



## Eco-design and Degrade Remanufacturing Based Fossil Carbon Emissions Reduction

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### **Authors' contributions**

*This work was carried out in symbiotic collaboration between all authors. Author ZTA designed the study, performed the technological path and algorithm construction, power monitoring, and statistical analysis, wrote the protocol and wrote the manuscript. Authors GSS and SBY managed the analyses of the study and literature searches and provided stream feed backs for modifying. All authors read and approved the final manuscript.*

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### **ABSTRACT**

Eco-design and degrade remanufacturing of steel shells of high remanufacturability through increasing of disassembly and accumulation of drawbacks that prevent facilitation of recovery to be of smallest partition. Recovered steel is small uniform pieces which can be nested within base of new steel strips by means of riveting. Emerged composite shape steel strips can be formed into structural steel sections and thus value creation and both power and fossil carbon emissions reduction can be satisfied. To help fossil carbon emissions reduction based value creation for human development, environmental education and employment.

**Aims:** Two steps eco-design and degrade remanufacturing based fossil carbon reduction producers are studied and which include:-

- 1- Eco-design to reduce power consumption currently of oil filter steel shells production.
- 2- Design for degrade remanufacturing potentials planting to be end-of-life processing strategy

**Methodology:** Power consumption is monitored and eco-audit is recorded for each manufacturing process of technological path for oil filter shells production to study possibility of power reduction.

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Eco-design is applied after reviewing of current designs of shells and modifications are applied to certain power reduction to help, in role, reduction of fossil carbon emissions. Current reduction will be followed by strategically reduction through degrade remanufacturing of end-of- life shells into structural steel.

**Results:** Welding process is used for assembly, which let disassembly is hard to perform. Eliminate welding process can enable current reduction of power, fossil fuel and carbon emission. Also facilities degrade remanufacturing at the end of life of shells into construction steel sections.

**Conclusion:** Mitigation effect of eco-design through saving both of time and power where sustainable human power is exploited can allow educational institutions of developing countries without industrial infrastructures conduct remanufacturing of end-of-life steel with high flexibility by increasing percentage of disassembly process.

*Keywords: Eco-design; degrade remanufacturing; carbon emissions reduction; degraded construction steel sections.*

## 1. INTRODUCTION

### 1.1 Fossil Carbon Emissions Situation

Large scale of direct combustion of fossil fuels, 32% of petroleum, 27% of coal, and 21% of natural gas, to generate primary energy, results in significant emissions that allow shortwave light radiation to enter the earth's atmosphere and restrict the exit of longwave heat radiation. Such an imbalance between incoming and outgoing radiation results in an accumulation of energy within the earth system [1]. Manufacturing is one of the leading energy consuming and heavy pollutant process, which is also accountable for CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub> emissions and some heavy metal discharging [2]. Climate destabilization and consequent impacts to physical, biological, and social systems raise concern about the industrial sector which consumes about 19% of the total societal energy and contributed 30% of the total global carbon dioxide emissions. Since manufacturing is responsible for about 98% of the total direct carbon dioxide emissions due to production activities, so it is required strategic ways to reduce energy consumption and waste emissions in manufacturing processes which is critical to achieving energy savings and emissions reductions. Costs and impacts of human health due to air pollution from fossil fuel using for electricity generation are not considered in market prices and not taken into account during strategic energy planning, so eco-design and degrade remanufacturing can substitute this lack. For electricity demand, 48% of global CO<sub>2</sub> emissions are generated by 50% of coal consumption, no more than 884 Gt CO<sub>2</sub> will be emitted globally between 2012 and 2050, which equivalent to burning approximately one third of current global carbon reserves [3,4]. Also methane emissions can be significant, ranging from 3% to 56% of total emissions depending on

type of technology and region. Total greengages emissions vary considerably according to the region of the power plant, plant type, and the choice of associated methane emissions, with values as low as 0.08 kg CO<sub>2</sub>-eq./kWh and as high as 1.52 kgCO<sub>2</sub>-eq./kWh [5,6]. Utilization of the thermal energy requirement from fossil fuels is the worst to emit 187 kg CO<sub>2</sub> eq/MWh even through coal hybridization [7]. Continuous growth of the world's population and consumption of energy causes combustion of fossil fuels to be continued to increase, and the optimized utilization of energy is one of the greatest challenges which are required environmental management and sustainable development for mitigation which can include degraded remanufacturing as a strategy.

### 1.2 Remanufacturing

Sustainable development, and according to fossil carbon emission situation, to meet the needs of the present with keeping the ability of future needs can be realized through sustainable production of closed supply chain through reverse logistic and closed product lifecycle by remanufacturing. Remanufacturing can be highlighted as a trade mark of sustainability which is most preferable reuse scenario since a like new recovered product can be guaranteed to satisfy customer. Value creation-oriented remanufacturing copes with depletion of world resources which causes environmental and ecological burdens that lead to inevitable economic and social problems. Innovation should be focused to lengthen product use phase, sustain end-of-life processing and employ product upgradability, instead of to be as uncertainties that freeze remanufacturing feasibility within viability stage [8]. Energy-saving and fossil carbon emission reduction by degrade remanufacturing induce sustainable development

which should be adopted by developing countries to substitute the lack of extended manufacturer responsibility. Manufacturer should be encouraged to supply common technical services system to know-how and learning to support design for remanufacturability and innovation. Also innovative technologies that disseminate economic and societal values to harvest high financial, societal, and environmental returns, reduce costs, increases jobs, and conserve scarce resources are necessary to practice which required global collaboration. Eco-design and degrade remanufacturing can together satisfy customers while degrade services to relieve environmental burdens. Such efficient paradigm removes consumer dissatisfaction through integrating users' satisfaction and environmental aspects to certain technical performances through application of eco-design [9,10]. Sustainability can be certain through waste management as sustainable production to reduce capital investment, save resource, create jobs to strength local communities' economies to be incorporated as an integrated global economy of sustainability [11]. Remanufacture, reuse, and recycling incorporated design-for-x are environmentally-friendly end-of-life strategies for environmental protection and economy and social developments for sustainability. Economical minimizing of negative environmental impacts and conserving of energy and natural resources can be through developing processes and products to release the innovation of the dialectic (eco-design + manufacturing process) to outcome monitoring ,control, and evaluation of energy consumption , strength value creation and implement efficient and effective usage of energy and resources [12]. Direct product reusing demand is of nascent stages in developing countries due to scatter based prevention. Remanufacturing is of intensive complex theoretical models issue to predict returned cores quality, prices, capacity, and demand and to know-how based technical infrastructure. Thus remanufacturing processes improvements are usually based on sustainability indicators to return products cores and restore full functionality to continue lifecycle for low-income markets. Life cycle costing and life cycle analysis are a potential long-term remanufacturing sustainability assessment as an environmental impact based tool. Environmental performance can also be used as a direct assessment of remanufacturing sustainability status such as consumption of materials and energy and generation of waste [13,14]. Smelting for recycling alters remanufacturability of end-of-

