Streamlined Life Cycle Assessment of a Coffee Machine

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Coffee Machine Streamlined Life Cycle Assessment

Introduction

Coffee machines consume a significant amount of energy. It is estimated that they account for about 4% of the total electric consumption of a typical household in Europe. There were approximately 100 million coffee machines in the European Union as of 2006 consuming 17TWh of power per year. [**1**] There is a large room for improvement in the sustainability of current coffee machine designs.

Overview

The aim of this paper is to carry out a streamlined life cycle assessment (LCA) of a baseline coffee machine. An improved product will be designed for delivery in 2020 and a streamlined LCA will again be carried out. A quantitative assessment will be done of how the environmental impact of the product has been reduced.

Baseline CED Assessment study

Introduction

The cumulative energy demand (CED) of a product refers to the total energy usage of a product throughout its life cycle. A baseline CED assessment was carried out on a typical coffee machine to provide a reference against which improvements can be made.

Overview

The cumulative energy demand of the coffee machine shown in the figure below (taken from "Materials and the Environment" by Michael F. Ashby) [**2**] was examined by looking at the CED of its production stage, usage stage and, finally, disposal stage.

Figure 1 Baseline coffee machine

Production CED

Material Extraction & Manufacture Process

The housing of the coffee machine is manufactured from moulded polypropylene. The carafe is made from glass. There are several small steel and aluminium components. The electrical components consist of a heating element, a cable and a plug. Some electronics and a LED indicator are used in the control system. The table below shows the energy demand for the materials and processes used in the manufacturing stage of the coffee machine

Table 1 Material and Process Energy Demand

Component	Material	Process	Mass kg	Material Energy MJ	Process Energy MJ	Total Production Energy MJ
Housing	Polypropylene	Polymer moulding	0.91	85.54	7.826	93.36
Small steel parts	Steel	Def. Processing	0.12	9.72	0.408	10.13
Small Aluminium parts	Aluminium	Def. Processing	0.08	16.8	0.208	17
Glass Jug	Glass (Pyrex)	Moulded	0.33	8.25	2.706	10.96
Heating element	Ni-Cr alloy	Def. Processing	0.026	3.38	0.0676	3.45
Electronics & LED	Electronics	Assembled	0.007	21	0.91	21.91
Cable sheath, 1m	PVC	Polymer extrusion	0.12	7.92	0.912	8.83
Cable core, 1m	Copper	Def. Processing	0.035	2.485	0.07	2.55
Plug body	Phenolic	Polymer moulding	0.037	3.33	0.481	3.81
Plug Pins	Brass	Def. processing	0.03	2.16	0.069	2.23
Packaging, Padding	Polymer foam	Polymer moulding	0.015	1.65	0.165	1.82
Packaging, box	Cardboard	Construction	0.125	3.5	0.0625	3.56
Other materials	Proxy material: Polycarbonate	Polymer moulding	0.04	4.4	0.44	4.84
TOTAL			**1.875**	**170.135**	**14.33**	**184.45**

Transport

The coffee machine is manufactured in South-East Asia and shipped 17,000km to Europe. The energy used in shipping a product is 0.16 MJ/(metric ton x km). The transport energy used by shipping a 1.87kg can be calculated to be:

$$0.16 \times 0.001875 \times 17{,}000 = 5.1\ MJ$$

Usage CED

The Cumulative Energy Demand of a 640-watt coffee machine was examined. This coffee machine uses full power to make 4 cups of coffee in 5 minutes. The coffee is then kept hot for a further 30 minutes, requiring one sixth of full power. This is equivalent to 5 minutes at full power. The total power usage of a single use-cycle is therefore equivalent to 10 minutes consuming 640-Watts of electrical power. Assuming the machine is used once a day over a lifespan of 5 years, the total electrical power consumed is 194kWh.

The coffee machine examined consumes 0.3W in standby mode. A total annual standby time of 7000 hours was assumed. Based on this the total power consumed over a 5 year life span can be calculated to be:

$$0.3 \times 7000 \times 5yrs = 10.5kWh$$

The total power consumption for the coffee machine over its 5 year life can now be calculated.

$$194\ kWH + 10.5\ kWH = 204.5\ kWh$$

To calculate the energy consumed by the coffee machine it is necessary to look at the energy required to generate the power it uses. The table below shows the energy sources used to generate electricity in Ireland.

