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Application of 6R principles in sustainable supply chain design of Western Australian white goods

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Abstract

The 6 R's of sustainability are implemented to the life cycle of a washing machine, refrigerator and air-conditioner in a Western Australian scenario. A detailed life cycle assessment of each white good was carried out and new scenarios 1, 2 and 3, increasing the combined reuse and remanufacturing rate to 80%, 50% and 30% were implemented. Scenarios 1, 2 and 3 will save 2487.1, 2057.5 and 1772.2tonnes of material from washing machines and 1594.5, 1044.7 and 739.9tonnes from refrigerators respectively. The mass saved implementing 100% recycle rate to air-conditioners is 450.1tonnes. GHG emissions saved from remanufacturing a washing machine and refrigerator instead of producing a new model are 956.2 and 1636.3 kg CO2-e respectively. The embodied energy saved from remanufacturing and recycling washing machines for scenarios 1, 2 and 3 are 482.7x10^6, 254.0x10^6 and 101.5x10^6 MJ and for refrigerators are 566.3x10^6, 250.8x10^6 and 42.29x10^6 MJ respectively. Although remanufacturing white goods significantly decreases the environmental impacts, selling the refurbished products can be a challenge due to fashionable obsolesce, technology advancement and the stigma of remanufactured goods.

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1. Introduction

This paper compares the material lifecycles of three white goods; a washing machine, refrigerator and air conditioner, with application of the 6 R's of sustainability to the current scenario in Western Australia (WA).

When white goods are sent to landfill, not only is the embodied energy of the products and materials lost, but also environmentally harmful bi-products are emitted from the landfill. Furthermore, as the amount of landfill increases, the amount of land needed to house the landfill increases, destroying the natural environment (M. Haynes, Henderson Waste Recovery Park, Perth, personal communication, 23rd October 2014). As the number of users of household appliances increase with time, the material mass would increase landfill size. This means that as time progresses raw material resources will become scarce and emissions from landfill will exponentially increase. With only a finite amount of materials available on Earth, applications of life cycle sustainability to products will aid in conservation of raw materials and in reducing other harmful environmental impacts.

The 6 R's of sustainability include; reduce, reuse, recycle, recover, redesign and remanufacture [1]. In this study redesign is not investigated to the detail of the other R's but is discussed in relation to its applicability and environmental benefits. In particular, redesigning a product can ease the remanufacturing process or allow capability for remanufacture. Reduce involves reducing the use of the product, which is unrealistic to apply to white goods in Western Australia. Reuse encompasses reusing parts or whole components with no or very little changes to the part. Recycle consists of applying further machining and/or chemical processes to a component so that the raw material is useable for another purpose. In this study metal-recycling processes at Sims Metal Management facilities in WA were investigated. Recovery is the process of retrieving the whole units or parts from the preceding users or processes [1,2,3]. For this study the recovery involves city council services, product seller recovery or product users taking responsibility for the used white goods and buyers and sellers of scrap metal in the

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upstream stage of end of life (EoL) products. These recovery providers deliver the units or parts to EoL facilities, with varying levels of environmental impacts. Remanufacture is the restoration of the product to its original state or like new form [3]. This initial EoL scenario gives the majority of parts of a product a new life, with little energy and material input. For the case of white goods, units are refurbished or reconditioned instead of remanufactured, as the intensive processes in remanufacturing are not economically viable [3]. In this study the terms “refurbishing” and “remanufacturing” will be used equivalently.

In terms of applying these 6 R’s to the EoL white goods in WA, this study offers possible scenarios, which increase the remanufacturing and recycling rates of white goods by manipulating the recovery paths. Redesign a product is out of the scope of this study, hence are not applied to the EoL of the white goods investigated. Current companies such as Fuji Xerox, have successfully redesigned their printer/photocopiers to improve remanufacturability and product reliability but this took intensive, time consuming studies [4].

The aim of this research is to investigate material, carbon and embodied energy saving opportunities in WA due to application of 6Rs. The specific objectives to attain this aim for this study are as follows:

- Understand the current EoL situation in WA through a sample of white good users
- Follow the life paths of the white goods until a new life cycle has begun, the unit or component is at landfill or the unit or component leaves WA
- Create a material balance for each white good using the life cycle study and material and component breakdowns for each unit
- Investigate possible improvements on the current EoL situation using 6R strategies
- Use streamlined life cycle assessment (SLCA) to analyze material and energy data to estimate carbon footprint and embodied energy implications of 6Rs.
- Identify strategies to overcome challenges in implementing the improved scenarios/6Rs in WA

2. Method and materials

The four key components of this methodology of this study are as follows; the consumer survey, the development of the three alternative scenarios, the material balance at each end of life option and the SLCA analysis.

