Preliminary Cradle to Gate Environmental Assessment for Cooking Devices

Author: Dr Jacquetta Lee

Author Affiliation: S2A Associates Ltd, for GAMOS

Status: For comment

Version: 1.0

This material has been funded by UKAid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies.

Executive Summary

The objective of this working paper is to provide an environmental assessment of cooking options from cradle to gate and was conducted following the principles of BS/EN ISO 14040 and 14044 and other good practice systems.

Bespoke models for four cooking devices (simple electric pressure cooker (sEPC), a single ring hotplate (HP), a twin ring LPG burner (LPGB) and a street charcoal burner (sCHB)) and three fuel/power systems (Lithium iron phosphate battery (LFP), lead acid battery (LA) and charcoal (CH) (from earth mound kilns) have been created. These have been analysed as stand-alone systems to identify key design issues, and as combined systems (device and power/fuel) to assess the relative impacts of the fuels consumed to the manufacture of the cooking device, and to assess the relative impact of each combination to each other. Eighteen midpoint and three endpoint indicators were analysed, using the ReCiPe(H) assessment methodology. The location for the assessment was Kenya.

In every assessment, the normalised midpoint categories of greatest concern were those relating to fresh water and marine ecotoxicity, and the impact on human health was found to be the dominating endpoint issue.

Potential issues that were identified with respect to the design of the devices included:

- The use of aluminium for the simple Electric Pressure Cooker (sEPC), linked to the waste treatment of redmud from bauxite production,
- The energy intensive enamelling process used on the Hotplate (HP),
- Chrome plating for the LPG burner, linked to the waste treatment for Na-dichromate,
- The treatment of sulphidic tailings from copper production, for the copper used in the anode current collector and anode paste of the lithium iron phosphate battery. Alternative lithium ion chemistries exist, and these may have lower environmental impacts, but they would need to provide a similar charge/discharge profile to LFP batteries to be a suitable substitute,
- The use of lead in the production of the lead grid for lead acid batteries. There is no alternative for this within the lead acid battery, but the knowledge and systems to recover and recycle the lead do exist (although not necessarily in all areas). Provided high standards of health and safety are followed, some of this impact can be mitigated.

When looking at the devices in combination with power/fuel sources, the following conclusions can be identified:

- Charcoal shows the highest environmental impact of all cooking combination options,
- LFP battery systems have a lower impact than Lead Acid battery systems,
- Grid charged batteries have a worse impact than PV charged batteries. This result is only valid for Kenya, as other countries have different grid fuels which will affect the environmental impacts.
- In Kenya, due to the mix of generating sources in 2016, grid based cooking is marginally better for the environment than LPG. These results are very close and further investigation is required to ascertain if the difference is real, or as a result of data gaps.

Glossary

sEPC - simple electric pressure cooker

sCHB - street charcol burner

LA – lead acid battery

LFP – lithium iron phosphate battery

LPG – liquified petroleum gas

LPGB – liquified petroleum gas burner

K - kerosene

CH - charcoal

PV – multi-crystalline photovoltaic panel

MECS – Modern Energy Cooking Systems programme

Table of Contents

1. Introduction

This working document reports on the initial findings from the environmental assessment of the MECS project. Its main focus is the cradle to gate assessment of various cooking and power source devices. The assessment at this stage is very generic and provides general guidance only.

Two levels of analysis have been undertaken, firstly, a review of the hotpots for each of the devices, identifying materials and/or processes that provide the greatest contribution to overall impact for the device. This information is aimed at the design of the devices. The second level of analysis looks at the combination of device/power/fuel source, for a range of functional units, designed to provide insight into the implications of these different combinations. This information provides the basis for determining which device/power/fuel combinations are best employed for varying local conditions, and is further explored and presented in Working Paper titled 'Environmental Assessment of ESMAP scenarios 1 and 5, cradle to end of use'.

The software used for the analysis was Simapro. It should be noted that the results presented here are interim results, and may change in the light of further data or changes to the underlying model. The study was conducted following the principles of BS/EN ISO 14040 and 14044 and other good practice systems.

2. Limitations and Assumptions for models

There are a number of assumptions that must recognised in reading this working paper.

a) Data

The data used in the model this far is a combination of data provided by ecoinvent[1] database, and specific data gathered for a particular product design or location. Table 1 shows for each product from where the main source of data has been gathered.

Item	Information source
Simple Electric Pressure Cooker (sEPC)	Teardown for Bill of Material (BoM) and process Data sources: Ecoinvent
Street Charcoal Burner (sCHB)	Materials from internet. BoM estimated from dimensions. Data sources: Ecoinvent
Liquified Petroleum Gas Burner (LPGB)	Teardown for BoM and process Data sources: Ecoinvent
Hotplate (HP)	Teardown for BoM and process Data sources: Ecoinvent
Lithium Iron Phosphate Battery (LFP)	Academic Papers for BoM and process Data sources: Ecoinvent
Lead Acid Battery (LAB)	Academic Papers for BoM and process Data sources: Ecoinvent
Charcoal production in Kenya	Academic Papers for BoM and process Data sources: Ecoinvent
Grid Electricity for Kenya	Data sources: Ecoinvent
LPG	Data sources: Ecoinvent
Multi-crystalline PV panel	Data sources: Ecoinvent
Fuelwood	Data sources: Ecoinvent

[1] https://www.ecoinvent.org. Accessed 14.07.20

Table 1: Sources of information

Where location specific data is required, relevant data sets from ecoinvent have been used, if available. If not available, appropriate averaged regional or global values have been used.

Where it is not known where a particular material/process occurs, the regional (if appropriate) or global values have been used.

The data system used is such that recycled resources are considered to be 'free' in terms of impact, and are not assigned any proportion of the original processing impacts. This is the simplest system to build, and may be reviewed as more knowledge about the systems becomes available.

b) Data gaps

There are significant data gaps in the model in its current form. This has resulted from insufficient knowledge of production routes, or unavailable/non existant data relating to emissions. In order to reduce inappropriate or skewed results from the study, a similar level of data granularity was attempted thoughout the systems under review. As more data becomes available, this will be reviewed and updated.

c) System Boundaries

This report is NOT a LCA study as defined by ISO 14040 series. This report is limited to cradle to gate (raw materials to finished product leaving the factory gate) for the analysis of the cooking devices in isolation, and cradle to end of use stage for power/fuel/device combinations.

d) Functional Unit

The functional unit for the cradle to gate assessment of the individual devices is 1 unit.

For the combined power/cooking device analysis, the functional unit for the different combinations is given in Table 3, with the rational for each combination analysed.

e) Impact Assessment Methodology.

There are no environmental assessment systems that currently focus on the African continent. For global impacts, such as climate change, this is not a concern. However, for local pathways and associated impacts, the different regions can affect the potential impacts created. The ReCiPe system (which has built on CML 2002 and Eco indicator 99 systems) will be used to assess the midpoint and endpoint environmental categories. ReCiPe integrates the midpoint and endpoint approaches in a consistent framework. See Table 2 for details of ReCiPe approach.

Principle	**Comment**
Intended purpose of the method:	Combining midpoint and endpoint methodologies in a consistent way
Midpoint/endpoint:	Midpoint and endpoint characterisation factors are calculated on the basis of a consistent environmental cause-effect chain, except for land-use and resources
Handling of choices:	Cultural perspectives are used to distinguish three different sets of subjective choices. User can choose which version to apply. • **Individualist (I)**: short term, optimism that technology can avoid many problems in future.

	• **Hierarchist (H)**: consensus model, as often encountered in scientific models, this is often considered to be the default model. • **Egalitarian (E)**: long term based on precautionary principle thinking.
Data uncertainties:	Data uncertainties are discussed in the text but not always quantified.
Regional validity:	Europe. Global for Climate change, Ozone layer depletion and resources
Temporal validity:	Present time
Time horizon:	20 years, 100 years or indefinite, depending on the cultural perspective
How is consistency ensured in the treatment of different impacts: In characterisation, normalisation and weighting?	For all emission based categories similar principles and choices are used. All impacts are marginal. All impact categories of the same area of protection have the same indicator unit. Same environmental mechanism for midpoint and endpoint calculations is used.
Midpoint impacts covered:	climate change; ozone depletion; terrestrial acidification; freshwater eutrophication; marine eutrophication; human toxicity; photochemical oxidant formation; particulate matter formation; terrestrial ecotoxicity; freshwater ecotoxicity; marine ecotoxicity; ionising radiation; agricultural land occupation; urban land occupation; natural land transformation; depletion of fossil fuel resources; depletion of mineral resources; depletion of freshwater resources
Endpoint impacts covered:	Human health (DALY); ecosystem quality (biodiversity, PDF.m^2.yr); resources (surplus cost)
Approximate number of substances covered:	Approximately 3000 substances

Table 2: Features of the ReCiPe approach, reproduced from ILCD Handbook: Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment, First edition.[2]

The specific ReCiPe impact assessment chosen was Endpoint Hierarchist. This contains data on midpoints characterisation and end point (impact on human and ecological health, and resource availablility) information. Since the main output of this stage of analysis is not to calculate absolute values but to highlight hotspots of concern, this impact assessment system can simplfy the final results, whilst still allowing for deep dives into areas of concern. Figure 1 below shows the relationship between the midpoint and endpoint indicators. All normalised data relates to averaged global impact per capita per year for the year 2010.

[2] https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-LCIA-Background-analysis-online-12March2010.pdf. Accessed 20 July 2020

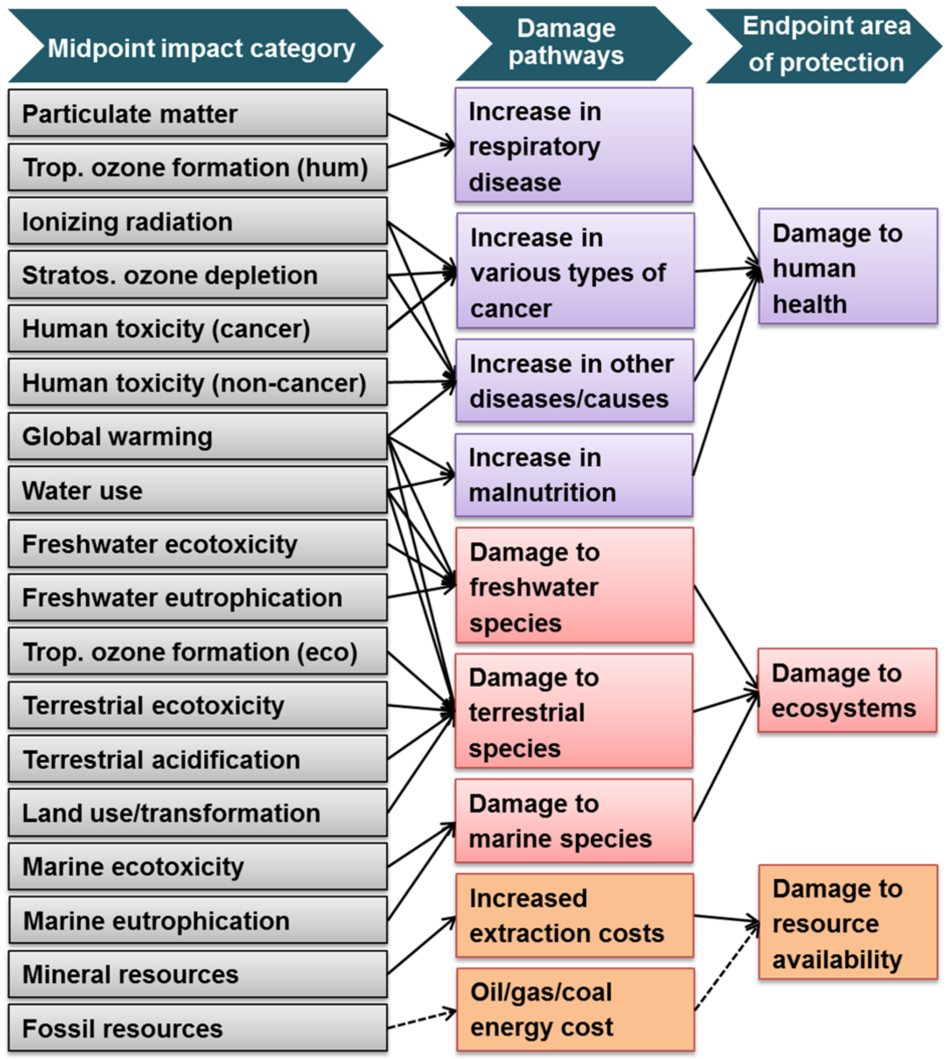


Figure 1: Relationship between midpoint and endpoint indicators.[3]

3. Cradle to Gate assessment for cooking devices

This section details the results for the individual devices that have been modelled using bespoke data for the materials and processes used. Underlying data for these has been taken from ecoinvent. Where models for LPG production, Kerosene production, Multi-crystalline PV panel, inverter, grid electricity already existed in the ecoinvent database, these have been used in the first instance. More details on the assumptions taken for these are discussed in section 3(h). For Sections 3a to 3f, Figure 2 shows a generic system flow diagram for the devices/product when analysed in isolation.

---

[3] 2017, ReCiPe 2016 v1.1 A harmonized life cycle impact assessment method at midpoint and endpoint level. Report I: Characterization, RIVM Report 2016-0104a. National Institute for Public Health and the environment. www.rivm.nl.en. https://www.pre-sustainability.com/download/Report_ReCiPe_2017.pdf. Accessed 28 July 2020

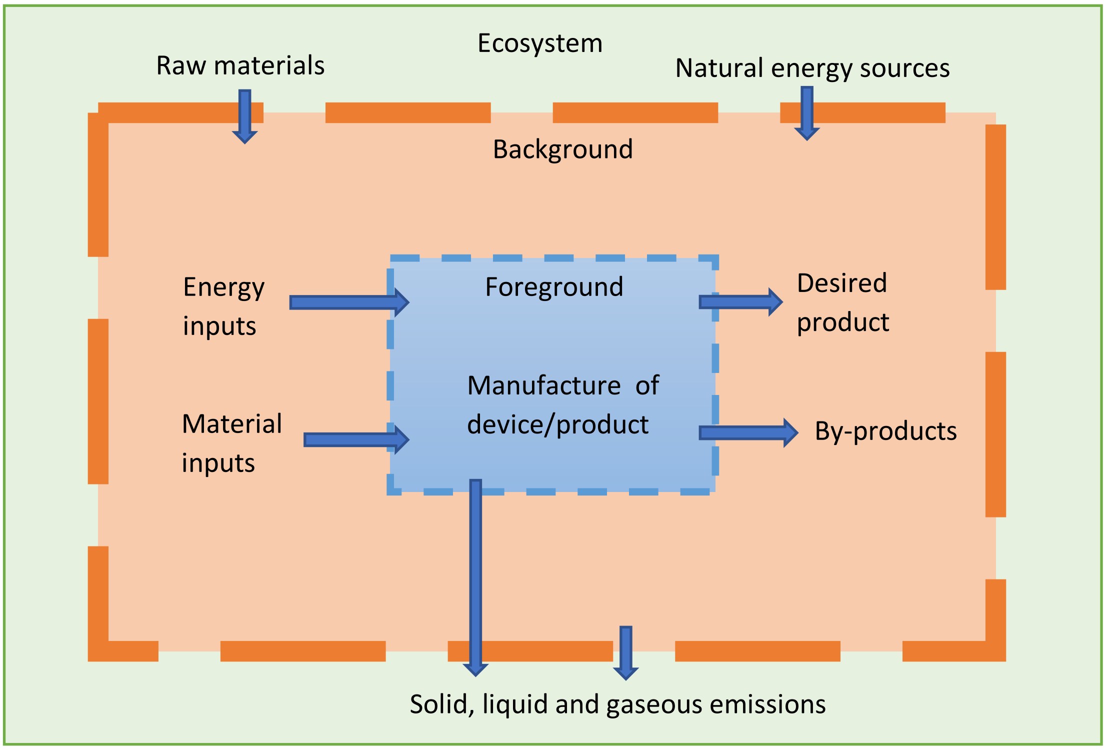
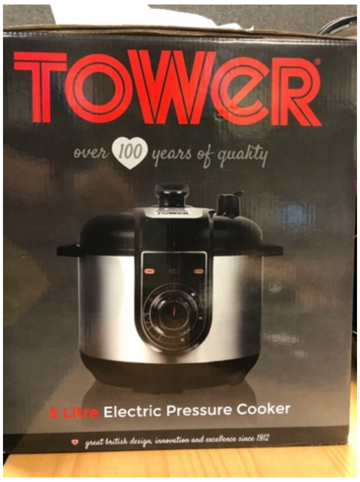


Figure 2: Generic systems boundary for devices/product in isolation

a) Simple Electric Pressure Cooker (sEPC)



Background

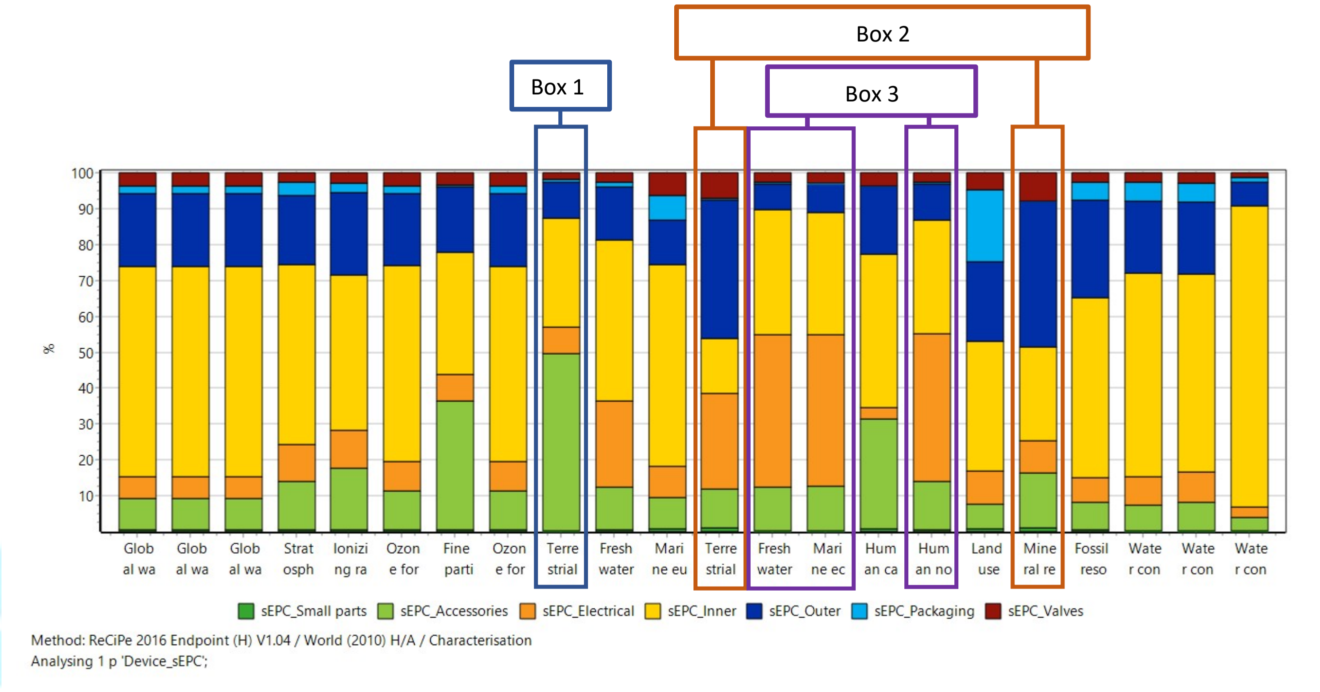
The data for this item was provided by a 'tear-down' of Tower Health T16004 One Pot Express Electric Pressure Cooker, 5 Litre, 900 Watt, Silver. This device has limited electronics, with no additional charging ports. The item was dismantled to single material components (where possible), weighed and the most likely production route determined [4].

The components were split into 7 main categories: Electronics, Accessories, Inner, Outer, Packaging, Small parts, and Valves (see Appendix A for tear-down information). This information was used to build a model of an EPC in Simapro, with the limitations and assumptions given in section 2. The graphs below show the environmental impact that occurs as a result of the manufacture of a sEPC.

[4] Thanks to N. Monk at CREST, Loughborough University for lab space and knowledge on production processing.