Table 2 Electricity Generation Sources for Ireland

Country	Fossil Fuel %	Nuclear %	Renewables %
Ireland 2010	92.1%	0	7.9%
2020	60%	0	40%

If the machine is used in Ireland 92.1% of the electrical power (188.3445 kWh) is generated using fossil fuel energy. This is then multiplied by 3.6 to get the electrical energy and then divided by the conversion efficiency 0.40. This gives the fossil-fuel equivalent energy which is 1695.1MJ

Each use cycle also consumes a filter paper, weighing approximately 2 grams. Over 5 years 1,825 of them (3.65kg of paper) are used. The embodied energy of paper is 28 MJ/kg. The total energy from these filter papers can be calculated to be:

$$28 \times 3.65 = 102.2MJ.$$

The total CED from the usage stage is found by adding the electrical energy demand and the filter paper energy.

$$CED_{use} = 1695.1\ MJ + 102.2\ MJ = 1797.3\ MJ$$

Disposal CED

The energy used disposing of these materials in a landfill is equal to 0.1MJ/kg. The total energy used disposing of these materials in a landfill can therefore be calculated to be 0.187 MJ.

Total CED

The total CED of the coffee machine can be found by adding the CEDs from the production, usage, and disposal stages.

Table 3 Total CED

Production CED					
Materials MJ	Manufacturing MJ	Transportation MJ	Usage CED MJ	Disposal CED MJ	Total CED MJ
170.135	14.33	5.1	1797.3	0.187	1987

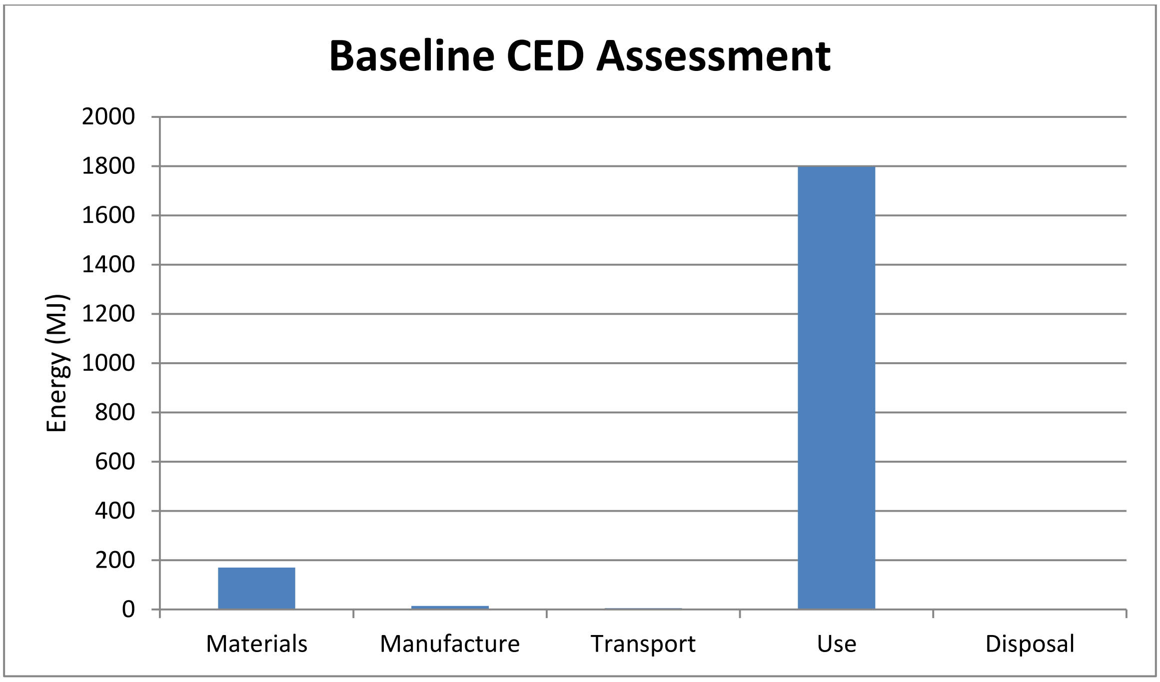

Figure 2 Baseline CED Graph

Baseline CED Assessment Observations

From examining the quantitative CED assessment it can be seen that the use stage of the examined coffee machine has the highest total, while the production and disposal stages have a comparatively insignificant CED. The largest potential reduction of energy usage could be achieved by altering the use stage of the coffee machine

Redesign CED Assessment

Overview

For the improved design of this product it was decided that reducing the CED of the coffee machine's use stage would be the primary focus of the redesign. Achieving this would likely result in increased energy usage in the production stage, however if the overall CED of the product could be reduced significantly and the sustainability of the product improved then the redesign could be deemed a success.