2.1. Consumer survey

To find the existing white good life cycles in WA, a survey collecting data on users method of disposal of white goods and use of remanufactured units was distributed. The survey asked users what they did with their unused white goods and if they had purchased remanufactured models. For these surveys approximately 100 respondents were recorded for each white good, with the results used as an approximation of the EoL scenario in WA. The next step was to investigate the products life cycle including local council roadside collection and white goods store. Ten city councils in Perth were asked about their disposal of white goods after roadside pick-up with all except Cockburn City Council taking the collected white goods to a nearby Sims Metal Recycling facility. Cockburn City takes their collected white goods to Cockburn Landfill. Cockburn Landfill has a recycling facility associated with it, Henderson Waste Recovery Park, which recovers metal components from white goods and sells the metals to a metal recycler [M. Haynes, personal communication, 23rd October 2014]. Therefore it was assumed that white goods collected by Cockburn City Council would undergo the same recycling processes that the other nine city councils undergo at Sims Metal Management. All products or metals, including white goods, which arrive at a Sims Metal Recycling facility undergo shredding to separate the ferrous metals, non-ferrous metals and non-metals, then bailing which compresses each type of metal into blocks for ease of transportation. The non-metals collected are sent to waste. From the Western Australian Sims Metal Management facilities the bailed metals are sold to various locations in Asia for melting and purifying processes because currently there are no foundries in WA for scrap metal. At Sims facilities in the Eastern States the metals undergo the chemical treatments at some onsite locations or are sold to local foundries that specialize in scrap metal melting [Jamie, Sims Metal Management facilities, Perth, personal communication, 1st May 2015].

2.2. Development of alternative scenarios

Once the current life cycle paths of EoL white goods and their relative weightings were established, three new scenarios were defined with each being an improvement, in terms of environmental impact, on the current situation.

This improved scenario is based on the Electrolux white good refurbishing facility in Motala, Sweden, where 81.6% of the white goods that arrive at the facility are able to be refurbished, with the other 18.4% unable to be refurbished due to age or physical state [5]. From this study, it was approximated that 20% of white goods can’t be refurbished, hence for the first scenario, the combined reuse and refurbishing rate was set at 80%. Due to large difference between this 80% rate and the combination of the current rate of refurbishment, 3%-10%, and the rate of reuse, 11%-23%, two conservative scenarios were formed with their refurbishing and reuse rates being 50% and 30%. These two scenarios would more likely to successfully implement in WA, predominantly due to the issues with fashionable obsolesce and advancement of technology, both explained later on. In each of these 80%, 50% and 30% refurbishing and reuse scenarios the recycling rate was set at 20%, 50% and 70% respectively and they are known as Scenarios 1, 2 and 3, respectively.

2.3. Material balance of end of life scenarios

Once the current and three new scenarios were established, material and component breakdowns for each of the white goods in terms of materials were determined through material balance. The material balances incorporated the current and new life EoL scenarios along with material breakdowns of each of the white goods.

Dehoust and Shuler approximated a refrigerator material balance which was used in this study [6]. This material breakdown gave the masses of the materials except that of the compressor, which it gave a separate compressor weight [6]. The individual compressor material breakdown was approximated using the given total mass from Dehoust and Shuler and the percentage material breakdown of a compressor from 'A greenhouse gas assessment of remanufactured refrigeration and air-conditioning compressors' by Biswas and Rosano [7]. In the recycling of EoL product's material balance it was assumed that all metals would be recycled and all non-metals would be taken to landfill with the exception of the refrigerant gas which is extracted before shredding at the recycler. Due to lack of available information about refrigerator refurbishing in WA, a refrigerator refurbisher and repairer in Melbourne was contacted for refurbishing information. Melbourne Metro Refrigeration stated that the most common parts that needed replacing during refurbishment are the compressor and its electrical components, thermostats and temperature sensors [Sergio, Harvey Norman, Perth, personal communication, 16th March 2015]. Due to the relatively negligible mass of domestic refrigerator thermostats and temperature sensors, these two components' replacement during refurbishment was ignored. Hence as a worst-case refurbishment scenario, it was assumed that the compressor would need to be replaced during refurbishment.

