Preliminary Environmental Assessment of ESMAP case studies 1 and 5, cradle to end of use.

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Executive Summary

This working paper describes the **preliminary** environmental assessment for Case Studies 1 and 5 as described in the ESMAP report 'The viability of cooking with electricity in Sub-Saharan Africa and South/Southeast Asia – a cost perspective'. The intention is to provide accompanying environmental information to the cost analysis, thus providing detail on two of the three sections of sustainability assessment, the final section being a social impact analysis. The assessment has been carried out using ReCiPe (H) midpoint and endpoint environmental impact categories. The study was conducted following the principles of BS/EN ISO 14040 and 14044 and other good practice systems.

The preliminary results show that for both case studies, charcoal has the worst environmental impact of all fuel/power and cooking device options.

For case study 1, there is little difference between electric cooking from the grid, LPG and kerosene and further investigation with more bespoke data is need to refine these systems, but these results suggest a combination of LPG/kerosene with electric cooking would deliver an appropriate cooking system with lower environmental impact than using charcoal. For weak grid systems where the grid is backed up by a battery, this incurs additional impacts. As a result, the relative environmental cost of upgrading a grid system to provide stable electrical delivery versus supplying all users with a battery backup would require investigation on a case by case basis. Additionally, these results are highly dependent on the mix of fuels used to generate the grid electricity and will change on a country by country basis.

For case study 5, electric cooking using a PV/LFP power system shows a significant environmental benefit over charcoal cooking. When combined with either LPG or kerosene, there appears to be no significant difference, and similarly to case study 1, further investigation with more bespoke data is needed to fully assess these differences.

Additional areas for investigation include the use of hotboxes to replace/reduce the need for pressure cookers, and their associated burden on electricity demand, the effect different diets between urban and rural environments may have on heavy cooking requirements, and the potential impact that bio-derived liquid and gaseous fuels may have on the environmental impacts associated with LPG and Kerosene.

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

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1) Introduction

This working paper presents an environmental assessment results of case studies 1 and 5 as described in the ESMAP report 'The viability of cooking with electricity in Sub-Saharan Africa and South/Southeast Asia – a cost perspective'. The results presented here are preliminary, do not cover any end of life options and have not been externally verified. As such, the results may not be published into the public domain.

The assessment follows the guidelines for ISO 14040[1].

2) Goal and scope definitions

The goal of this study was to provide an environmental assessment for streamlined version for case studies 1 and 5 of the ESMAP paper. A general description of the each of the case studies is given in Table 1 below.

	Case Study 1 (2020)	**Case Study 2 (2020)**
Power Generation Source	National Grid	Solar PV
Baseline fuels	Charcoal, LPG, Kerosene	Charcoal, LPG, Kerosene
Appliances	Efficient devices (EPC) and Hotplates	EPC
Location	Nairobi, Kenya	Nakuru County, Kenya

Table 1: Outline of case studies under review

The results are intended to add depth and understanding to the cost modelling of cooking options, and provide data needed to assess the sustainability of modern energy cooking services (the three pillars commonly understood as: economic, environmental and social aspects). The intended audience at this time is the MECS community, with the potential for public dissemination at a later date once externally verified.

The scope of the assessment was cradle to end of use. The model has been built using variables, that allow for devices and power sources to be switched on/off. Called an elastic model, it provides flexibility to create a wide variety of cooking devices and power/fuel combinations across a number of geographic areas. It is attributional in nature, and uses data that assumes recycled or recovered materials are not allocated a percentage of the environmental burdens from the previous processing 'life', e.g. recycled copper is free from the burdens generated as a result of the primary mining functions.

Functional Unit

The functional unit was one day of cooking. To meet this, the environmental burdens associated with the cooking devices were apportioned appropriately.

Allocation

Any allocation issues have been eliminated by system expansion, where this has not been possible, burdens have been allocated on a mass basis between the desired output and by-products.

Impact Categories

[1] BS EN ISO 14040:2006. 'Environmental management- Life cycle assessment - principles and framework. 2006

ReCiPe (H) midpoint categories, and endpoint categories were analysed, as this impact assessment system is global in nature. No African specific impact assessment system currently exists.

Limitations and assumptions

There are limitations in the models built for the EPC and battery technologies (see Working paper 'Cradle to gate environmental assessment for cooking devices'. Grid electricity for Kenya was used from Ecoinvent, as was the model for PV panel. To date, it has not been possible to create a model for a wick kerosene stove. However, the results for the cradle to gate assessment suggest strongly that the contribution of impacts from the manufacture of the cooking device to total impact over the life of the cooking device is negligible. Thus, whilst the results for kerosene scenarios will be lower than what would be expected, it is not considered inappropriate to include kerosene in the analysis.

The expected lifetimes for each device are listed below in Table 2. Whilst these are apportioned to represent one day of cooking, it is assumed that they last the stated lifetime, irrespective of how much they are used, e.g. a sEPC will last 5 years if used for 100% cooking or 50% cooking. This represents worst case scenario.

Device	Assumed lifetime
Simple Electric Pressure Cooker (sEPC)	5 years
Hotplate (HP)	5 years
LPG Burner (LPGB)	5 years
Street Charcoal Burner (sCHB)	6 months
Lithium Iron Phosphate Battery (LFP)	8 years
Lead Acid Battery (LA)	5 years
Photovoltaic panel (PV)	20 years

Table 2: Assumed device lifetimes

The results presented are preliminary and useful for initial comparative analysis. Absolute figures should not be taken from the graphs presented and used with any degree of confidence.

Data and Data Quality

Working Paper 'Cradle to gate environmental assessment for cooking devices' provides details and references on the data sources used to build sub models for the environmental assessment of the case studies. Effort has been made to retain a similar level of data granularity throughout the elastic model, to minimise the potential danger of a hotspot occurring simply as a result of higher data quality. Where data gaps exist, these have either been filled using data from ecoinvent or by proxy data.

