option under the hierarchy of waste management. Over a period, even landfills get stabilised and converted to the inert material due to biological and chemical processes within the landfill. However, the time for this stabilisation process is long and throughout this degradation and stabilisation period, greenhouse gases such as carbon dioxide, methane etc are continuously emitted from landfills. Leachate (liquid material that drains from landfills with undesirable contaminants) management is another challenge with landfills (Hogland and Stenis, 2000; Williams, 2005).

4.1 Economics of waste management

The major drivers of waste minimisation and prevention initiatives are increasing costs of pollution control and waste disposal and stringent legal implications if the norms are not met (Berry and Rondinelli, 1998). Waste minimisation and prevention attracts added significance when the total cost of waste management is reckoned. Thus, the cost of waste management can be calculated as (Williams, 2005):

$$\text{Total Cost} = \text{Capital Costs} + \text{Operational Costs} + \text{External Cost to Environment}$$

Once the external costs to the environment is added to the total cost of waste management, waste minimisation and prevention becomes at the top of the hierarchy of waste management options. Increasing the recyclability of a product through material selection and product design reduces recycling costs (Calcott and Walls, 2000). Economics of waste management is thus a driver for sustainable waste management (Winston, 2009). When the cost to environment gets added to the total cost of waste management, the conventional preferences change and justify the proposed hierarchy of waste management.

5 The pillars of sustainable waste management

The goal of sustainable waste management is to push the waste management up the hierarchy of waste management (refer Figure 2). The methods to reach those goals, i.e., to achieve the higher echelons in the waste management hierarchy, are the pillars of sustainable waste management. The pillars of sustainable waste management are identified based on extensive literature survey and case study. These pillars represent the current and innovative approaches to sustainable industrial waste management. The six pillars are briefly evaluated in the succeeding section.

5.1 Eco-efficiency

Eco-efficiency is a doctrine that helps business to look for environmental improvements at the same time generates parallel economic profits. The focus of eco-efficiency is on innovative business practices that facilitate organisations to become more environmentally responsible and profitable. Businesses have come to realise that modern industrialisation with an aim for maximising profit and growth almost always is detrimental to environmental degradation. The reason for this is briefly presented at the introduction of this paper. In this context, the concept of eco-efficiency becomes relevant as it is related to creating increased value with less adverse environmental impact.

The World Business Council for Sustainable Development (WBCSD) defines eco-efficiency as (Madden et al., 1997): “eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth’s estimated carrying capacity.” El-Haggar (2007) describes industrial ecology as the practice of industrial systems that operate more like natural ecosystems. Industries can adapt natural eco-system by making one industry’s waste into another’s inputs and thus facilitating re-circulation of materials and energy. Integrating of stakeholder forces adds to eco-efficiency. Associating producers with recyclers, consumers and related stakeholders generates eco-efficiency in sustainable waste management (Calcott and Walls, 1999).

Stimulating creativity and innovation is an expected result of eco-efficiency. Eco-efficiency initiatives are not normally limited to areas within a company’s boundaries but valid for activities upstream and downstream of the supply chain. It is also applicable over the entire lifecycle of the product. Many businesses incorporate eco-efficiency as part of their policy or mission statements and set eco-efficiency objectives for their integrated management systems.

5.2 Design for environment

Design is the declaration of intent before a product is made. DfG or DfE is the approach of the organisation to formalise and cater for the environmental and societal aspects in their product and process design (Hauschild et al., 2004). The DfE framework offers specific guidelines and a list of facts and suggestions in the different stages of product and process design. Material selection, designs for disassembly and green manufacturing are given high priority from design stage itself. The DfE protocol includes a detailed assessment of all materials used for manufacturing a product. The main objectives of material assessment are:

1 assess the level of danger the material might present to plants and animals

2 biological degradability of the material (compostability)

3 re-usability (up-recyclable)

4 environmental impact during extraction of the material from nature etc. (Braungart et al., 2007; Lindahl, 2005).

Another criterion is to design products so that they are easy to disassemble and have its different components clearly marked which will help in easy dismantling and recycling (Rose, 2000). The other design considerations are using of materials in such a way that only minimum amount of the product ends up in landfills and maximum use of recycled material as raw material inputs (Calcott and Walls, 2000; Rose, 2000).