The washing machine component and material breakdown was taken from Biswas [pers comm. Sustainable Engineering Group, Curtin University]. Born Again Washing Machines, a washing machine refurbisher in Perth was contacted for information regarding washing machine refurbishing. This source stated that the most common parts that need replacing during refurbishing are the electric motor, the circuit board, the water valves and the plastic bowls [M. Krausa, Born Again Washing Machines, Perth, personal communication, 5th November 2014]. Similarly in the refrigerator refurbishment analysis, the mass of water valves replaced in refurbishment was ignored due to the negligible mass, hence as a worst case scenario it was assumed that the motor, circuit board and plastic bowl would need replacing during refurbishment.

The air-conditioner material breakdown was taken from the LCA from DeKline [7]. Due to the design of reverse cycle air-conditioners, removal of units involves breaking many parts which limits the components available for re-use in remanufacturing. For this reason, and there is no existing literature on air conditioner remanufacturing or companies that remanufacture air conditioners in Australia, the option of remanufacturing air-conditioners was not explored in this study; instead the best-case scenario would be to recycle all units at a metal recycler. Although there were some respondents from the consumer survey stating their use of refurbished air-conditioners it is likely they may have not understood the question and were referring to portable air-conditioners, which can be refurbished.

The average mass of a material recycled per unit disposed of was found using the following equation:

$$m_{recycle} = x_{re} \times m_{re}'$$

Where:

$m_{recycle}$ *is the average mass recycled per unit disposed*

x_{re} *is the percentage of whole units sent to a metal recycler*

m_{re}' *is mass of material retained in recycling*

For metals m_{re}' is the total mass of that material in one unit of the white good while for metals it is zero.

The average mass of material remanufactured per unit disposed was found using the following equation:

$$m_{remanu} = x_{rm} \times m_{rm}'$$

Where:

m_{remanu} *is the average mass remanufactured per unit disposed*

x_{rm} *is the percentage of whole units remanufactured*

m_{rm}' *is mass of material retained in remanufacture*

The value of m_{rm}' is the mass of the individual material retained in remanufacture.

The average mass of material reused per unit disposed was found using the following equation:

$$m_{reused} = x_{reused} \times m_{reused}'$$

Where:

m_{reused} *is the average mass reused per unit disposed*

x_{reused} *is the percentage of whole units reused*

m_{reused}' *is mass of material retained in reuse*

In this case the mass of material retained in reuse is the total mass of that particular material.

Finally the material mass in landfill was found using the following equation:

$$m_{landfill} = m_{total} - m_{re} - m_{remanu} - m_{reused}$$

Where m_{total} is the total mass of that particular material.

The material mass for each particular scenario were added to get the total mass for each EoL stage for each scenario for each respective white good.

2.4. Greenhouse gas and carbon footprint analysis

Due to the lack of information at refurbishing and recycling facilities in WA, the energy requirements for the refurbishment and recycling of each of the white goods were estimated from previous studies and machinery used. The estimated energy use of scrap metal shredders that process white goods is 32 BTU per pound, from a British white goods recycling study [9]. This value was converted to kWh and combined with the white good masses to get an energy value for each white good. The bailer energy requirements were estimated from the study 'Description of the material recovery facilities process model: design, cost and life cycle inventory' to be 12 kWh per ton of metal [10]. Since the bailed metals leave the WA boundary for further recycling processes, this study does not take into account environmental impacts after bailing.

The study 'Energy implications of product leasing' estimated the manufacturing and remanufacturing energy requirements for washing machines as 750kWh and 24kWh respectively and that for refrigerators as 1182 kWh and 20kWh [11].

These energy requirements and the required materials balances were put into the life cycle assessment software SimaPro, to estimate the embodied energy and carbon footprint for remanufacturing, recycling and mining to manufacture of a new product output [12].