3) System Boundary

Figure 1 below shows the generic system boundary for the environmental assessment.

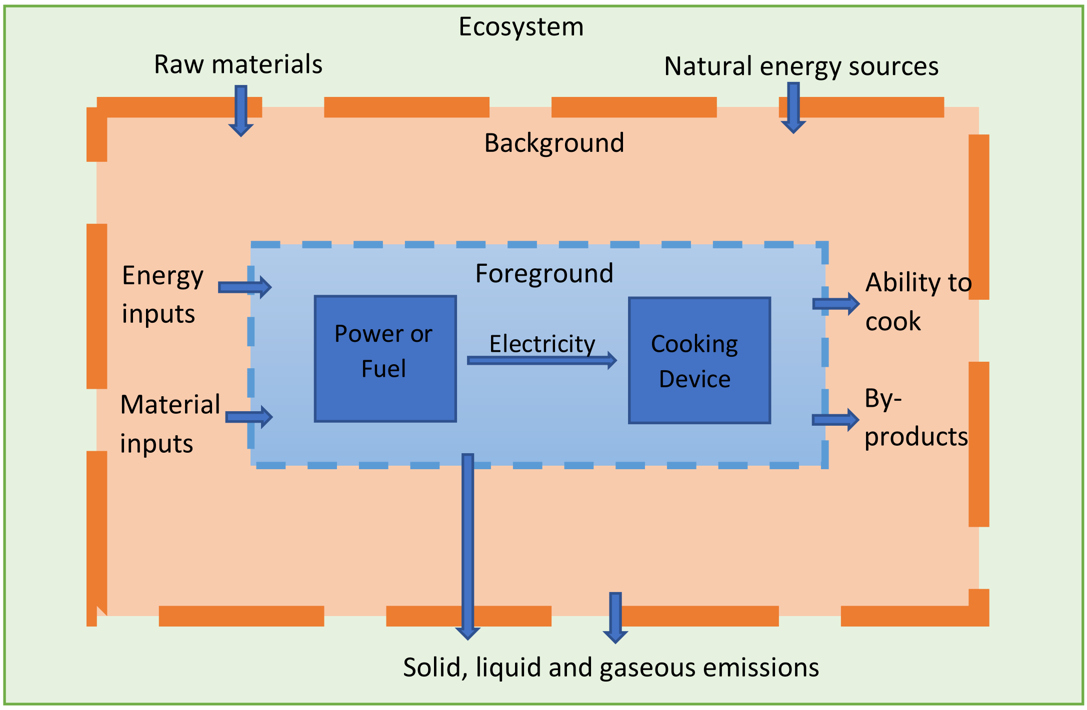


Figure 1: System representation

4) Scenarios for case studies

The power/fuel source and cooking device represent the combinations given in tables 3 and 4 for case studies 1 and 5 respectively. For case study 1, each of the fuel/device options have been compared to the electric cooking options in isolation, and the results of all scenarios brought together as a single score in graph 16. For case study 5, all scenarios have been considered together.

Nairobi, Kenya			
Urban households, switch from charcoal to eCook & LPG			
	%		
	Fuel	Grid	Battery
Grid	**	100	**
Battery and Grid	**	50	50
Battery	**	**	100
Traditional CH	100	**	**
Grid and charcoal	50	50	**
Battery and charcoal	50	**	50
Traditional LPG	100	**	**
Grid and LPG	50	50	**
Battery and LPG	50	**	50
Traditional Kerosene	100	**	**
Grid and Kerosene	50	50	**
Battery and Kerosene	50	**	50

Table 3: Scenarios for case study 1

Echariria, Kenya			
Offgrid solar-battery cooking			
	%		
	Fuel	Grid	Battery
PV/ Battery	**	**	100
Traditional CH	100	**	**
PV/Battery and charcoal	50	**	50
Traditional LPG	100	**	**
PV/Battery and LPG	50	**	50
Traditional Kerosene	100	**	**
PV/Battery and Kerosene	50	**	50

Table 4: Scenarios for case study 5

5) Results

5.1 Case Study 1

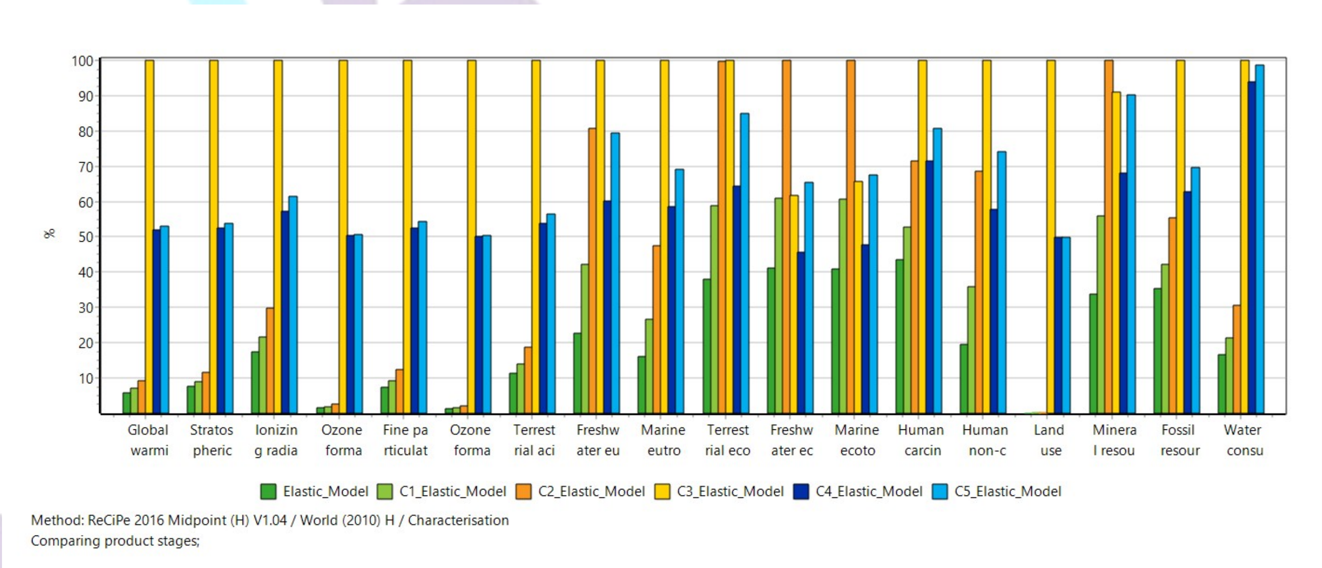
Case study 1 is based in urban Kenya (Nairobi) and investigates the opportunity for households to remove charcoal from their cooking options and move to a combination of electric cooking with LPG. Kerosene is included as this is an existing cooking option for urban communities.