life steel which is required collaborative service-oriented eco-design. In this contrast, extended producer responsibility is inevitable to mature remanufacturing and extract guidelines for eco-design improvements to certain economic and social induced huge environmental benefit of developing countries [15]. Landfill and materials recycling are the most diffused end-of-life practices that delay remanufacturing based sustainable economic, environmental and societal growth of developing countries. Such growth is required major technology, methodology and business oriented innovations to be developed as enablers for remanufacturing. This directly affects the energy footprint and the raw material consumption through closing both supply chain and product lifecycle by remanufacturing as a service [16]. Remanufacturing is the ultimate form of recycling can restore the used products of high value-added which can be evaluated in terms of energy saving, material saving and pollution reduction. That is highly required to innovate great recycling value and potential for remanufacturing and of absolute remanufacturability through disassembly [17].

## **2. DESIGN THEORY AND METHODOLOGY FOR SUSTAINABILITY WITH ADVANCED MANUFACTURING**

Optimization strategies can be adopted to convert environmental objectives and constraints into structural and geometrical parameters which enable the generation of alternative green scenarios according to interaction of shape-material-production [18]. Mitigation of fossil carbon emissions includes strategy of rationalizing energy consumption through measure, control and assessment through advanced manufacturing, eco-design and remanufacturing application. This paper functions within environmental management and sustainable development for mitigation through eco-design and degrade remanufacturing application to be of the following strategy:- Developed countries are responsible on earth resources depletion and climate change, by realizing "use and throw" as a high life style and transporting this unsustainable behavior as ideological directive to developing countries. This study is aimed to add eco-design and degrade remanufacturing to the list of fossil fuel carbon emission mitigation procedures which reduce energy consumption during manufacturing phase and plant potentials within product architecture

for secondary saving through degrading remanufacturing of composite shape structural steel. Steel shells are nested within continues strips of steel by mechanical bonding to be rolled into standard structural steel. Eco-design is a pre pro-environmental procedure to be applied to certain degrading remanufacturing procedure as the end-of-life processing strategy. A developing country without industrial and modern communication infrastructures is aimed to conduct sustainable degrading remanufacturing business model for value creation, seeking for employment, human development and sustainable development. The value creation potentials are framed through eco-design to appear at end-of-life products. Eco-design application prompts disassembly and environmental conscious production to cut down fossil fuel carbon emissions. Substitutionally, educational institutions, universities and institutes of technology, are proposed to start establishing, management and carrying out eco-designs to be substitution of legislations to extend manufacturer responsibility toward end-of-life processing. Imported products will certain degrading remanufacturing which is also carried out by developing country educational sectors according to the following ac road map:-

- 1- Eco-design syllabus and practices are emerged to increase remanufacturability of imported products to decrease electricity using and fossil fuel consumption for manufacturing and degrading remanufacturing.
- 2- Degrading remanufacturing business model establishing, managing and carrying out by educational sector of the aimed developing countries of non-industrial and non-modern communication technologies.
- 3- Product service system establishing to strength relationships with end users to collect information about products during beginning-of-life, middle-of-life and end-of-life. Pro-environmental education and training are offered by educational sector to facilitate environmental product using, maintenance, repair and remanufacturing of complete products and modules.
- 4- Private reverse logistics strengthening through financial incentives such as tax credits, rebates and low-interest loans to collect end of life product and take-back from landfills sites.

Since 85.4% of people live in developing countries so high consumer products will be at

end-of-life which makes developing countries as big landfills. In the another hand, to substitute the lack of acceptance of unconventional advanced manufacturing processes by industrial countries, a global cloud storage of end-of-life products to be global warehouse instead of landfilling can be emerged to initiate stream of remanufactured products and modules to be entered the global production supply chain again which reduce energy consumption and related carbon emissions as closed sustainable manufacturing strategy. Additive manufacturing, as advanced remanufacturing treatments, with eco-design in the heart of computer cloud based design can cut down virgin resource and depletion of eco-system by carbon emissions. Thus crucial economic competitiveness among manufacturers and sustainability of the industry are emerging to be global scale cooperation. Cloud manufacturing and additive processes can certain personalization and customization that reduce material's wastes and avoid producing products out of expectations of customers. New materials and technologies of advanced manufacturing emerging requires new processes and global scale remanufactured modules integration further to new analytical and simulation models for manufacturing controlling and process parameters optimization in the insight of cost, quality, product flexibility, modularity and upgradability, energy consumption and fossil carbon emission reductions. Eco-design facilitating, process planning, scheduling, material handling, workforce planning, quality control, and inventory management. Furthermore, the effectiveness of adopting advanced manufacturing can only be maximized by following a holistic systems approach from product conceptualization, product design and manufacturing to product delivery and service for the customers as well as in the management of the used products at the end of their useful lifetimes. This will require innovations and improvements in forward and reverse supply chain management, which are designed to catalyze system's changes from labor-intensive and capital-intensive traditional manufacturing to information-based advanced manufacturing. Advanced manufacturing and environmental conscious innovations deliver new processes that required supply chain designs and operations allow global supply-chain management in the cloud emerging. Supply-chain networks and mechanisms should be encourage information sharing among enterprises to make manufacturing processes more distributed, decentralized and collaborative

through cloud manufacturing. Such adoption of advanced manufacturing could make supply chains more responsive and cost efficient. Rather than shipping physical prototypes, designs could be shared digitally so that large amounts of energy consumption and emissions during freight transport could be saved. Additive manufacturing could significantly reduce the lead-time for obtaining products and parts with high customization and great variety and therefore facilitate just-in-time or nearly just-in-time systems, which can reduce inventory levels and supply chain risks. Flexibility of advanced manufacturing helps supply chains to respond to mass customization and personalization of customer needs. The interactions between advanced manufacturing and product service systems in the cloud can satisfy information of different phases of the product lifecycle which can achieve optimal sustainability benefits. The potentials of advanced manufacturing are saving energy and resources by exploiting all stages of product life-cycles to certain multiple lives through remanufacturing. Enhance and promote low-fossil carbon and societal sustainability economy as an integration of advanced manufacturing at all phases of product life cycles, that include eco-design, process, planning, supply chain management, delivery, and service to be delivered as all as services in the cloud. Eco-design, designs for degrading remanufacturing and eco-innovative remanufacturing processes are full of environmental factors considering. New products and manufacturing systems should be designed, planned and scheduled for low carbon emission for sustainability through advanced manufacturing contribution of developing countries. First of all, unsustainable consumption of resources and efforts should be stopped in the educational institutions, Fig. 1.

