Product Lifecycle Management and Sustainable Development in Nigerian Manufacturing Sector

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Abstract – The global society has undergone paradigm shift from environmental protection towards sustainability. The issue of sustainable development has not been fully integrated into Nigeria system; that is why we still witness indiscriminate dumping of recyclable end of life products on the road sides. The roles effective and efficient product life cycle management which considers the entire life cycle of product from inception, through engineering design and manufacture, to service and disposal of manufactured products can play in ensuring sustainable development in any given country can never be overemphasized. This paper reviews product lifecycle management using plastics as a case. It brings out the roles effective and efficient lifecycle engineering can play in supporting sustainable development in Nigeria, and the strategies that can be adopted in achieving sustainable manufacturing in Nigerian manufacturing sector.

Keywords – Product lifecycle, Product lifecycle management, Sustainable development, Sustainable manufacturing.

1. INTRODUCTION

The global society has undergone paradigm shift from environmental protection towards sustainability. Sustainability does not only focus on the environmental impact, it rather consists of the three dimensions: environment, economy and social well being, for which society needs to find a balance or even optimum [1]. Sustainability has become the mainstream these days. It is accepted by all stakeholders - be it multinational companies, governments or NGOs.

Achieving sustainable development requires methods and tools to help to quantify and compare the environmental impacts of providing products to our societies. These products are created and used because they fulfil a need, be it actual or a perceived one. Every product has a 'life', starting with the design/development of the product, followed by resource extraction, production (production of materials, as well as manufacturing/provision of the product), use/consumption, and finally end of life activities (collecting/sorting, reuse, recycling and waste disposal). All activities, or processes in a product's life result in environmental impacts due to consumption of resources , emissions of substances into the environment, and environmental exchanges (e.g radiation) [2]. Life cycle analysis is the systematic approach of looking at a product's complete life cycle, from raw materials to final disposal of the product [3]. It offers a "cradle to grave" look at a product or a process, considering environmental aspects and potential impacts.

The challenges of global sustainable development can be addressed through innovative products and manufacturing technologies. To meet the material and immaterial needs of a continuously growing global population, technology must be adapted to achieve higher utilization with fewer resources. Non-renewable resources must no longer be disposed off, but utilized in multiple phases of product and material cycles. Renewable can substitute non-renewable, but must not be used to an extent higher than they can be regained. Immaterial needs include educational and qualification measures to increase people's awareness, thus enabling them to cope with the interrelated economical, environmental and social challenges of sustainability by initiatives in innovative technology.

Nigeria environment is marked by indiscriminate use of both renewable and non-renewable resources, emission of high quantity of Carbon dioxide into atmosphere by vehicles, domestic and industrial activities, indiscriminate dumping of recyclable waste products on the roadside etc. The issue of sustainable development has not been properly integrated into Nigerian system. Making development sustainable in Nigeria is in general a challenging and complex undertaking, involving such factors as technology and engineering, economics, environmental stewardship, health and welfare of people and the communities in which they live and work, social desire and government strategies, procedures and policies.

This paper explores the roles of effective and efficient product life cycle engineering in supporting sustainable

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development in Nigeria. The rest of this paper is arranged as follows: section 2 covers the concept of sustainable development. Section 3 discusses product life cycle, explaining all the phases in product life cycle. Section 4 discusses Product life cycle management using life cycle management of plastics products as a case. Section 5 discusses the roles of effective and efficient life cycle engineering in supporting sustainable development in Nigeria. Section 6 looks at sustainable manufacturing including possible ways or strategies for achieving it in Nigeria. Section 7 concludes the paper.

2. THE CONCEPT OF SUSTAINABLE DEVELOPMENT

The United Nations World Commission on Environment and Development (WCED) in its 1987 report "Our Common Future" - The Bruntland Commission [4] defines sustainable development as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs". This definition sees sustainable development as a mission that seeks to meet the needs and aspirations of the present without compromising the ability to those of the future. Under the principles of the United Nations Charter - the Millennium Declaration identified principles and treaties on sustainable development, including economic development, social development, and environmental protection.

Needham [5] referred to sustainable development as the ability to meet the needs of the present while contributing to the future generations' needs. There is an additional focus on the present generation responsibility to improve the future generation's life by restoring the previous ecosystem and resisting contributing to further ecosystem degradation.