a) Charcoal and eCook

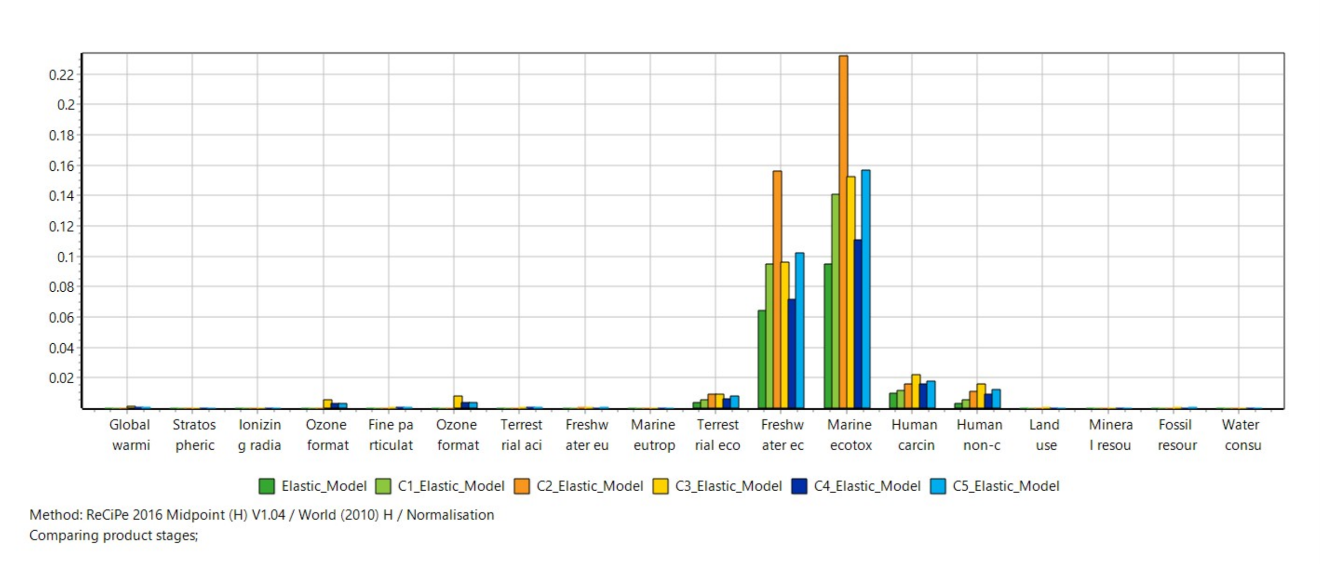
Tables 3 shows the detail for the investigation of charcoal versus electric cooking. Graphs 1 and 2 show the midpoint characterisation and normalised results respectively. Unsurprisingly, 100% charcoal is generally seen to have the highest relative impacts across the majority of the midpoint indicators. Form the normalised graph 2 freshwater and marine ecotoxicity is seen to be the greatest midpoint category of interest; this is a result of the treatment of sulphidic tailings from copper production. This is the cause for all of the scenarios shown here, and comes from the production of electricity. Whilst the production of charcoal is rural, and does not require electricity, the charcoal is transported to point of sale by vehicles, that would have required electricity in their manufacture, and in the production of the fuel to run them.

Nairobi, Kenya								
Urban households, switch from charcoal to eCook								
			%				Battery Size	Devices
	Model Refernce	Fuel	Grid	Battery	Charcoal/LPG/kerosene	Electricity from Grid		
					kg	kwh		
Grid	Elastic Model	**	100	**	**	2.78	2.78	sEPC/HP
Battery and Grid	C1 Elastic Model	**	50	50	**	1.92	**	LFP/sEPC/HP
Battery	C2 Elastic Model	**	**	100	**	2.21	0.93	LFP/sEPC/HP
Traditional Charcoal	C3 Elastic Model	100	**	**	1.75	**	**	sCHB
Grid and charcoal	C4 Elastic Model	50	50	**	0.87	0.64	**	sEPC/sCHB
Battery and charcoal	C5 Elastic Model	50	**	50	0.87	0.93	0.93	LFP/sEPC/sCHB