3. Results and discussions

3.1. The existing waste generation scenario for white goods in Western Australia

In the current end of life situation for white goods in WA, 37.5 kg of material waste is generated per 73.5 kg washing machine model, 25.85 kg material waste is generated per 77.5 kg refrigerator and 19.35 kg of waste us generated per 70.3 kg air-conditioner. Assuming each white good fulfills its expected lifetime of 11, 13 and 15 years for a washing machine, refrigerator and reverse cycle air-conditioner, it is estimated that one product owner in every 11, 13 and 15 years respectively disposes of their product each year.[M Krausa, Born Again Washing Machines, Perth, Norman, Perth, personal communication, 16th March 2015][13]. In 2008, an Australia study estimated the number of households with reverse cycle air-conditioners, domestic refrigerators and washing machines in WA to be $344x\ 10^3$, $826.3\ x\ 10^3$ and $809.4\ x10^3$ respectively [14]. The WA population has grown from 2.17 million in 2008 to 2.589 million in 2014, a 19.3% increase in population. Assuming the number of households in WA also increased at this rate, the number of households with washing machines, refrigerators and reverse cycle air-conditioners are extrapolated to be $956.6x10^3$, $985.8\ x10^3$ and $410.39x10^3$ respectively [15,16]. Assuming one washing machine, refrigerator and air-conditioner is disposed of every 11, 13 and 15 years respectively the number of units of each white good disposed of in 2014 is estimated to be $86.96x10^3$, $75.83x10^3$ and $27.36x10^3$ respectively. Using the average material waste produced for each white goods gives a total mass of waste generated in 2014 for washing machines, refrigerators and reverse cycle air-conditioners to be 3261, 1960 and 529tonnes.

3.2. Analysis of the new scenarios

By applying new rates of remanufacture and recycling to the EoL scenarios of the white goods, the waste generation significantly decreases. For scenario 1 (i.e. 80% refurbishing and reuse), scenario 2 (i.e. 50% refurbishing and reuse) and scenario 3 (i.e. 30% refurbishing and reuse) the average new masses of waste generated are 8.90, 13.84 and 17.12 kg per washing machine and 4.82, 12.07 and 16.90 kg per refrigerator, respectively. These correlate to 68%, 50% and 38% decreases in waste generated from washing machines in scenarios 1, 2 and 3 and 81%, 53% and 35% decreases in waste generated from refrigerators in scenarios 1, 2 and 3. These percentages indicate the percentage of material mass reused either in recycling or remanufacture for the two white goods. In terms of total mass saved from landfill in 2014, scenarios 1, 2 and 3 will save 2487.1, 2057.5 and 1772.2tonnes from washing machines and 1594.5, 1044.7 and 739.9 tonnes from refrigerators.

If every air-conditioner is sent to a metal recycler at the end of its life, 2.92 kg of waste will be produced which is an 85% decrease in mass generated, with a total mass saved from landfill per year being 450.1tonnes.

These results convey that, remanufacturing is the favored option over recycling in terms of the reduction in waste generation, although it is challenging to achieve higher rates of remanufactured refrigerators in the current market. The dominating challenge facing the remanufacturing industry of white goods in developed societies is customer acceptance due to fashionable obsolesce, technology advancement and the stigma of remanufactured goods [2,3]. The appearance and superficial features of white goods change according to the fashions of a society over time and much like fashions in appearance of people, purchasers of white goods take into account current superficial fashions of the time which may rule out many older styles remanufactured white goods.

Similarly technology advancement sways buyers to purchase more recently designed models. This includes the energy efficiency of the product, which has improved dramatically over time, and new features. In developed societies remanufactured white goods have the stigma of being inferior to new products, not just due to fashion and technology, but warranties and life expectancies [2,3]. This is often not the case; Recom Engineering, a compressor remanufacturer in Perth, promises the same or better warranties as new compressors [P. Frey, Recom Engineering, Perth, personal communication, 2014].

As successful metal recycling industries already exist in WA, increasing the rate of recycling of white goods is easily possible and can be considered the next best option to remanufacture.

Table 1. Raw material savings from landfill

	Scenario 1	Scenario 2	Scenario 3
Washing machine	2487	2058	1772
Refrigerator	1595	1045	740
Air conditioner	450		

3.3. Carbon footprint and embodied energy savings from the application of the 6 R s

The GHG emissions associated with mining to manufacture of a new product and remanufacture of washing machines are 1036.75 CO_2-e and 80.56 CO_2-e, and for refrigerators are 1771.04 and 134.74 respectively. This is a 956.19 kg CO_2-e decrease in GHG emissions per washing machine and a 1636.3 kg CO_2-e decrease per refrigerator. The GHG emissions associated with mining to material and recycling for the recyclable materials in a washing machine are 221 and 2.60 kg CO2-e respectively, 486 and 2.75 kg CO_2-e for that of a refrigerator and, 591.14 and 2.53 kg CO_2-e for that of an air-conditioner. This is a 218.4 kg-CO_2-e decrease in emissions per washing machine, 483.25 kg CO_2-e for a refrigerator and 588.61 kg CO_2-e for an air-conditioner. Using these information, the total annual GHG emissions saved are; 40.8, 21.5 and 15 kilo tonnes for washing machines for scenarios 1, 2 and 3 and 41.6, 15.5 and 6.9 kilo tonnes for refrigerators respectively. For the 100% recycle rate of air-conditioners the embodied energy saved is about 0.4 kilo-tonnes (Table 2).