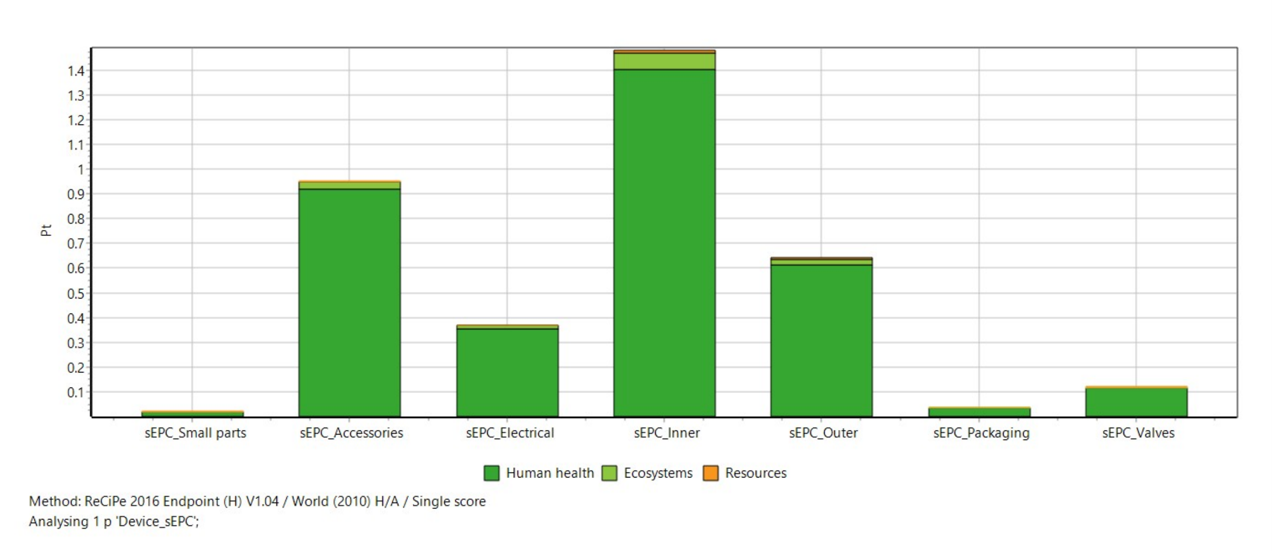
Results

From Graph 1 above it is possible to see the % contributions of the main component groups of the sEPC to the midpoint environmental categories. It can be seen that generally the sEPC Inner (yellow) contributes most to the all of the midpoint categories impact, with the exception of Freshwater and Marine ecotoxicity, and Human non carcinogen. sEPC Accessories (Box 1) contributes most to terrestrial ecotoxocity, sEPC Outer (Box 2) contributes most to terrestrial acidification and mineral resource consumption and sEPC electrical (Box 3) contributes most to Freshwater and marine ecotoxicity and human non carcinogen toxicity. The midpoint categories of most interest perhaps, are those for global warming (the first three columns), fine particulates (as these can lead to health implications particularly in enclosed spaces) and resource availability (mineral and fossil).



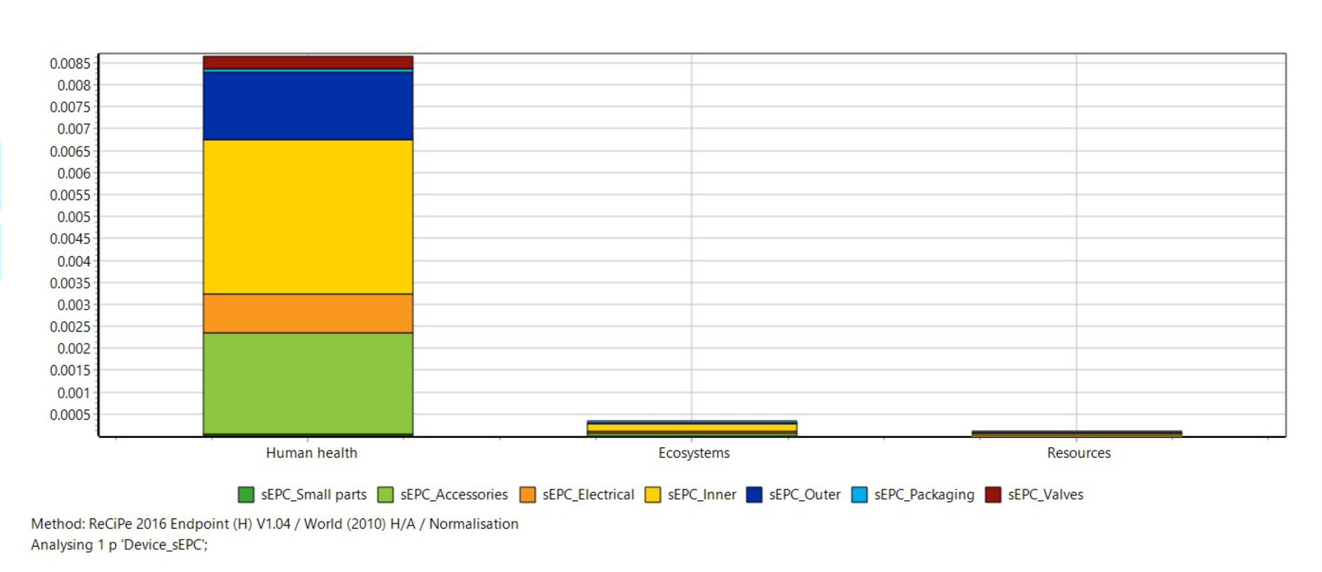
Graph 1: Midpoint category impacts for sEPC

Graph 2, shows the single score data of damage for the sEPC. This shows how the contribution of the midpoint categories (see figure 1 for the relationships between the midpoint and endpoint categories) to the effect on human health, ecosystems and resource availability. It can be seen that the top three component groups are the sEPC inner, sEPC Accessories and sEPC Outer. For all of the component groups, Human health is seen to be impacted most, with effects on resource availability almost negligible by comparison.



Graph 2: Endpoint category single score result for sEPC

It is useful to understand the size of the impact in terms of averaged global impact per capita. Graph 3 shows the normalised contributions of the component groups to the each of the endpoint impact categories and it can be seen the human health category dominates the results.



Graph 3: Normalised endpoint category results for sEPC.

Deeper investigation into the sEPC Inner data shows that the top three activities that contribute to the impact on human health are: the treatment of redmud from bauxite production (even though the global aluminium market contains recycled aluminium, a proportion is derived from virgin material), production of heat at coal furnace, and treatment of slag from electric arc furnace. This would suggest that the use of aluminium is an area that needs thought in the design of an EPC, and that alternative materials, such as steel, may reduce impact.

The sEPC accessories include plastic spoons, a nickel steam/drain tray and a chromium plated steel wire rack. Unsurprisingly, the top activities in the production of these items are nickel mining, treatment of residue from Na-Dichromate production, and the hard chromium coating. It would suggest that it might be worth the manufacturers conducting some customer analysis to see how much, if at all, these accessories are used.

The sEPC outer impacts result from production of the chromium steel used for the lid and casing. The chromium steel is predominately used for aesthetic values, as it is easy to keep clean, and resistant to corrosion. Alternatives could include a lower grade of steel with a paint coating.

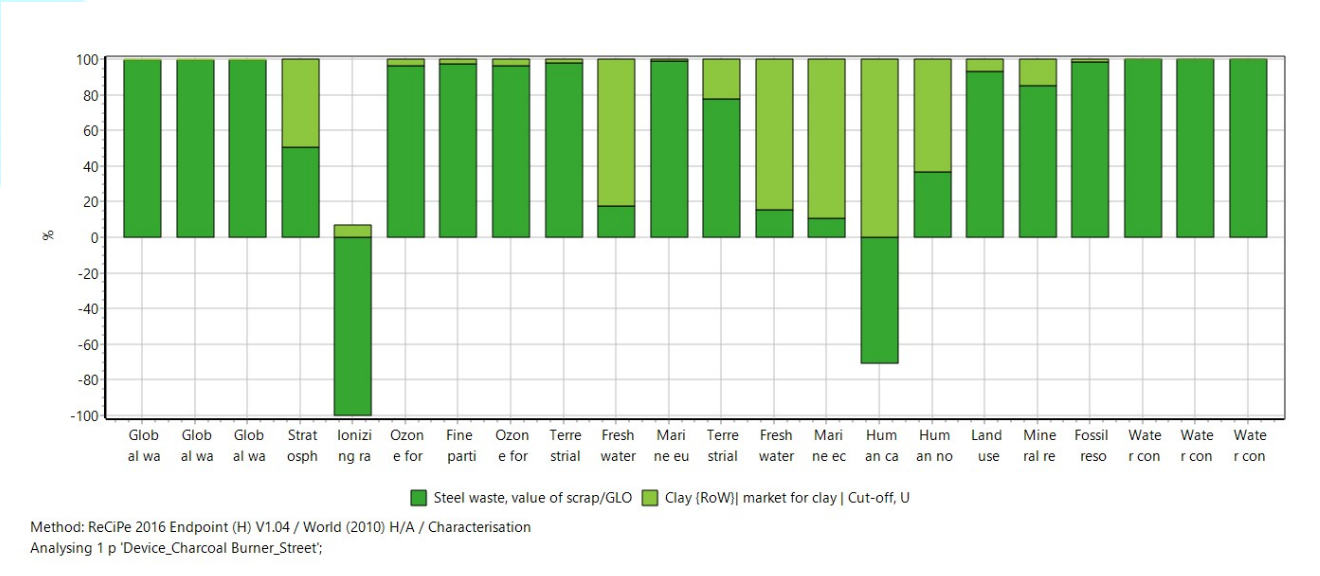
b) Street Charcoal Burner (sCHB)

Background

This is a relatively simple product, comprising of two materials, scrap steel, found through the informal economy, and a ceramic insert. Using very basic measurements, the quantities of materials required to manufacture the charcoal burner were calculated (see Appendix B). No manufacturing data for the ceramic insert was available, and it was assumed that the steel outer was formed into shape in the informal economy.

Results

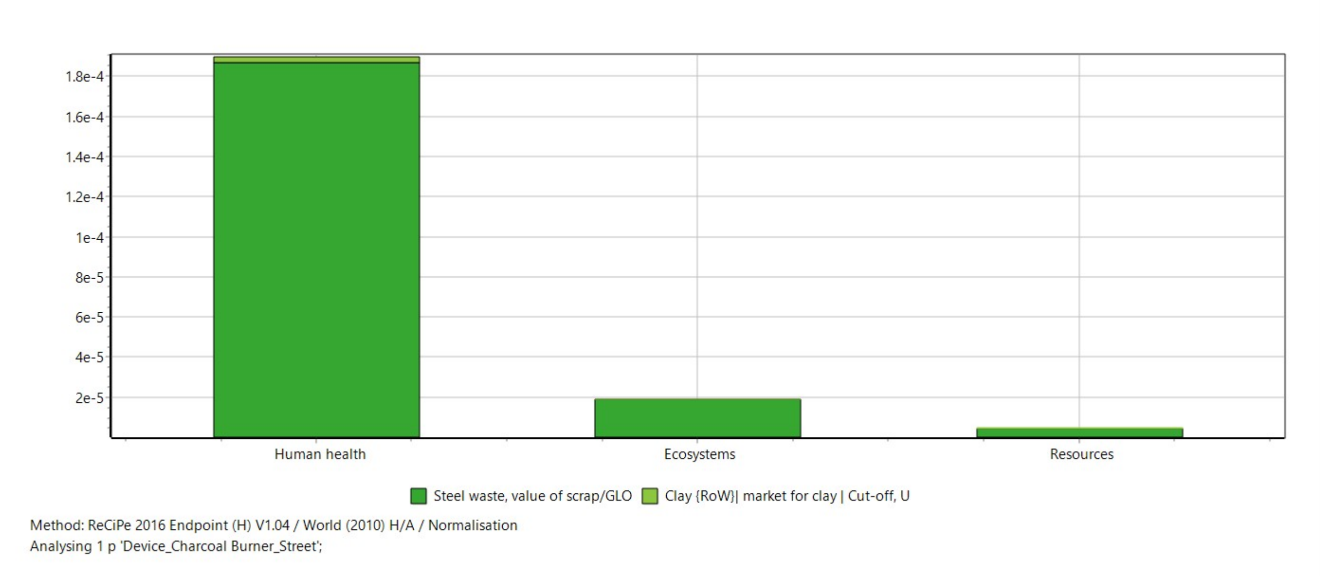
Given the simplicity (and lack of specific data available) for the manufacture of the sCHB, graph 4 show that the steel is the greatest contributor to impact.



Graph 4: Midpoint impact categories for sCHB

It can be seen that negative impacts occur, and these are the result of the use of scrap material. However, the use of the ecoinvent data for Global Steel Scrap, does not accurately reflect the reuse of steel scrap used in the informal economy where these devices are often made. Further investigation into the manufacture of these devices is thus required.

The endpoint impacts resulting from the data (Graph 5) available suggest that the human health impacts are again of greatest concern, and that most of these results from the use of steel scrap. However, given the very limited accuracy of the input data, this result should be viewed with a low degree of confidence.



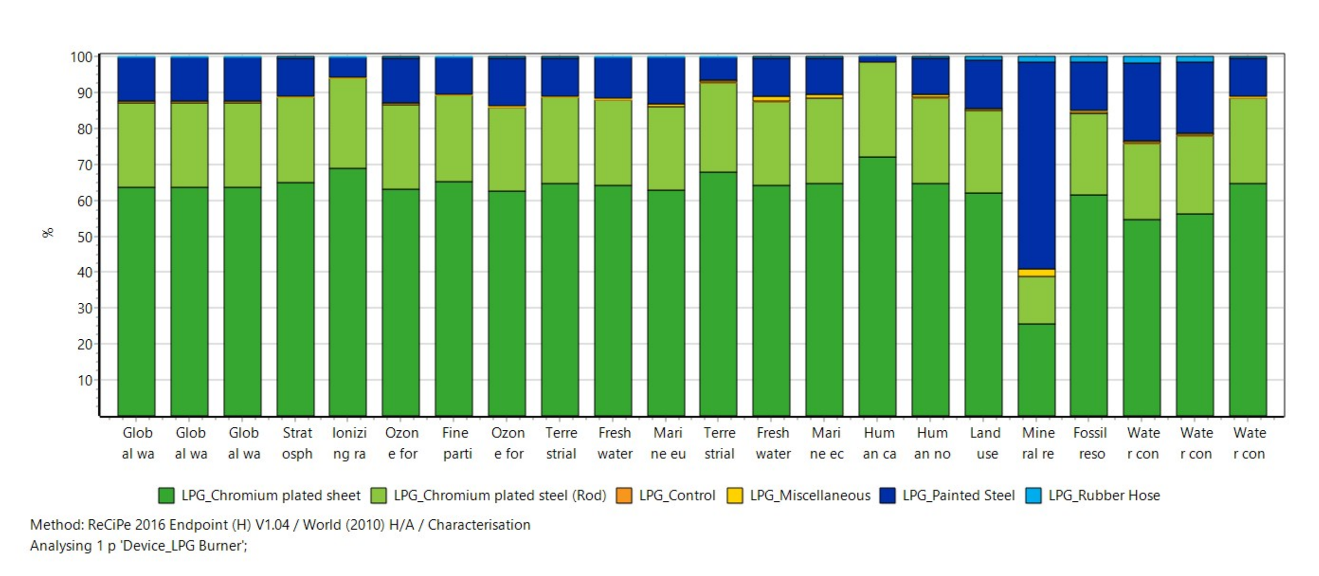
Graph 5: Normalised endpoint category results for sCHB.

c) Liquified Petroleum Gas burner – twin rings (LPGB)

Background

The data for this product was provided by a tear-down of a twin ring camping gas stove. Twin ringed LPG devices are more common in urban areas (rural areas tend to single ring devices that attach directly to the gas canister. A separate pot stand may also be employed to provide greater stability). It is recognized that this type of stove would not be relevant for rural studies. As for the EPC, the item was dismantled to single material components where possible, weighed, and most likely material and manufacture route determined. See Appendix C for details for tear-down details.

Results

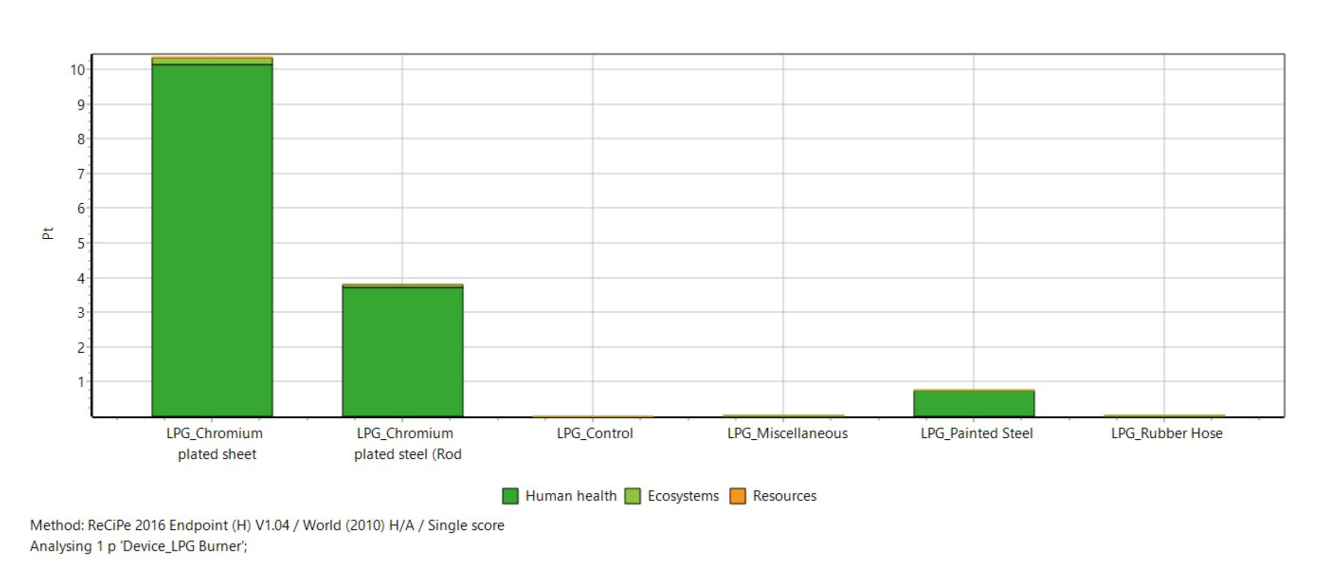


Graph 6: Midpoint impact categories for LPGB

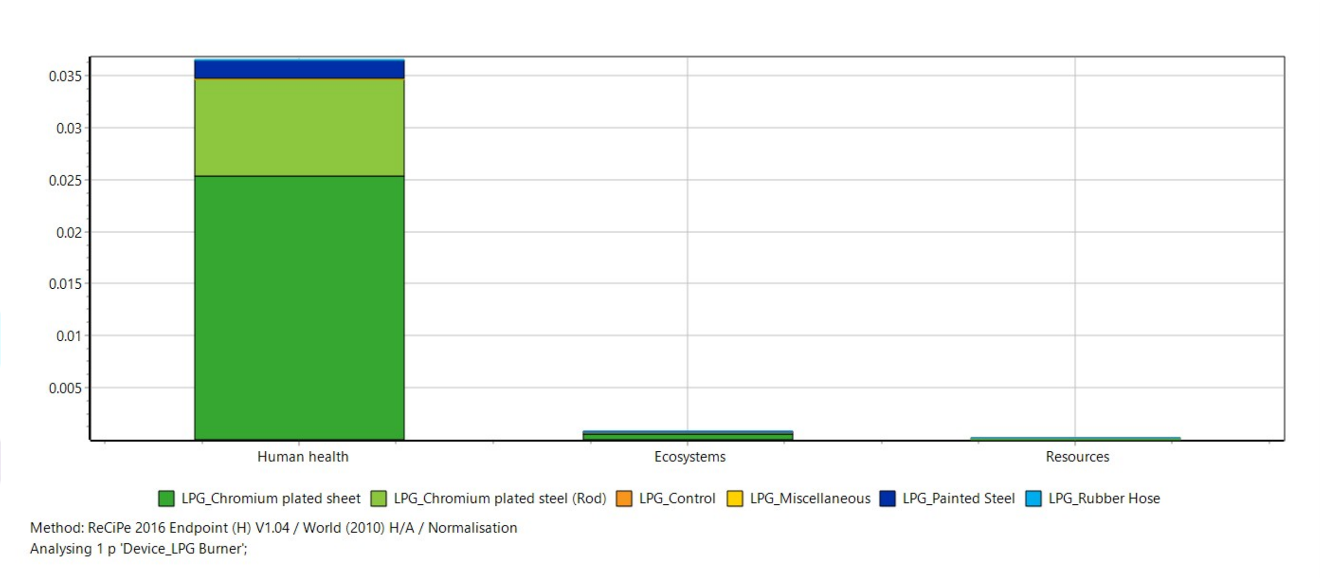
Graph 6 above shows the midpoint category results for the LPGB. It can be seen that the two component groups of concern are the chromium plated sheet and chromium plated steel rod (that forms the gird over the gas rings) for all categories except mineral resource use, when the painted steel shows the greatest contribution.

