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LCA Case Studies

Life Cycle Assessment of Commercial Furniture: A Case Study of Formway LIFE Chair

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Abstract

Background, Aims and Scope. In current global industry, environmental aspects of companies and their products are quickly becoming significant in heightening competitive advantage. While there has been a relative slow response to the use of environmental criteria for competitive purposes in Australasia as compared to the European Union, there is a gathering momentum for adopting sustainability principles; hence a focus on reduction of environmental impact is seen as a priority. Formway Furniture Ltd., a designer and manufacturer of office furniture products, is a New Zealand based company that is committed to sustainable development. As a result, this study was aimed at the following goals: 1) Determine environmental hotspots, 2) Compare the life cycle impacts of the two distinctive models of the LIFE chair: one with an aluminium base and the other with a glass filled nylon (GFN) base, and 3) Compare two potential waste management scenarios. The study also includes sensitivity analysis with respect to recycled content of aluminium in the product.

Methods. The LIFE chair models consist of a mix of metal and plastic components that are manufactured by selected Formway suppliers according to design criteria. Hence the research methodology included determining the specific material composition of the two chair models and acquisition of manufacturing data from individual suppliers. This data was compiled and used in conjunction with pre-existing data, specifically from the EcoInvent database purchased in conjunction with the SimaPro7 LCA software, to form the Life Cycle Inventory (LCI) of the two chair models. The life cycle phases included in the study consist of raw material extraction through to waste management. Impact assessment was carried out using CML 2 baseline 2000, the methodology developed by Leiden University's Institute for Environmental Sciences.

Results. Since the study was aimed at obtaining information on the overall impacts of the LIFE chair models, default impact categories given by CML 2 were adopted. However, this paper presents results for global warming potential (GWP100). The study showed significant impact contribution from the raw material extraction and refinement stage for both chair models. This part of the life cycle was investigated further and it was determined that aluminium extraction and refinement contributed to the highest GWP100. The comparison of the two LIFE chair models showed that the model with the aluminium base contributed to higher impact than the model with the GFN base. The waste management scenario compared impact when 1) Both chair models were sent to landfill, and 2) All metal components were recycled with the remainder sent to landfill. The results showed that the recycling scenario contributed to avoided GWP100. Since aluminium was found to be significant, a sensitivity analysis was carried out to determine the impact of using aluminium with different recycled contents (0%, 34% and 100%) considering both waste management scenarios. The results show that the use of aluminium with recycled content was insignificant if both chairs are recycled at end of life. However, when considering the landfill scenario, use of primary aluminium led to very high GWP100, while using 100% recycled aluminium gave near equivalent results to that of the recycling scenarios.

Discussion. The results show that the main hotspot in the life cycle was the raw material extraction and refinement stage. This can be attributed to the extraction and refinement of aluminium, a material that is highly energy intensive. The LIFE chair model with the aluminium base contributed more GWP100 as it has more aluminium in its composition. The waste management scenario showed that avoided burdens can result from recycling, hence the recycling scenario lead to significantly less GWP100 than the landfill scenario. Sensitivity analysis pertaining to the recycled content of aluminium showed that use of aluminium with high recycled content was beneficial. This is because recycling aluminium is less energy intensive than extracting and refining raw materials for virgin aluminium.

Conclusions. With respect to goal 1, the study found that the raw material extraction and refinement stage of the life cycle was significant for both LIFE chair models. This was largely due to the use of aluminium in the product. For goal 2 it was found that the LIFE chair model with the aluminium base contributed more GWP100 than the GFN model. Again this is directly attributed to the material content of the two chair models, where the aluminium content was higher in the chair with the aluminium base. Results for goal 3 illustrated that recycling at end of life is beneficial where the recycling scenario contributed to avoided burdens. Sensitivity analysis pertaining to the recycled content of aluminium showed that use of higher recycled contents lead to lower GWP100 impact if the chair models are landfilled. Recycled content of aluminium has negligible effect on GWP100 if the chair models are recycled.

Recommendation and perspective. Most of the GWP100 impact was contributed during the raw material extraction and refinement stage of the life cycle, thus overall impact may be reduced through engaging in heightened supply chain management with respect to environmental requirements. The study identified aluminium components as a major

contributor to GWP100 for both LIFE chair models and also highlighted sensitivity of results to its recycled content. Thus it is recommended that the use of aluminium in future product designs be limited unless it is possible to use aluminium with high recycled contents. With respect to the waste management scenario, it was found that substantial reductions in GWP100 impact would occur if the chairs are recycled, rather than landfilled. Thus recycling the two LIFE chair models at end of life is highly recommended.