Successful sustainable design of products and services including choice and management of criteria, modeling of life cycles, management of the eco-design process, levels of calling into question of products and services, integration of industrial stakeholders, integration of civil stakeholders. Achieving this goal required describing tools and supporting eco-design education trajectories to educate engineering designers at university and practice to take into consideration the need for a progressive education to eco-design practice [16]. Remanufacturing and resource effective society through waste utilizing as a resource and waste generation preventing to reduce material costs

due to eco-design and increase material efficiency and recovery rate and reducing landfilled fraction [19]. Multidisciplinary, creativity and environmental knowledge further to experimentation play a significant and essential role to incorporate environmental concerns for eco-innovation such as degrading remanufacturing [11]. Eco-design for a product family commonality and modification of one product will affect the performance of the family to meet particular customer requirements through modularity to develop an eco-product family to improve the reusability and remanufacturability of waste products based on integration of environmental performance with design constraints [20]. Raw material consumption, energy consumption, and CO<sub>2</sub> emission are environmental indicators that can play with economic indicators to fulfil eco-efficiency for simultaneously quantifying the economic and environmental performances [21]. Developing low-carbon products required intensive corporation as a respond to advances in climate change mitigation through complete platform of eco-innovation, sustainable supply chain and climate change. Eco-design, remanufacturing and environmental factors should be included within all technical requirements of advanced manufacturing syllabuses, so sustainable consumption and production can be a behavior. Traditional starting point of product design is based upon customer requirements can be developed to consider environmental requirements through eco-design, design for remanufacturing and design for sustainability. Take back for remanufacturing represents good reserves of eco-design ideas which can be extracted and exploited through educational institutions for sustainable employing of students efforts. Such powerful practical design methods can be developed to directly guiding product design based on both customer and environmental requirements. Assessing affordability-based design methodologies that consider environmental factors for advanced manufacturing; designing and applying decision-support models, which consider environmental requirements in supply chains; environmental requirement modeling, elicitation and evaluation in engineering design; uncertainty in analyzing environmental requirements; environmentally friendly innovative design; systematic approaches for meeting customer's needs and environmental requirements; design for diverse customer usage requirements; design for remanufacturing, recycling and recovery.



**Fig. 1. Unsustainable consumption of resources and efforts in the educational institutions**

### **3. LOW FOSSIL-CARBON PROCESS PLANNING**

Process planning and production scheduling should be well studied to deliver eco-design of product which can emerge eco-manufacturing to be the most important functions of advanced manufacturing processes. Closed process plan can certain feedbacks about how to translate cut down in electricity into eco-design idea. Performance of the advanced manufacturing system to optimize energy consumption and production of waste emissions should be directed to prompt the strong relation between low fossil-carbon and sustainability. Advanced manufacturing requires new models for manufacturing resources management, planning and scheduling are highly required to substitute new materials and manufacturing processes involvement to cut down demand of electricity of developing countries. Optimizing process planning and process scheduling of advanced manufacturing for low fossil-carbon and sustainability are under multiple sustainability criteria of economic feasibility, fossil-carbon emissions, and energy consumption. Monitoring and reducing of fossil-carbon footprint by reducing energy demand through non-conventional manufacturing processes planning and scheduling, so energy demand increasing is strong function to the economic growth in developing countries, what is required in these countries . Advanced manufacturing can be fulfilled as cloud manufacturing between educational institutions internet of things, which also drive product service systems, and manufacturers to enable that advanced

manufacturing is advanced art of manufacturing resources management.

Simple monitoring of power consumption can be realized through linking meters (kWh) to power source of each machine through the whole production line, Fig. 2. The recorded values are collected manually every day and better understanding can be gotten through graphical representation. Fig. 3 is the first step for low fossil-carbon process planning which should be passed through conventional process planning so that the way of eco-design practicing can be enabled through closed loop interaction with current design. Thus, leak points can be understood and fossil-carbon mitigation can be fulfilled. Fig. 3 also shows an isolation area of the welding process where the eco-design of the oil filter shells can satisfy sustainable approach through current cut down of power by eliminating the welding process and degrading remanufacturing application at the end of the life due to increasing disassembly of shells into construction steel sections.

### **4. REMANUFACTURING OF END-OF-LIFE STEEL INTO CONSTRUCTION STEEL PIPES**

Shearing into strips to be nested within new six meters length strips to form composite shape steel and assembling by mechanical bolting is what the idea of the study rotating about it. Energy consumed is measured and accordingly Co<sub>2</sub> standard emission values are selected, eco-audit can be offered by Fig. 4, for end-of-life oil filter steel shells into strips recovering procedure.



**Fig. 2. Meters (kWh) for power consumption monitoring**

Consequences of bench and hand fly cutting operations can change the shells into small pieces. The remanufacturing of steel oil filter shells contains removing of handles, bottoms and inlet-outlet pipes and the rest shell is sheared at one side to form long sheet by unfolding. Shearing and fit to size can help obtaining of regular recovered steel to be nested within bases of new strips of steel. Since the remanufactured end-of-life vehicle recovered steel strips are mixed with new strips and since recovered steel is painted so its weldability is very low and mechanical bonding is more suitable. Aluminum rivets are strong enough to be used and self-locked pipes are another alternative.

Arranging successive layers of recovered and new steels can certain new strips to be of new outer surfaces to deliver like new appearance and thus the required thickness can be obtained.

Oil filters shells remanufacturing barriers statements:-

1. Oil filter shells are of unnecessary highly variety in shape and size while they supply the same function.
2. Customer based design without integration of environment factors.
3. Recycling and smelting are the indented end-of-life processing strategy.
4. Inlet and outlet pipes and handles are welded to make disassembly of energy and time consuming.
5. Inlet and outlet pipes are distributed to waste the uniform part of the shell with holes.

6. Bent edges are of negative effect on remanufacturing.

Produce construction steel pipe of 22 mm diameter and 3 mm wall thickness required steel strip of 64 mm width. Recovered steel shells should be changed into pieces of 64 mm width to be nested by remanufacturing within bases of new steel of 64 mm also. Finally coil of 64 mm remanufactured steel can be obtained by repeating the nesting processes, Fig. 5. Design for disassembly strongly appears to weak application of remanufacturing of steel oil shells. Oil flow pipes and installation bases are welded to main body of the steel shell which is required elimination of welding area by mechanical processing so such non eco-design alters remanufacturing by consuming power and time.