Converting the midpoint categories to a single score of corresponding damage on human health, ecosystems and resource use combined, Graph 7 confirms that the chromium plated component categories dominate impact. Graph 8 show the normalised score for each of the endpoint impact categories, again showing that impacts to human health are the greatest concern.

Digging into the detail for the LPGB, it is not surprising that the chromium plated components of the device are the cause of the greatest impact to human health. Like the chromium coating for the griddle accessory of the sEPC, the main impacts result from the treatment of Na-Dichromate waste, and the hard chrome plating process. For the painted steel impacts, the top three activities that contribute to human health issues result from the treatment of waste from an oxygen furnace, the production of the iron/steel, and the coking process.



Graph 7: Endpoint Single score result for LPGB



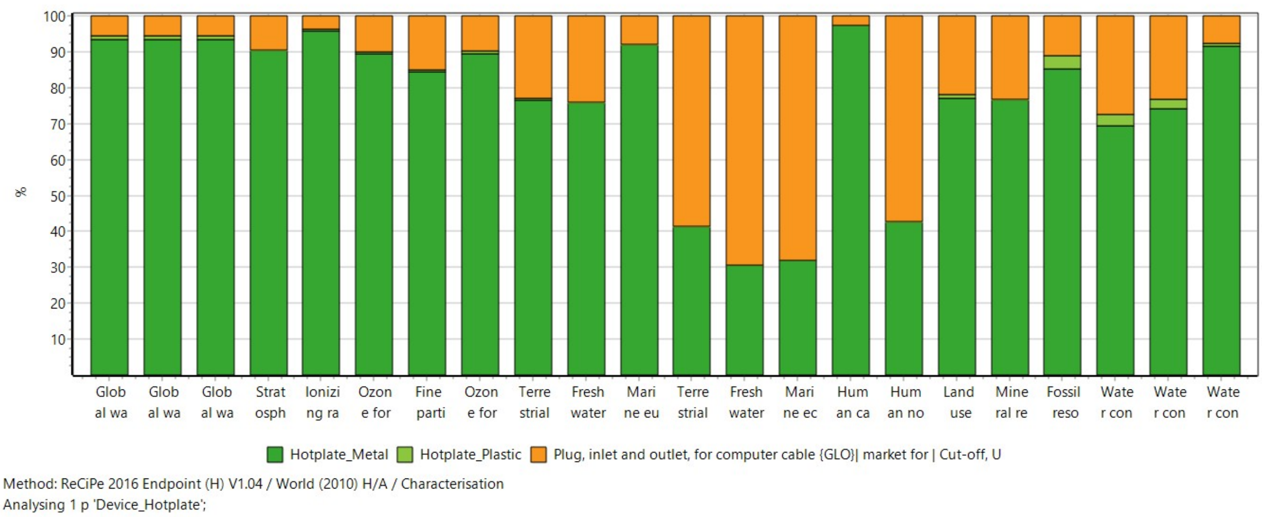
Graph 8: Normalised endpoint categories for LPGB.

d) Hotplate (HP)

Background

The data for this product was obtained through a tear-down of a single ring hotplate electric stove[5]. The product consists predominately of metal and plastic components, and a power cable. Details of the tear-down data can be found in Appendix D.

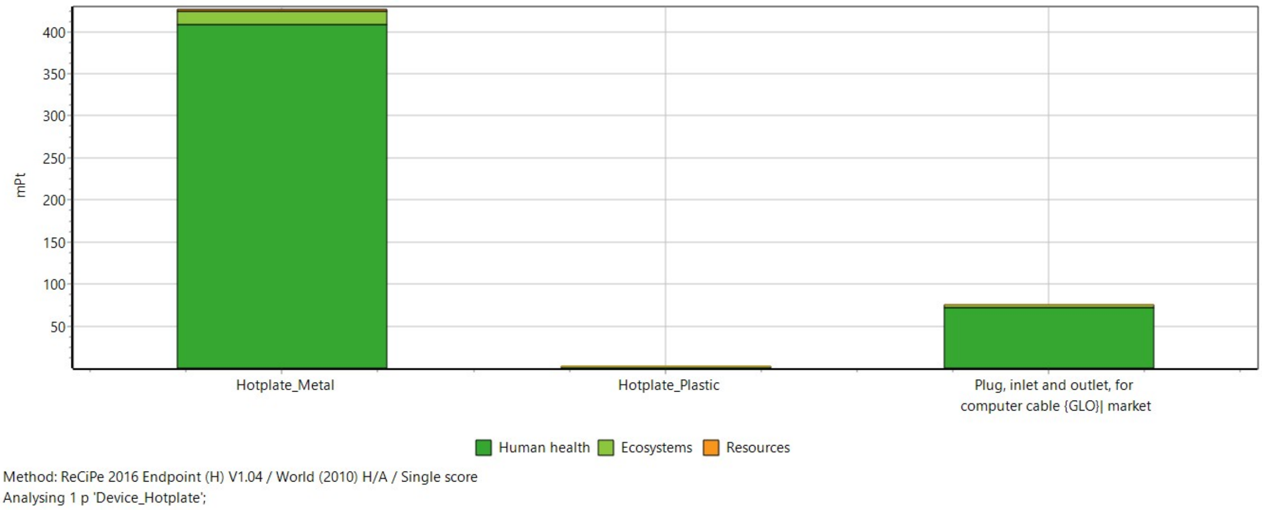
Results



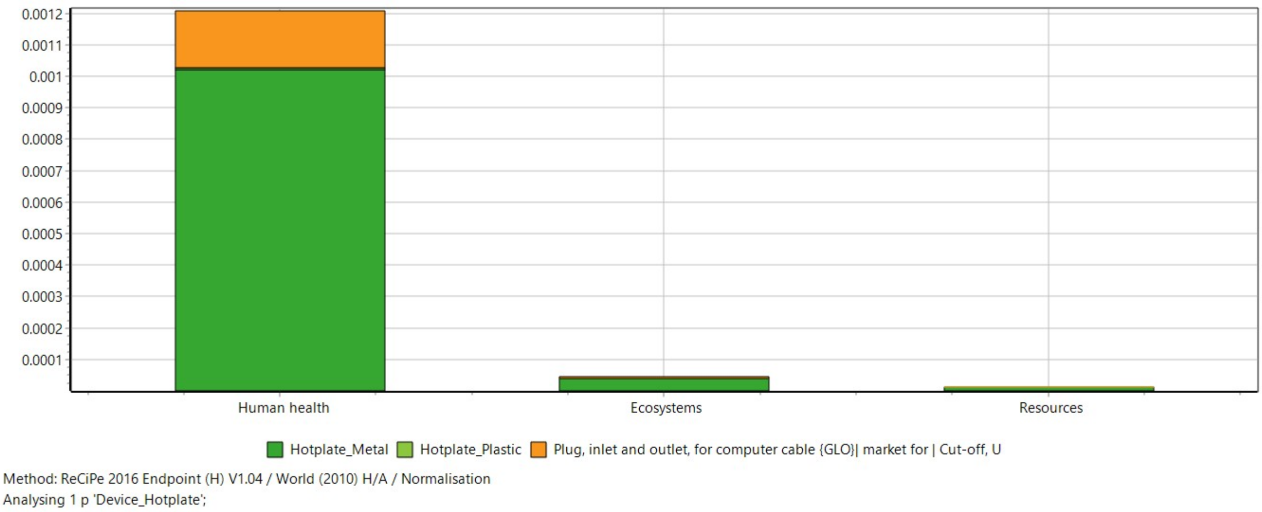
Graph 9: Midpoint impact categories for HP

Graph 9 shows clearly that the metal components dominate the midpoint indicators with the exception of terrestrial, fresh water and marine ecotoxicity and human non carcinogen toxicity. Graph 10 shows that the metals combine to have the largest single point score, most of which can be linked to the effect on human health. This is confirmed by Graph 11, that shows the normalised scores for the production of a hotplate device.

[5] Thanks to V. Vasilie for undertaking the tear-down at CREST, Loughborough University



Graph 10: Endpoint Single score result for HP



Graph 11: Normalised endpoint categories for HP.

Looking into the metals in more detail reveals that there are 4 materials/processes (listed in order of importance) that show significant impacts; cast iron, enamelling process, low/unalloyed steel and chromium steel. The cast iron is used in the production of the heating plate, and it is the treatment and landfilling of slag from an electric arc furnace that is the main issue here. For the enamelling process, it is the production of the energy needed for the process, and the treatment of coal mining spoil that are the greatest contributors. For the low/unalloyed steel, the waste treatment of residue from the oxygen furnace, pig iron production, coking and the iron sinter process that are the main contributors and finally for the chromium steel, it is the steel production itself that contributes most to the impacts relating to this material.

e) Lithium iron phosphate battery (LFP)

Background

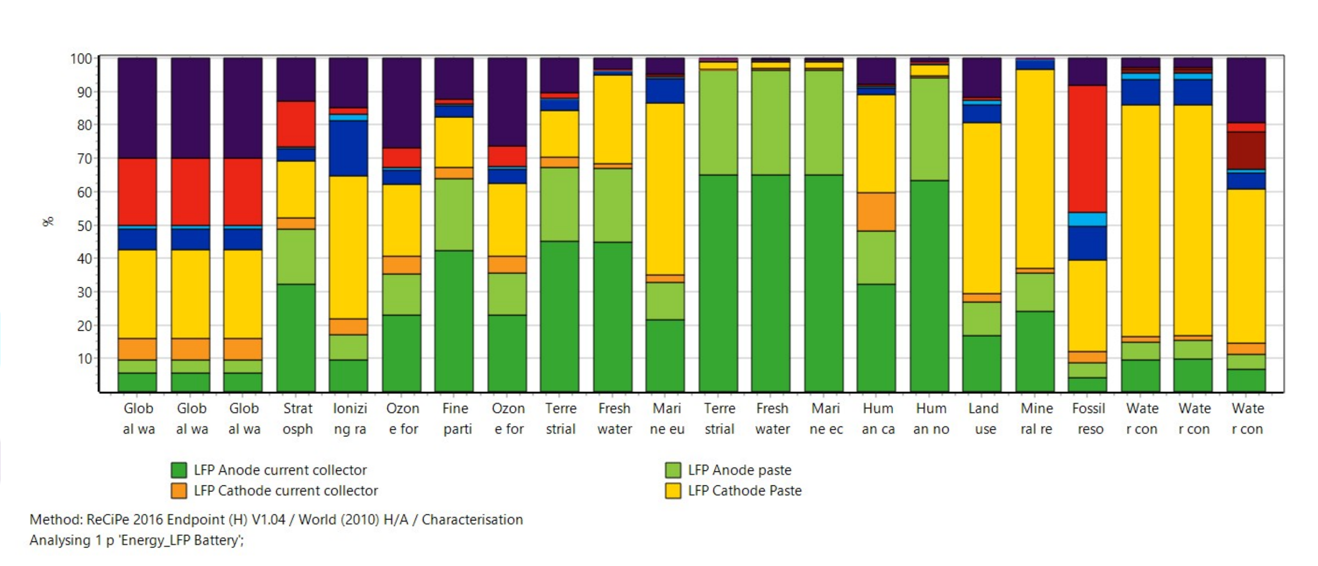
There is a significant extant body of literature for lithium ion battery, driven by the increase in hybrid and electric cars, alongside the potential as energy storage mechanisms. However, up to date LCA data is not readily available, and most papers refer back to two journal articles, produced between 2011 and 2013. The model used here has also referred to these data sources, namely:

Majeau-Bettez, M. et al. 'Life cycle environmental assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles'. Environmental Science and Technology, 2011, 45, 4548-4554. DOI: 10.1021/es103607c

Ellingsen, L. et al. 'Life cycle assessment of a lithium ion battery vehicle pack'. Journal of Industrial Ecology, 2013, 18, 1. DOI:10.111/jiec.12072

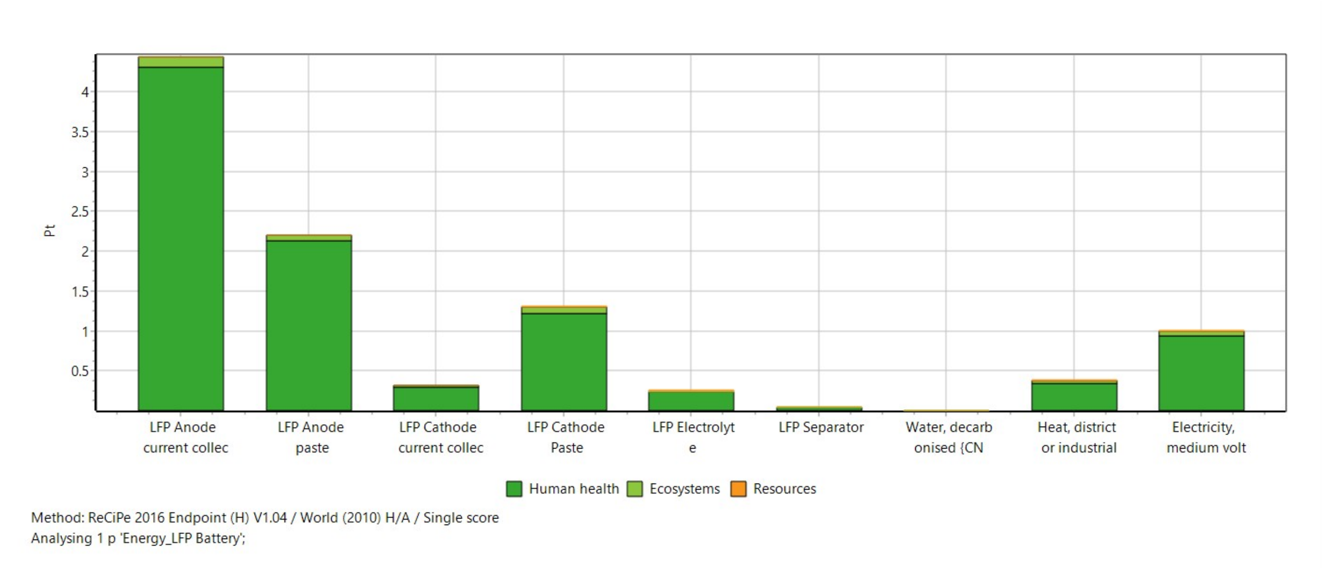
It is noted that these papers refer to batteries for vehicles, rather than stationary applications. Whilst this is not ideal, it is not considered to be a significant source of error, given the overall granularity of the data in the model at the current time. Appendix E provides the raw data used for the lithium iron phosphate battery model.

Results



Graph 12: Midpoint impact categories for LFP

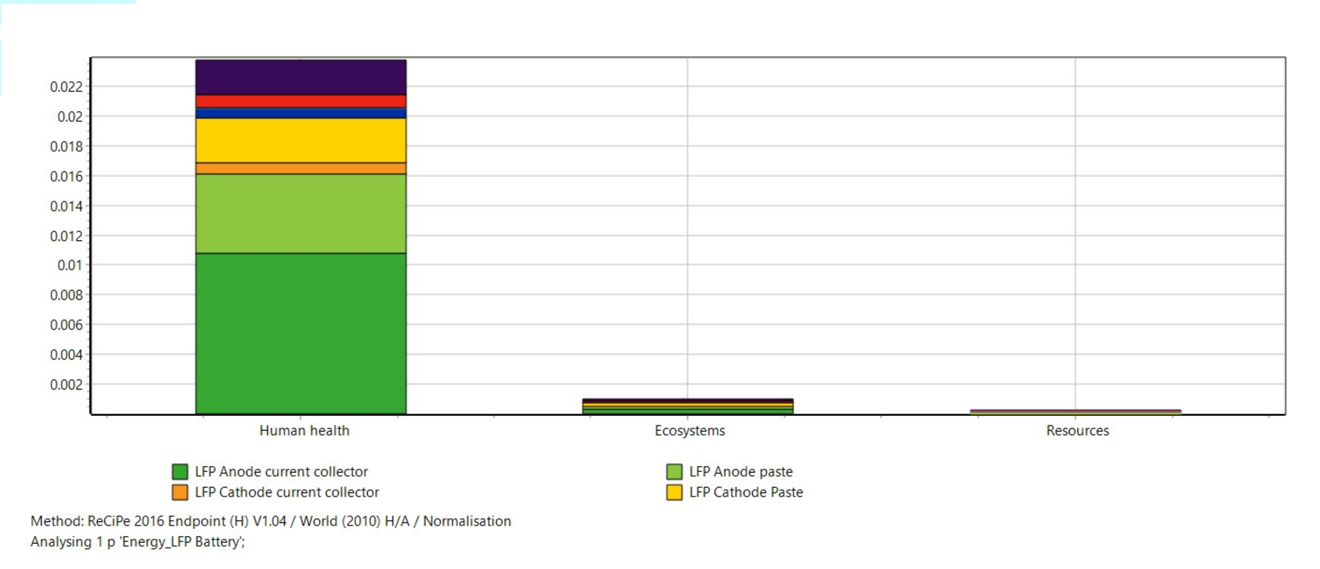
Graph 12 above shows the contributions of the component groups to the midpoint categories. Three component groups stand out in particular, the anode current collector, the cathode paste and the anode paste. Graph 13 shows the single score for the LFP battery, highlighting which of the component groups contributes the greatest end point impact; the anode current collector has twice the impact to the next biggest component category, the anode paste, closely followed by the cathode paste.



Graph 13: Endpoint Single score result for LFP

Graph 14 shows the normalised results for a LFP battery, identifying more clearly how the endpoint categories can be attributed to the different component groups, and which of the endpoint impacts is of most concern.

Looking in more detail to identify the causes of the impacts on human health, for both the anode current collector and anode paste, it is the production of copper, and the subsequent treatment of sulphidic tailings that account for much of the impact. For the cathode paste, the impacts result from, (in order of magnitude) heat production, purification residue waste treatment of H_3PO_4, and sulphuric acid production.



Graph 14: Normalised endpoint category results for LFP.

Other notable concerns come from the ethylene and propylene production (for the separator and electrolyte), and sulphuric acid production and quicklime production, again for the electrolyte (blue). The cathode current, raises the issue of the treatment of redmud waste from the production of bauxite.

The purple and red sections of graphs 12-14 relate to the electricity and heat requirements respectively for the manufacture of an LPF battery system. Investigations into the suitability of different battery chemistry in terms of power delivery for use with electric cooking have been investigated by MECS[6].

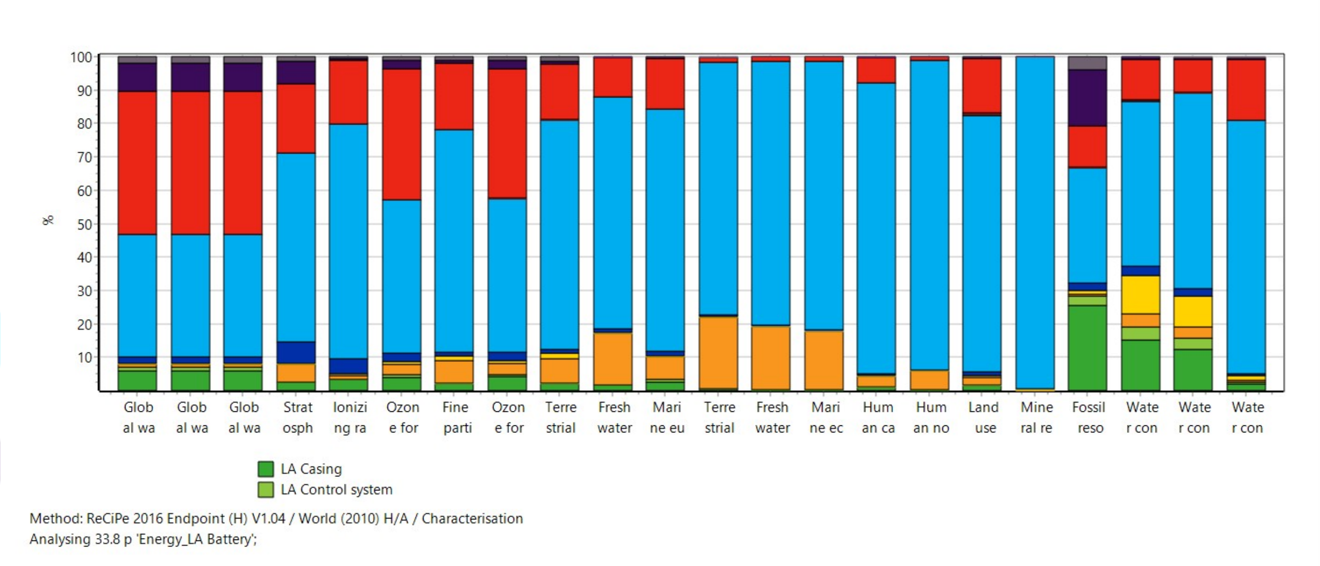
f) Lead acid battery (LA)

Background

Lead acid batteries are common for both vehicles and stationary applications. However, there is little detailed information in the public domain relating to the life cycle assessment of their production. One study was commissioned in 2014 by the key players in the supply chain for lead based automotive batteries. The detail of this has not been publicly released but an executive summary is available[7]. This assessment is based on the data provided by Spanos[8] and summarised in Appendix F.