Keywords: Global warming potential; LIFE chair; Life Cycle Assessment; office furniture; SimaPro7

Introduction

In the office furniture sector, manufacturers are increasingly required to provide information on environmental performance of their products. Market requirements, for example in Australian and New Zealand corporate and government sectors are moving towards including environmental sustainability considerations as key elements of procurement policy. Therefore, the availability of product ecolabel certification and/or sound environmental product declarations (EPD) [1] is an increasing necessity to maintain commercial competitiveness while avoiding claims that may be perceived as greenwash [2]. Design for Environment (DfE), cleaner technologies and Life Cycle Assessment (LCA) [3, 4, 5, 6, 7] tools and approaches have long been used to minimize environmental impact of production and assist in creating environmentally preferable products. Within the commercial office furniture sector, companies such as Herman Miller [8] and Steelcase [9] have carried out environmental studies in this aspect. Additionally, a recent Norwegian project has developed Product Category Rules (PCR) for EPDs based on LCA [10], further highlighting the use of product Life Cycle Assessment. Some public EPD declarations according to PCR, including office furniture, are publicly available [1, 10, 11].

Formway Furniture is an office furniture designer and manufacturer based in Wellington, New Zealand. The company is committed to improving its environmental performance to ensure that its products and processes are aligned with sustainability principles. Formway's product, the LIFE chair (acronym for Light, Intuitive, Flexible and Environmental), was designed during 1997/98 with environmental sustainability principles incorporated into the product during the design process. The product design concept also incorporated the 'Reduce, Reuse, Recycle' eco-design [12] principles effectively. The LIFE chair and specific material components are given in **Fig. 1**.

Fig. 1

The purpose of this research was to develop an in-depth understanding of environmental impacts associated with the LIFE chair's life cycle. The resulting information would be used to improve the product's environmental performance as part of Formway's environmental sustainability program and also to provide direction for new designs.

1 LIFE LCA

1.1 Methodology and framework

Since the LIFE chair is manufactured from components supplied by numerous suppliers, the LCA study required information on materials and processes to be gathered from within Formway and from suppliers as shown in **Fig. 2**. The process information from within Formway was gathered by audits whereas questionnaires were used to obtain supplier information.

Fig. 2

One significant outcome of the questionnaires was that in addition to the process information collected, the level of responses gave an indication of supplier's environmental awareness, application of cleaner production strategies and achievement of environmental standards such as ISO14001 [13]. It was found that generally, the internationally based companies were more forthcoming to the questionnaires and provided a high level of information. Some of the smaller suppliers, including those located in New Zealand, however, did not have documented information regarding their materials and processes. This is in part due to the lack of pressure from government or customers to provide such information and also due to confidentiality issues in a competitive environment.

The LCA framework includes four phases, namely: goal and scope, inventory analysis, impact assessment and interpretation, as outlined by the International Standards Organisation's LCA framework [14]. The four phases are described with particulars pertaining to this study.

2.2 Goal, Scope and Functional Unit

(a) Goal

The aim of the study was to develop a better understanding of the life cycle environmental impacts associated with the LIFE chair. The specific goals of the study were to:

1. Determine hotspots in the life cycle of the LIFE chair.
2. Compare the life cycle environmental impacts of the two main models of the LIFE chair (one with aluminium base and the other with GFN base).
3. Investigate the importance of different waste management options for the LIFE chairs.

The first and second goals inform Formway's environmental design improvement initiatives, by first acquiring a greater understanding of the environmental impacts of each chair model. The third goal was identified as a specific focus within the LCA study because Formway is actively investigating the best end of life (EOL) strategy for the LIFE chairs as part of a company stewardship program. Initially, a streamlined version of this LCA study [15] was conducted using EcoIndicator99 methodology, and this was later extended to include a full range of life cycle stages. Furthermore, sensitivity analysis was carried out to determine sensitivity to aluminium recycled content.