## **5. PARAMETER OPTIMIZATION FOR DEGRADING REMANUFACTURING**

Optimization techniques should be applied to prompt eco-design through design for remanufacturing so that resource usage, cost and performance can achieve evidence-based resource-cost-performance trade-off. Process technologies for transforming scrap are optimized to maximize the quantity and quality of material recovery with minimum resources and costs. Remanufacturing processes are optimized to ensure quality assurance of remanufactured products. Eco-design, designs for remanufacturing and remanufacturing processes are concurrent to maximize energy and material efficiencies toward low carbon emission and sustainability. Optimizing the design and

remanufacturing processes for optimizing energy and material efficiencies can be divided into optimizing process technologies for transforming scrap into reusable raw materials, optimizing remanufacturing processes and optimizing techniques for low fossil-carbon. Sustainability and remanufacturing applications can be partially carried out through two stages procedure, eco-design to cut down current energy demand for manufacturing, and remanufacturing potentials farming to be appeared at the end-of-life as optimization for low fossil-carbon and sustainability. Principle of using changing to be upside-down, Fig. 6, can help eco-design of oil filter inlet and outlet pipes. This can help development for accumulation of forming and welding at the cover of small hulk part while keeping the shell of the bigger hulk part full of disassembly and free of holes to be of high embodied value at the end-of-life to be degraded into construction steel sections, Fig. 5.

This can help raise embodied value at the end of life but cannot fulfill current mitigation of power and carbon emissions. Eco-design should be applied to eliminate welding processes of technological path of oil filter shells manufacturing. Eco-design is applied through reviewing current designs of shells and modifications are applied to certain power reduction to help reduction of fossil carbon emissions. Eco-design for remanufacturing application for shell hulk free of welding is illustrated in Fig. 11. Degraded remanufacturing practice and application embed end-of-life pieces of Teflon into structure of oil filter shell cover as connection nuts to eliminate power and fossil fuel consuming and CO<sub>2</sub> emitting of welding processes further to free of holes shell hulk at the end of life. The procedure is of two routes, while preparation of cover can lead to integrate the forming and welding processes, Fig. 7, the assembly of handles to main hulk can keep it free of welding as eco-design for degraded remanufacturing Fig. 10. End-of-life processing strategy can help fossil carbon emissions reduction based value creation for human development, environmental education and employment. This will satisfy the planning of manufacturing route that prompted current reduction of power and biggest bulk saving through degrading remanufacturing potentials planting and mitigation of fossil fuel will be certain in both cases.

Bad effect of welding assembly can be sought in Fig. 8, where time and power consuming

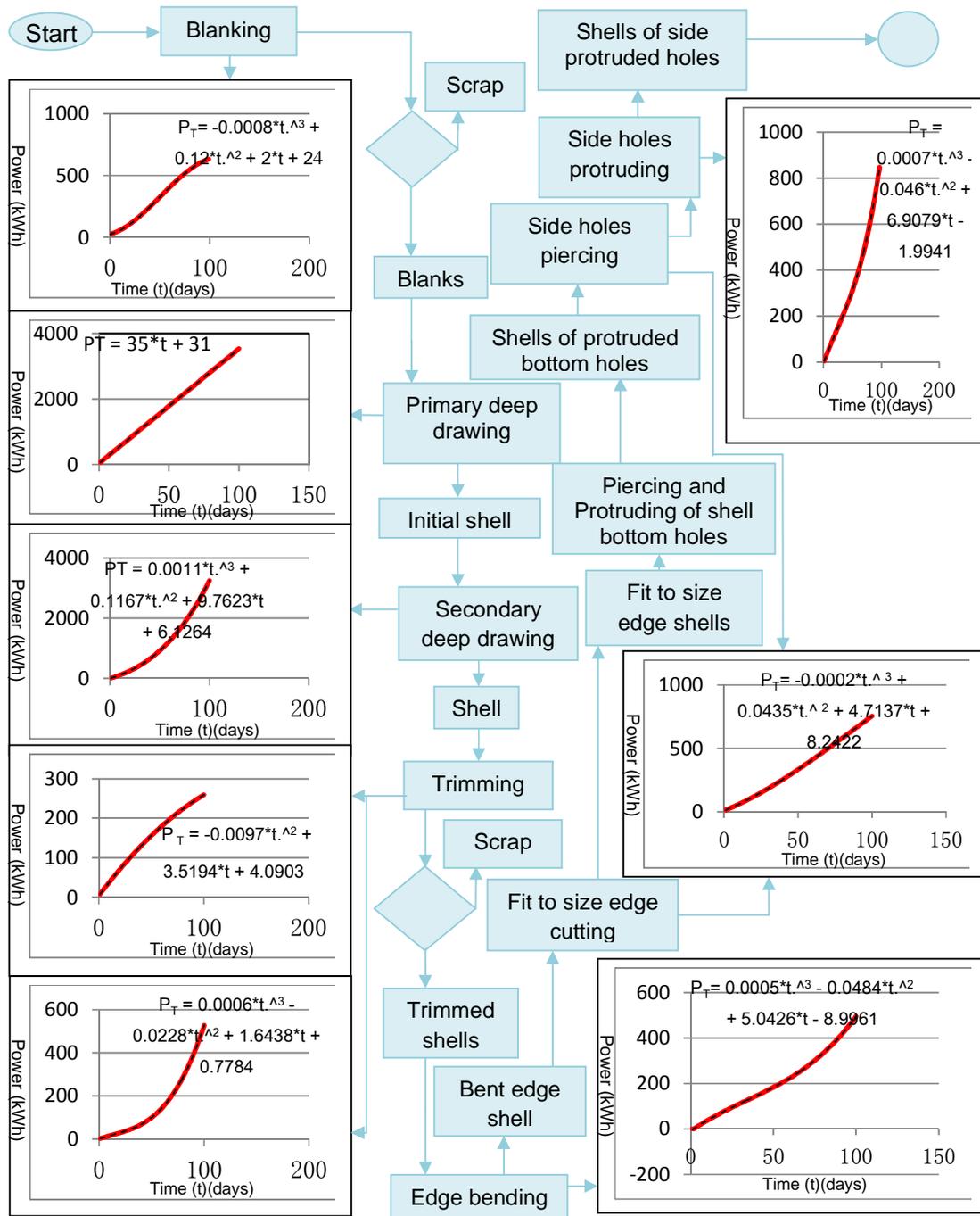
disassembly can lead to only very degraded shells at the end of life, while shearing the edges of handles can fulfill simple assembly-disassembly of high embodied value shells, Fig. 10. This can substitute conventional manufacturing route of welding assembly. Extensive remanufacturing and recovering case studies are practiced to conclude an experience to conduct remanufacturing based on educational institution infrastructures conventional manufacturing processes which usually are exploited to train student within practical syllabus and graduation requirement projects. Such sustainable power can be exploited through remanufacturing business model that is conducted by educational institutions.