DfG approach helps in incorporating pollution prevention technologies in manufacturing which includes process modification, materials substitution, materials reuse within existing processes, materials reuse within different processes and materials recycling to a secondary process (Lindahl, 2005). Businesses are realising that it is far more efficient and smarter to design products for recyclability, disassembly, maintainability, upgradeability and disposal at the concept stage and design stage itself. It becomes much more complicated to deal with disposal problems at the end of the product’s life if the product is not designed for disposal. Industries are finding more and more innovative ways to design products for easy disassembly and recyclability than to address the issue of waste disposal at the last phase of a product’s life cycle. Anastas and Zimmerman (2003) proposed twelve fundamental maxims of green design approach. These twelve principles can act as a framework for designers and engineers to engage in while designing new products or processes.

New and emerging technologies can be another set of drivers for DfE. Progress in nanotechnology, genomics, bioinformatics, biomimicry, and information technology hold many possibilities for reducing environmental impacts caused by industrialisation (Hart and Milstein, 2003). Nanotechnology and biotechnology helps to design products at molecular or micro level, preventing waste generation. Biomimicry helps in innovating sustainable solutions to industry challenges by designing products based on nature's time-tested patterns and strategies. The idea of biomimicry is to create products and processes based on God’s design principles of designing nature. Information technology and micro alternative power generation can take industries to villages and near sources of raw material and consumers (de Pauw et al., 2014; Hart and Milstein, 2003).

5.3 Cradle to cradle approach

C2C approach is a whole new level after eco-efficiency. Here, the focus is not on eco-efficiency, but on *eco-effectiveness*. The whole idea being that while the ultimate extension of eco-efficiency is a *zero-emission* approach, eco-effectiveness however moves beyond that by concentrating on developing products and industrial systems that don't just satisfy minimum norms but are designed to increase the productivity and quality through subsequent life cycles. In addition, this approach addresses some of the shortcomings of its predecessor eco-efficiency (Braungart et al., 2007).

While eco-efficiency largely looks at industrial flow as a linear one: extraction, production, usage and disposal, i.e., it has a *cradle to grave* approach of the product flow. Eco-effectiveness also aims at zero waste. Even though many items are traditionally recycled, it is not so much as *recycling* as much as it is a form of *down cycling* in the sense that we normally see a decrease in quality. Hence there is not a 100% reusability of the material as it originally had been. In fact, this follows the same old linear pattern until final disposal. Eco-effectiveness thus is an approach where the aim is to re-use everything possible and design the whole cycle in a way to achieve this aim (El-Haggar, 2007). The aim here is optimal re-use of product material. The designers of a product bear in mind what could be done to be able to fully recycle the product to whatever state it originally was in. C2C protocol strives for closed loop material flows. This is also why it is called the *cradle to cradle* approach (Braungart et al., 2007). It follows in the line of TTL approach in the essence that less bad is not necessarily good.

5.4 Waste is food

Waste is food essentially talks about making use of all the waste we produce. This concept is the brainchild of the proponents of the *C2C* approach, William McDonough and Michael Braungart (2002; Braungart et al., 2007). Waste is food concept is an application of the *C2C* approach in industrial waste management. The central design principle of eco-effective approach is that waste equals food. Waste can be treated as 'food' in two different cases; firstly, as biodegradable material for the *biosphere* so that once we are done using what nature gave us, we can give back to it. And secondly, as perfectly re-usable material for what is termed as the *techno sphere*, i.e., back to the industry itself (Braungart et al., 2007). El-Haggar proposed the 7Rs Golden Rule which consists of regulations, reducing, reusing, recycling, recovering, rethinking and renovation (7Rs) as a tool for waste is food approach (El-Haggar, 2007).

5.5 Product stewardship

Product stewardship is a product management concept which focuses on minimising pollution and wastes throughout the life cycle of the product (Snir, 2009). All parties involved in the lifespan of the product are called upon to take up responsibility to reduce its adverse environmental, health, and safety impact (Berry and Rondinelli, 1998). While the manufacturing company takes care of DfG and green manufacturing, the other entities in the supply chain, including consumers, also cater for minimum or no environmental impact when the product passes through their custody (Hart, 1997).

Stakeholder engagement is an effective method to ensure organisations follow product stewardship. There are case examples where stakeholder engagement, sometime even with opposing priorities kept the organisation on the track of product stewardship. Product stewardship also communicates to the stakeholders their responsibility in sustainability. Good product stewardship practices reduce risks and improve public image and goodwill in addition to minimising environmental impacts.