(b) Scope

The scope of the study was aimed at conducting a quantitative LCA that included all possible processes from cradle to grave within practical limitations. The inventory of inputs and outputs of the product included the following stages:

- Extraction of raw materials from the earth's crust and subsequent refining to commercial quality.
- Utilisation of raw materials to manufacture the components by Formway's direct suppliers.
- Transportation of the components from the sites of manufacture to the production facility at Formway, Wellington.
- Assembly and packaging of the LIFE chair.
- Transportation of manufactured products from Formway to customer.
- Use phase and waste management.

Fig. 3 indicates the relevant boundary of this LCA. This incorporates inputs and outputs in terms of raw materials, energy, emissions, wastes, etc. per life cycle stage component.

Fig. 3

The main inventory assumptions made were:

- Aluminium with the world average recycled content of 34% [16] was used for both the aluminium and GFN base chairs.
- An average recycled content of 20% for steel components was used in both chairs (with validation from suppliers).
- Polyethylene terephthalate (PET), which was used as a proxy for Hytrel-crastin, displays similar environmental effects as Hytrel-crastin.
- The customer is considered to be in Sydney, Australia, where the manufactured chairs are transported to from New Zealand.

(c) Functional unit

The function of the LIFE chair is to provide stable, ergonomic, seating support for an office workstation. The functional unit for one LIFE chair was defined as provision of comfortable office seating, with the features stated in the product description [17], over a period of 10 years in line with the product warranty.

2.3 Inventory Analysis

As mentioned previously, there are two distinct models of the LIFE chair where it is manufactured with either an aluminium base or with a glass filled nylon (GFN) base. The two models weigh approximately 18kg and 17kg respectively. The percentage material composition for the two chair models is given in **Table 1**. The most significant difference between the two LIFE models is their aluminium and GFN contents; the aluminium base model has approximately 2kg more aluminium by weight than the GFN base model, and the GFN base model has approximately 1.5kg more GFN than the aluminium base model.

Table 1

For the study, data were used directly from suppliers where possible. Where supplier data were unavailable, SimaPro7 databases, specifically the EcoInvent v1.3 database [18], were used directly with modifications to electrical energy models. The reason for the modification is that EcoInvent consists primarily of European data, whereas Formway materials come from NZ, Australia, China, Germany and USA. **Table 2** shows the percentage source of materials for this study. The electricity modifications were deemed sufficient to reflect the process data for Formway suppliers. Some support materials to capital goods and manufacturing processes were included as available in SimaPro7. If possible, data for the relevant time periods were also chosen. Description of inventory data and assumptions is given in online appendix 1.

Table 2

2.4 Impact Assessment

Impact assessment was carried out using SimaPro7 LCA software by PRé Consultants [19], employing CML 2 baseline 2000 methodology [20]. The overall study enabled a compilation of results with respect to the default impact categories such as aquatic depletion, ozone layer depletion, acidification, eutrophication, etc. For the purpose of this paper, only characterisation results for Global Warming Potential (GWP100) are presented. This category expresses GWP over a time horizon of 100 years and is measured in kg CO_2 equivalent. The category was chosen for two reasons: 1) Global warming is a significant issue for businesses and 2) other categories follow a similar pattern of result as the global warming potential category.

3 LCA Results

The first set of results in the report is the baseline case, which includes all the life cycle stages discussed above using the average aluminium recycled content (34%) and considering landfill for the waste management scenario. The remaining results are presented according to study goals. The GWP100 results are presented as a percentage relative to the total GWP100 of the LIFE chair model with the aluminium base. **Fig. 4** illustrates the results for the baseline case. Note that results showing the nine default impact categories as per CML 2 for the baseline case are included in online appendix 2.

3.1 Goal 1: Determine hotspots in the lifecycle

Fig. 4 illustrates the individual contribution from each life cycle stage of the two LIFE chair models. This clearly shows that the raw material extraction and refinement and component production stages contribute to high GWP100. However, the raw material extraction and refinement stage is of most significance, contributing over half of the total GWP100 impact for both LIFE chair models. The two transport stages and the waste management stage show negligible GWP100 contribution in comparison. Since the raw material extraction and refinement stage was the most significant life cycle stage, it was investigated further to determine the material responsible for this impact contribution as shown in **Fig. 5**. This figure compares the percentage GWP100 results contributed from the raw material extraction and refinement stage relative to the total GWP100 impact of the LIFE chair model with the aluminium base.