The initial step in the redesign process was to look at where most of the electrical energy required in the use of the product was being used. The coffee machine uses full power for 5 minutes to heat a Ni-Cr alloy heating element which warms the water to near boiling point to produce 4 cups of coffee. The coffee is then kept warm in a glass carafe using 1/6th of full power for 30 minutes. The energy demand to keep the coffee warm could be reduced or eliminated completely by introducing a better insulated carafe. A vacuum flask is one of the best ways of keeping a liquid hot. A vacuum flask carafe was implemented in this redesign and completely eliminates the energy needed to keep the coffee warm.

Another large factor in the CED of the use stage was the requirement of single-use paper filters for each use-cycle of the coffee machine. Over the lifespan of 5 years, the CED of these filters amounted to over 100MJ. The improved redesign incorporates a stainless steel reusable filter. This filter can be reused indefinitely as long as it is emptied and rinsed under tap water after every use cycle. By incorporating this design into the product, the CED from paper filter paper can be removed from the use stage.

A coffee machine is composed of only a few key components, e.g. housing, boiler, carafe. This makes it an ideal product for modular design. A modular design (using a snap-fit jointing system for example) allows products to be easily disassembled at their end of life. This increases the amount of materials in the product that can be recovered for recycling or reuse. A modular design could be incorporated into this design without significantly increasing the amount of materials or altering manufacturing process.

Ensuring that products are properly processed at their end of life is key to a sustainable design. This can be achieved by guaranteeing that the product is returned to the manufacturer who knows the best practice for remanufacture, recycling or disposal of the product. One of the ways this can be implemented in a product is by introducing a take-back scheme. The redesigned coffee machine includes a take-back scheme where a deposit is included in the consumer price and the deposit is refunded to the consumer when the product is returned. This financial incentive is one of the best ways of ensuring the product is returned to the manufacturer.

The energy usage of the baseline coffee machine could be reduced by ensuring that it never turns on unnecessarily. The redesigned product achieves this by integrating a smart phone application (app) which examines the user's GPS location and determines if they are in the home before switching the machine on. This guarantees that the machine never turns on when the user is away from home. Standby mode is maintained to support app integration at all times.

Production CED

The two redesign changes which impact the production stage are the replacement of the glass carafe with a vacuum flask carafe and the inclusion of the reusable stainless steel filter.

Material Extraction & Manufacture Process

Table 4 Material and Process Energy Demand

Component	Material	Process	Mass kg	Material Energy MJ	Process Energy MJ	Total Production Energy MJ
Housing	Polypropylene	Polymer moulding	0.91	85.54	7.826	93.36
Small steel parts	Steel	Def. Processing	0.12	9.72	0.408	10.13

Small Aluminium parts	Aluminium	Def. Processing	0.08	16.8	0.208	17
Thermos Jug 350ml (4 cups)	**Stainless Steel**	**Def. Processing**	**0.24**	**19.2**	**1.68**	**20.88**
Thermos Jug (Handle)	**Polypropylene**	**Polymer moulding**	**0.019**	**1.843**	**0.186**	**2.029**
Heating element	Ni-Cr alloy	Def. Processing	0.026	3.38	0.0676	3.45
Electronics & LED	Electronics	Assembled	0.007	21	0.91	21.91
Cable sheath, 1m	PVC	Polymer extrusion	0.12	7.92	0.912	8.83
Cable core, 1m	Copper	Def. Processing	0.035	2.485	0.07	2.55
Plug body	Phenolic	Polymer moulding	0.037	3.33	0.481	3.81
Plug Pins	Brass	Def. processing	0.03	2.16	0.069	2.23
Packaging, Padding	Polymer foam	Polymer moulding	0.015	1.65	0.165	1.82
Packaging, box	Cardboard	Construction	0.125	3.5	0.0625	3.56
Other materials	Proxy material: Polycarbonate	Polymer moulding	0.04	4.4	0.44	4.84
Stainless Steel reusable filter	**Stainless Steel**	**Rolling**	**0.4**	**12.8**	**1.08**	**14.6**
TOTAL			2.204	195.728	14.5651	210.999

Transport

The transport process for the redesigned products remains unaltered from the baseline assessment. The increased weight of the product results in a slightly higher calculated CED of 6MJ.