Table 5: Detail and model reference for charcoal/eCook scenario

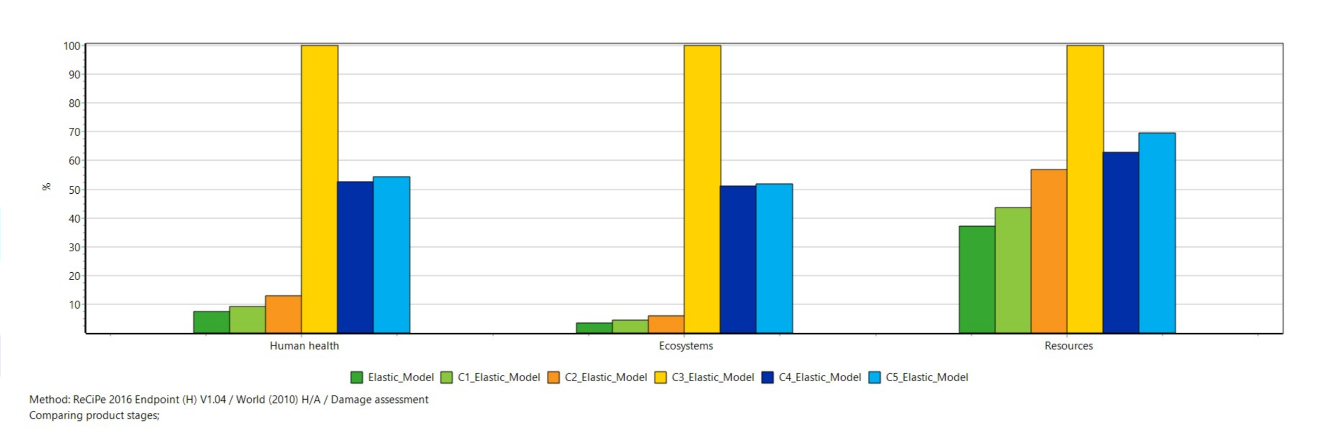


Graph 1: Midpoint categories for Charcoal and eCook scenarios

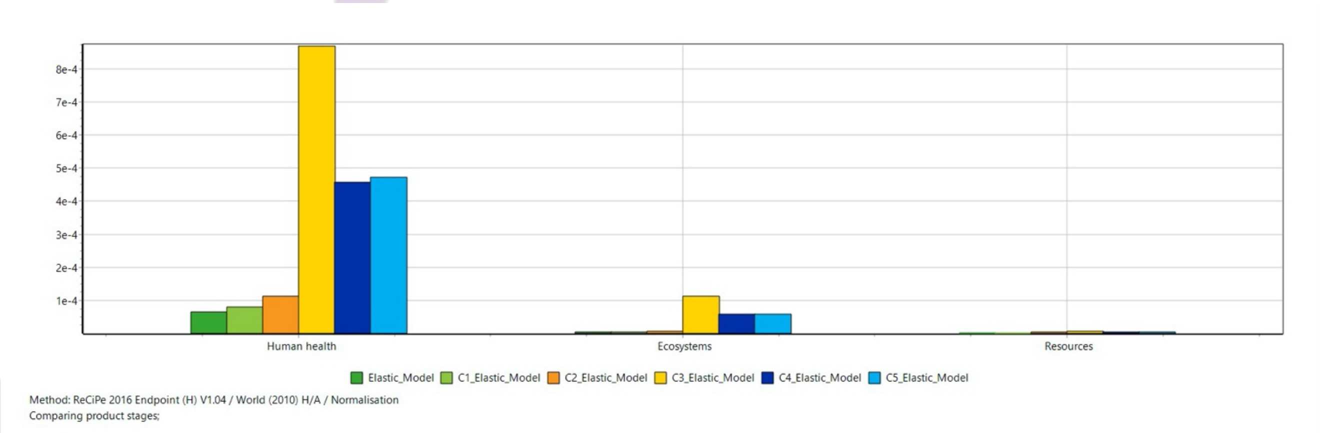


Graph 2: Normalised midpoint categories for charcoal and eCook

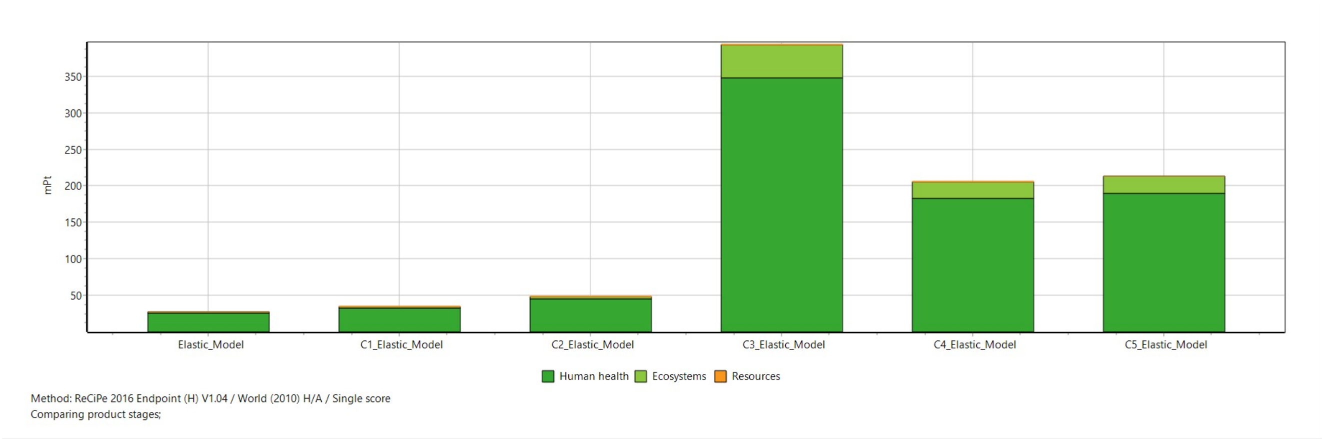
Graphs 3,4 and 5 show the endpoint impacts for charcoal and eCook. Graph 3 shows the relative damage from each of the scenarios to the endpoint categories, Graph 4 shows the normalised impacts (i.e. against global average per capita per year impact) and graph 5 show the three endpoint impact categories wrapped into a single score.