Fig. 5

It was found that aluminium was the major contributor to the GWP100 impact. For the LIFE chair model with the aluminium base, aluminium was found to be responsible for approximately 78% of the GWP100 impact at the raw material extraction and refinement stage. Aluminium contributes to 59% and 50% of the total weight of the LIFE chair models and it also has relatively high energy requirement to produce, therefore it is not surprising that environmental impact from aluminium dominates the raw material and refinement stage.

3.2 Goal 2: Comparison of LIFE chair models

Fig. 4 and **Fig. 5** also contain the comparison of GWP100 for the two LIFE chair models. According to the results, the LIFE chair model with the aluminium base contributed approximately 10% more GWP100 than the GFN base model for the entire life cycle. Sine the main difference between the two chair models is the content of aluminium and GFN, the main difference between the two chair models for the raw materials extraction and refinement stage is also the impacts contributed by aluminium and GFN (**Fig. 5**). Given that the chair model with the aluminium base has more aluminium in its material composition, the GWP100 contribution from aluminium is higher than that of the GFN base model. Likewise, since the chair model with the GFN base has more GFN, GWP100 contribution from GFN is greater for this model during the raw material extraction and refinement stage. Hence the results directly reflect the difference in the two material contents of the respective chairs.

3.3 Goal 3: Waste management

With respect to waste management, both chairs are technically over 90% recyclable; however, this study compares the two scenarios where 1) the entire chair (including packaging) is landfilled, and 2) all metal components are recycled and the remainder landfill. The transport of components to the nearest landfill/recycling facility is also included.

The results from the comparison of EOL processes and transport to the EOL facilities are given in **Fig. 6**. This figure compares the percentage GWP100 from transport and EOL scenario for the two LIFE chair models relative to the total life cycle GWP100 impact of the LIFE chair model with the aluminium base.

Fig. 6

The results indicate that landfilling both LIFE chair models result in very similar GWP100 impact. The recycling scenario however, results in avoided impact, which is depicted by negative figures. This avoided impact can be thought of as the avoided burdens from recycling materials in relation to the production of raw materials. Since there is more metal in the chair model with the aluminium base, it has more avoided impact. With regard to recycling, the benefits of recycling both models clearly outweigh the impact generated from transport to recycling facilities.

With respect to goal 2, the difference between the total GWP100 for the entire life cycle of the two LIFE chair models was found to be approximately 10%, where the chair model with the aluminium base contributed to the higher impact. When the two models are recycled, there is negligible difference between them. Thus the investigation of the waste management options indicate that recycling at EOL is fundamental in reducing GWP100 impact.

3.4 Sensitivity analysis

Sensitivity analysis was carried out to determine the relative effect of recycled aluminium content, since aluminium is a major contributor of GWP100 in the study. Three scenarios were considered:

- Primary aluminium use (P).
- 34% recycled aluminium – baseline case (RA1).
- 100% recycled aluminium (RA2).

The total results considering the sum of all life cycle stages for both LIFE chair models are given in **Fig. 7**. Note that this figure compares the percentage GWP100 relative to the total life cycle GWP100 from the baseline case (considering 34% recycled content in aluminium and landfilling at EOL) of the LIFE chair model with the aluminium base.

Fig. 7

The total results highlight sensitivity to the recycled content of aluminium depending on the chosen waste management option. When considering the landfill scenario it was found that GWP100 impact decreases with increased recycled content in aluminium for both chairs. However since the chair model with the aluminium base has more aluminium, it incurs higher GWP100 than the GFN model. When considering the recycling scenarios for both LIFE chair models, it was found that the total life cycle impact was equivalent for the two models. This is because of the way the recycling of aluminium was modelled; e.g. recycling the chair with 34% recycled aluminium would essentially avoid the manufacture of 66% primary and 34% secondary aluminium; recycling the primary aluminium would avoid the production of primary aluminium; and recycling 100% recycled aluminium would avoid production of more 100% recycled aluminium. Thus the final output from recycling would be considered as secondary aluminium for the next available life cycle.

4 Conclusions and recommendations

The study was useful in providing better understanding of the life cycle GWP100 impacts of the LIFE chair. As such, it was found that the raw material extraction and refinement stage of the life cycle was significant for both LIFE chair models.