Usage CED

The coffee machine uses full power to make 4 cups in 5 minutes. The need to keep the coffee hot for a further 30mins using 1/6 of full power has been eliminated by a thermos jug. Therefore the electrical power consumed is halved, to 97 kWh.

The standby mode of the redesigned product remains the same as the baseline study, 10.5 kWh.

The total electrical power demand can be calculated as:

$$194\ kWh + 10.5\ kWh = \ 204.5\ kWh$$

If the redesigned coffee machine is used in Ireland 92.1% of the electrical (107.6kwh) power (99.09KwH) is generated by fossil fuel energy. This is multiplied by 3.6 to get the electrical energy and divided by 0.4 (the conversion efficiency). This gives the fossil fuel equivalent energy which is 891.81MJ

In 2020, if Ireland meets its targets, 40% of electrical energy will be generated using renewable sources. Only 60% of the electrical power needed to for the coffee machine (64.56KwH) would be generated using fossil fuel energy. This figure is then multiplied by 3.6 to get the electrical energy and divided by 0.4 (conversion efficiency). This gives the potential fossil-fuel equivalent energy to be 581MJ assuming Ireland meets its targets.

Disposal CED

The table below shows the embodied energy of materials used in the redesigned coffee machine.

Table 5 **Embodied Energy of Recycled Materials**

Material	Weight in Product (Kg)	Embodied Energy, Recycling MJ/kg	Embodied Energy, Recycling MJ per Weight in Product
Polypropylene	0.91	40	36.4
Steel	0.12	23	2.88
Aluminium	0.08	19.5	1.56
Steel(Thermos)	0.24	23	5.52
Steel Filter	0.4	23	9.2
PP Jug Handle	0.019	40	0.76
Ni-Cr alloy	0.026	33	0.86
Electronics	0.007	-	-
PVC	0.12	33	3.96
Copper	0.035	18	0.63
Phenolic	0.037	-	-
Brass	0.03	-	-
Polymer Foam	0.015	-	-
Cardboard	0.125	19	2.375
Polycarbonate	0.04	46	1.84
Totals:	**2.204**	**317.5**	**65.985**

From the table above it can be seen that the total embodied energy of the recycled materials is 65.985MJ. The total weight of un-recycled materials is 0.089kg. The energy used disposing of these materials in a landfill is equal to 0.1MJ per kg of material. The total energy used disposing of these materials in a landfill can therefore be calculated to be 0.009 MJ.
The total CED from the disposal stage can be calculated by subtracting the embodied energy from recycled materials from the energy used to dispose of un-recycled materials in a landfill.

$$CED_{disposal} = 0.009\ MJ - 65.985MJ\ =\ -65.976\ MJ$$

Total CED

The total CED of the coffee machine can be found by adding the CEDs from the production, usage and disposal stages.

Table 6 **Total CED**

Production CED MJ					
Materials	Manufacturing	Transportation	Usage CED MJ	Disposal CED MJ	Total CED MJ
195.728	14.651	5.1	891.81MJ	-65.975	1041.314