Graph 3: Relative damage to endpoint categories for charcoal and eCook



Graph 4: Normalised endpoint impact for charcoal and eCook



Graph 5: Single Score endpoint impact for charcoal and eCook

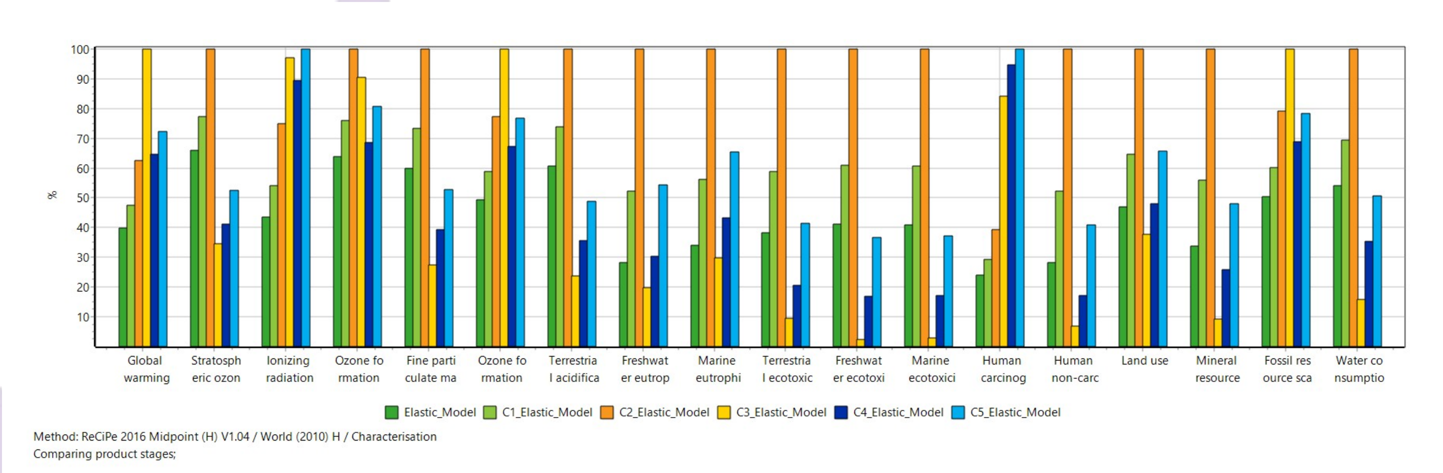
The results show that the best option is 100% grid-based cooking, and the worst is 100% charcoal. Human health is the endpoint worst affected. Battery use (when trickle charged via the grid) as a support system is worse than grid alone (primarily due to the battery charging characteristics), and worse again if used as the main source of power for cooking.

b) LPG and eCook

Table 6 shows the detail for the investigation of LPG and eCook and graphs 6 and 7 show the results of the midpoint impact assessment.

Nairobi, Kenya								
Urban households, switch from LPG to eCook & LPG								
			%				Battery Size	Devices
	Model Reference	Fuel	Grid	Battery	Charcoal/LPG/kerosene	Electricity from Grid		
					kg	kwh		
Grid	Elastic Model	**	100	**	**	2.78	2.78	sEPC/HP
Battery and Grid	C1 Elastic Model	**	50	50	**	1.92	**	LFP/sEPC/HP
Battery	C2 Elastic Model	**	**	100	**	2.21	0.93	LFP/sEPC/HP
Traditional LPG	C3 Elastic Model	100	**	**	0.23	**	**	LPBG
Grid and LPG	C4 Elastic Model	50	50	**	0.11	0.64	**	sEPC/LPGB
Battery and LPG	C5 Elastic Model	50	**	50	0.11	0.93	0.93	LFP/sEPC/LPGB

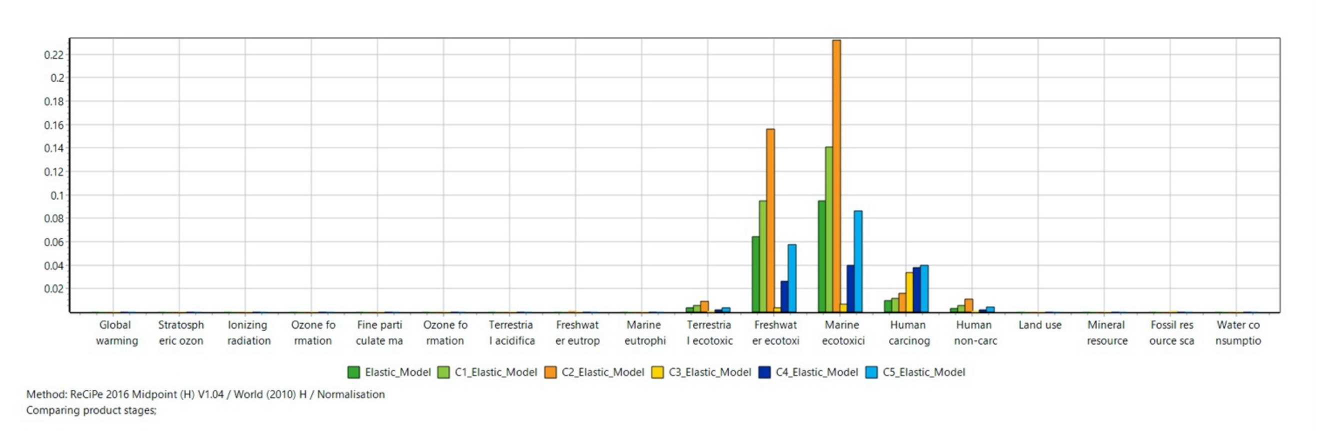
Table 6: Detail and model reference for LPG/eCook scenario