Table 2. GHG emissions and embodied energy consumption savings

	Scenario 1	Scenario 2	Scenario 3
GHG savings (tonnes CO_2-e)			
Washing machine	40794	21476	15037
Refrigerator	41643	15461	6854
Air conditioner	386		
Embodied energy saving (GJ)			
Washing machine	483	254	102
Refrigerator	566	251	43
Air conditioner	4.5		

These emission values show large decreases in GHG emissions for each of the white goods but some factors were not considered in this study and need to be further discussed. These emissions ignored transportation of new products from the manufacturer to the purchaser, from purchaser to landfill, purchaser to remanufacturer, purchaser to recycler and outbound from the recycler. Comparatively the dominating transport energies will be the international trips; from the manufacturer and from the recyclers. Therefore the decrease in emissions between mining to manufacture and remanufacture is a conservative result. It is unknown how including transportation energy will affect the decrease of GHG emissions between mining to material and recycling due to the unknown travelling distances.

When a product is disposed of in landfill, not only is the material lost but also all energy put into the formation of that material lost. The embodied energies of a washing machine, refrigerator and air-conditioner are 12577.63, 185776.1 and 6885.57 MJ respectively and 636.6x10^6, 776.6x10^6 and 4.66x10^6MJ are lost per year in the current scenario. By adding the embodied energies of the materials saved in remanufacture, reuse and recycling for the current and new scenarios, the total embodied energy saved per year for each of the white goods can be calculated. For scenarios 1, 2 and 3 the embodied energies saved are; 482.7x10^6, 254.0x10^6 and 101.5x10^6 MJ for washing machines and 566.3x10^6, 250.8x10^6 and 42.49x10^6 MJ for refrigerators respectively. For the 100% recycle rate of air-conditioners the embodied energy saved is 4.47x10^6MJ(Table 2).

3.4. Introduction of redesign and alternate recovery methods

The remanufacturing process often experiences difficulties to adapt with the used products because the original used products were not designed to be remanufacturable. Therefore, redesign has become one of the important remanufacturing technologies and has received more attention recently since it directly affects the quality of the remanufactured products [17]. Fuji Xerox is a company that has successfully implemented the ongoing redesign of its photocopiers resulting in ease of remanufacture [4]. The strong communication and knowledge of designers and remanufacturers in the company have allowed the photocopier's design to change to improve the ability to remanufacture the product. The redesign of a product could also reduce the use of a product by increasing its life expectancy. If the life expectancy of a product were increased, the amount of material and embodied energy lost in landfill would decrease. However, the complexity of the redesign process of used products and the needs of quality performance of remanufactured products should be taken into future consideration.

The recovery methods play an important role in the disposal of white goods. Currently at the end of a products initial life they are likely taken by the local city council or a white goods store and from here they are mostly taken for recycling. These current recovery methods give little opportunity for remanufacturers to collect products, hence to increase rates of remanufacturing, along with having available remanufacturers, there must be some method for remanufacturers to receive used products.

4. Conclusions and recommendations

By applying new rates of remanufacture and/or recycling to the end stages of the life of a white good, GHG emissions can be greatly decreased, the finite amount of materials on earth are conserved and the land use from landfills is decreased. Higher rates of remanufacturing significantly decrease the environmental impacts of white goods but the implementation of remanufacturing comes with difficult challenges including fashionable obsolesce, technology advancement and the stigma of remanufactured goods. Recycling of a white good is the next best option in terms of environmental impact, and its current successful implementation in West Australian society means higher rates of recycling can be easily applied.

There is an infinite number of ways to improve the environmental impact of a white good's lifecycle but the applicability and ease to introduce them in WA society limits these possibilities. Therefore the following improvements are recommended for most effective impact and availability for implementation.