5.6 Triple top line

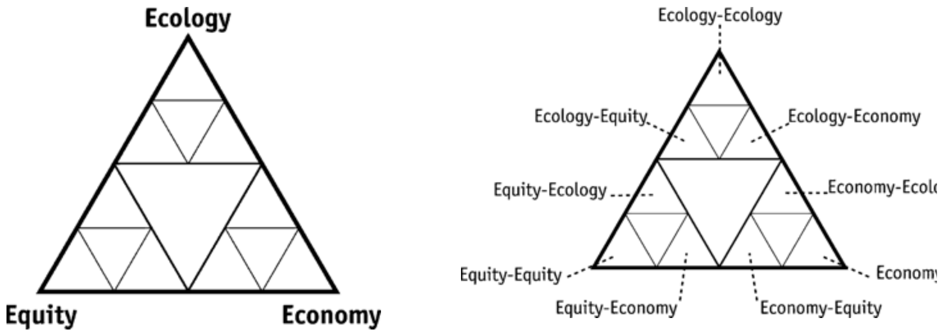
The TBL, a term coined by John Elkington in 1994 is considered as the 'three pillars of sustainability'. These pillars are: 'Ecology, Economy and Equity' or in other words: People, Planet and Profit (Elkington, 2001). The idea behind the TBL is that for sustainable development in any industrial practice, one must observe at least a minimum level of balance between these three factors, while none of the three factors can be sacrificed for the sake of another. The success or health of a business organisation should be measured by its social (people) and environmental (planet) performance in addition to the traditional financial bottom line (profit), the proponents of TBL claims that objective measurement of social and environmental performance is possible, and those companies should use these measures to improve their social and environmental standing. Reporting of these performance measures helps companies to remain focussed on TBL (Ahmad et al., 2018; Ansari and Qureshi, 2015).

The TBL approach considered that a circular flow of resources and goods cannot go on for ever and resources will diminish over time (Lodder et al., 2014). A circular economy is defined as a regenerative system where resource inputs are restored (Yuan et al., 2008). The TTL approach is a new perspective in industrial practices that seeks to improve on the TBL approach and to build on the foundations of circular economy (Braungart and McDonough, 2002; Lodder et al., 2014). The TBL has now become an industrial standard for companies to minimise liabilities in the three fields (profit, planet and the people) whereas in the TTL approach, the accountability is moved to the beginning (of the design process). TTL focuses to enhance ecological gain while generating economic value. Instead of limiting liabilities (staying above a bottom line) in TTL designers try to maximise their performance in the three fields of ecology/planet, equity/people and economy/profit (going for the top most standards) (Edgeman et al., 2015; Lodder et al., 2014). Figure 3 is a depiction of the TTL as fractal triangle.

The TBL approach is generally seen as a balancing one. Though the proponent of TBL *John Elkington* might not have visualised it to be so, it has ended up being a way to measure the final product or the industrial process against minimum standards and compromising on some to keep the three ratings above the bar. However, in the TTL; there is a key insight offered by the illustration of the fractal triangle as seen below. It turns this basic idea of TBL on its head: Going for intelligent design instead of balancing the profit, people and planet motives to achieve much greater value. In order to explain how this does so, consider a triangle with each of its vertices as one of the key aspects that must be improved. Traditionally, one would look at this as a normal equilateral triangle where to really improve ratings in one field; the standards in the others must be sacrificed.

However, in the fractal triangle approach, you can easily from the very beginning see that every design decision taken is an interconnected one. So, if a decision is taken from a purely economic perspective, it will still have a huge impact on the ecological and social world as well. Each of the vertices represents a school of thought: capitalism, socialism and ecologism. Each of them is a genuine way to improve our lives, but any taken to the extreme has adverse effects in the long run. While designing, instead of trying to limit the influence of one of these schools over the others, TTL thinkers try to discover opportunities, so they can honour the requirements of all the three top lines (McDonough and Braungart, 2002).

Figure 3 The triple top line: fractal triangle



Source: McDonough and Braungart (2002)

6 Foundations of sustainable waste management

The foundations on which the house of sustainable waste management is built are:

1 stakeholder forces

2 governance structure

3 performance measurement system.

These three foundations support the six pillars of sustainable waste management ultimately facilitates the hierarchy of sustainable waste management. Aligning the organisation's culture, values and vision with organisational sustainability initiatives is mandatory for its success. In fact, the organisation's culture, values and vision are derived from the three foundations. The business's strategy of resource utilisation and process design get derived from the foundations. The significance and role of the foundations are deliberated in the succeeding sections.