According to Nyere (1970) in Alebiosu and Famuyiwa [6], sustainable development is characterised by a promotion of the equality of the people; absence of exploitation; dignity and respect for human beings; promotion of national independence and self-reliance; and transformation of economic growth to social development.

Ajayi [7] posits that sustainable development is hung on three pillars of environment, economy and society. He argued that education tuned towards environment and sustainability should be understood as the common basis and the prerequisite foundation of the entire structure of sustainable development. In the words of Okpetu and Nwankwo [8], sustainable development should bring about a lasting improvement in the quality of life and not just short-term improvement that disappears rapidly at a project cycle.

3. PRODUCT LIFECYCLE

Product life cycle generally indicates the whole set of phases which could be recognized as independent stages to be passed/followed/performed by a product, from its cradle to its grave.

According to Kiritsis et al. [9], product life cycle consists of three main phases:

1. Beginning of Life (BOL); including design and manufacturing. Design is a multi level phase, since it comprises product, process and plant design. Product development requires a computational framework that enables the capture, representation, retrieval and reuse of product and process knowledge. Manufacturing means production of artefacts and related plant internal logistic. At this stage, product information has to be shared along the production chain, to be synchronised with future updates.
2. Middle –of –life (MOL): Including distribution (external logistic), use and support (in terms of repair and maintenance). In its life, a product passes from the company's hands to service suppliers (e.g. transportation suppliers, but also after–sales assistance suppliers) to arrive at customer's hand. These passages could happen many times, in reiterative ways. Product usage data are to be collected, transformed and used for various purposes in the service chain. For example, data on product behaviour during the usage phase can be fed back in BOL and used for design improvement.
3. End–of–life (EOL): This is where products are retired - actually recollected in the company's hands (reverse logistic) – in order to be recycled (disassembled, remanufactured, reused, etc) or disposed. Recycling and dismissal activities require and provide useful information on product components, materials and resources from/to the design and manufacturing stages. Many different actors are involved in this phase (company's service suppliers; customer's environment sensibility has a relevant role to the management of such phase).

4. PRODUCT LIFECYCLE MANAGEMENT

In industry, product life cycle management (PLM) is the process of managing the entire lifecycle of a product from inception, through engineering design and manufacture, to service and disposal of manufactured products [10]. It is a systematic concept for the integrated management of all product related information and processes across the extended enterprise through the entire lifecycle, from concept and design, to production, distribution, maintenance, and retirement [11], [12]. Product lifecycle management integrates people, data, processes and business systems and provides a product information backbone for companies and their extended enterprise [10]. The lifecycle management of the three phases stated above are discussed below using plastic products as a case.

4.1 Plastics Products Lifecycle Management

Plastics are known as one of the most resource efficient and flexible materials available in Nigeria. Their low weight, strength and versatility make them applicable to a broad range of uses, ranging from packaging (e.g. crates, pallets, bottles, and foil), household (e.g. micro–proof containers), construction (e.g. insulation, pipes/guttering, PVC windows), furniture, transport (e.g. automobile interior/exterior parts), electrical goods (e.g. televisions, mobile phone), to medical and space travel. Due to its diverse usage, it is perhaps not surprising that each of us consumes in excess of 100Kg of plastic every year [13].

In terms of manufacturing plastic products, a range of different technologies are applied, including injection moulding, blow moulding, rota moulding, thermo set processing, extrusion, thermoforming and vacuum forming. All of these technologies typically involve raw materials polymer being shaped in a mould or die using a combination of heat, pressure and cooling [13]. The lifecycle of plastic products, like any other product has three phases: Beginning of life, middle of life, and end of life. The various phases of plastic product are discussed below.

4.1.1 Product Beginning of Life Management

This phase involves product design and manufacture. Product design is one of the most important sectors influencing global sustainability, as almost all the products consumed by people are outputs of the product development process. Product development requires a computational framework that enables the capture, representation, retrieval and reuse of product and process knowledge.