Graph 6: Midpoint categories for LPG and eCook scenarios

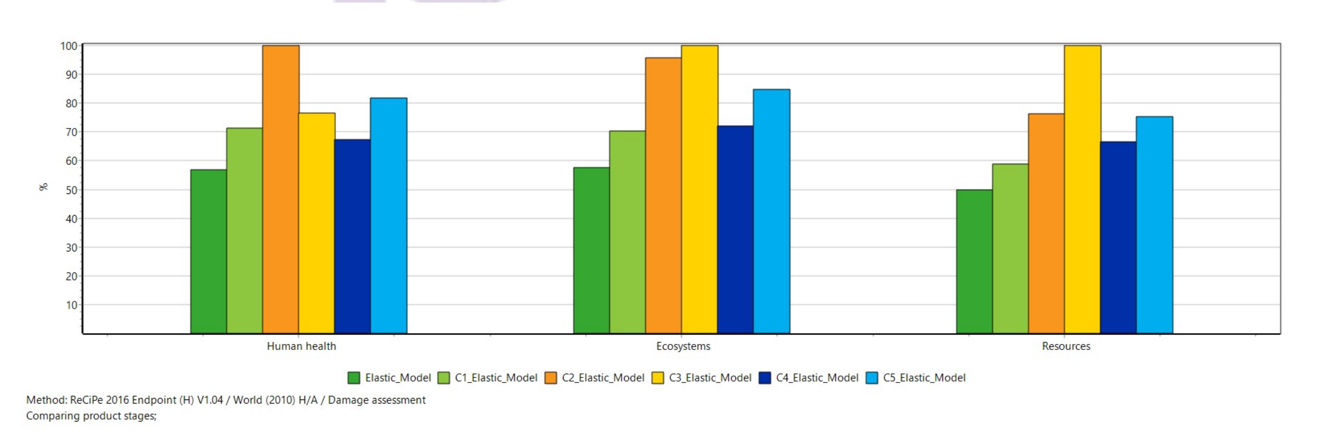
The midpoint categories show a different picture here, with the 100% battery option causing the greatest relative impact across the majority of the categories. Results for LPF manufacture from Working paper ‘Preliminary cradle to gate environmental assessment for cooking devices’, shows that, for both 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. 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. The cathode current, raises the issue of the treatment of redmud waste from the production of bauxite

Graph 7 shows the normalised results, and like the charcoal and eCook scenario, the midpoint categories of most interest are freshwater and marine ecotoxicity. As detailed above, this is due to the treatment of sulphidic tailings in copper production.

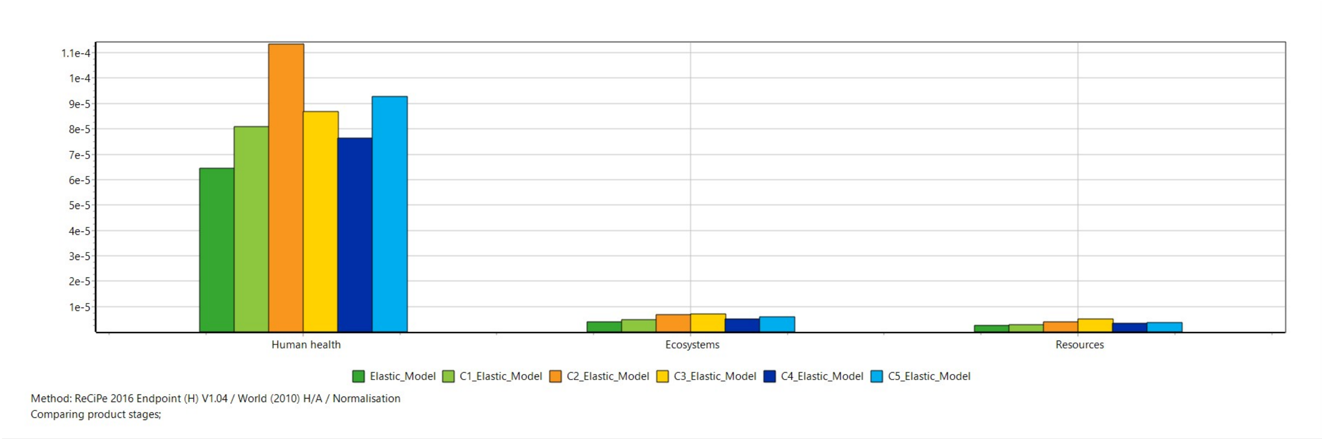


Graph 7: Normalised midpoint categories for LPG and eCook

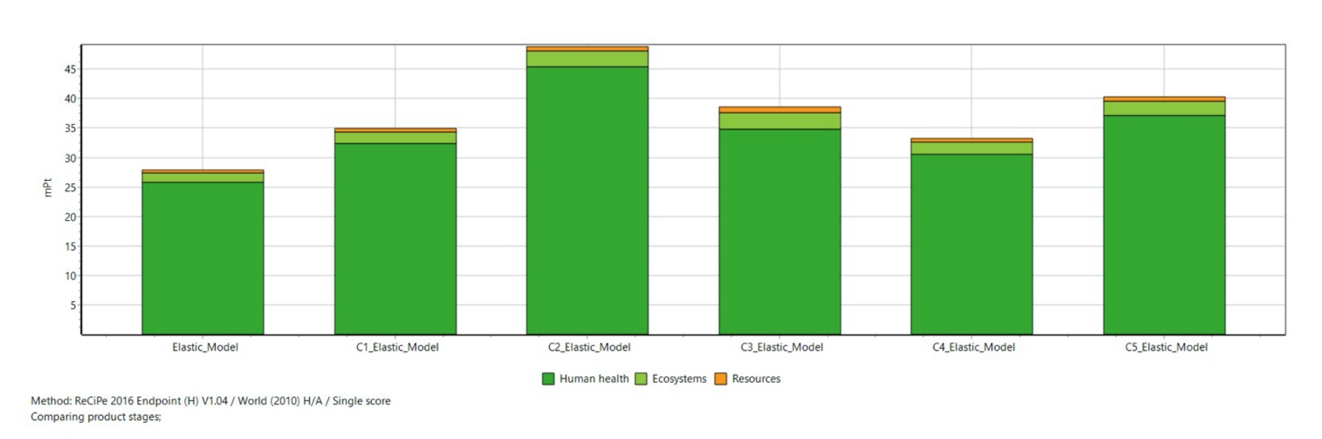
Graphs 8,9 and 10 show the endpoint impacts for charcoal and eCook. Graph 8 shows the relative damage from each of the scenarios to the endpoint categories, Graph 9 shows the normalised impacts (i.e. against global average per capita per year impact) and graph 10 show the three endpoint impact categories wrapped into a single score.