Results

Graph 15 below shoes the midpoint indicators for the production of a lead acid battery. The results are dominated by the production of the lead grid (light blue) and the electricity required in the manufacturing processes (red).

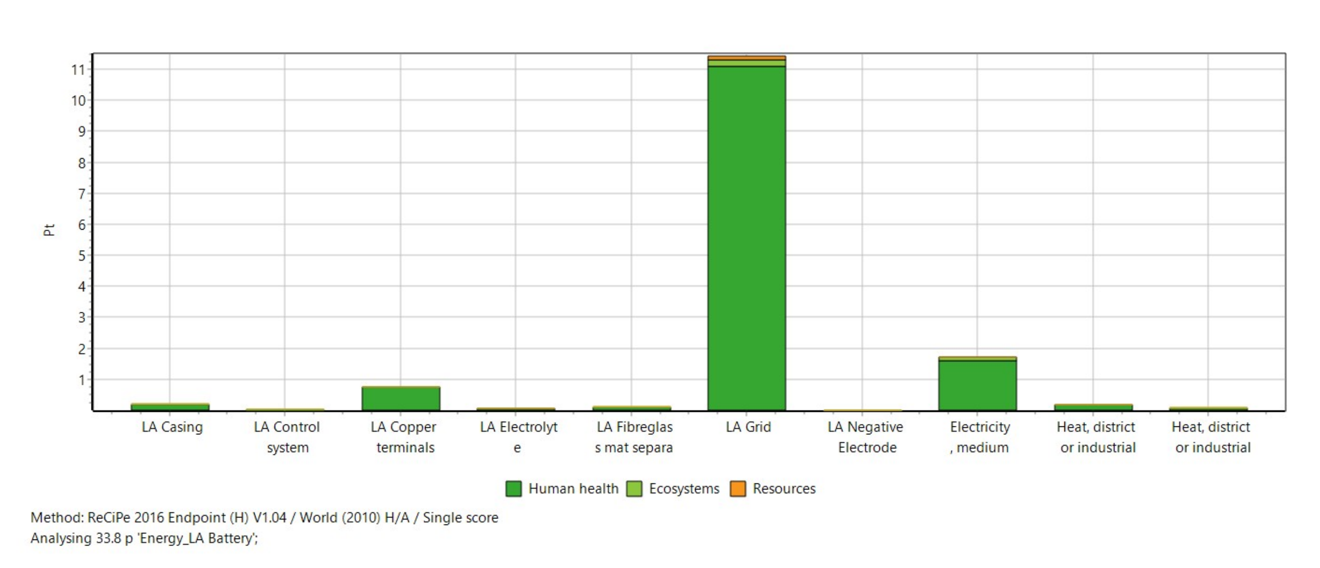


Graph 15: Midpoint impact categories for LA battery

[6] Comparison of Batteries for the MECS Project, Dr John Barton, Dr Nigel Monk, Dr Richard Blanchard, Centre for Renewable Energy Systems Technology (CREST), Loughborough University. https://mecs.org.uk/download-category/working/

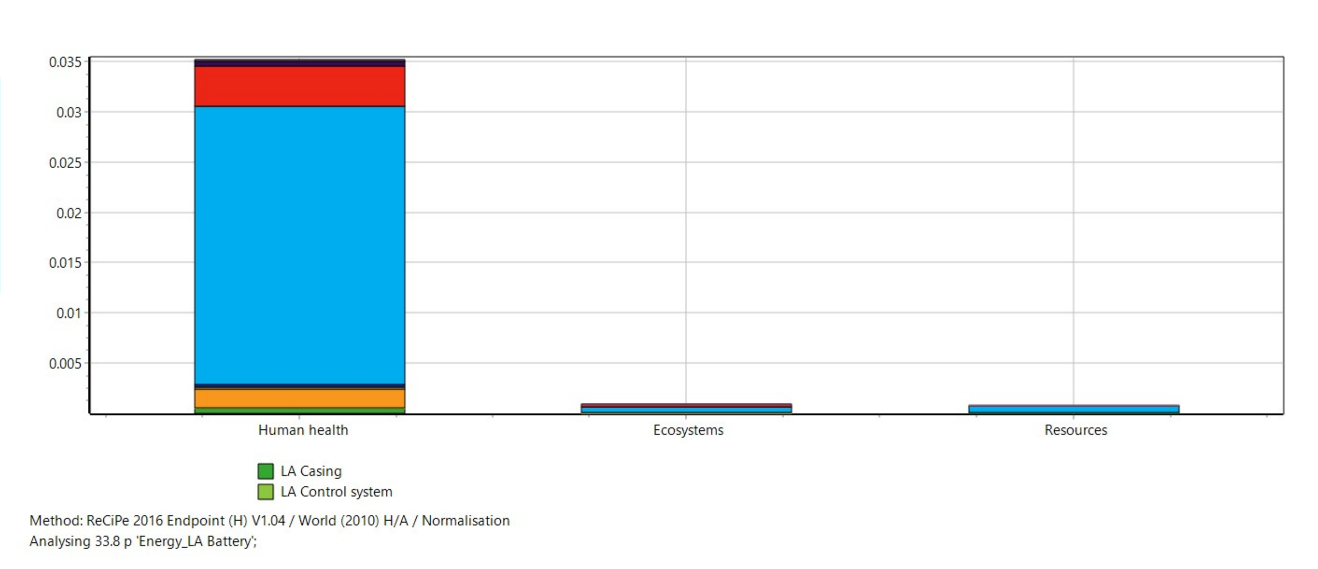
[7] European Car Manufacturers Association web page (ACEA 2015). https://www.acea.be/publications/article/life-cycle-assessment-lca-of-lead-based-batteries-for-vehicles

[8] Spanos et al. 'Life cycle analysis of flow-assisted nickel zinc-, manganese dioxide- and valve regulated lead acid batteries designed for demand charge reduction. 2015, Renewable and Sustainable Energy Reviews 43, 478-494. DOI 10.1016/j.rser.2014.10.072



Graph 16: Endpoint category single score result for LA battery

Graph 16 shows the single score data for the LA battery system. This shows very clearly that it the manufacture of the lead grid that causes the greatest impact. It should be noted that in general, lead has a high recovery rate and much of the lead used is recycled, which would suggest that it is not the lead production per se that is of concern, but the processes used to convert lead billet into leads grids.



Graph 17: Normalised endpoint category results for LA battery.

Graph 17 shows the normalised endpoint category results for the manufacture of lead acid battery. Again, the impact in human health dominates, from the lead grid manufacture.

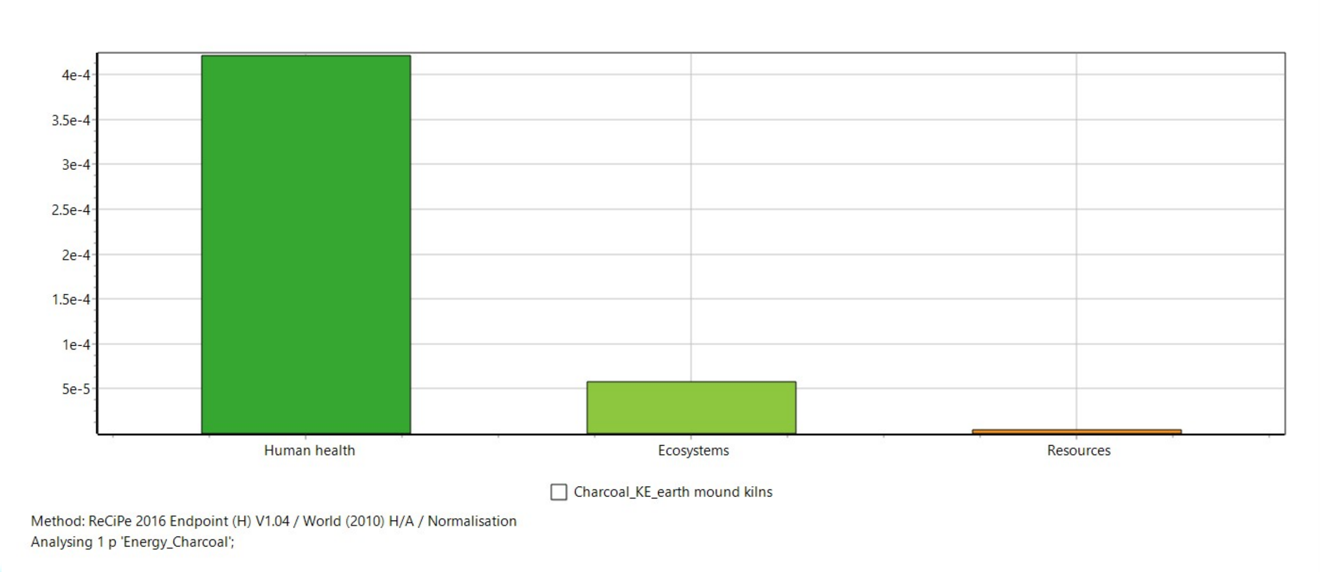
Looking into the lead grid manufacturing in more detail, the top three issues relate to the treatment of slag from the lead smelters, which would occur for both virgin and recycled material, treatment of sulphidic tailings, and the production of lead from lead ore. The issues manifest through zinc and arsenic in groundwater, and water need for turbines in electricity generation.

g) Charcoal production (CH)

Background

The dataset included in ecoinvent for charcoal production was based on the industrial process. This is not how the majority of charcoal for domestic consumption is produced in Kenya and the wider SSA region. Thus, a new model was built, utilising the technology commonly used in Kenya to produce charcoal; the earth mound kiln, based on data from Pennise[9]. Appendix G provides the details and assumptions made in determining the inputs to and emissions from the manufacture of charcoal in this manner.

Results

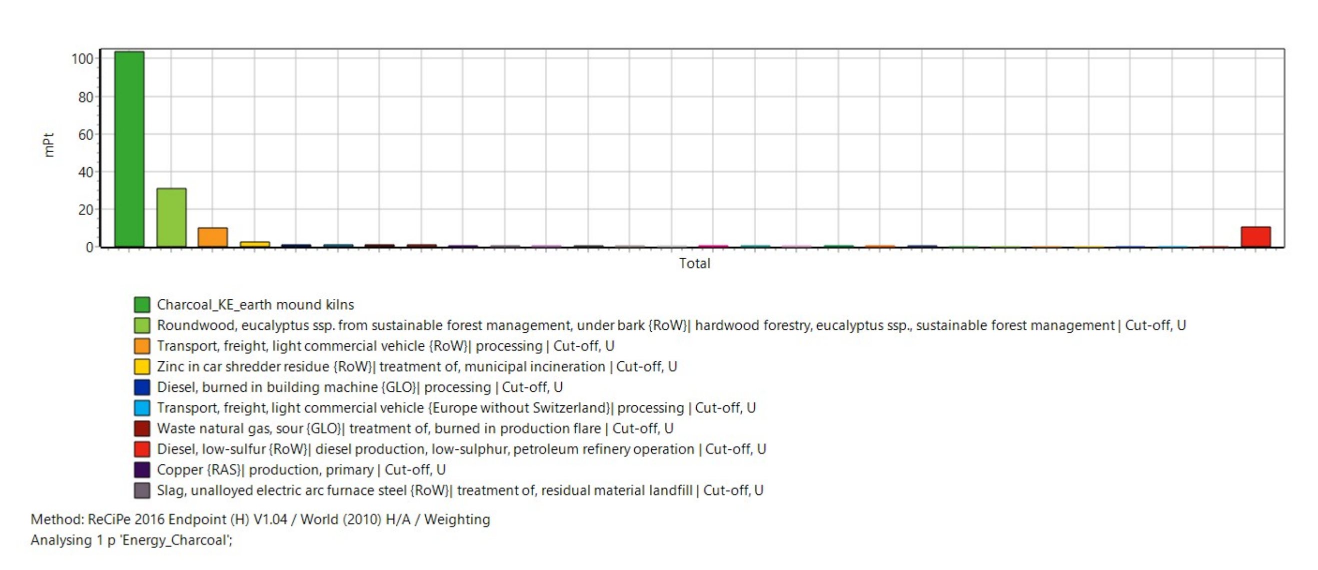


Graph 18: Normalised endpoint impact category results for Charcoal endpoint categories.

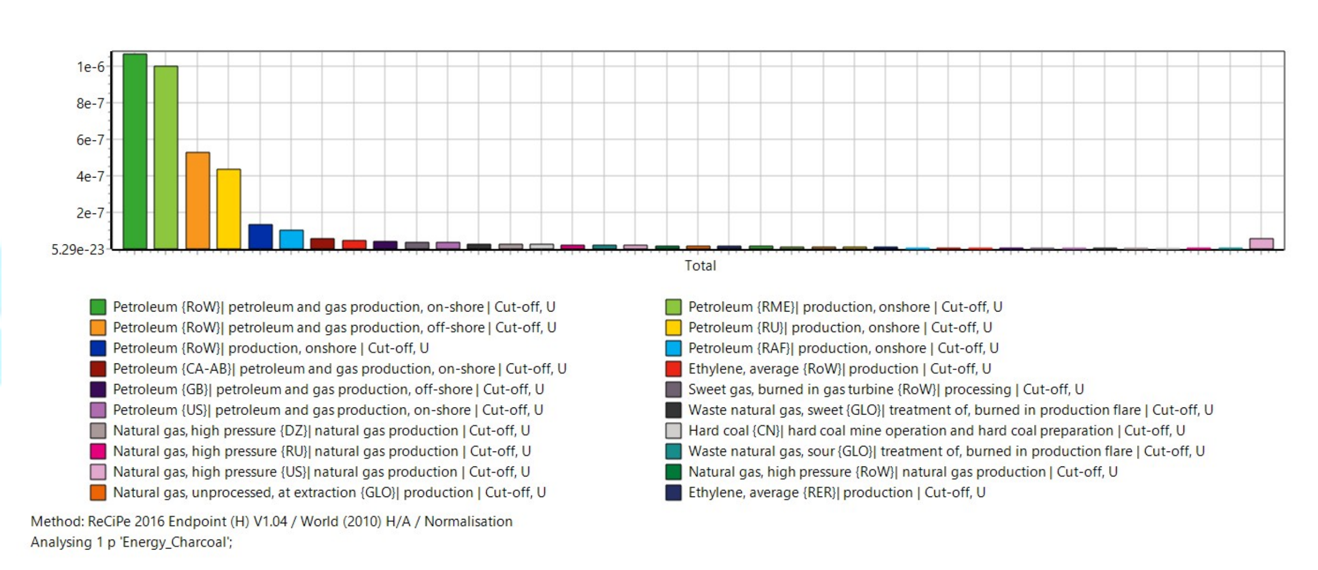
Graph 18 shows once again that charcoal production has the greatest effect on the Human health endpoint category. Looking at the charcoal production system in more detail, Graph 19 shows the effect on human health and ecotoxicity can be seen to originate predominately from the earth mound kilns themselves – the emissions from the kiln during the charcoal process, and then the production of wood from a sustainable plantation (it is assumed that 50% of the wood comes from a eucalyptus plantation, whilst the remainder is a mixture of other wood collected). Transport of the charcoal to point of sale is the third largest contributor.

Graph 20 show the main causes of impact on resource availability. Here it can be seen that petroleum production, for use in transport and for the activities in the sustainable plantation is the greatest contributor.

[9] Pennise, D.M et al. 'Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil'. Journal of Geographic Research, Vol 106, D20, p24,143-24,155. October 2001



Graph 19: Main causes of impact on Human Health and Ecotoxity endpoints for charcoal production



Graph 20: Main causes of impact on Resource Availability endpoint for charcoal production

h) Devices/fuels/power sources taken from ecoinvent

A number of devices, fuels and power sources were already available for use in the ecoinvent datasets: electricity, multi-crystaline PV panels, inverters, LPG production and kerosene production.

Electricity generation in most of the MECS selected countries is available, up-to-date and therefore appropriate to use.

The data relating to PV production, represents the global average (check, might be RoW) for its manufacture from XXX year. Since it is not known with confidence where the PV cells that are used in SSA are manufactured (although it could be assumed to be China), this is considered to be suitably representative at the current time.

LPG and Kerosene production techniques vary widely in efficiency across the globe. Until recently, Kenya was a net importer of oil, with no known reserves. This has now changed, and Kenya will, in the future, start to produce and refine its own oil. However, at the current time, derivatives from crude oil are either refined within the country, or bought ready refined. References from EPA suggested that Kenya bought its oil from Algeria, transported by sea to Kenya and refined in country. However, data from one of Kenya's leading fuel dealers[10] suggests that Kenya imports the majority of its oil from the Middle East. Given this conflicting information, the model uses the global average data for the production of LPG and Kerosene, with added local transportation to point of use.

Wood is more difficult to quantify as some rural users may collect their own wood from forest/scrub land, others may buy from firewood vendors and it not clear of the source of wood, and yet others may collect/buy wood from sustainable forest plantations. The trees traditionally found in Kenya and SSA are not represented in the ecoinvent database, so the global average value of bundle of wood for fuelwood has been used. This assumes the source is a managed sustainable plantation, and it is recognised that this does not necessarily accurately represent the wood source for all fuelwood users. Any conclusions drawn from the use of this value needs to be considered with some scepticism.

i) Summary

The above sections have provided a basic insight into issues that arise from the manufacture of different cooking devices and power/fuel options. For the cooking devices, there are some simple design concerns that need to be considered, namely, the use of aluminium, chrome plating and enamelling. Where these processes/materials are used, it may be possible to replace them with materials and/or coating with lower impact.

For the fuel/power options, it is less clear where environmental benefits can be realised. Charcoal is the exception to this, and it is well known that there are more efficient charcoal production systems that could be employed to deliver domestic charcoal. Bio-based liquid and gaseous fuels could deliver lower environmental impacts, but this would need further investigation and consideration of appropriate technology level applications for different locations. Similarly, there are a number of different lithium ion battery chemistries available, and new technology in this subject area is rapidly advancing as a result of the interest in battery technology for transport. It is possible that one of these may have better environmental performance that either the LFP and LA battery systems. However, one of the requirements for application of battery technology into the modern energy cooking system field is that it needs to be low cost, and new technology takes several years for cost to reduce to levels where it might be appropriate. In addition, the end of life aspects of battery technology also need to be considered. Whilst not considered within this working paper, it is worth noting that LA batteries have an established and well-known recycling system (although perhaps not operational in SSA) and most lead form these batteries is recovered and reused. The recycling systems for LFP batteries is not so well established, and at the current time, there is no widescale official system for the collection and recovery/recycling of LPF battery materials in SSA.

[10] https://asokoinsight.com/content/market-insights/kenya-leading-fuel-dealers. Accessed 27/7/2020

4. Cooking device and power combinations

It is not realistic to assess the environmental performance of a cooking device or power/fuel device in isolation, as they will always be used in combination. Thus this section details and compares the results from a range of combinations of cooking device and power options. The combinations reviewed are listed in Table 3. (B: Baseline, C1: comparison 1, etc). Daily usage rates for power/fuels have been taken from the ESMAP scenarios. The combinations below do not represent how the device may be used in reality as each combination are assumed to be the only cooking system used, when two or more systems are normally stacked together to provide the full range of cooking option for a family. The effect of fuel stacking is covered in Working paper Environmental Assessment of ESMAP Scenarios 1 and 5[11].