Product manufacturing process is the main stage in the lifecycle that consumes resources directly and produces environmental pollution as well as being the main factor that affects the result of enterprise performance in terms of sustainable development [14]. Efforts to minimize the environmental impacts of plastic manufacturing processes can roughly be classified into three categories [15]:1. Process improvement and optimization, 2. New process development, and 3. Process planning. Traditional manufacturing processes are generally designed for high performance and low cost with little attention paid to environmental issues. For example, metalworking fluids are widely used in a variety of machining operations, and fluid delivery is the common practice. Skerlos et al. [16] reviewed advances in the development of alternative metalworking fluid delivery strategies for sustainable manufacturing. They pointed out that it is possible to design more sustainable metalworking fluid systems either by extending dramatically the in–use lifetime of water based fluids, or better still, by switching to gas–based (air) minimum quantity.

In plastic manufacturing, one of the most important steps in converting a design concept into a manufactured product is process planning [17].The manufacturing plan outlines the selection of the manufacturing processes, sequencing of the processes, and parameters for each manufacturing process. Similar to product design, one can argue that in the early stage of process planning, selection and sequence of major processes are more critical than the parameters optimization of processes involved with regard to performance, including that of sustainability.

4.1.2 Middle of Life Management

Plastic products middle –of –life (MOL) phase includes distribution (external logistic), use and support (in terms of repair and maintenance). In its life, a product passes from the company's hands to service suppliers (e.g. transportation suppliers, but also after–sales assistance suppliers) to arrive at customer's hand. Efforts towards sustainable plastics realization must take into account manufacturing activities at three different levels: process, factory and supply chain [18]. A sustainable supply chain should be designed for cost and environmental impact minimization.

The scope of green supply chain management practice implementation ranges from green purchasing to integrated life cycle management supply chains flowing from supplier, to manufacturer, and to customer, and then closing the loop with reverse logistics [19]. The problem does not only involve the willingness and ability of customers to return products but also the existence of a streamlined reverse supply chain [20].

The plastic entire lifecycle has to be carefully considered in supply chain management. A company can select those suppliers that generate the least pollution in each individual phase. Gehin et al. [21] introduced a method to deconstruct the supply chain in order to target the product's phase (distribution, packaging etc.) that carried the most environmental impact. This paves way to a concerted effort to reduce the total environmental load of the product in cooperation with suppliers, distributors, users, recycling companies, and waste–processing firms. Product usage data are to be collected, transformed and used for various purposes in the service chain. For example, data on product behaviour during the usage phase can be fed back in BOL and used for design improvement.

4.1.3 Product End–of–life Management

Managing end of life products has become a field of rapidly growing interest for product manufacturers. As environmental regulations urge stronger stewardship for product retirement, disposal can no longer be the primary retirement strategy for end–of–life products. Manufacturers need to find more proactive ways to reduce waste and save resources. EOL management of used products is a promising solution to this problem.

EOL management is the process of converting end–of–life products into remarkable products, components, or materials [22]. It enables manufacturers to comply with legislation while gaining some economic advantage as well.

EOL management starts from product take–back which is the process of collecting products that reach an end–of–life status. White et al. [23] presented an overview of challenges in end–of–life management at each stage of the product recovery process and showed that better information about the product design, product quality, and timing can improve EOL opportunities. Since product take–back determines the volume, type, and quality of feedback processed later in the recovery process, how many cores and which types of cores should be acquired are major concerns for manufacturers.

After product take–back, the collected plastic products (see figure 1) move to a recovery plant and pass through EOL recovery process (see figure 2). After testing functional and cosmetic quality, unrecoverable units move to disposal sites for landfills or incineration (see Figure 3). Recoverable products are reprocessed with various options, including reuse, refurbishing, remanufacturing, and material recovery. Finally, recovered units are sent to various demand sites, such as manufacturing plants, second-hand markets or component markets.

Fig. 1: Collection site for waste Products

Fig. 2: Plastic Product Recycling (Source: www.Piranha.com)

Fig. 3: Disposal site for unrecoverable Products

5. THE ROLES OF PRODUCT LIFECYCLE ENGINEERING IN SUPPORTING SUSTAINABLE DEVELOPMENT IN NIGERIA

Effective and efficient product life cycle engineering is every important tool in achieving sustainable development in any country. To achieve sustainable development in Nigeria, effective and efficient product life cycle engineering has the following roles to play:

1. Effective and efficient product life cycle engineering plays important roles in reducing the total environmental burden from product development by finding sustainable solutions for the needs of the society. Environmental burden has two impact categories: resource depletion and ecological and health effects [24]. With effective and efficient life cycle engineering in Nigeria, products that will not pose ecological and health challenges will be designed, manufactured and recovered for other purpose (reuse, remanufacture, recycle etc.) at the end of its useful life.
2. Effective and efficient life cycle engineering plays an important role in conservation of resources. Depletion of non-renewable resources and overuse of renewable resources limit their availability to future

and future generations. There can be no product development without available resources. Product lifecycle is focussed on promotion of prevention strategy that minimizes raw material losses and reduces long-term liabilities. With proper lifecycle management in place in Nigeria, the rate at which non-renewable resources are being used will be checkmated leading to conservation of resources.