6.1 Stakeholder forces

Identifying and involving stakeholders are fundamental to sustainability. ISO 26000: 2010 defines stakeholder as "individual or group that has an interest in any decision or activity of an organisation". Stakeholder forces are the result of right stakeholder identification and their engagement by the firm. The performance prism developed by researchers from the Centre for Business Performance at Cranfield School of Management, England, and Accenture for measuring organisation's performance takes account of the two-way relationships between an organisation and all its stakeholders (Neely et al., 2001). Organisations create value for stakeholders and stakeholders can in turn create value and direction to organisations. Neely A argues that strategy should follow or derive from stakeholder engagements (Neely, 2005). The operational aspects of all the sustainability programmes should have derived from 'stakeholder forces' which in turn builds the organisations purpose, values and culture. The dynamic nature of stakeholder forces is also to be noted. Organisations should therefore have systems to adapt to and adopt the changes in stakeholder forces.

6.2 Governance structure

The governance structure can be defined as the system and the method by which an organisation makes its decision in accordance with its objectives. Governance structure, in addition to making decisions, also takes care of the mechanism for implementation of the decisions taken (ISO 26000:2010). Organisations aiming to have sustainable waste management should have an organisational governance system enabling the organisation to facilitate oversight and take decisions according to the six pillars of sustainable waste management. Research indicates that generation of significant portion of waste can be avoided by implementing preventive standards, normally associated with managerial and governance improvements (Formoso et al., 2002). The governance structure supports the implementation of sustainable initiatives; it is the organisations muscle power for implementation and monitoring. Another important aspect of governance is fixing the ownership of the material at all stages. In a way, abandoning of ownership or intension of abandoning ownership turns a material to waste (Pongrácz and Pohjola, 2004), therefore a good governance system controls and changes ownership of material so that material remains in the useful category for a prolonged period before it is abandoned as waste.

6.3 Performance measurement system

A good performance measurement framework measures, monitors and controls the activities and results of the organisation. Performance measurement systems act as a means to align their processes and resources with strategy and to achieve their organisation objectives (Kurien and Qureshi, 2011; Simons, 1990). Performance measurement systems encourage proactive rather than reactive management. It is also a strong medium of communication to the internal stakeholders (Tangen, 2004). An effective, integrated and balanced performance measurement framework engages the organisation's performance measurement system as a vehicle for organisational change (Schaltegger and Burritt, 2014). It also provides insight to reveal the effectiveness of strategies and to identify potential opportunities (Tangen, 2005). It makes an indispensable contribution to decision making, particularly in re-designing business goals and strategies, and re-engineering processes (Charan et al., 2008). In the present case, performance measurement system can act as a vehicle for sustainable waste management initiatives.

Measurement of waste generation at each stage of manufacturing is an effective indicator of the performance of the manufacturing system, because waste generation indicates stations of inefficiency and thus the potential for improvement (Formoso et al., 2002). The performance measurement system should be capable of answering the questions:

1 Why did it become waste?

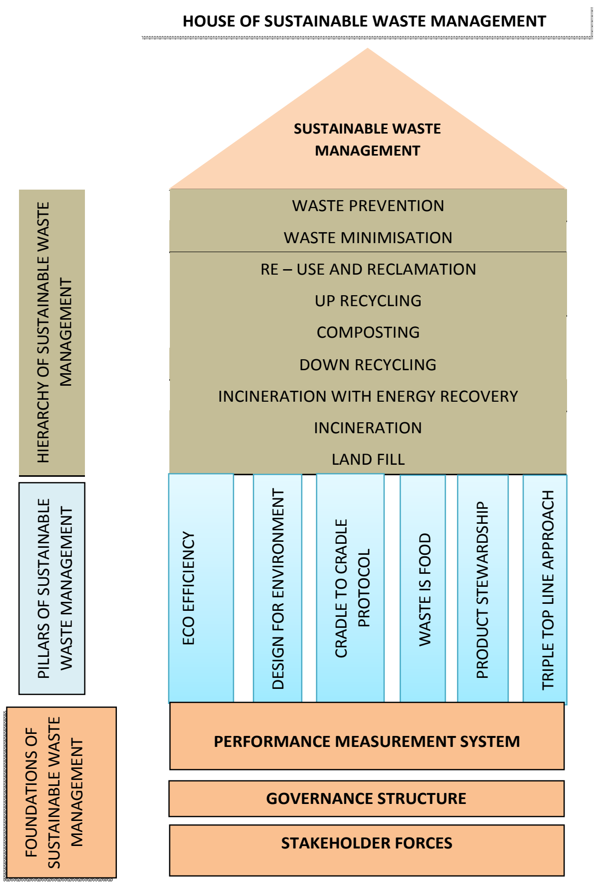
2 Where in the chain did it become waste?