## 6. RESULTS AND CALCULATION

Fig. 13 illustrates power consumption curves of welding machines through technological path of oil filters shells manufacturing, which is elicited from Fig. 12, where the power is monitored for three months to find out the power consumption of the manufacturing line. Through design study, Fig. 3, the leak points are the cover forming and the welding. Forming is merely for decorative purposes so it can be eliminated. To focus on welding process power consumption, the power curves of four welding machine that are used to satisfy technological path for assembly of oil filter shells are drawn together and curve fitting is also applied to find out the theoretical power consumption. For better understanding, curve fitting is applied to find out the controlling value of power consumption that called Footprint Ingredient Number for each manufacturing process. Areas under the curves represent the total consumed powers (kWh) which are extracted to simulate the consumption theme of welding processes. The aim of eco-design is to make these powers equal to zero as indicated by the green line in Fig. 14. Design study concludes that to satisfy current power reduction according to Fig. 14, four welding machines can be stopped which is flowed by reduction through application of degrade remanufacturing of end-of-of life shells into structural steel. For better representing and dealing with registered power values, each machine through the whole manufacturing line is represented by process number which is called Footprint Ingredient Number. Total footprint of power consumption of welding machines is of the theme that is modelled in Fig. 15. In this stage of study, eco-design is applicable for welding process only to

increase disassembly for remanufacturing at the end-of-life and also power reduction through welding process removing as a sustainable manufacturing procedure. Power consumption and CO<sub>2</sub> emission, Fig. 16, is followed by power consumption kWh, fossil fuel equivalent per kWh, and CO<sub>2</sub> release per kWh, Fig. 17, and both of

them are modeled based on Footprint Ingredient Number to conclude the whole manufacturing line theme, Fig. 18. This theme obviously shows that deep drawing operations consume high power, between 2 and 3 Footprint Ingredient Numbers and the powerful mitigation of welding elimination.



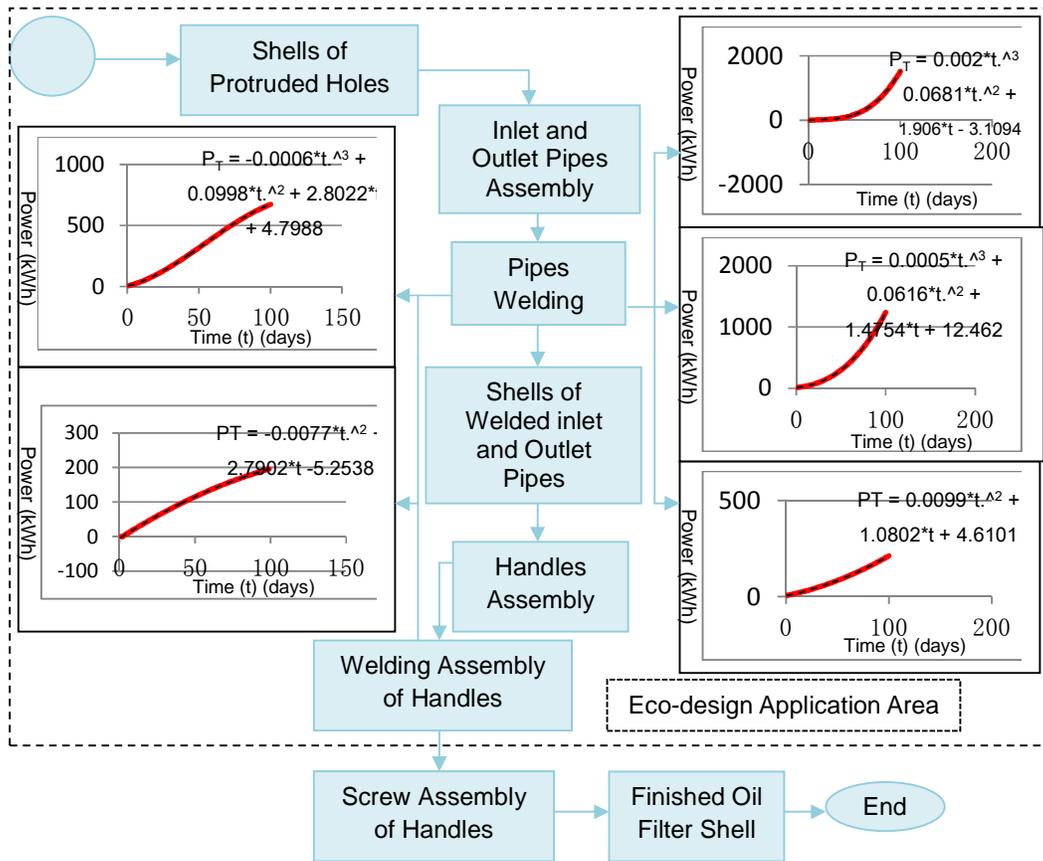


Fig. 3. Process planning to localize carbon mitigation through power reduction by applying eco-design to eliminate welding