3. Product life cycle engineering plays important role in recovery, recycling, remanufacturing and reuse of waste products. Recovery is a process of restoring materials found in waste stream to a beneficial use, which may be for purposes other than the original use. Recycle is a resource recovery method involving the collection and treatment of waste products for use as raw material in the manufacture of the same or similar product. Reuse means using waste as a raw material in a different process without any structural changes. Remanufacturing is substantial rebuilding or refurbishment of machines, devices or other objects to bring them to a reusable or almost a new state. Effective and efficient life cycle engineering will help in ensuring end of life product recovery, recycling, remanufacturing and reuse in Nigeria, hence ensuring sustainable development in Nigeria. Take for instance, recycling and re-utilization of waste plastics have several advantages. Recycling and re-utilization of waste lead to a reduction of the use of virgin materials and of the use of energy, thus also a reduction of carbon dioxide emissions. Economically, in some cases, plastics recycling may be profitable. However, a number of factors can complicate the practice of plastics recycling, such as the collection of the plastics waste, separation of different types of plastics, cleaning of the waste and possible pollution of the plastics. But, proper collaboration with the necessary stakeholders will help to eliminate the above factors. Reusing plastic is preferable to recycling as it uses less energy and fewer resources.
4. Effective and efficient product life cycle engineering will help in achieving sustainable development through sustainable use of resources, pollution prevention, maintenance of ecosystem structure and function, and environmental equity. Effective and efficient life cycle engineering ensures the design and manufacture of products that have few parts with renewable raw materials and will also ensure that the rate at which these materials are being used does not exceed the rate at which they are replenished.
5. Product lifecycle engineering plays important roles in product design and development, manufacturing, use and dismissal. Product life cycle engineering which is an integrated approach takes into consideration sustainability objectives in product design, manufacturing, use and end of life of a product. If this approach whereby companies or industries are expected to incorporate sustainability measures starting from the beginning of life to end of life their products, are properly employed in Nigeria, it will no in small measure support sustainable development of this country Nigeria.

6. SUSTAINABLE MANUFACTURING

The link between manufacturing and its operations to the natural environment is becoming more and more recognized. Progress, profitability, productivity and environmental stewardship are now seen as needing consideration by manufacturing organizations [25]. Improving environmental stewardship and sustainability while maintaining profitability and productivity are increasingly viewed as strategic goals of manufacturing companies [26]. Sustainable manufacturing has obtained many attentions from the industrial and research communities, as the plethora of strategies, methods, procedures and tools existing in literature demonstrate. According to US Department of Commerce (www.trade.gov), sustainable manufacturing is defined as the creation of manufactured products that uses processes that minimize negative environmental impact, conserve energy and natural resources that are safe for employees, communities and consumers and are economically sound. Glavic and Lukman [27] outline some of the many contributions that have been developed in the ambit of sustainable manufacturing practices, in terms of principles, tools and strategies:

- Principles are fundamental concepts that serve as a basis for actions, and as an essential framework for the establishment of a more complex system. The principles include: Reuse, Recycle, Recover, Repair, Regeneration, Remanufacturing etc.
- Tools contain a group or cluster of principles related to the same topic, building a more complex system, showing how to apply specific practices in order to contribute to an improved industrial performance. The tools include: design for environment, green manufacturing, green chemistry, waste

minimization, zero emission, life cycle assessment, cleaner production, life cycle management etc.

- Strategies consist of approaches and systems connected together that are to be met in order to incorporate the principle of sustainability into everyday business activities. The strategies include: Pollution prevention (P2), Industrial Ecology, Environmentally Conscious Manufacturing, Total Quality Environmental Management etc. [27].