The baseline case showed that GWP100 impact from transport and waste management (landfill) was negligible compared to the raw material extraction and refinement stage. Investigation of the raw material extraction and refinement stage illustrated that aluminium was the main contributor of the high GWP100 in both chair models. When comparing the overall life cycle, it was found that the chair model with the aluminium base contributed more GWP100 than the GFN model. This is directly attributed to the material content of the two chair models. The waste management scenario comparing landfilling and recycling illustrated the benefits of recycling at end of life where the recycling scenario contributed to avoided burdens. Since there is more aluminium available for recycling in the LIFE chair model with the aluminium base, it yielded higher avoided impact than the GFN base model. Sensitivity analysis pertaining to the recycled content of aluminium showed that use of higher recycled contents lead to lower GWP100 impact if the chair models are landfilled. When considering the recycling scenario, it was found that recycled content of aluminium has negligible effect on the overall GWP100 impact. These results highlight the need for supply chain management, use of materials that are less energy intensive and recycling at the waste management stage. Additionally, the LCA technique highlighted limitations pertaining to data availability specific to the New Zealand manufacturing arena. Research into the relevance of other impact categories (eutrophication, acidification, etc.) for a New Zealand specific case would also be beneficial in the future.

5 Summary

This study was aimed at conducting environmental Life Cycle Assessment in order to quantify impacts of Formway's LIFE chair models (with aluminium base and GFN base respectively), so as to gain a better understanding of the associated life cycle impacts. The study included all life cycle stages from raw material extraction to waste management. Data was gathered from suppliers and used to modify existing data records from the EcoInvent database. Impact assessment was carried out using the CML 2 baseline 2000 methodology available in SimaPro7. This paper presented the Global Warming Potential (GWP100) results from the study. It was found that for both chair models, GWP100 impact was significant at the raw materials extraction and refinement stage where impact accounted for over 60% of the total GPW100 contribution for both chairs. Of the two chair models, the one with the aluminium base contributed to 10% more GWP100 when considering the entire life cycle. Aluminium was found to be the most significant contributor of GWP100 impact at the raw material extraction and refinement stage. Since the aluminium base chair model has more aluminium than its GFN counterpart, the aluminium base model had more impact from aluminium. The waste management scenarios showed that recycling at end of life is beneficial, allowing for avoided GWP100 burdens. Sensitivity analysis determined that a high use of recycled content in aluminium is beneficial. In addition to determining the environmental burdens of the products, the project also assisted in compiling valuable data on Formway products and processes including investigation of the cleaner production efforts of companies within Formway's supply chain.

Acknowledgements

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Table 1

	LIFE % Weight component	
Material	**Aluminium base model**	**GFN base model**
Aluminium	59.3	49.8
Steel	9.1	9.6
Glass filled nylon (GFN)	6.3	15.6
Polypropylene	0.8	0.9
Glass filled polypropylene	0.3	0.3
PUR (polyurethane)	4.6	4.8
POM (Acetyl)	1.8	1.9
ABS	2.1	2.2
Fabric	0.8	0.8
Hytrel-Crastin (PBT)	7.1	7.6
PA6 (nylon)	2.2	2.3
Packaging	5.7	4.2
Total	**100**	**100**

Table 2

Material	Location of component manufacture
Aluminium	Al base model: 58% USA/ 41% China/ 1% NZ GFN base model: 72% USA/ 27% China/ 1% NZ
GFN	Al base model: 100% USA GFN base model: 43% USA / 57% Australia
Mesh/fabric	100% Germany
Steel	8% NZ/ 92% China
Hytrel-crastin	100% NZ
Other plastics	5% NZ/ 95% USA

Fig 1

	Component	Material
1 -	Mesh back	Polyester
2 -	Back frame	Glass filled nylon
3 -	Lumbar	ABS
4 -	Lumbar hinge	Nylon
5 -	Arm	Aluminium
6 -	Arm pads	Polyurethane foam
7 -	Arm components	Acetal
8 -	Seat cushion	Polyurethane foam
9 -	Seat moulding	Hytrel Crastin(PBT)
10 -	Seat carriage	Aluminium
11 -	Mechanism assembly	Aluminium
12 -	Gas spring tube	Steel
13 -	Base	Nylon / aluminium
14 -	Castors	Nylon
15 -	Castor axle, spring	Zinc
	Springs, bolts, pivots	Steel