Comparison between Baseline and Redesign

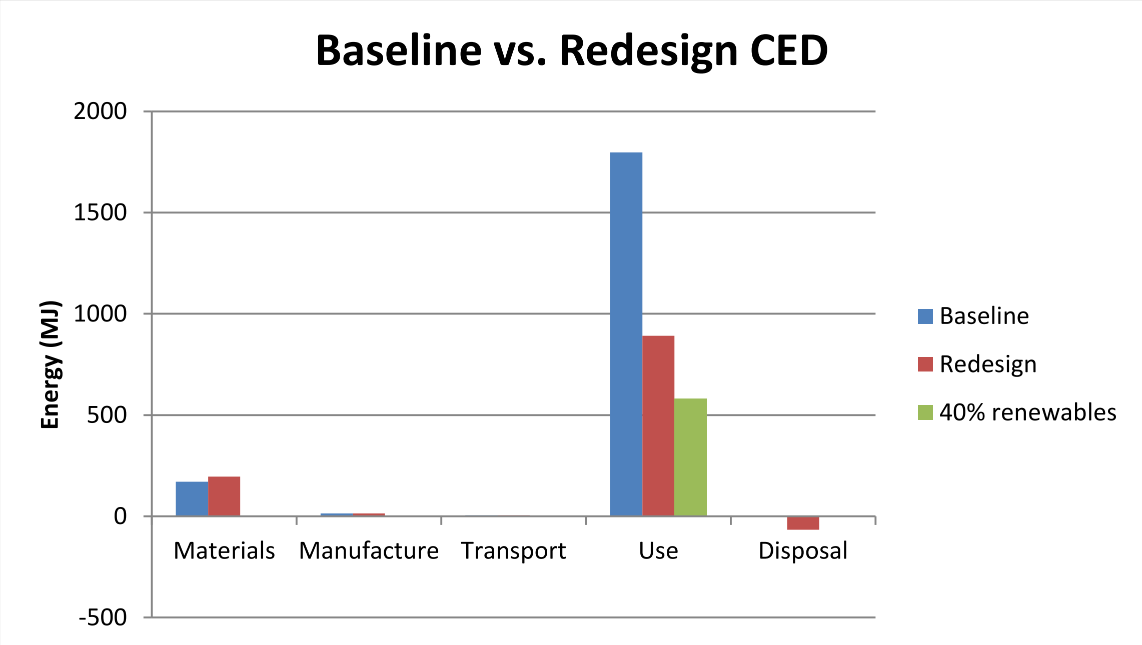

Figure 3 **Baseline CED vs Redesign CED**

From the graph above it can be seen that, while the redesigned product has a slightly higher energy usage in the production stage, the use stage has been reduced by almost half. There is also an increase in the amount of recovered energy in the disposal stage, caused by the recycling of the product. The graph above also includes an estimate for energy demand in the use stage if Ireland meets its target to use 40% renewable energy sources by 2020. In this scenario the energy usage has been reduced by almost two thirds.

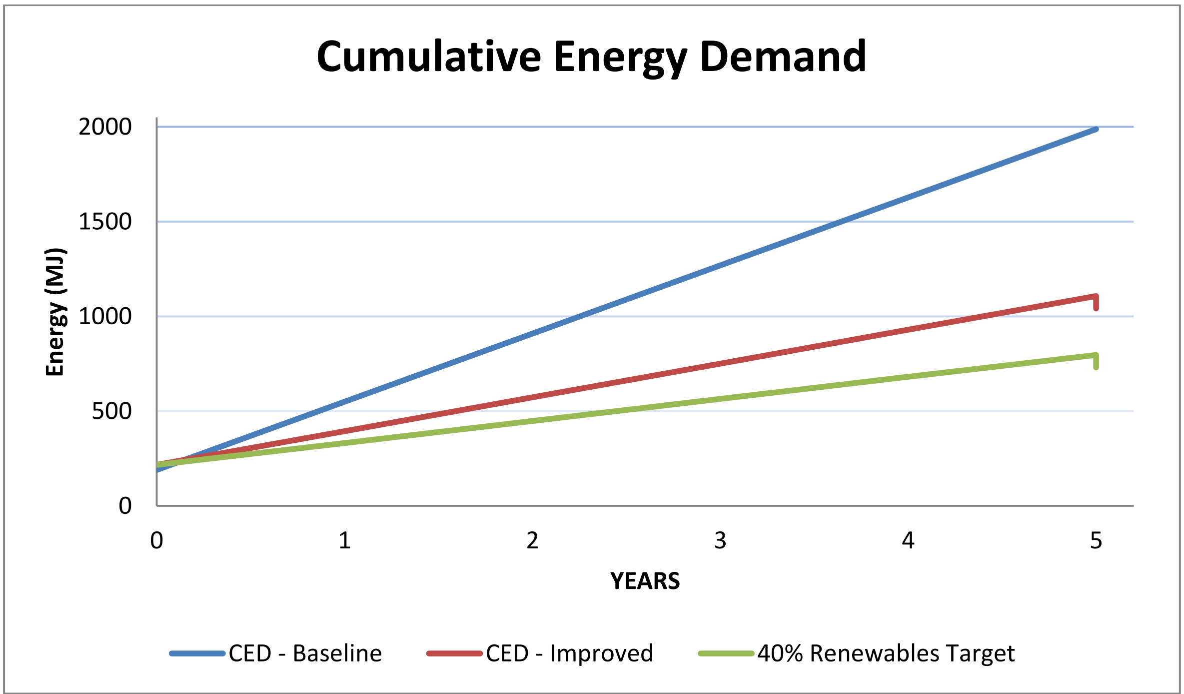

Figure 4 **CED over 5 years**

The graph above shows the cumulative energy demand of the baseline and redesigned products over 5 years. The graph demonstrates that the redesigned product becomes more energy-efficient almost immediately after production. By the end of the 5 years the energy usage of the redesigned product is almost half that of the baseline. As before, an estimate for energy demand assuming a successful 40% renewables target has been included.