Section	Combination	Justification of combination
4a	B: Grid electricity with hotplate (HP) C1: Grid electricity with simple EPC (sEPC)	To investigate the relative contribution of electricity and cooking device to overall impact over the life of the devices. **FU: 5 years.**
4b	B: Grid electricity with sEPC C1: LFP (grid charged) with sEPC C2: LA (grid charged) with sEPC	To investigate how the effect of battery chemistry effects the environmental impact, and contribution to overall impact over the life of the devices. **FU: 8 years.** This is the expected life of an LFP battery. The expected life of a LA battery is 5 years, thus the LA data has been adjusted accordingly to match 8 years use.
4c	B: Grid electricity with sEPC C1: LFP (PV charged) with sEPC C2: LA (PV charged) with sEPC C3: LFP (grid charged) with sEPC C4: LA (grid charged) with sEPC	To investigate the effect of electricity from the grid compares with electricity provided by PV panels and batteries, over the life of the PV panels. **FU: 20 years.** The data for the LFP and LA have been adjusted accordingly.
4d	B: Grid electricity with sEPC C1: LPG with LPGB C2: CH with sCHB C3: Wood with three stone fire (TSFP)	To compare electrical cooking with more traditional fuel sources and contribution to overall impact, over the life of the devices. **FU: 5 years.** The expected life of a sCHB is 6 months, thus the sCHB data has been adjusted accordingly.
4e	B: Grid electricity with sEPC C1: LPG with LPGB C2: CH with sCHB C3: LFP (PV charged) with HP C4: LA (grid charged) with sEPC	To compare one day of cooking for various fuel/cooking device combinations. **FU: 1 day.** All material and fuel/power inputs have been adjusted accordingly.

Table 3: Details of device and fuel/power combinations reviewed.

[11] Environmental Assessment of ESMAP Scenarios 1 and 5[11]. J.Lee. S^2A Associates Ltd. https://mecs.org.uk/download-category/working/

a) Grid electricity and electrically powered cooking devices.

Figure 3 below shows the system set up for the comparison of grid electricity and electric cooking devices. This combination would typically be seen in areas where there is a strong and stable grid energy supply. The objective of this comparison is to evaluate the relative contributions of power used over the life of the cooking device to the material/energy needed for the production of the device. For both sEPC and HP, it is assumed they have a life of 5 years.

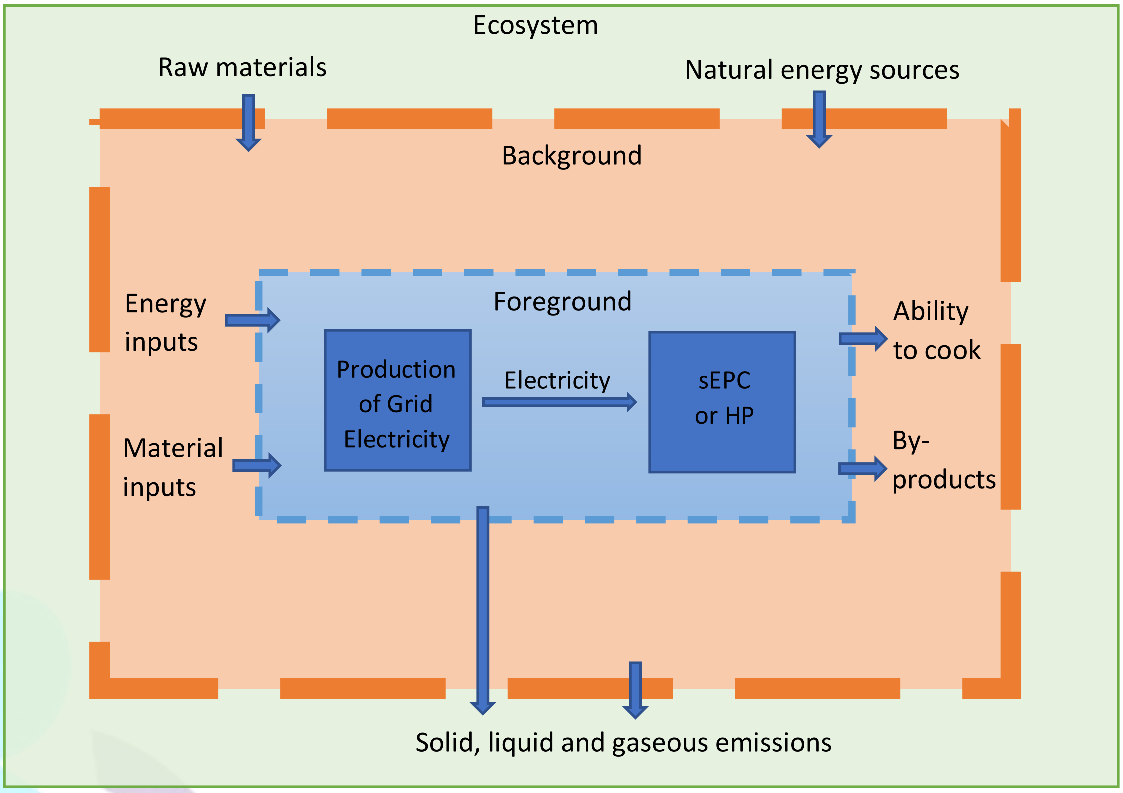
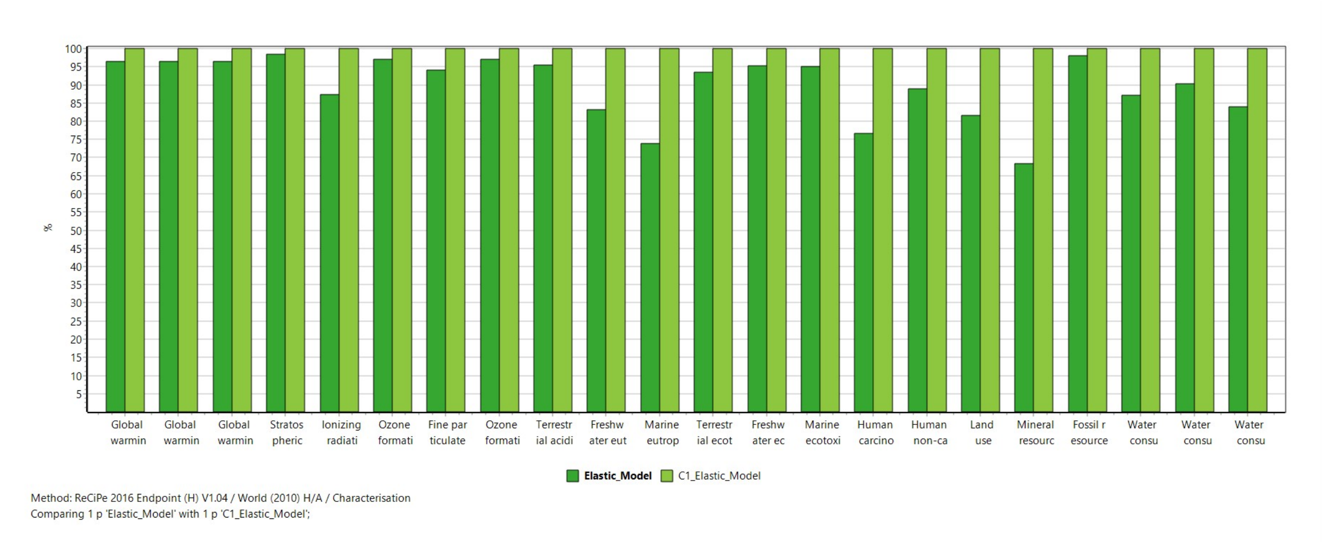
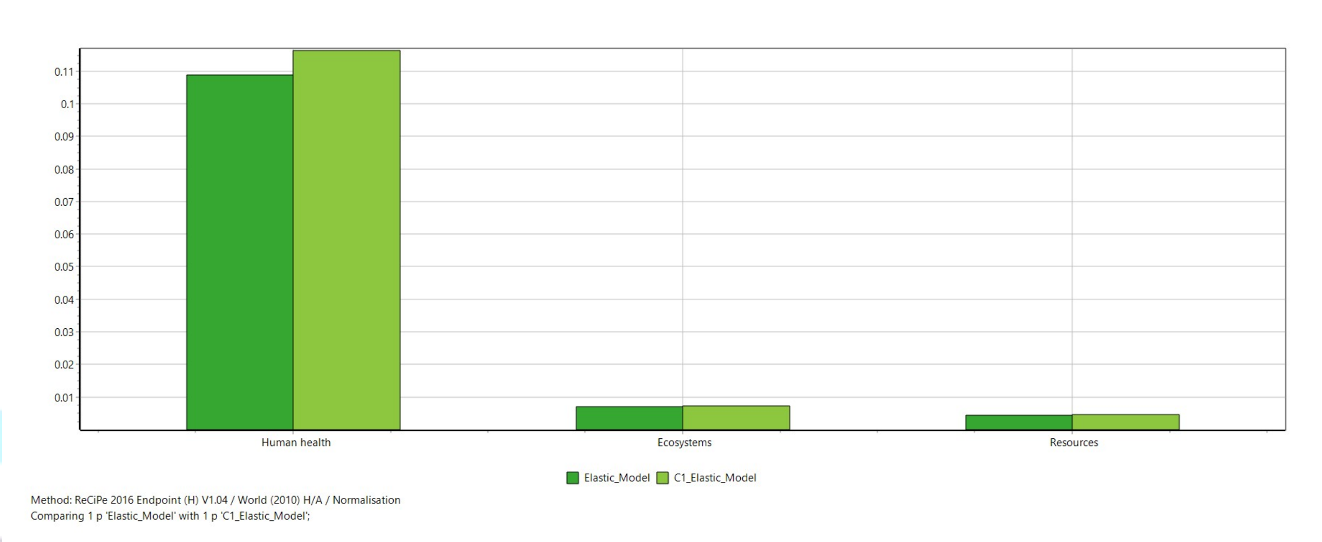


Figure 3: System representation for electric cooking

Graph 21 below shows the relative contributions of the cooking device (a sEPC or HP), combined with the power needed to use them over the 5 year life of the product. As to be expected, the sEPC shows higher impacts than the HP, because it is a more complex device with more materials.

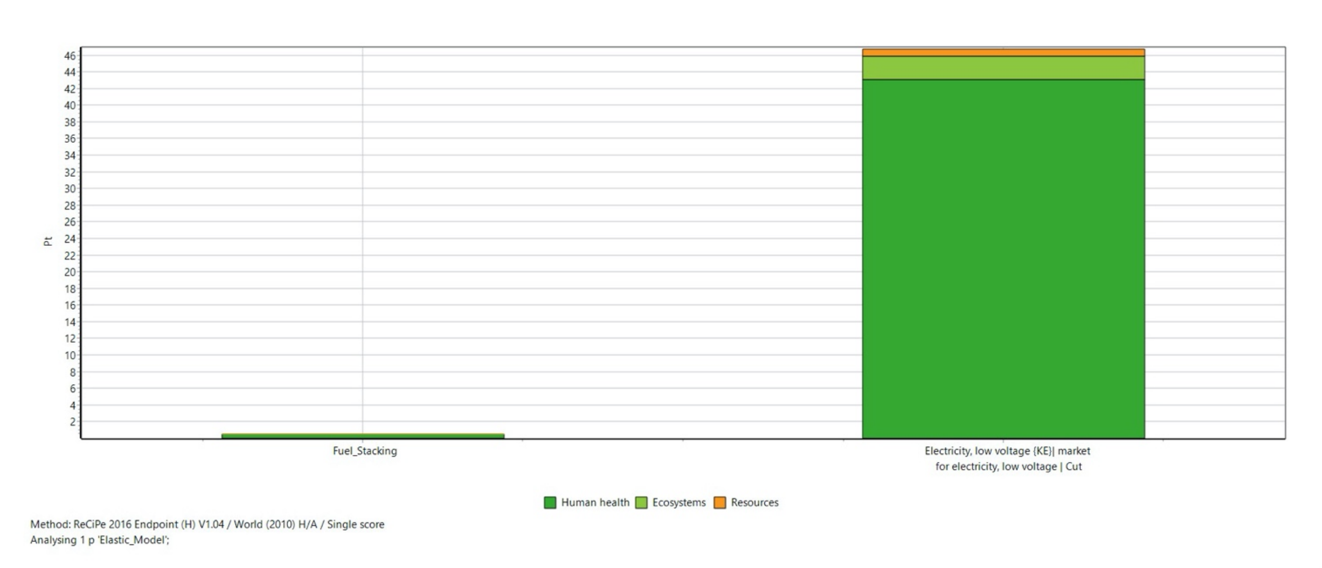


Graph 21: Midpoint Comparison of HP (Elastic Model) with sEPC (C1_Elastic_Model)

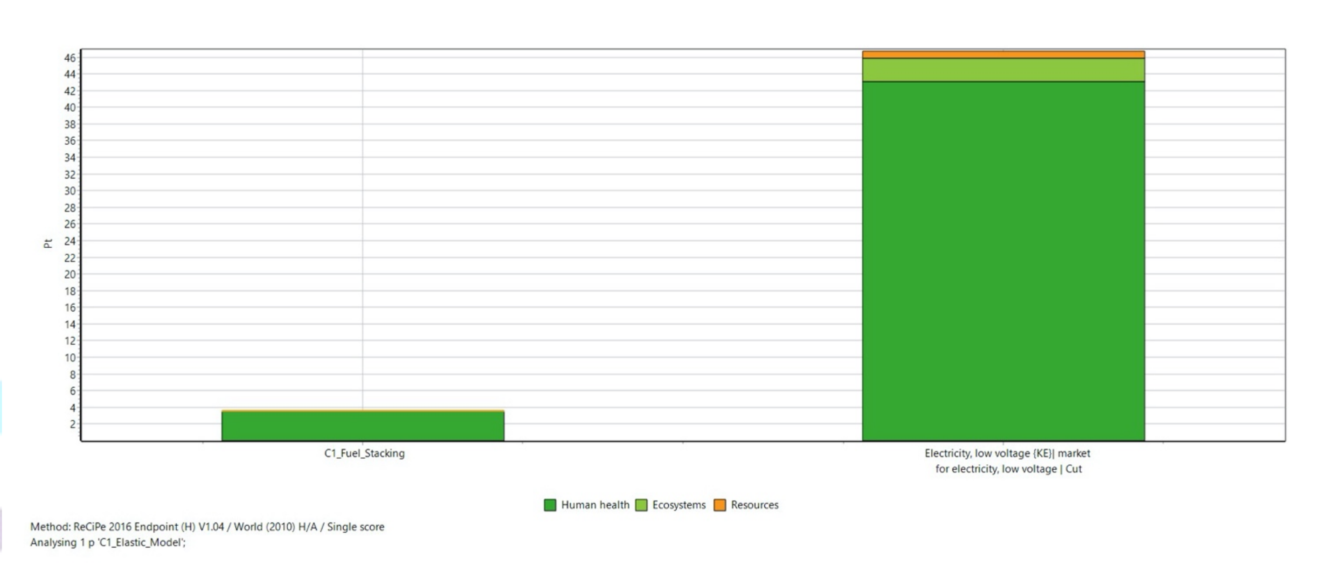


Graph 22: Normalised Endpoint comparison for HP and sEPC systems

Graph 22 shows that again, human health is the endpoint of greatest concern, with the sEPC causing more damage than the HP. Looking more closely at the relative contributions of device and power, graphs 23 and 24 show that in both cases, the endpoint impacts resulting from the manufacture of the device (fuel stacking) are dwarfed by the impact of the production of electricity needed to power them. This is a typical result for energy using products, and emphasises the need to place energy efficiency at the centre of design options, especially for locations where grid electricity is based heavily around fossil fuels.



Graph 23: Single score endpoint for HP and Grid electricity



Graph 24: Single score endpoint for sEPC and Grid electricity

b) Comparison of grid charged battery chemistries with sEPC.

Where the electrical grid is unstable, and susceptible to power outages, one solution is to use a battery as a backup to ensure that it is still possible to cook meals. This can be referred to as a weak grid. Different battery chemistries require different charging levels from the grid, but for this example it has been assumed that both the LFP and LA battery charge and discharge to the same depth and are of the same KWh size. Figure 4 shows the system for electric cooking with a battery backup. It should be noted that LFP and LA batteries have different life spans, (8 and 5 years respectively). Thus the environmental impact for LA batteries has been adjusted accordingly to match an 8 year life.

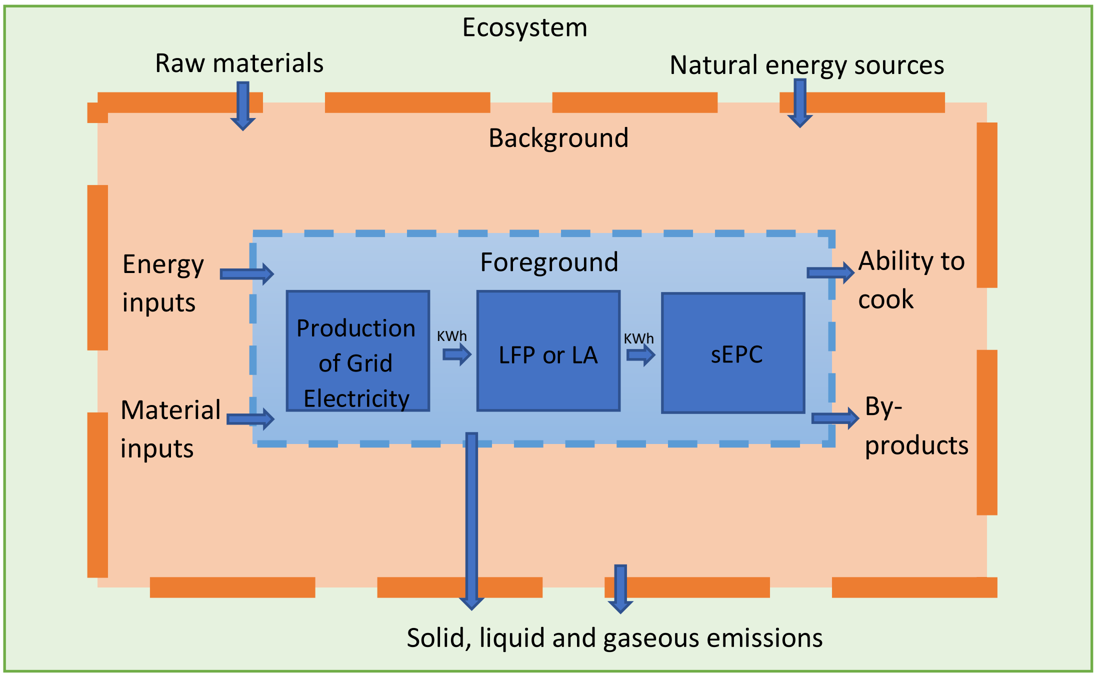
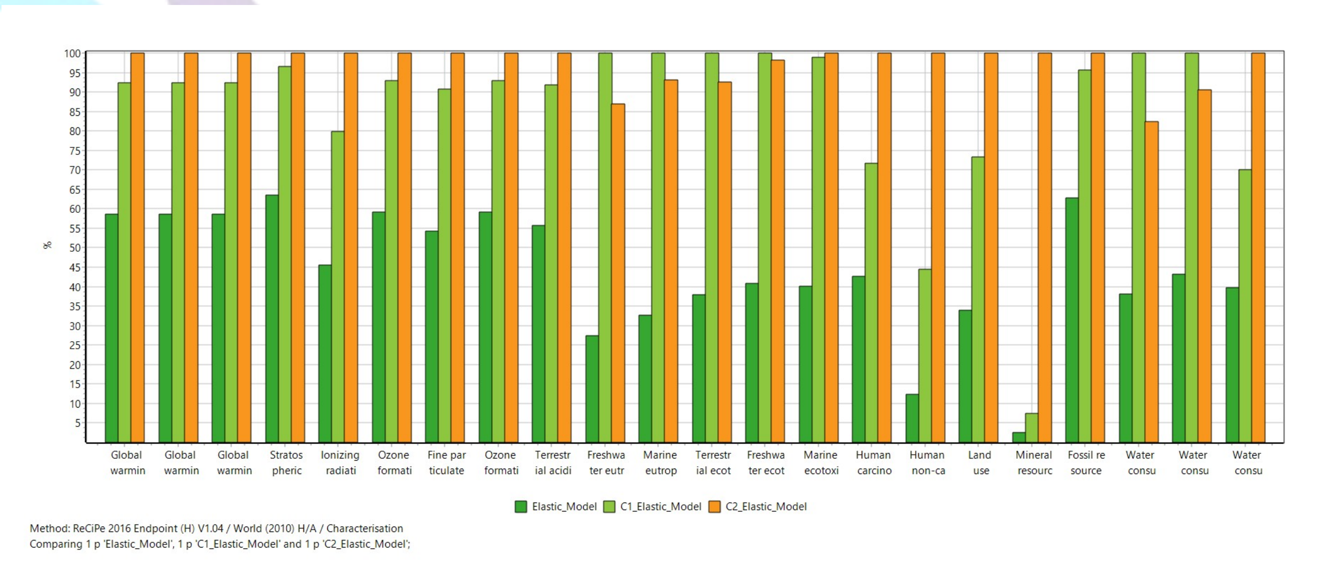
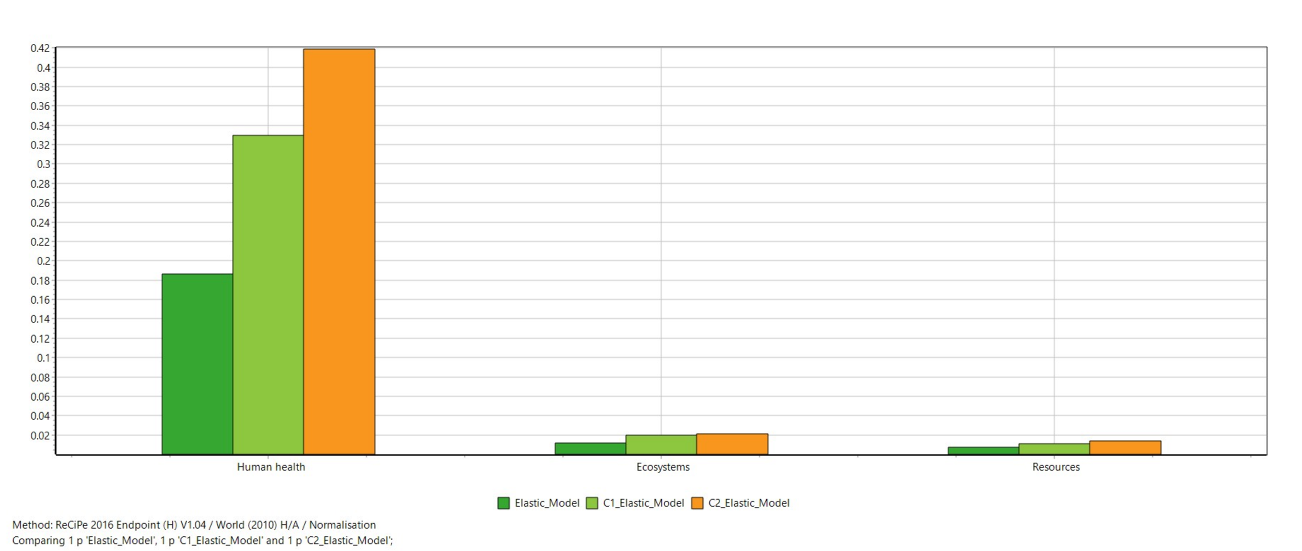