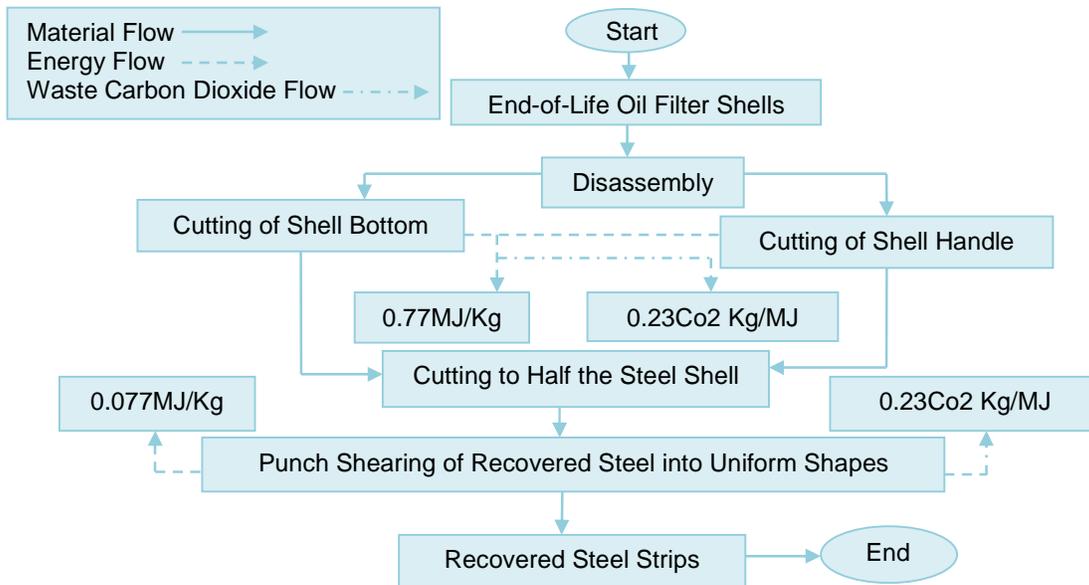


Fig. 4. End-of-life oil filter steel shells into strips recovering procedure

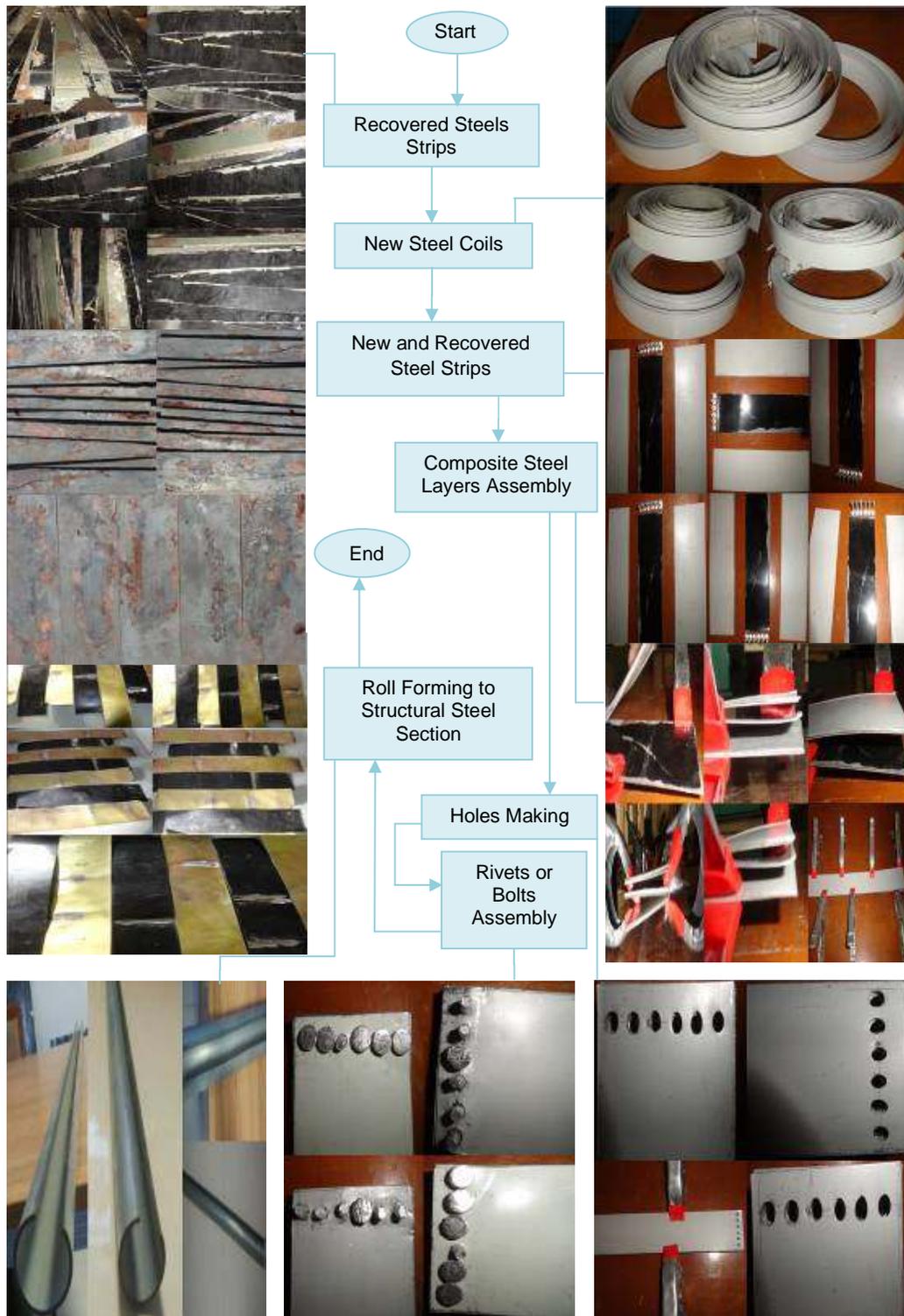


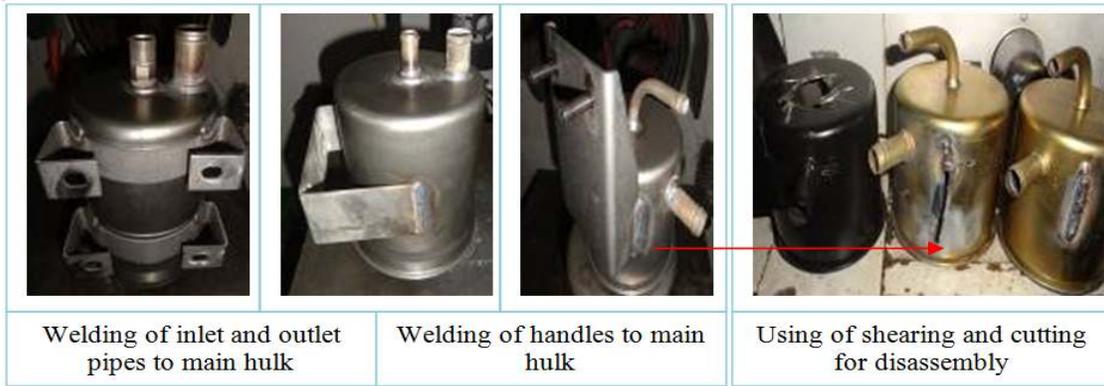
Fig. 5. Illustration of composite shape steel remanufacturing process algorithm



Fig. 6. Eco-design idea to keep the shell bulk with high remanufacturability, using direction is changed upside down to accumulate forming and welding at the cover while and keep bulk free



Fig. 7. Eco-design for remanufacturing application for shell hulk free of welding and holes



**Fig. 8. Non-remanufacturability due to design for non-disassembly by welding**



**Fig. 9. Remanufacturability due to design for disassembly**



**Fig. 10. Remanufacturability due to design for disassembly to certain current power and carbon emission reduction and application of degrading remanufacturing at the end-of-life**