The answers to these questions will contain indicators on how the substance can be prevented from becoming waste (Verrier et al., 2014).

7 House of sustainable waste management

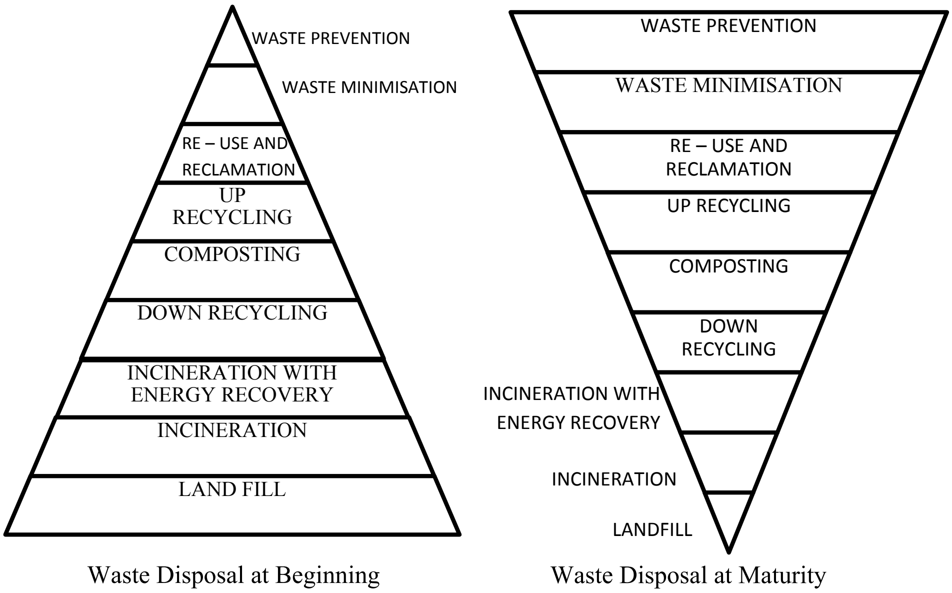
The present study proposes the 'House of Sustainable Waste Management' which is a reference framework for industrial waste management. The 'House of Sustainable Waste Management' has three parts, 'the hierarchy', 'the pillars' and 'the foundations' of industrial waste management. The house of sustainable waste management framework is depicted in Figure 4. The hierarchy of sustainable waste management gives direction and purpose for the industrial waste management strategy. The six pillars provide the ways and methods to attain the objectives of the hierarchy of sustainable waste management. The current and latest concepts of sustainable approach to waste management have been the 'pillars' of the proposed framework. There are three foundations identified and put in the framework which will facilitate the 'pillars' to function.

Figure 4 House of sustainable waste management (see online version for colours)



The maturity of the framework for waste management depends on how much waste management is pushed up the hierarchy (refer Figure 5). The framework is conceptual in nature and provides a direction for implementation of sustainable industrial waste management.

Figure 5 Maturity model for sustainable waste management



8 Conclusions

The present research looks at the current and innovative practices of industrial waste management and proposes a new framework for sustainable industrial waste management. Waste elimination is the major focus for process improvement in the *lean production* paradigm. Organisation's sustainability is a more complex, multi-dimensional concept that cannot be addressed by any single corporate action. However, sustainable waste management contributes in a significant way to the overall sustainability of the organisation. Less waste means better utilisation of inputs and longer use of outputs resulting in lower costs and reduced risks.

The 'House of Sustainable Waste Management' incorporates the foundations, Pillars (methods) and hierarchy (targets) for industrial waste management. A strong 'foundation' and 'pillars' of the waste management framework will drive waste management up the proposed hierarchy of waste management. The new framework can be a reference model for industries while they plan and implement their waste management initiatives. Waste management can thus fulfil its purpose of protecting the environment, conservation of resources and economic benefits.

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