Fig 2

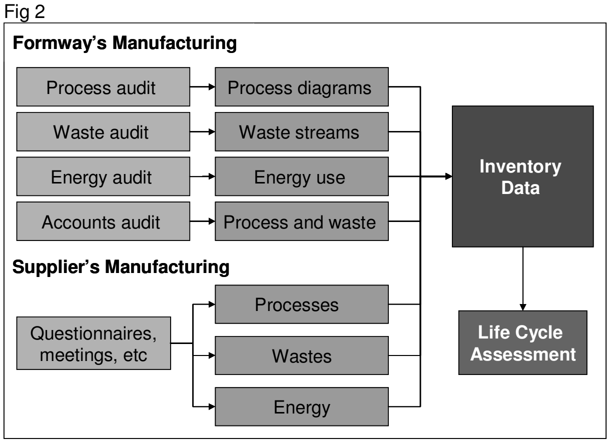


Fig 3

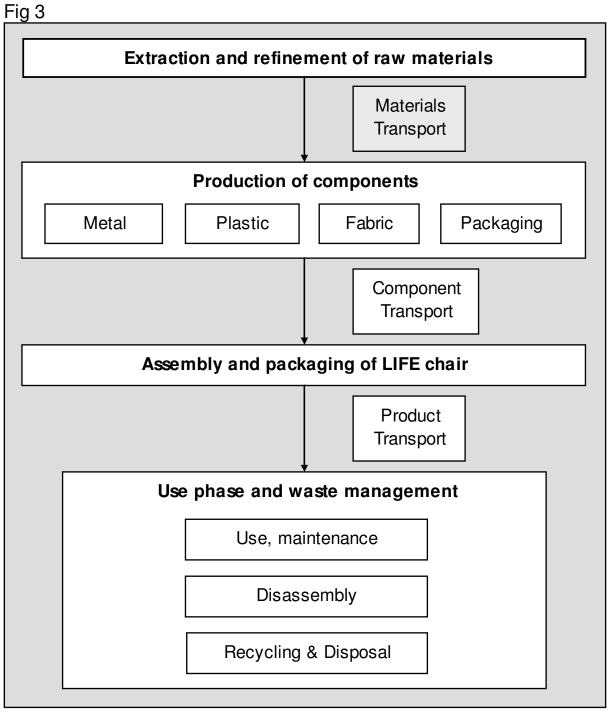


Fig 4

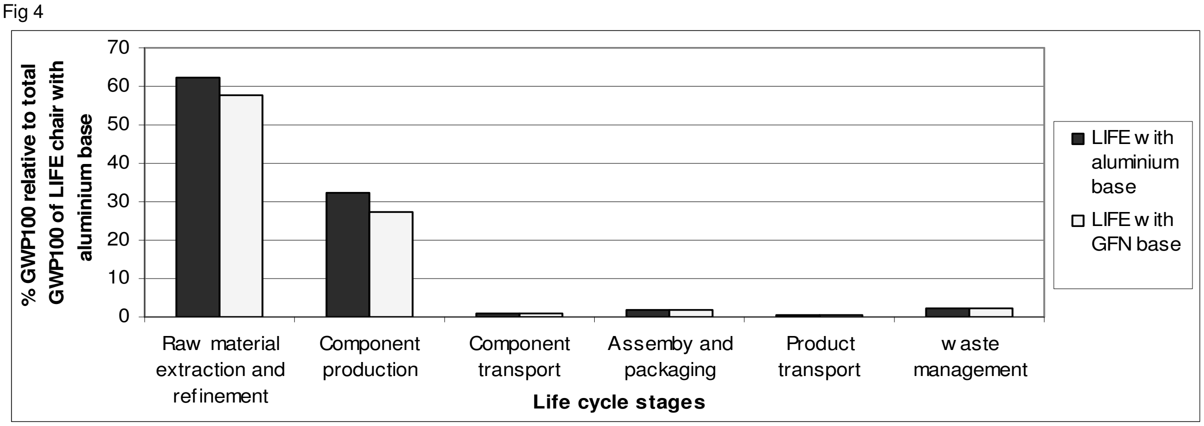


Fig 5

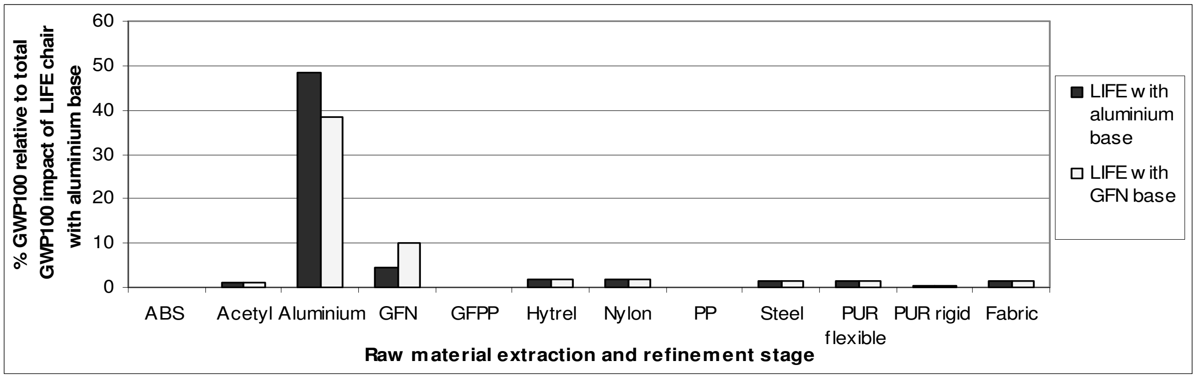

% GWP100 relative to total GWP100 impact of LIFE chair with aluminium base
60
50