Graph 8: Relative damage to endpoint categories for LPG and eCook



Graph 9: Normalised endpoint impact for LPG and eCook



Graph 10: Single Score endpoint impact for LPG and eCook

Graph 8 shows that the relative damage impacts for LPG are only slightly higher than those occurring for grid and/or battery cooking, with 100% battery and 100% LPG looking slightly higher overall. Graph 9, the normalised scores shows once again that human health is the endpoint of most concern. Graph 10 shows the single scores for the endpoint impact categories. Here it can be seen that 100% battery is the worst option, with 100% grid still best. Using LPG with the grid appears to be the best option if using LPG as a fuel. However, all these results are very close, and an uncertainty assessment of the data would reveal if the results are significantly different, or data quality/gaps such that a clear best option cannot be determined.

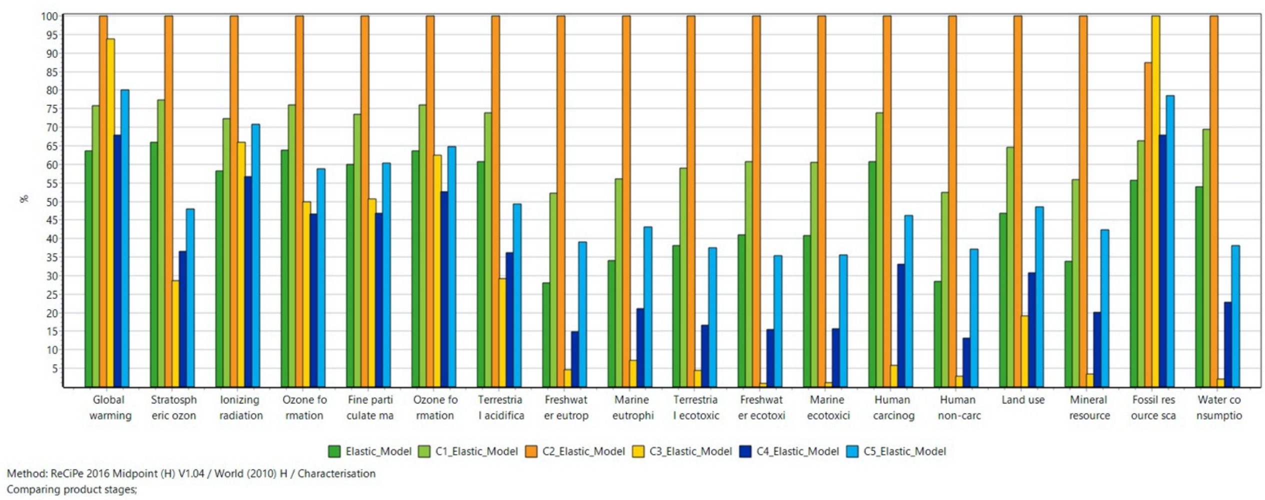
c) Kerosene and eCook

Table 7 shows the detail for the investigation of LPG and eCook and graphs 6 and 7 show the results of the midpoint impact assessment.

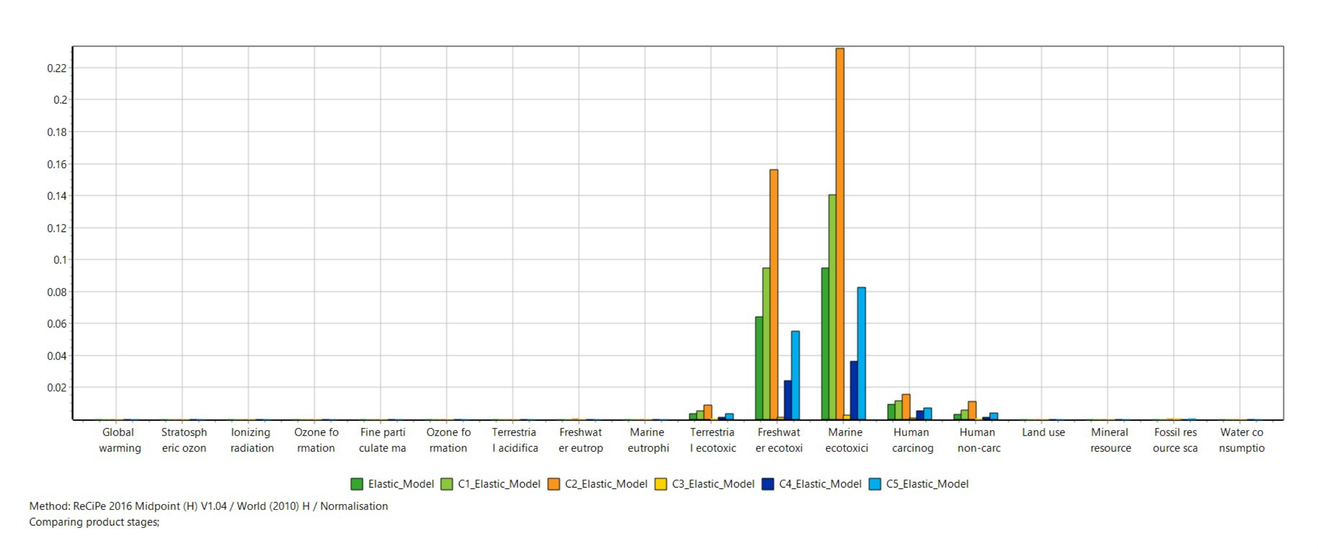
Nairobi, Kenya								
Urban households, switch from kerosene to eCook								
			%				Battery Size	Devices
	Model Reference	Fuel	Grid	Battery	Charcoal/LPG/kerosene	Electricity from Grid		
					kg	kwh		
Grid	Elastic Model	**	100	**	**	2.78	2.78	sEPC/HP
Battery and Grid	C1 Elastic Model	**	50	50	**	1.92	**	LFP/sEPC/HP
Battery	C2 Elastic Model	**	**	100	**	2.21	0.93	LFP/sEPC/HP
Traditional Kerosene	C3 Elastic Model	100	**	**	0.25	**	**	KB
Grid and Kerosene	C4 Elastic Model	50	50	**	0.12	0.64	**	sEPC/KB
Battery and Kerosene	C5 Elastic Model	50	**	50	0.12	0.93	0.93	LFP/sEPC/KB