- To create a market for remanufactured white goods, the stigma that remanufactured goods are inferior, needs to be changed. The Australian government needs to aid sellers in some form of advertisements to promote white goods, not just for their environmental benefits but their equal quality compared to that of a new white good.
- Once a market is created and white goods come into demand, increased training in the remanufacture of white goods needs to be available. This training needs to be conducted for a particular product so they remanufacturers are specialized. This program could potentially become a trade apprenticeship, increasing available jobs.
- The remanufacturers will need a way to receive the white goods after initial use. Since the current method of city council collections is successful, the path that the white goods take after this collection, could be changed. Instead of taking white goods to a recycler, a certain amount could first be taken to a remanufacturer. The remanufacturer could then assess the product for possible remanufacture. This would involve communication between councils and remanufacturers including the amount of products wanted by the remanufacturer. There may need to be some sort of compensation for the city councils for being apart of this program.
- If there was some type of communication between remanufacturers and designers the white goods could be redesigned to favor remanufacturing.

The vital variable in implementing the 6 R's to improve the environmental impact from white goods is the market for remanufactured goods. Once some sort of market is established improvements in remanufacturing, recovery, redesign and recycling could take place. By aiding in the introduction of higher rates of remanufacturing, the local and state governments will reap multiple benefits. These include less money spent buying landfill space, creating specialized jobs in the remanufacturing industry and promoting the fact that they are a sustainable government.

References

[1] Jayal, A. D., Badurdeen, F., Dillon, O. W., &Jawahir, I. S. (2010). Sustainable manufacturing: Modelling and optimization challenges at the product, process and system levels. *CIRP Journal of Manufacturing Science and Technology*,*2*(3), 144-152

[2] Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T. (2007).Development of design for remanufacturing guidelines to support sustainable manufacturing. *Robotics and Computer-Integrated Manufacturing*, *23*(6), 712-719.

[3] King, A. M., Burgess, S. C., Ijomah, W., & McMahon, C. A. (2006). Reducing waste: repair, recondition, remanufacture or recycle?. *Sustainable Development*, *14*(4), 257-267.

[4]Kerr, W, Ryan, C: Eco-efficiency gains from remanufacturing a case study of photocopier remanufacturing at Fuji Xerox Australia. J. Clean Prod. 9, 75-81 (2001)

[5] Sundin, E., & Tyskeng, S. (2003). Refurbish or Recycle Household Appliances.*An Ecological and Economic study of Electrolux in Sweden.* Conference: Environmentally Conscious Design and Inverse Manufacturing, 2003. EcoDesign '03. 2003

[6] Dehoust, G & Shuler, D. (2007). Life cycle assessment of the treatment and recycling of refrigeration equipment containing CFCs and hydrocarbons. RAL Quality Assurance Association for the Demanufacture of Refrigeration Equipment. Retrived from http://www.oeko.de/oekodoc/1108/2007-226-en.pdf

[7] Biswas, WK, Rosano, M. (2011). A life cycle greenhouse gas assessment of remanufactured refrigeration and air conditioning compressors. Int J. Sustainable Manufacturing 2(2-3), 222-236 (2011)[8] De Kleine, R. (2009). *Life cycle optimization of residential air conditioner replacement* (Doctoral dissertation, University of Michigan

[9] Bole, R. (2006). *Life-cycle optimization of residential clothes washer replacement* (Doctoral dissertation, The University of Michigan).

[10] Nishtala, S. R., &Solano, E. (1997). Description of the material recovery facilities process model: Design, cost, and life-cycle inventory. *Internal Rep*.

[11]Intlekofer, K., Bras, B., & Ferguson, M. (2010). Energy implications of product leasing. *Environmental science & technology*, *44*(12), 4409-4415.

[12] Simapro 8.02, Life-Cycle Assessment Software Package, Version 36. Plotter 12, 3821 BB Amersfoort, The Netherlands

[13]Monaro Air. (2014). FAQ's. Retrived from http://www.monaroair.com.au/faqs/#8

[14] Australian Bureau of Statistics. (2008). Environmental Issues: Energy Use and Conservation (No. 4602.0.55.001). Retrived from http://abs.gov.au

[15] Australian Bureau of Statistics. (2014). Australian Demographic Statistics (No. 3101.0). Retrived from http://abs.gov.au

[16] Australian Bureau of Statistics. (2008). Population by Age and Sex,Region of Austrlia (No. 3235.0). Retrived from http://abs.gov.au

[17] Du Y., Cao, H., Chen X., Wang, B. (2012). Reuse-oreonted redesign method of used products based on axiomatic design theory and QFD. *Journal of Cleaner Production*, 39, 79-86.