6.1 Factors Affecting Sustainable Manufacturing

The successful implementation of sustainability into manufacturing organizations is dependent on many factors. Rosen and Kishawy [26] presented some of the factors that affect implementation of sustainability into manufacturing. They include:

1. Information: The quantitative and qualitative information required to make assessments is needed, for example, the quantity and type of metal a process uses, the quantity and type of pollutants emitted. However, such information is not always readily available and can be sometimes be difficult if not impossible to acquire.
2. Management and Culture: Sustainability issues, for example, environmental stewardship efforts, tend to be dealt with in specialized departments rather than holistically by management. This can lead to inconsistent application and tends to discourage the development of a sustainability oriented culture in the organization.
3. Procedures: Decision makers and staff are often not provided with the methodologies and procedures needed to ensure an organization's sustainability objectives and strategies are applied effectively, efficiently, consistently and robustly. One reason for this problem is that the number of variables to be taken into account in decision making is usually very large.

6.2 Achieving Sustainable Development in Nigerian Manufacturing Sector

The present section highlights the importance of integrating sustainability, design for environment, life cycle assessment and other tools with manufacturing and relevant decision making structures in Nigerian manufacturing sector. Rosen and Kishawy [26] outline several specific needs or strategies to enhance manufacturing sustainability. These strategies as discussed below if apply in Nigeria manufacturing sector will help in achieving sustainable manufacturing in industries.

1. Approach: A more comprehensive, broad and integrated approach is needed for sustainability, which encompasses economic, social, environmental and other relevant considerations. An approach that goes beyond individual companies can make the manufacturing industry more sustainable.
2. Methods and Tools: Enhanced methods and tools for manufacturing are needed to foster and support sustainability.
3. Data: More detailed, comprehensive and robust data are needed to support environmental impact and sustainability assessments and measures across the overall product lifecycle. Such data needs to be standardized where feasible.
4. Manufacturing Company Practices: Manufacturing companies should incorporate sustainability into their practices holistically. Practices that would be helpful include: improved measuring and monitoring of sustainability indicators by companies, company policies and governance that focus on sustainable development, improved efforts to control a company's environmental impact, establishing a sustainability support company culture and working conditions, enhancing awareness of sustainability among suppliers and customers, responding to their requirements and to measures, and engaging the community to promote sustainable development.
5. Government Policies: Government and relevant agencies need to incorporate into policies, programs and operations stronger consideration of sustainability, environmental factors, and clean processes. This requires cooperation between internal and external partners.
6. Research: Significant collaborative research is needed in industry and academia in the fields of sustainability, manufacturing, design and environmental impact.

7. CONCLUSION

Making development sustainable in Nigeria is in general a challenging and complex undertaking, involving such factors as technology and engineering, economics, environmental stewardship, health and welfare of people and the communities in which they live and work, social desire and government strategies, procedures and policies. This paper viewed the roles effective and efficient life cycle engineering can play in achieving sustainable development in Nigeria. The roles took into consideration three dimensions of sustainability: environment, economy, and social well being from the cradle to grave of a product. This paper looked at plastics lifecycle management covering the three phases of product lifecycle and also took a closer look at some of the strategies or means that can be adopted in making Nigerian manufacturing sector sustainable.