Figure 4: System representation for battery supported electric cooking

Graph 25 below compares grid only with the two battery chemistries for an 8 year period (the life of a LFP battery). It can be seen that both battery systems have higher impacts than grid alone (elastic model) (expected since the batteries are trickle charged from the grid). The LA battery (C2_Elastic_Model) shows higher impact across more of the midpoint categories than the LFP (C1_Elastic_Model), although the differences for the majority of midpoint impact categories are not large and could be due to data quality issues rather than a true difference in environmental impacts.

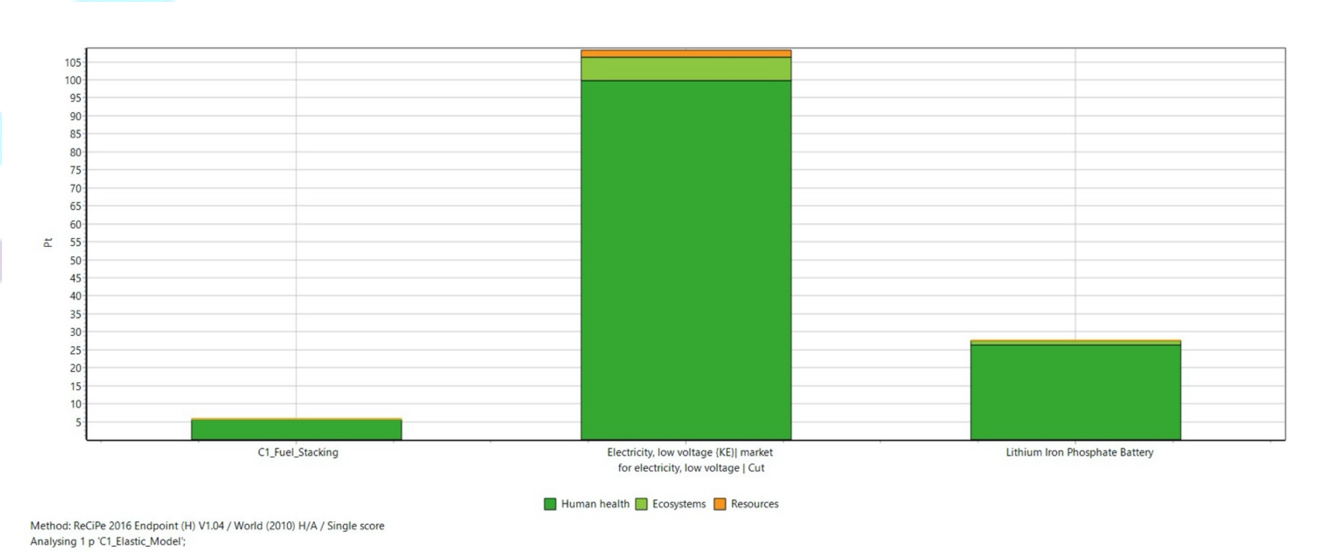


Graph 25: Midpoint Comparison of Grid only (Elastic Model) with LFP battery (C1_Elastic_Model) and LA battery (C2_Elastic_Model)

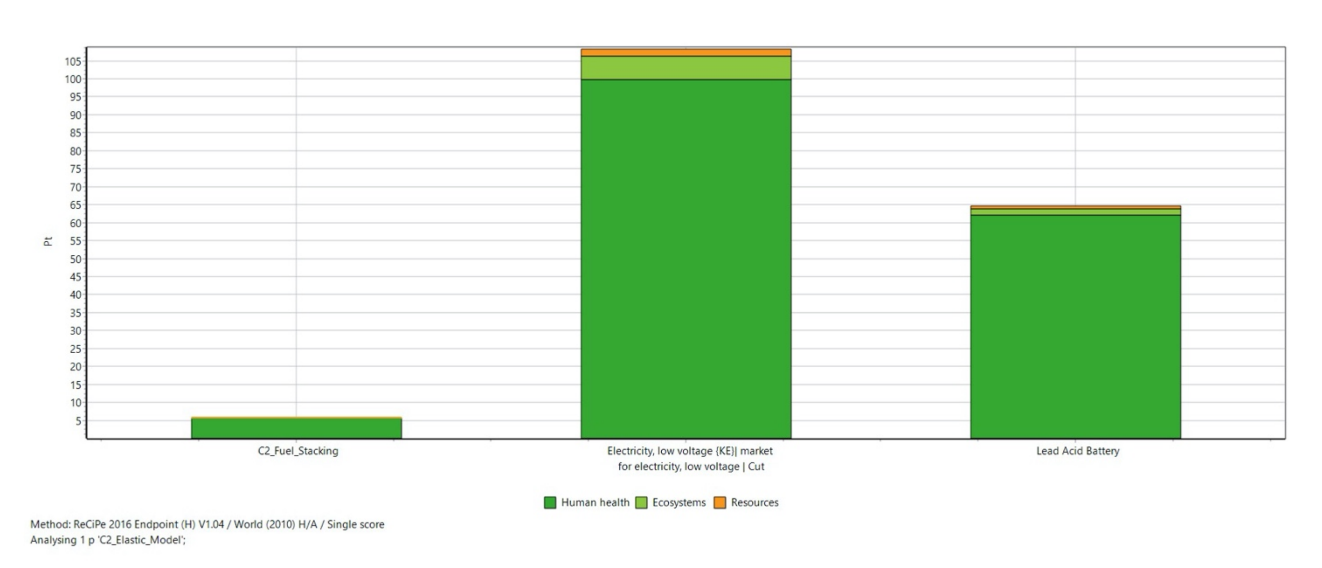


Graph 26: Normalised Endpoint of Grid only (Elastic Model) with LFP battery (C1_Elastic_Model) and LA battery (C2_Elastic_Model)

The normalised results show that human health is the endpoint most affected, with LA, LFP and then grid in order of magnitude. Graphs 27 and 28 show the single score for the LFP and LA battery systems respectively. From these it is clear that the impact from the electrical cooking device (Fuel Stacking) has the lowest impact score, followed by the impact for the manufacture of the battery device. In both cases, it is the generation of electricity for the grid that creates the greatest impact. However, the LA battery can be seen to have approximately twice the endpoint impact of the LFP battery.



Graph 27: Single score Endpoint for LFP battery (C1_Elastic_Model) system



Graph 28: Single score Endpoint for LA battery (C1_Elastic_Model) system

c) Comparison of electric cooking, PV charged battery and grid charged battery

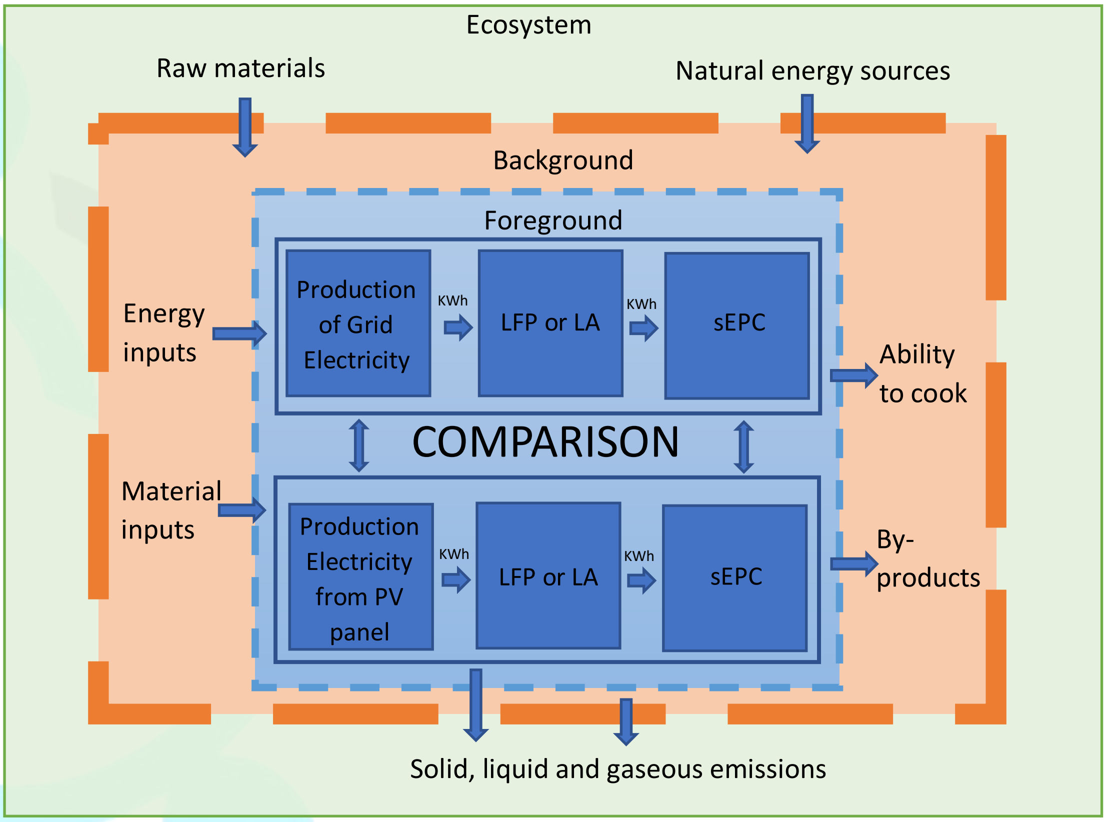
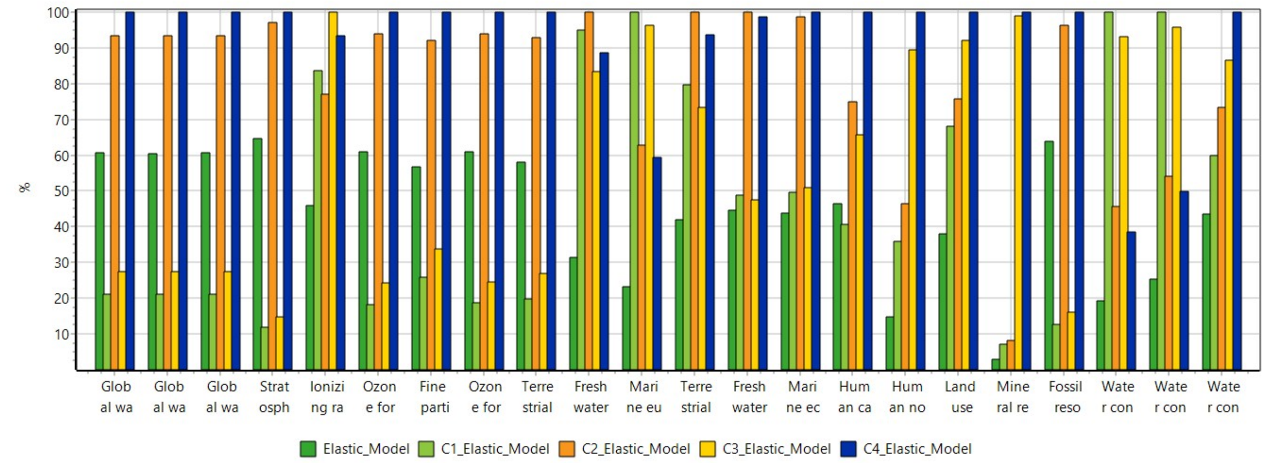


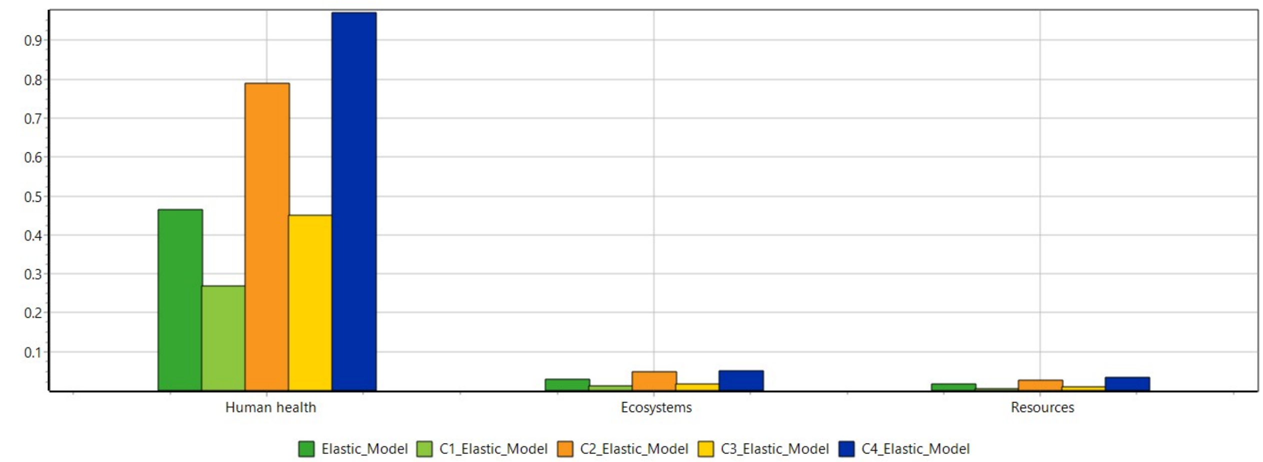
Figure 5: System representation for the comparison of grid charged battery and PV charged battery for electric cooking

This analysis compares grid charged and PV charged battery systems as shown in Figure 5. Graph 29 below shows the midpoint results. This would suggest that grid charged LA battery system (C4_Elastic_Model) is the worst option, as it can be seen to have the highest impact for more of the impact categories than any other combination.

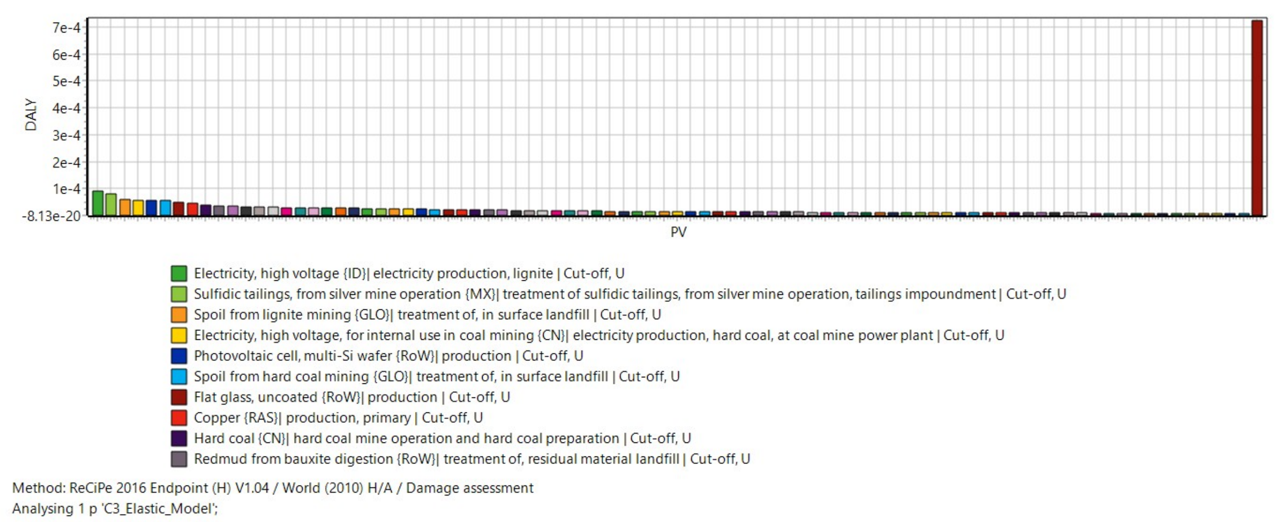


Graph 29: Midpoint Comparison of Grid only with sEPC (Elastic Model) against: PV charged LFP battery with sEPC (C1_Elastic_Model), grid charged LPF with sEPC (C2_Elastic_Model), PV charged LA with sEPC (C3_Elastic_Model), and grid charged LA with sEPC (C4_Elastic_Model).

Graph 30 gives the normalised results, showing once again human health is the endpoint category with the greatest impact. It can also be seen, as expected, that the grid charged batterys are worse for impact than either the grid on its own, or the PV charged batteries, and that PV charged batteries score better than the grid. Looking at the PV system in more detail, Graph 31 looks at the highest contributing factors for human health impact from the manufacture of solar panel. The top impacts resulting from the generation of electricity, and the treatment of sulphidic wastes in the production of silver.



Graph 30: Normalised endpoint comparison of Grid only with sEPC (Elastic Model) against: PV charged LFP battery with sEPC (C1_Elastic_Model), grid charged LPF with sEPC (C2_Elastic_Model), PV charged LA with sEPC (C3_Elastic_Model), and grid charged LA with sEPC (C4_Elastic_Model).



Graph 31: Top impacts contributing to human health endpoint impact category from the manufacture of PV panels.

d) Comparison of electric cooking with more traditional fuels

This section compares grid based electric cooking with a range of more traditional cooking fuels, LPG, charcoal, and wood. Figure 6 shows the system for the comparisons. It can be seen from Graph 32, the midpoint category impacts, highlighting clearly that charcoal (C2_Elastic_Model) score highest for all except two, Human carcinogen, where LPG (C1_Elastic_Model) scores highest, and Land use, where wood (C3_Elastic_Model) scores highest.