System Boundary

The system boundary refers to the processes which are included in a Life Cycle Assessment.

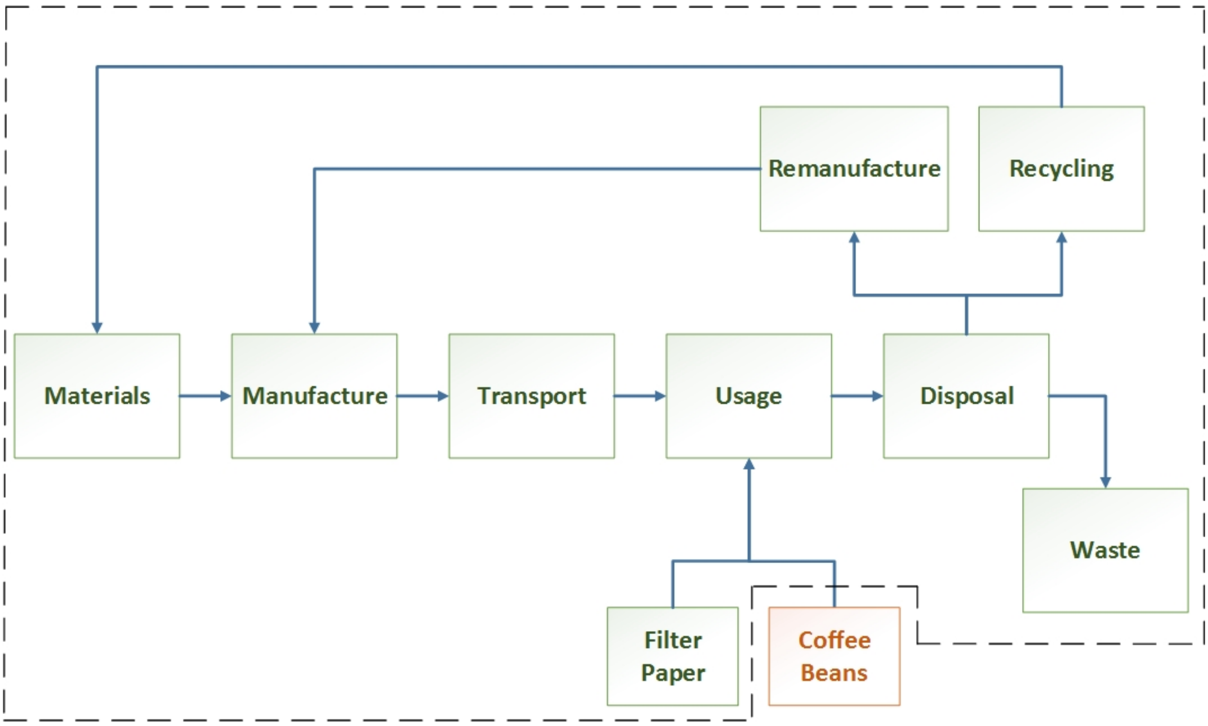

Figure 5 System Boundary

In the streamlined Life Cycle Assessment of a coffee machine the system boundary incorporated the energy use of the production stage (material extraction, manufacture processes, and transport), the usage stage (including filter papers), and the disposal stage (including three possible option; remanufacture, recycling and waste).

It was decided not to include coffee beans as an input in the system boundary.

Functional Unit

The functional unit quantifies the service that a product offers and provides a reference to which a redesigned product can be compared.

The functional unit for the baseline coffee machine is the ability to produce 4 cups of coffee (80g) in 5 minutes and keep coffee warm for a minimum of 30 minutes.

Assumptions

To allow for a quantitative assessment of both a baseline and improved design scenario, several assumptions had to be made. These largely relate to how the coffee machine is used as usage patterns in real life will vary from customer to customer. Therefore, assumptions are necessary to allow a functional unit to be established.