40
30
20
10
0
ABS
Acetyl
Aluminium
GFN
GFPP
Hytrel
Nylon
PP
Steel
PUR flexible
PUR rigid
Fabric
Raw material extraction and refinement stage
LIFE w ith aluminium base
LIFE w ith GFN base

Fig 6

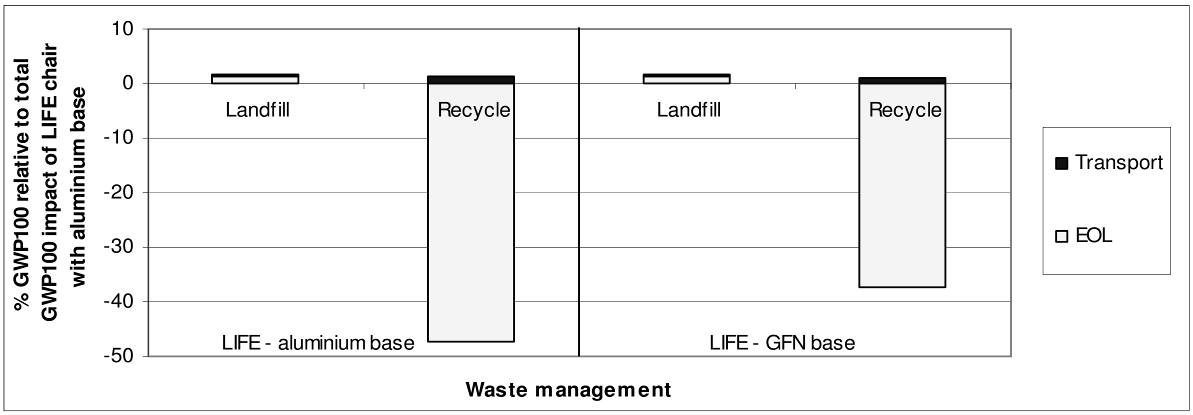
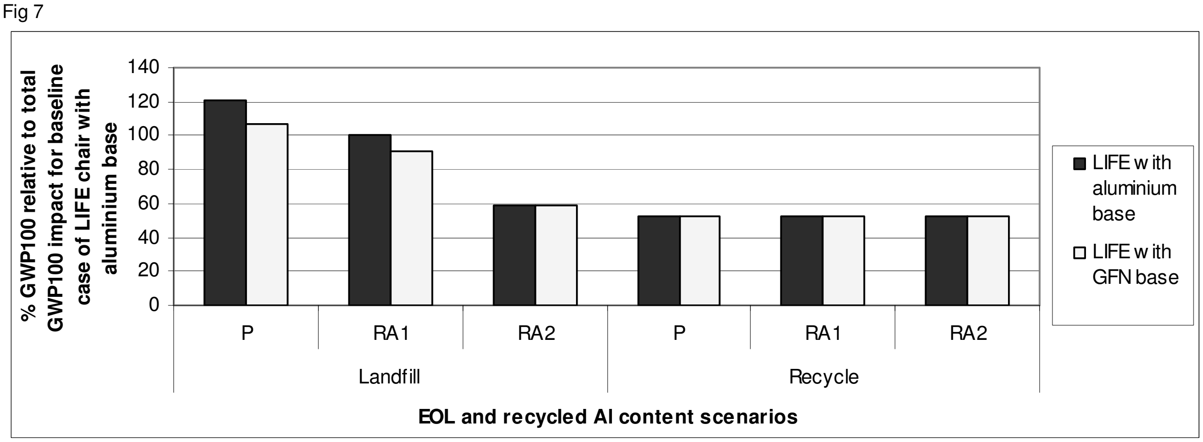