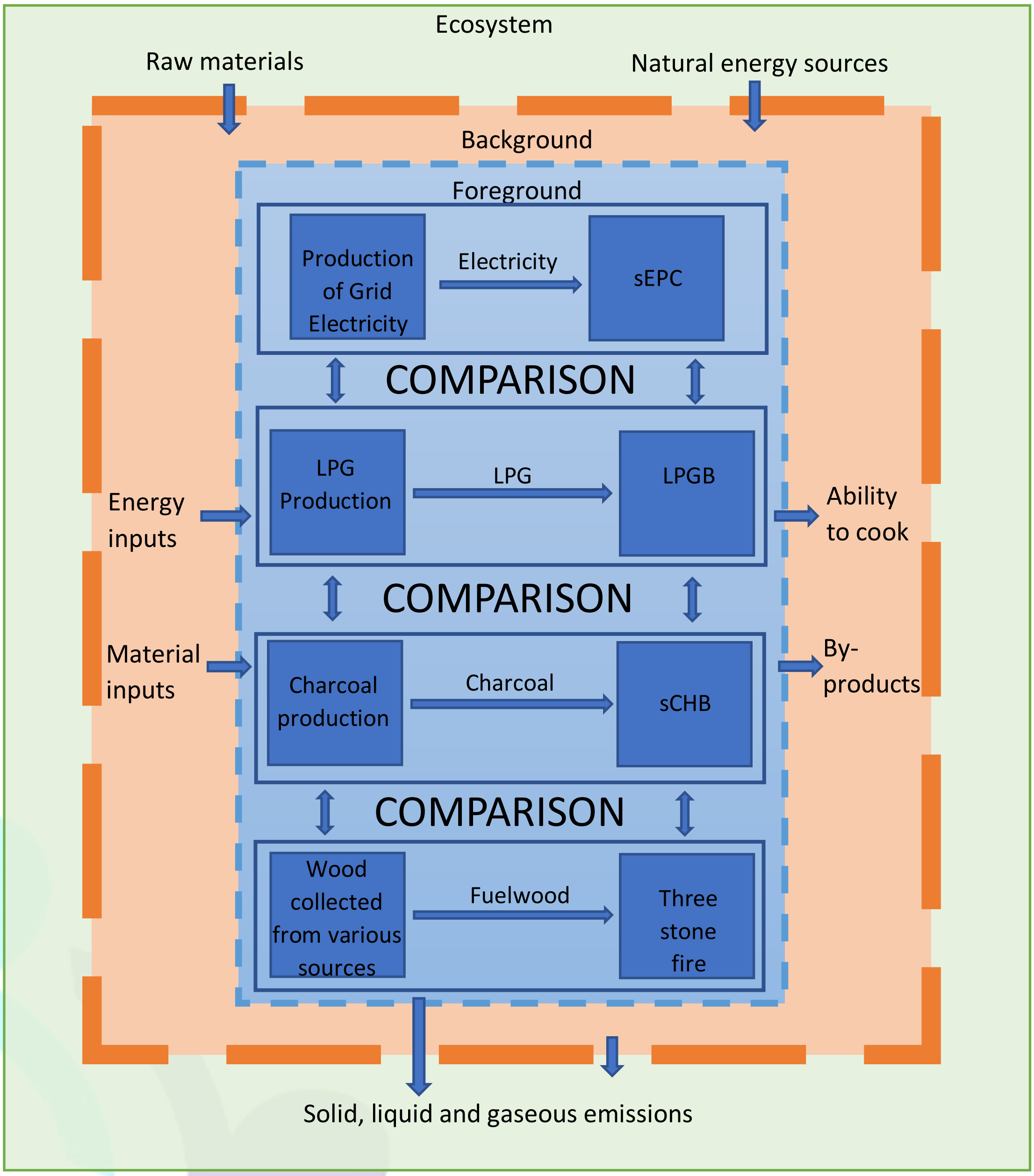
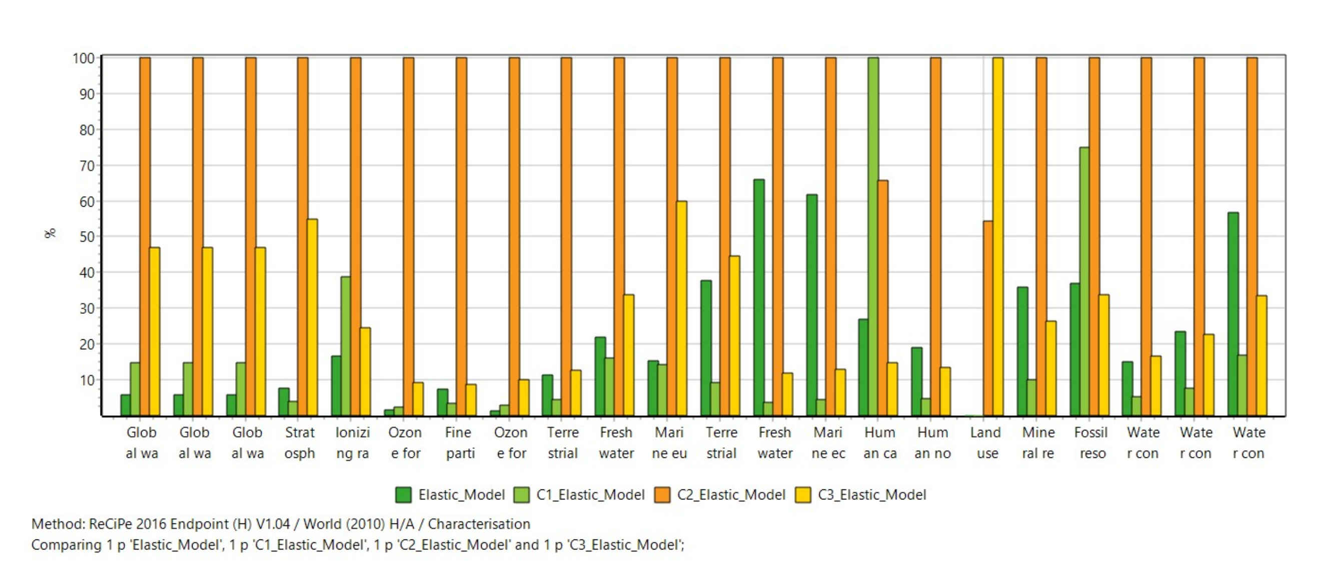
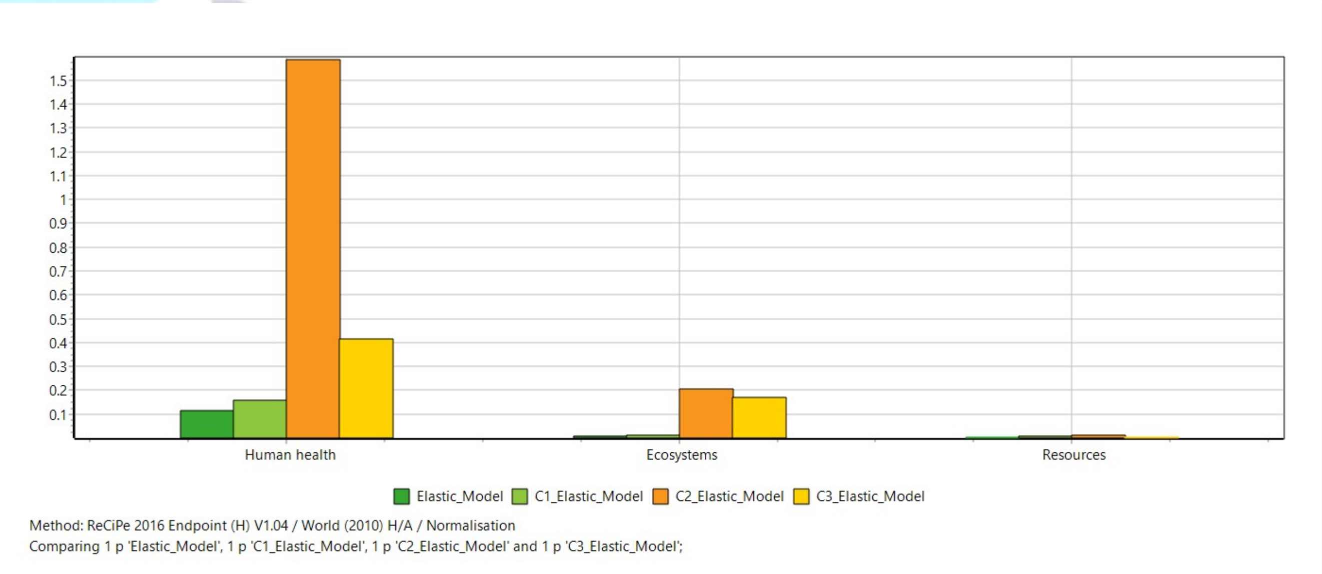


Figure 6: System representation for the comparison of electric cooking to more traditional fuels

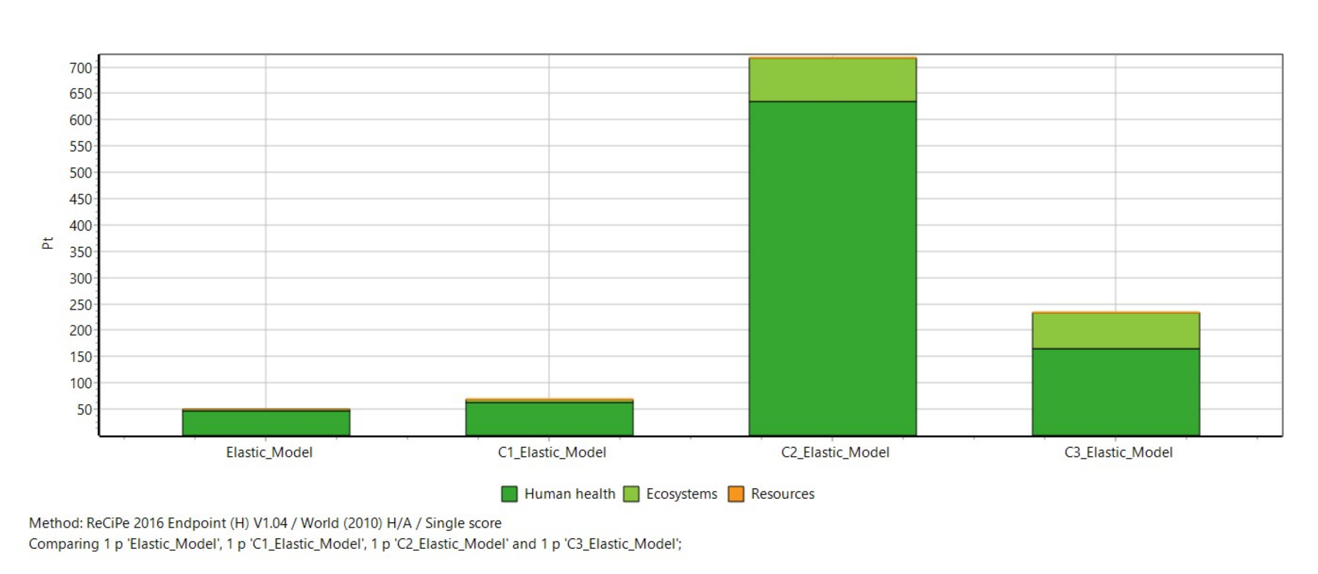


Graph 32: Midpoint Comparison of Grid only with sEPC (Elastic Model) against: LPG with LPGB (C1_Elastic_Model), Charcoal with sCHB (C2_Elastic_Model), and Wood with TSFP (C3_Elastic_Model)

The normalised results seen in Graph 33 show very clearly that human health is the endpoint most effected, but that also the wood and charcoal systems have an effect on ecosystems that is larger than for other comparisons completed thus far. The single score results (Graph 34), confirm that the wood and charcoal systems have the greatest impact, which is the expected result. It is interesting to note that LPG scores very slightly higher than grid based electric cooking. The closeness of the results could suggest it is a feature of the data quality, rather than a real effect, but this would need further investigation to confirm.



Graph 33: Normalised Endpoint Comparison of Grid only with sEPC (Elastic Model) against: LPG with LPGB (C1_Elastic_Model), Charcoal with sCHB (C2_Elastic_Model), and Wood with TSFP (C3_Elastic_Model)



Graph 34: Single score Endpoint for Grid only with sEPC (Elastic Model) against: LPG with LPGB (C1_Elastic_Model), Charcoal with sCHB (C2_Elastic_Model), and Wood with TSFP (C3_Elastic_Model)

e) One day cooking for a range of cooking options

This comparison is to provide a sense of impacts that result from one days cooking from a range of cooking device and fuel/power options. Figure 7 shows the system schematic for the options under consideration. As before, this is not representative of true cooking as it is assuming all cooking is performed on one system only, whereas in the field, multiple systems may be used by one family throughout the day for different dishes.

Graph 35 shows the midpoint indicator impacts for each of the systems under review. From this the two options that stand out are the charcoal with sCHB and the grid charged LA battery system with sEPC. Graph 36 shows the normalised endpoint impact category results. Again, human health is seen to be the impacts of greatest concern, with impacts from the charcoal system dominating the results. Graph 37 confirms this, and shows that the charcoal system has the biggest contribution to human health and ecosystem damage endpoint categories.

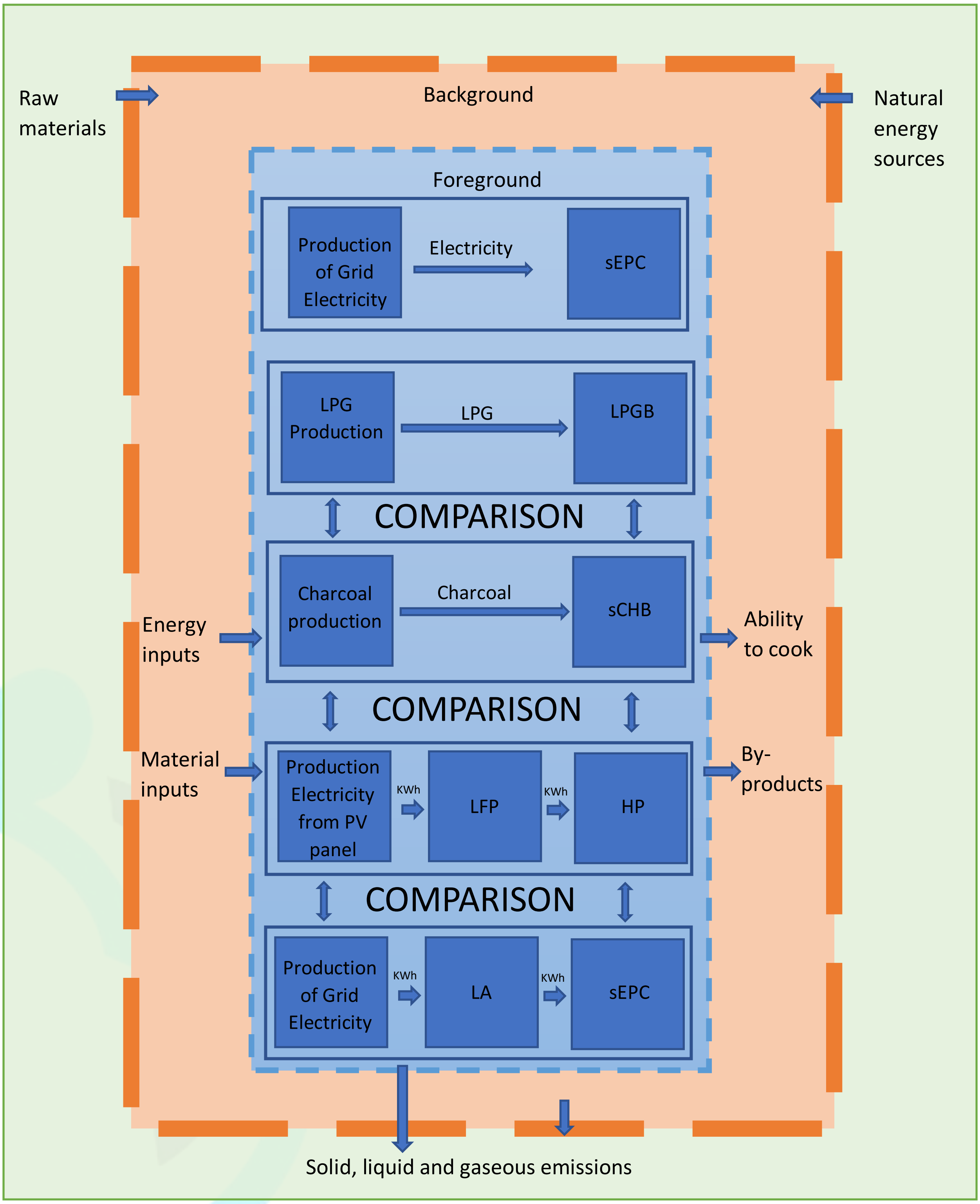
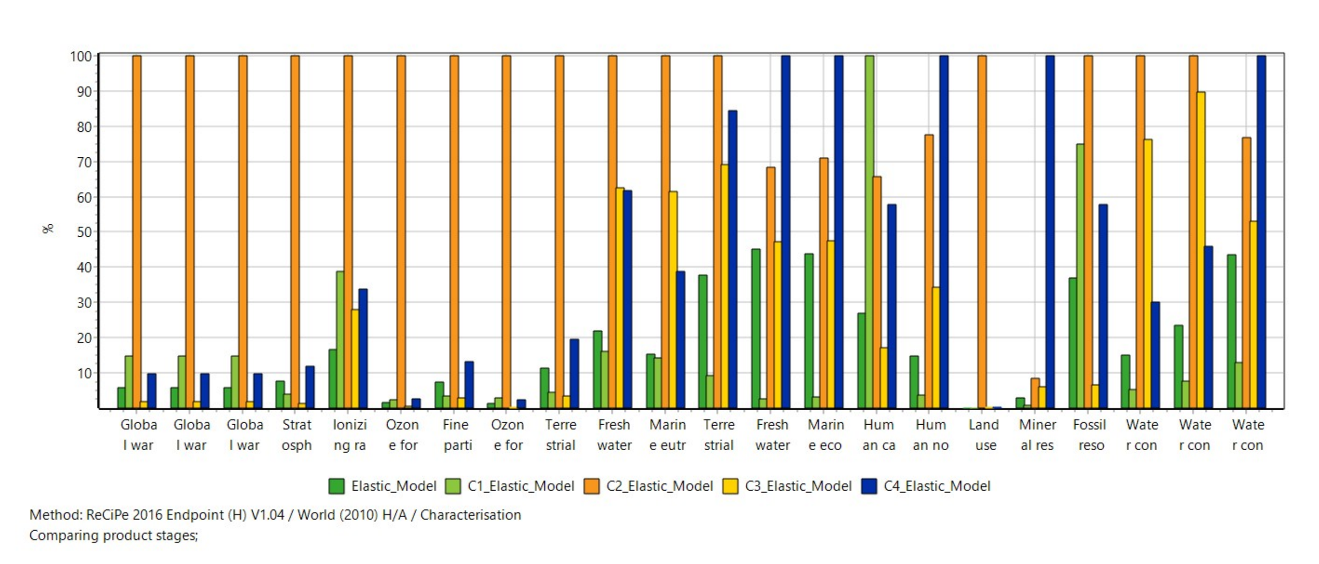
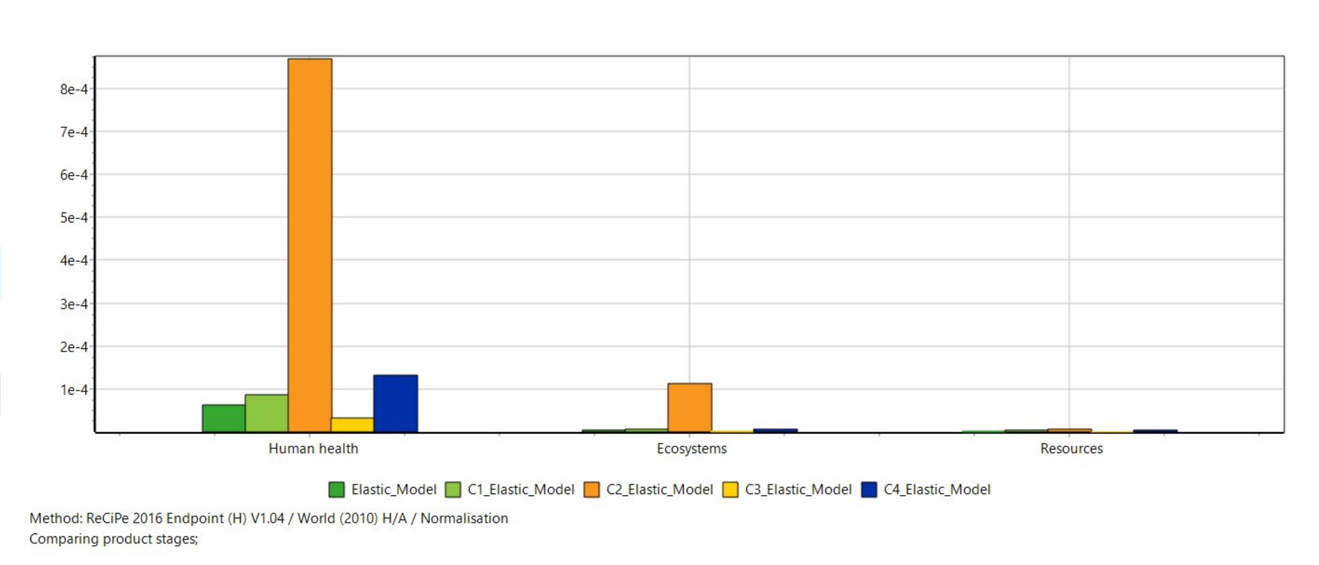


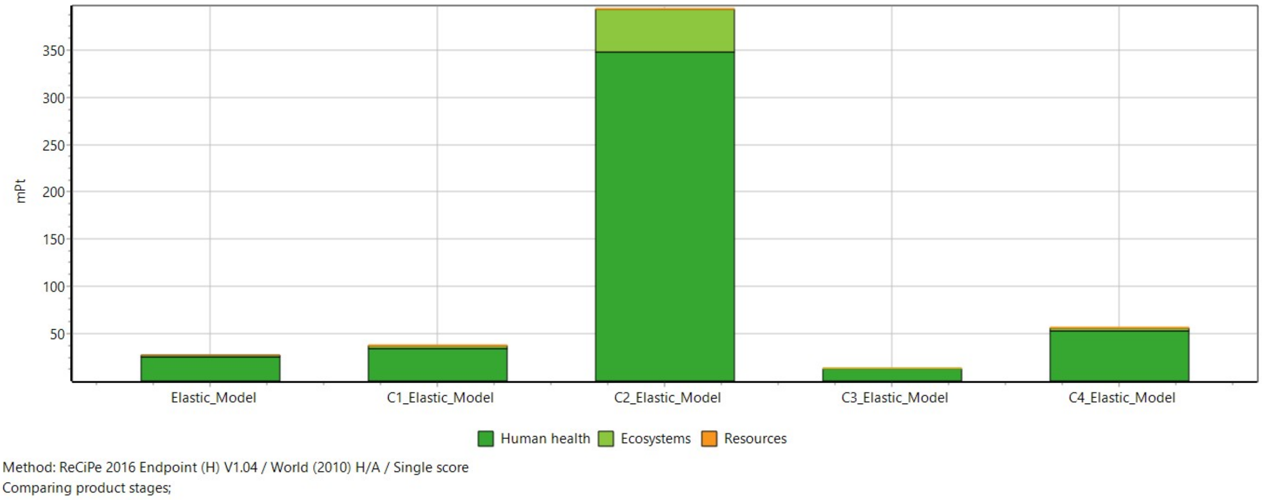
Figure 7: System representation for the comparison of 1 day of cooking for a range of devices and fuel/power systems.