The assumption was made that the coffee machine is used to make 4 cups of coffee (roughly 80 grams each) each day over an assumed lifespan of 5 years. It was also assumed that the machine would be left in standby mode for 7000 hours over the same lifespan. These assumptions were used for both the baseline and redesign calculations.

It is assumed that the increase in electronics needed to support app integration in the redesigned product is negligible and so the figures from the baseline study were also used in the redesign calculations. It is also assumed that the increase in materials needed to implement a modular design is negligible.

Assumptions were also made about the fate of the products at its end of life, since ultimately the consumer will decide how to dispose of the product.

For the baseline study it was assumed that the entire product is disposed of in a landfill. For the redesigned product, it was assumed that the financial incentive introduced by the take-back scheme will encourage the user to return the product to the manufacturer. An assumption was also made that, since the manufacturer is aware of the best way to disassemble the product and recover materials, all recyclable materials are recycled. It is then assumed that all non-recycled materials are disposed in a landfill.

Redesign Sustainability Issues

Resources

Overall, the resources required to manufacture the redesigned coffee machine are higher than the baseline study. The introduction of a vacuum carafe and a reusable filter are responsible for these increases and are largely made of stainless steel. Steel is one of the most widely recycled metals with recycled steel making up 42% of the current supply. [**2**] The take back scheme proposed in the redesign increases the amount of materials which can be recovered for recycling and also increases the amount of recovered products which can be remanufactured. Both of these processes reduce the demand for raw materials.

Climate Change

One of the key improvements made in the product redesign is in energy efficiency. The redesigned coffee machine consumes just over half of the total power of the baseline product. This reduction in power demand reduces the amount of electrical energy that needs to be generated. In Ireland, 92.1% of electrical energy is generated using fossil fuels (based on 2010 figures). Fossil fuels are a major source of CO_2. The improved energy efficiency of the redesigned product reduces its carbon footprint significantly.

E-Waste

As has been previously discussed, the financial incentive take back scheme which has been proposed will increase the amount of materials recovered for recycling and remanufacture. The e-waste from the coffee machine has been minimised significantly.

Feasibility of Redesign and Potential Barriers

The feasibility of the redesigned product refers to the practicality of implementing the specified changes in design. Overall, the redesigned product is very feasible. Vacuum carafes have already been implemented by some companies into their coffee machine designs. [**3**] Reusable stainless steel filters are already commonly available on the market. Many products also feature modular designs to allow for easier disassembly and remanufacture. App integration with household electronics is increasing, for example a kettle has been designed is controllable over a Wi-Fi network using an app. [**4**] Therefore, app integration with a coffee machine design is very feasible.

Potential barriers refer to obstacles that may be incurred in the implementation of design changes. One of the obvious barriers is the increased cost associated with the redesign. Implementing a vacuum carafe, reusable filter, modular design, and electronics associated with app integration will require major design changes and significant alterations to the manufacture process. These will necessitate a large amount of financial investment in the redesigned product. Another potential barrier is the requirement of an internet connection and a smart phone to utilise the coffee machine's app integration. However, with the increasing integration of smart electronics and internet in daily life this may not be a large problem by 2020. Ensuring that costumers participate in the take-back scheme is another potential obstacle. However, the financial incentive proposed is one of the most effective ways of ensuring costumer participation in a take back scheme.

Conclusions

A baseline product was quantitatively assessed and examined to see if any improvements could be made to the design to improve its sustainability. A redesign was proposed which successfully decreased the energy demand of the product. It can be concluded that a streamlined Life Cycle Assessment can be a useful tool in designing more sustainable products for the future.

Works Cited

[1] European Commission (DG ENER). (2011, July) Preparatory Studies for Ecodesign Requirements of EuPs (III) Lot 25 Non-Tertiary Coffee Machines. [Online]. http://www.ebpg.bam.de/de/ebpg_medien/ener25/025_studyf_11-07_coffeemachines.pdf

[2] Michael F. Ashby, *Materials and the Environment*, 2nd ed. Oxford: Butterworth-Heinemann, 2013.

[3] Capresso. CoffeeTec Instruction Book. [Online]. http://www.capresso.com/pdf/coffee_tec.pdf

[4] Firebox. iKettle. [Online]. http://www.firebox.com/product/6068/iKettle