REFERENCES

1. M. Finkbeiner, "Towards Life Cycle Sustainability Management," *Springer Science + Business Media*, 2011.
2. G. Rebitzer, T. Ekvall, R. Frischeknece and D. Hunkeler, "Life Cycle Assessment Part 1: Framework, Goal and Scope Definition, Inventory Analysis and Applications," Environmental International, vol.30, pp 701–720, 2004.
3. C. Feng, and X.O. Ma, "The Energy Consumption and Environmental Impacts of a Colour TV Set in China," Journal of Cleaner Production, vol.17, no. 1, Pp 13–35, 2009.
4. Brundtland Commission, "Our Common Future, Report of the World Commission on Environment and Development," United Nations, 1987.
5. M.T. Needham, "A Psychological Approach to a Thriving Resilient Community," International Journal of Business, Humanities and Technology, vol. 1, no.3, 2011.
6. K.A. Alebiosu and A.S. Famuyiwa, "Empowering Teachers for Sustainable Development through ICT," Proceeding of the 2nd National Conference of the Institute of Education, Olabisi Onabanjo University, Ago-Iwoye, pp 38–40, 2008.
7. O.O. Ajayi, "ICT for Sustainable Educational Development," Proceeding of 2nd National Conference of the Institute of Education, Olabisi Onabanjo University, Ago-Iwoye, Pp 53–54, 2008.
8. W.I. Okpetu and T.O. Nwankwo, "Home Economics and Sustainable Development in Nigeria: Research Issues in Home Economics," Home Economics Research Association of Nigeria, Nsukka, 2005.
9. D. Kristsis, A. Bufardi, and P. Xirouchakis, "Research Issues on Product Life Cycle Management and Information Tracking using Smart Embedded Systems," Advanced Engineering Informatics, vol. 17, pp 189–202, 2003.
10. Wikipedia, "Product Lifecycle Management," www.wikipedia.org/wiki/product–lifecycle–management, 2014.
11. K. Amann, "Product Lifecycle Management: Empowering the Future of Business," CIM Data, Inc., 2002.
12. A. Sääksvuori and A. Immonen, "Product Lifecycle Management," 2nd ed, Berlin: Springer, 2005.
13. Logility Inc., "Reducing Energy Costs for Plastic Manufacturers: The Role of Constraints Based Planning and Scheduling," www.logility.com, 2007.
14. T. Gutowski, "Design and Manufacturing for the Environment," Handbook of Mechanical Engineering, Berlin:Springer–Verlag, 2004.
15. K. Ramani, D. Ramanujan, W. Bernstein, F. Zhao, J. Sutherland, C. Handwerker, J. Choi, H. Kim and D. Thurston, "Integrated Sustainable Life Cycle Design: A Review," Journal of Mechanical Design, vol. 132, 2010.
16. S.J. Skerlos, P. Adriaens, K. Hayes, J. Zimmerman, and F. Zhao, "Ecological Material and Green Manufacturing: Design and Technology for Metalworking Fluid Systems," Proceedings of the World Engineering Congress, Shanghai, China, 2004.
17. B. Denkena, M. Shpitalni, P. Kowalski, Z. Molcho and Y. Zipori, "Knowledge Management in Process Planning," CIRP Ann., vol. 56, no.1, pp175–180, 2007.
18. D.T. Pham, P.T.N. Pham and A. Thomas, "Integrated Production Machines and Systems – Beyond Lean Manufacturing," Intl. Journal of Manufacturing Technology Management, Vol. 19, no.6, Pp 695–711, 2008.
19. Q.H. Zhu, J. Sarkis, and K.H. Lai, "Confirmation of a Measurement Model for Green Supply Chain Management Practices Implementation," Intl. Journal of Production Economics, vol.111, Pp 261–273, 2008.
20. Dolgui, J. Soldek and O. Zaikin, (2005). Supply Chain Optimization Product/Process Design, Facility Location and Flow Control, Boston: Springer, 2005.
21. Gehin, P. Zwolinskit and D. Brissand, "Towards the Use of LCA During the Early Design Phase to Define EOL Scenarios, Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses," Proceedings of 14th CIRP Conference on Lifecycle Engineering, Waseda University, Tokyo, Japan, 2007.
22. K. Ramani, D. Ramanujan, W. Bernstein, F. Zhao, J. Sutherland, C. Handwerker, J. Choi, H. Kim and D. Thurston, "Integrated Sustainable Life Cycle Design: A Review," Journal of Mechanical Design, vol. 132, 2010.
23. White, E. Masanet, C. Rosen and S. Beckman, "Product Recovery with some byte: An Overview of Management Challenges and Environmental Consequences in Reverse Manufacturing for the Computer Industry," Journal of Cleaner Production, vol. 11, pp 445–458, 2003.
24. G.A. Keoleian, J.E. Koch, and D. Menerey, "Life Cycle Design Framework and Demonstration Projects," Environmental Protection Agency, 1995.
25. J. Sakis, "Manufacturing's Role in Corporate Environmental Sustainability: Concerns for the New Millennium," Int. Journal of Operation Production Management, vol.21, Pp 666–686, 2001.
26. M.A. Rosen, and H.A. Kishawy, "Sustainable Manufacturing and Design: Concepts, Practices and Needs," Sustainability, vol. 4, pp 154–174, 2012.
27. P. Glavic and R. Lukman, "Review of Sustainability Terms and Their Definitions,"Journal of Cleaner Production, vol. 15, no.18, Pp 1875–1885, 2007.