Graph 35: Midpoint category comparison of Grid only with sEPC (Elastic_Model) against: LPG with LPGB (C1_Elastic_Model), Charcoal with sCHB (C2_Elastic_Model), PV charged LFP with HP (C3_Elastic_Model), and grid charged LA with sEPC (C4_Elastic_Model).



Graph 36: Normalised Endpoint category comparison of Grid only with sEPC (Elastic_Model) against: LPG with LPGB (C1_Elastic_Model), Charcoal with sCHB (C2_Elastic_Model), PV charged LFP with HP (C3_Elastic_Model), and grid charged LA with sEPC (C4_Elastic_Model).



Graph 37: Normalised Endpoint category comparison of Grid only with sEPC (Elastic_Model) against: LPG with LPGB (C1_Elastic_Model), Charcoal with sCHB (C2_Elastic_Model), PV charged LFP with HP (C3_Elastic_Model), and grid charged LA with sEPC (C4_Elastic_Model).

f) Summary

The systems analysed in section 4 provide a sense of the relative environmental impacts that could be expected from different device and fuel/power options. These examples were calculated for Kenya, and cannot be extrapolated to other countries as grid mix, charcoal production and LPG production systems are likely to vary. In all cases, the environmental impact resulting for the production and use of the fuel dominated the total impact. However, for the Kenyan context, a general hierarchy of cooking options could be suggested assuming that all options were available, possible (e.g. considering space requirements) and used for the full life of each device:

a) PV with LFP
b) PV with LA
c) Grid
d) LPG
e) Grid with LFP
f) Grid with LA
g) Wood
h) Charcoal

Wood and charcoal are highly dependent on the source of wood, and how far the fuelwood/charcoal then travels to point of use. The models used in this assessment assume that 50% of wood for charcoal comes from plantations, with associated travel and plantation impacts, whereas 100% wood come from local sources, picked up from the ground. Additionally, charcoal is assumed to be transported approximately 350km from point of production to point of use. It is for these reasons that charcoal is seen to have a worse impact than wood, despite the higher calorific value.

These results suggest that using the grid to trickle charge a battery in weak grid scenarios may not be the most environmentally friendly solution, and if possible, a solar panel should be used as the backup power delivery system. However, this is dependent on the number of solar panels needed in a particular area, and the investment in infrastructure needed to stabilise a grid supply for that same area.

Additionally, this initial hierarchy does not take into account the end of life (EOL) implications for each of the devices and power/fuel systems, essentially it is assumed there is no recycling or reuse, the devices are stored with no degradation or impact to the environment. Clearly this is not a realistic position, and it is expected that EOL will have some significant effect on overall impact, and may well alter the order provided above.

5) Conclusions

This working paper has presented the results of a cradle to gate study of cooking devices and fuel/power systems to support the sustainability implications of moving to cleaner cooking options. In section 3, bespoke models for four cooking devices (sEPC, HP, LBGB and sCHB) and three fuel systems (LFP battery, LA battery and charcoal) were presented and analysed, with suggestions for improved design put forward. However, it is not appropriate to look at the devices in isolation, and section 4 combined the devices with different power options (grid, battery and PV) to assess overall likely impact. Many of the results confirm what would be expected, for example, the more complex the cooking device, the higher its impact because of more material use and complex production systems. Additionally, the more energy inefficient the device the greatest the overall impact as the fuel/power is the dominant contributor for the combined system. This would suggest that devices that can accommodate effective insulation will result in significantly lower impact. The domination of the fuel consumption over life is such that the environmental impact resulting from more complex devices but with improved efficiency would be an appropriate design modification.

6) Recommendations

The results found in this working paper have highlighted a number of actions:

a) An uncertainty assessment is required for all data models
b) Creation of simple LPG stove and kerosene wick stove models to better capture the range of devices used for cooking in SSA
c) Improved knowledge of how sCHB are manufactured, and the creation of a model of an improved charcoal burner.
d) Details of the charging/discharging characteristics for LA batteries so they can be sized more appropriately for the combined models
e) Assessment of insulation materials and manufacturing processes that could be combined with cooking devices
f) External review of model and results to allow publishing of comparative results into the public domain.

Appendix A: Tower EPC tear-down data

Category	Item	Material	Mass (g)	Production process
Accessories	cup/spoons	pp	42	Cup Injection moulded, Spoons, Sheet and pressed
	Bags	PE		
	Steamer rack	Chrome plated steel wiore	62	Bent to shape, resistance welded, dipped in bath for chrome-plating
	Steamer plate	Nickel	60	Pressed and stamped
Electrical	Standard power lead		220.5	Length 1.5m
	Bezel (timer)	Thermoset plastic, Black	40	Injection Moulded
	Control Knob	thermoset plastic, Black	7	injection Moulded
	Mechanical timer switch	Mixed materials	76.5	Steel, spring steel, some plastic, electrical contacts
	Power socket	High temp thermoset, black	10	Injection Moulded, chrome plated brass pins
	Pressure actuated elecrical cut out switch/ thermal switch		18	Mixed steel, brass, insulating ceramic discs, bi metallic strip
	Bracket for pressure switch	NiO coated steel	20.5	Al bracket for thermal switch
	PCB	FR4	4.5	
	10 ring connectors	Al		Crimped to wires with heat shrink
	7 spade connectors	Al		
	Al bracket	Al	<0.5	Plate, formed and stamped
	Copper wires and fibre glass sheath	Fibre glass and PTFE (with connectors and sheaths)	34	

	Thermal fuse sheath		2	
	Thermal fuse		<0.5	
	Wire length mm		2632	

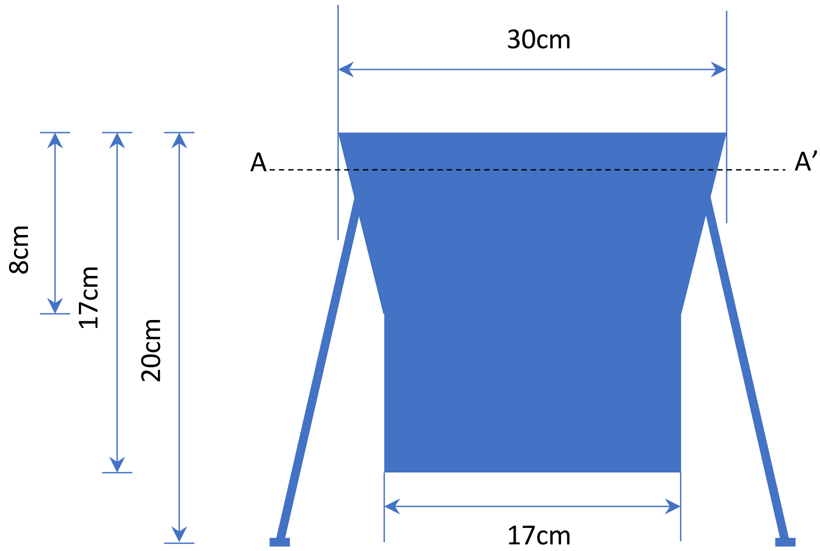
Inner	Main chassis	Steel	1233.5	Deep drawn, stamped to make holes, folded and trimmed. Hammerite powder coated, high temp oven curing
	Pan	Al, hard anodised, powder coated inside, Coating electrostatically attached and baked.	482	Disc Deep drawn, edges rolled trimmed, rolled and measurements stamped
	Legs for chassis	st Steel, NiO coating, stamped, dressed holed, forced screw thread	30	each leg 10 g
	Hot plate assembly	Al alloy	498	Heating element: Steel outer, wiring, ceramic di-electric, metal outer tube, nickel tags. Turned Al disc, hard anodised outside, low melting alloy encapsulation possibly injection moulded. Spigots machined for length and then drilled and tapped
	Moat	Thermoset plastic, Black	121	Injection moulded
	Thermal isolator, sealing ring	High temp Thermoset plastic, Black	50.5	Injection moulded
	Lid inner ring	Thermoset plastic, Black	82	Injection moulded
	Splash sealing ring and mounting gadget	Silicon	60	Moulded
	Spring	Steel	2	Spring steel - shiny
	Spring plate	Tempered steel	171	Stamped and heat treated
	Sprung button assesmbly	al	17.5	Stamped and pressed, includes one thermal switch

Outer	Bottom Cover	Thermoset plastic, black	57.5	Injection moulded
	Plastic base	Thermoset plastic, black	156	Injection moulded

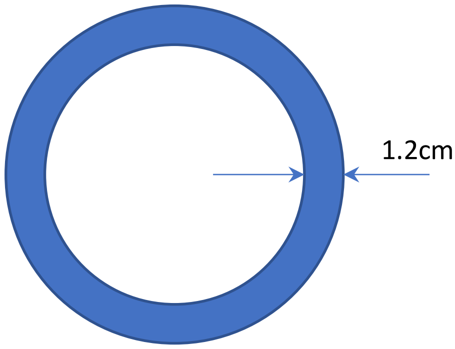
	Handle	Thermoset plastic, Black	21	Injection moulded
	Lid trim	Thermoset plastic, grey	21	Injection moulded
	Lid covers	Thermoset plastic, Black	200	Injection moulded
	Handle chrome trim	Thermoset plastic, brass and chrome	5.5	Injection moulded plastic, Hot spray molten brass, chrome plated
	Metal Cover	Brushed STST	263.5	Rolled st st, stamp to form holes.
	Steel lid	St St	543	Turned pin, resistance welded. Strip for handle, St st pressed to shape holes drilled resistance spot welded Blanking disc, spun to shape, pressed and stamped for PV holes, Holes punched through and dressed
	Condensation plate	Al,	43	Thin plate stamped and pressed.
Packaging	Box	Corrugated cardboard	616	
	Polystyrene packaging	PS	49.5	two pieces each of around 49.5. 200C steam from bead
	Plastic handle	flexible plastic	6.5	
Small bits	Rubber feet	Silicon	3.5	Extruded and cut to length (4 of)
	Condensation trap	Clear plastic	8.5	Injection moulded
	Screws and Miscellaneous	St Steel and Mild steel	64	
Valves	Interlock Lever	Aluminium Main body Al, Pin stainless steel, Spring, spring steel. Turned pin	10	Stamped and formed
	Interlock valve	Al	7.5	with 2 silicon rings
	Pressure relief valve	St st	17	Turned pin, al blind nut, washer silicon seal

	Al	2	
Top of relief valve	Thermoset plastic, Black	78.5	Turned weight, moulded silicon sealing pin, wire clip
	St st		

Appendix B: Street Charcoal Burner model data



Not to scale



From the above dimensions the mass of steel and ceramic were calculated as:

Steel 1.5kg

Ceramic 1.6kg

Appendix C: LPG burner, twin ring tear-down data

Part	Material	Mass/g	Production Process
Jubilee clip	Steel	11	Pressed
Gas tube	Thermoplastic Rubber	140	Extruded
Griddle	Chromium coated steel wire	538	Drawn wire, chromium coated
Bottom tray	Steel	727	Pressed, holes drilled and painted
Legs (x2)	Steel wire, chromium coated	72	Wire drawn and bent to shape. Chromium coated
Fuel pipe	Anodised nickel steel	31	Drawn
Fuel pipes to rings	Galvanised steel	55	Drawn
Brackets	Galvanised steel	16	Sheet Pressed
Back plate	Painted low carbon steel	332	Steel sheet formed and painted
Side panels	Painted low carbon steel	275	Steel sheet formed and pressed
Inner plate	Anodised steel	136	Stamped and pressed
Outer plate	Painted steel	355	Stamped and pressed
Ring surrounds	Chromium plated steel	335	Steel sheet stamped and formed
Control knobs	PP	29.8	Injection moulded

Appendix D: Hot plate tear-down data

Part	Material	Mass/g	Production Process
Plate with heating element	Cast Iron	977	Heating element: Steel outer, wiring, ceramic dilectric, metal outer tube, nickel tags. Spigot machined for length and then drilled and tapped. Diameter 187mm
Heating ring surround	St St	16.5	St St sheet, pressed. Diameter 195mm
Cover plate (heating element)	aluminium	29.5	Aluminium plate, pressed. Diameter 155mm
Screws and bolts	Steel	26	Impact for screws, Cast and drilled
Bottom legs	PP	6.5	Injection moulded
Three pin power	copper	20	
Rotating switch	pp	9	Injection moulded
Various plastic parts	pp	33.5	Injection moulded
Power cable (copper wires)	plastic+copper	89	900mm x 3pc (55g copper+ 34g plastic)
Metal case	Steel	465.5	230 x 620 mm, injection moulded and painted
On/Off switch (wires)	Steel+copper	42	Steel sheet, pressed and painted

Appendix E: Data for LFP production per kWh[12]

Component	Sub component	Material	Mass kg
Anode Paste			
	Active metal	Graphite	0.86
	Binder	Carboxymethyl cellulose	0.034
		SBR	0.014
	Conductive metal	Carbon black	0.048
	Current collector	Copper	0.94
Cathode Paste			
	Active metal	Lithium iron phosphate	2.5
	Binder	Polyvinylfluoride	0.23
	Solvent	N-methyl-2-pyrrolidone	0.79
	Conductive metal	Carbon black	0.14
	Current collector	Aluminium	0.41
Separator			
	Metal	LDPE	0.19
Electrolyte			
	Salt	Lithium hexafluorophosphate	0.16
	Solvent	Ethylene carbonate	1.4
Utilities			
	Electricity	Medium voltage, China	26 kWh
	Heat	Heat production from natural gas	450 MJ
	Water	Decarbonised water	33

[12] from Terlow et al. 'Towards the determination of metal criticality in home-based battery systems using a life cycle assessment approach'. Journal of Cleaner Production, 221 (2019) 667-677 DOI: 10.1016/j.jclepro.2019.02.250

Appendix F: Data for LA production per kg battery [13]

Component	Material	Mass g
Lead grid		
	Lead	710
	Calcium	0.3
	Aluminium	0.1
	Tin	4
	Silver	0.1
Negative electrode additives		
	Barium sulphate	1.2
	Carbon black	0.4
	Sodium lignosulphonate	0.5
Fibreglass mat separator		25
Copper terminals		5
Electrolyte		
	H2SO4	63
	Water	108
Casing	PP	75
Balancing and control electronics		
	Integrated circuit	0.002
	PCB	0.4
	ABS plastic casing	7.6
Grid manufacture		MJ
	Electricity	0.37
	Gas	3.85
	Oil	0.43
Paste manufacturing		
	Electricity	0.22
	Gas	0.65
	Oil	0.02
Plate manufacturing		
	Electricity	0.23
	Gas	0.68
	Oil	0.08
Plastic moulding		
	Electricity	0.78
	Gas	0.2
	Oil	0.02
Assembly/formation		
	Electricity	2.99
	Gas	0.93
	Oil	0.1

[13] Spanos et al. 'Life cycle analysis of flow-assisted nickel zinc-, manganese dioxide- and valve regulated lead acid batteries designed for demand charge reduction. 2015, Renewable and Sustainable Energy Reviews 43, 478-494. DOI 10.1016/j.rser.2014.10.072

Appendix G: Charcoal production in Kenya

- Charcoal production method: traditional earth kiln. 99% of charcoal produced in Kenya in this way. Original reference Pennise et al 2001. Cited by: EPA, Njenga (2013)
- % of carbon dioxide that can be assumed to be regenerative, i.e. absorbed during tree growth. Two methods available, Singh and Bailis. Values from Bailis used: 36% assumed to be regenerative, 64% assumed released to atmosphere

Earth Mound kiln: Calculation of mass of soil required.

Assume 4m diameter and 1.25m high an assume a 20 cm thickness of soil

Outer volume 10.47m3, Inner volume 10.2m3, therefore volume of soil required = 0.27 m3

Density of loamy soil, average 2000kg/m3

From D=m/V m = D x V

m = 2000 x 0.27

m = 540kg per mound

Quantity of wood per mound

Assume density of wood is between 495kg/m3 (Eucalyptus) and 730kg/m3 (Black acacia). 600kg/m3 assumed as average.

From D=m/V m = D x V

m = 600 x 10.2

m = approx. 6000kg wood per mound

There are spaces in the wood pile, average 25%, but up to 40%

This gives between 4500kg and 3600kg of wood per earth mound kiln

Charcoal production from wood in Kiln

4500Kg gives approx. 1440kg charcoal

3600Kg gives approx. 1150kg charcoal

Therefore average charcoal production yield 1300Kg per earth mound kiln

Emissions

From Bailis: only 36.1% of wood consumed is renewable. Therefore, for each kg CO_2 emitted from charcoal production and consumption, 36.1% can be regarded as biogenic (and not counted towards GWP – IPPC defined) and 73.9% must be emitted to atmosphere and contribute to GWP etc.

Emissions data taken from Pennise.

References for Charcoal Production in Kenya:

Bailis, R. 'The carbon footprint of traditional woodfuels'. Nature Climate Change, vol 5, 2015. DOI: 10.1080/09614524.2013.780529

EPA, 'Life Cycle Assessment of cooking fuel systems in India, China, Kenya and Ghana'. EPA/600/r 17/225 August 2017.

Njenga, M. et al. 'Charcoal production and strategies to enhance its sustainability in Kenya'. Development in Practice, Vol23, 3, 359-371. 2013. DOI: 10.1080/09614524.2013.780529

Pennise, D.M et al. 'Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil'. Journal of Geographic Research, Vol 106, D20, p24,143-24,155. October 2001

Singh, P. et al. 'Environmental footprint of cooking fuels: a life cycle assessment of ten fuel sources used in Indian households'. International Journal of Life Cycle Assessment (2014) 19:1036-1048. DOI:10.1007/s11367-014-0699-0