Fig. 11. Eco-design for remanufacturing application

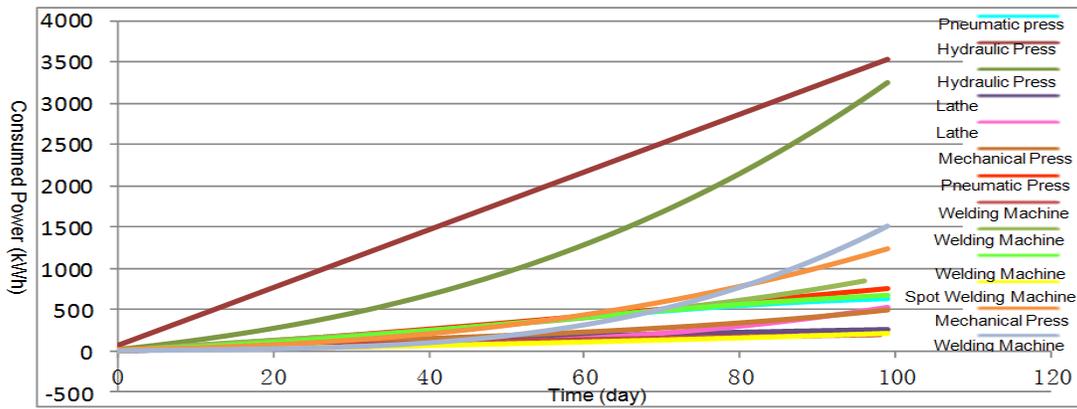


Fig. 12. Power consumption curves of manufacturing processes through technological path of oil filters shells manufacturing

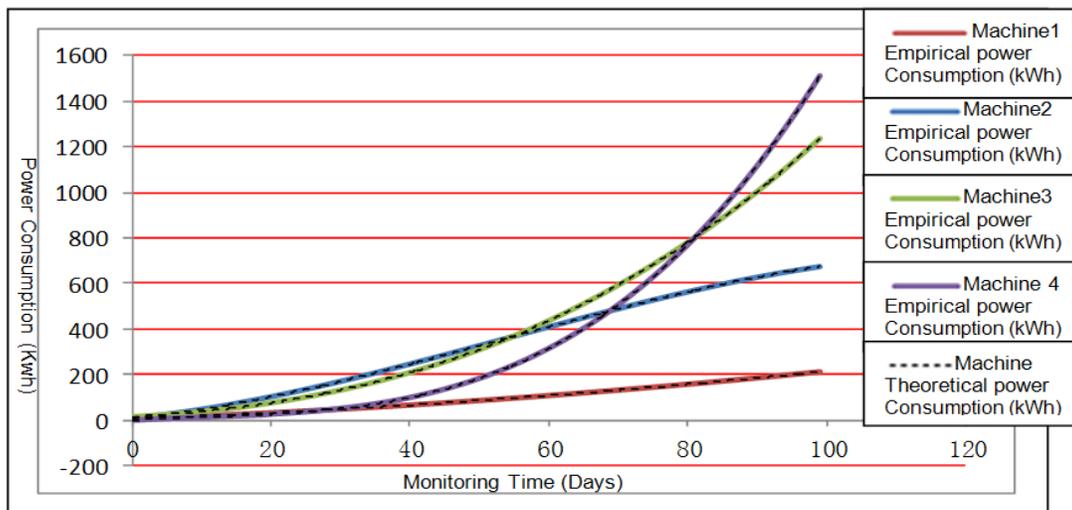


Fig. 13. Power consumption monitoring curves of welding processes through technological path of oil filters shells manufacturing