% GWP100 relative to total GWP100 impact of LIFE chair with aluminium base
10
0
-10
-20
-30
-40
-50
Landfill
Recycle
Landfill
Recycle
LIFE - aluminium base
LIFE - GFN base
Waste management
Transport
EOL

Fig 7


% GWP100 relative to total GWP100 impact for baseline case of LIFE chair with aluminium base
140
120
100
80
60
40
20
0
P
RA1
RA2
P
RA1
RA2
Landfill
Recycle
EOL and recycled Al content scenarios
LIFE w ith aluminium base
LIFE w ith GFN base

Online Appendix 1

(a) Raw material extraction and refinement

The materials required for manufacturing the LIFE chair are given in **Fig. 1**. The data used for raw material extraction and refinement were taken from the EcoInvent database. The electrical energy models were modified to reflect the respective locations as shown in **Table 2**. Note that transport of materials from raw material extraction and refinement to component manufacture was not considered due to insufficient data. This is because suppliers have numerous and variable sources of material supply according to market criteria such as material availability and price.

(b) Manufacture of LIFE components

At the component manufacture stage, suppliers use extracted and refined materials to manufacture components according to design criteria. The main processes used by Formway's suppliers are listed in **Table 3**. Data from suppliers were used to modify existing records in the EcoInvent database so as to determine a Formway specific case.

Table 3

(c) Transport of components to Formway

The transport scenario considers transportation of components from suppliers to final assembly at Formway via road and sea as given in **Table 4**. Where distances of less than 100km are considered, small trucks (capable of carrying 16 tonnes) are used for transport. For distances greater than 100km, large trucks (32 tonnes) are used. Commercial scale freight ships are used for all sea transport.

Table 4

(d) Assembly and packaging of LIFE

The components are assembled using hand and power tools at Formway's Wellington plant in New Zealand. Assembling only requires electrical energy and manpower.

(e) Transport of product to customer

This study considers the transport scenario where the assembled and packaged LIFE chairs are transported to a customer in Sydney, Australia. The respective transport modes and distances are given in **Table 5**. Road transport was carried out using the small trucks and freight ships were used for sea transport.

Table 5

(f) Use phase and waste management

No environmental exchange takes place during use of the chairs since the product does not require energy or water to function, and it was assumed that no significant repairs are made during its life. The only foreseeable need was the cleaning which includes wiping the surface to clear dust or any marks, and is expected to have negligible environmental consequences.

Table 3: Component manufacturing processes
Table 4: Transport 1: modes and distances from suppliers to Formway
Table 5: Transport 2: modes and distances from Formway to customer

Table 3

Material	Process
Aluminium	Die-casting
Steel	Machined
Polypropylene	Injection moulding
Glass filled nylon	Injection moulding
Acetal	Injection moulding
Polyurethane foam	Reactive injection moulding
Back suspension fabric	Extruded polyester filament

Table 4

Material	Location	Road (km)	Sea (km)
Aluminium	USA	17.3	10742
	China	45.3	8953
	New Zealand	190	-
GFN	Australia	35.3	1490
Fabric	Germany	429.3	11585
Steel	China	200	10050
	New Zealand	650	-
PBT	New Zealand	190	-
Other plastics	New Zealand	190	-
	USA	578	18761
Cables	USA	131.3	10176

Table 5

Location	Mode of transport	Distances (km)
Gracefield plant to Port of Wellington	Road	15.3
Port of Wellington to Port of Sydney	Sea	1236
Port of Sydney to Rockdale plant	Road	17.2
Rockdale plant to customer	Road	16.3

Online appendix 2

Fig 8: % impact comparison of the two LIFE chair models using default categories relative to each impact category of the chair model with aluminium base

Fig 8.