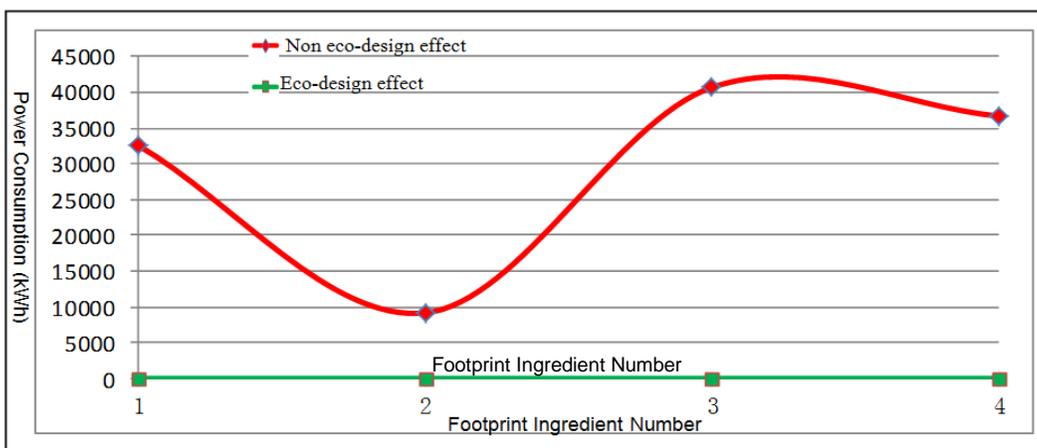


Fig. 14. Eco-design mitigation effect

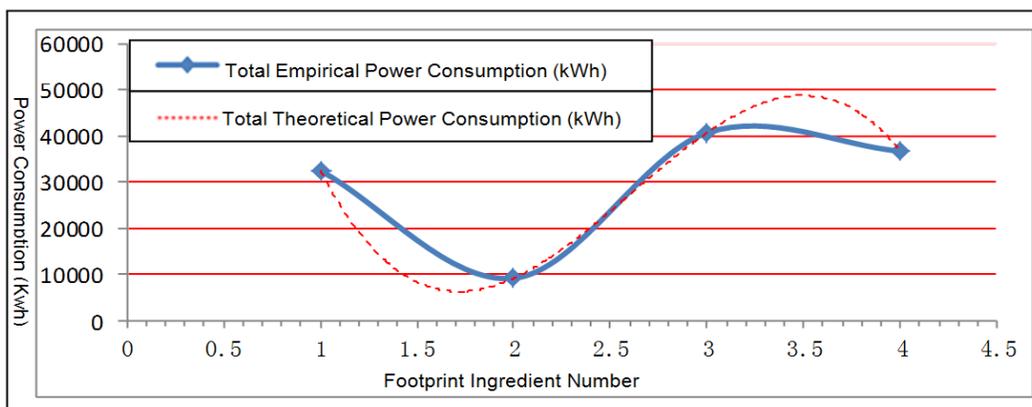


Fig. 15. Welding power consumption theme

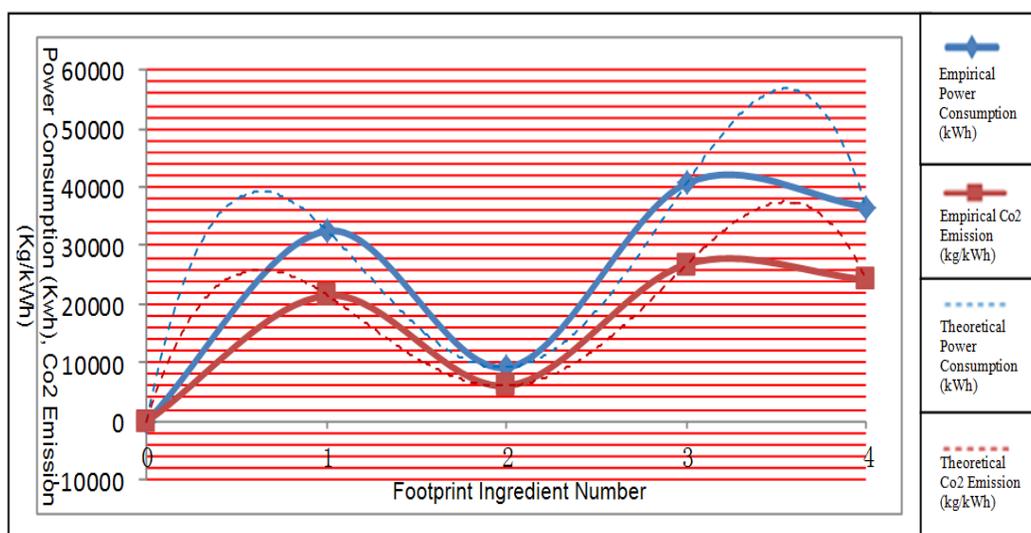


Fig. 16. Power consumption and Co2 emission variation according to footprint ingredient number, based on [22]

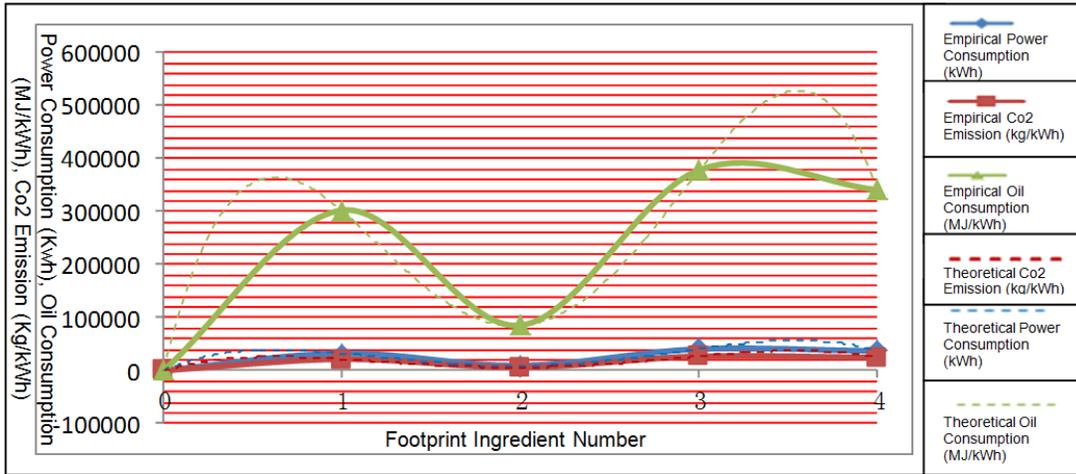


Fig. 17. Illustration of power consumption kWh, fossil fuel equivalent per kWh, and CO2 release per kWh, based on [22]

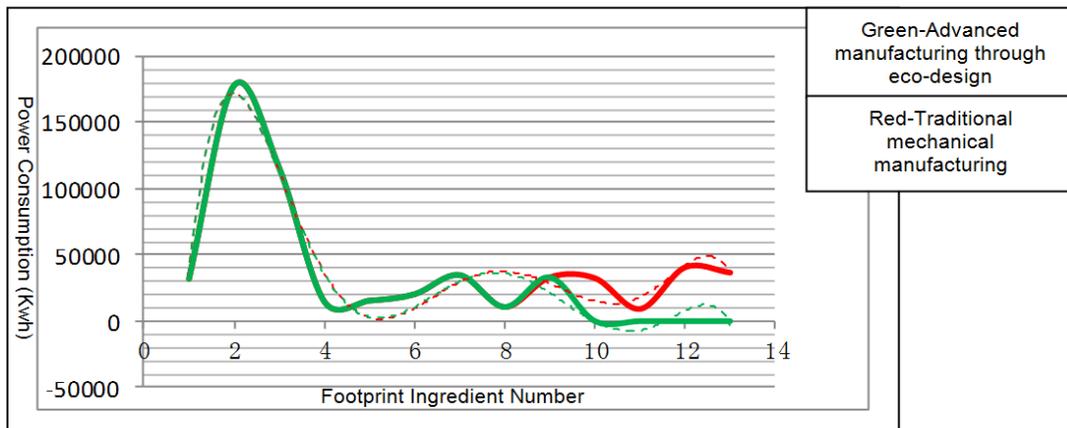


Fig. 18. Concluded Power consumption and Co2 emission variation according to footprint ingredient number of the whole manufacturing line

Table 1. Remanufacturing application mitigation for oil filter shells based on [22]

Saved electrical power consumption (kWh)	Saved power oil consumption (MJ)	Prevented Co2 emissions (kg)
84400 -374000	784920 – 835000	55704-57750

### 7. CONCLUSION

To highlight the role of degraded remanufacturing as a sustainable procedure to mitigate fossil fuel mitigation, Table 1 is illustrated to show that both of electrical power and its related oil consumption can be reduced which leads to prevent the realizing of Co2 emissions. Effect of eco-design is responsible on current cut of power and planting of degrade remanufacturing potentials. These potentials will

be responsible on saving both of time and power where sustainable human power can be exploited. This will allow educational institutions of developing countries without industrial infrastructures conduct remanufacturing of end-of-life steel with high flexibility by increasing percentage of disassembly process. This will be the nuclei of product services based remanufacturing philosophy. Thus remanufacturer societies can be emerged to close the loop of production cycle and satisfy the condition

of environment conscious manufacturing. And the human power of developing countries can be integrated with the global efforts to mitigate the deteriorating effects on environment due production activates through incorporation of attractive seeking for human development, value creation and employment through developing countries.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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