Table 7: Detail and model reference for LPG/eCook scenario

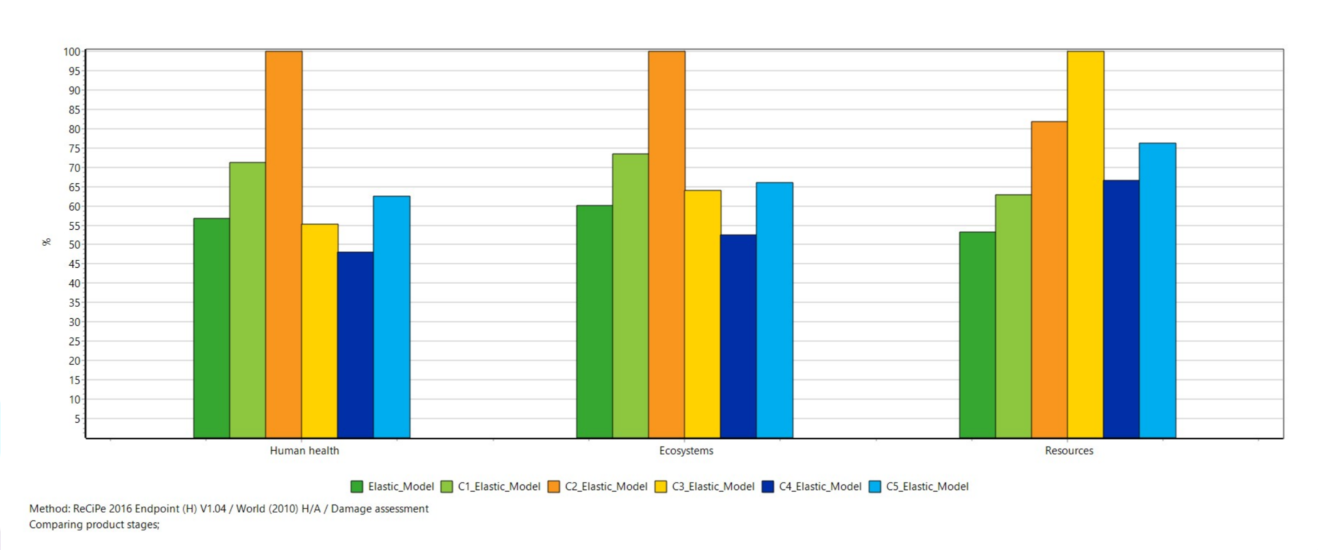
Graphs 11 and 12 show the midpoint impact category results for the kerosene and eCook scenario. As can be seen for Graph 12, the battery option shows the greatest relative impact across all of the impact categories except fossil resources, where 100% kerosene has the highest relative impact. The normalised results, shown in graph 13, show once again that freshwater and marine ecotoxicity are the key midpoint indicators. Graph 13, 14 and 15 show the results of the endpoint impact category assessment.



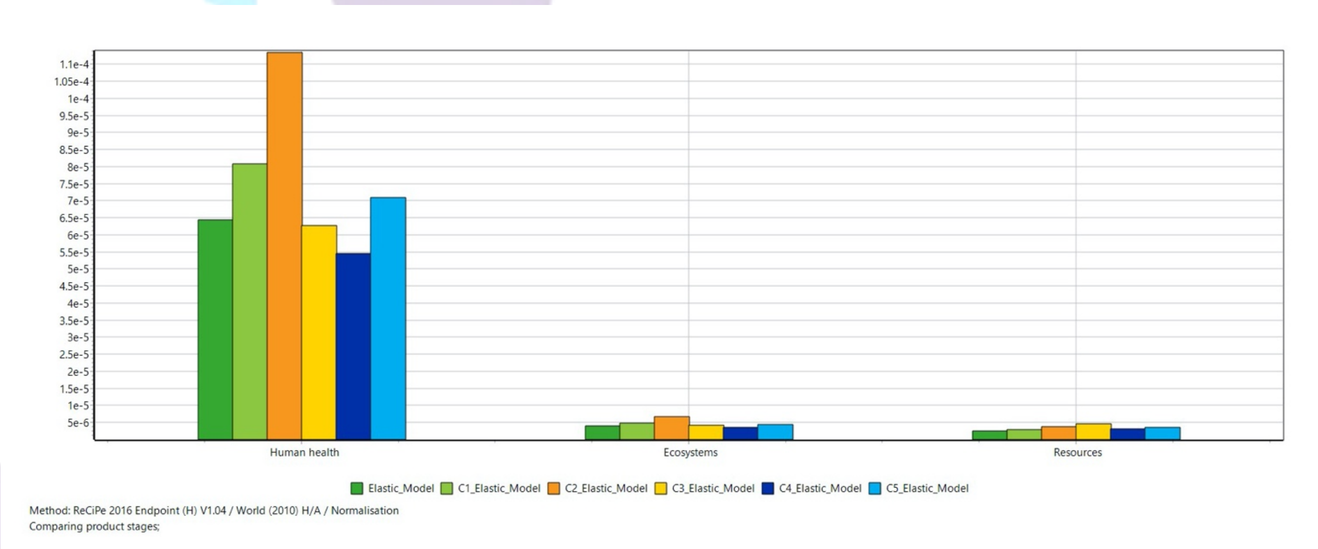
Graph 11: Midpoint categories for kerosene and eCook scenarios



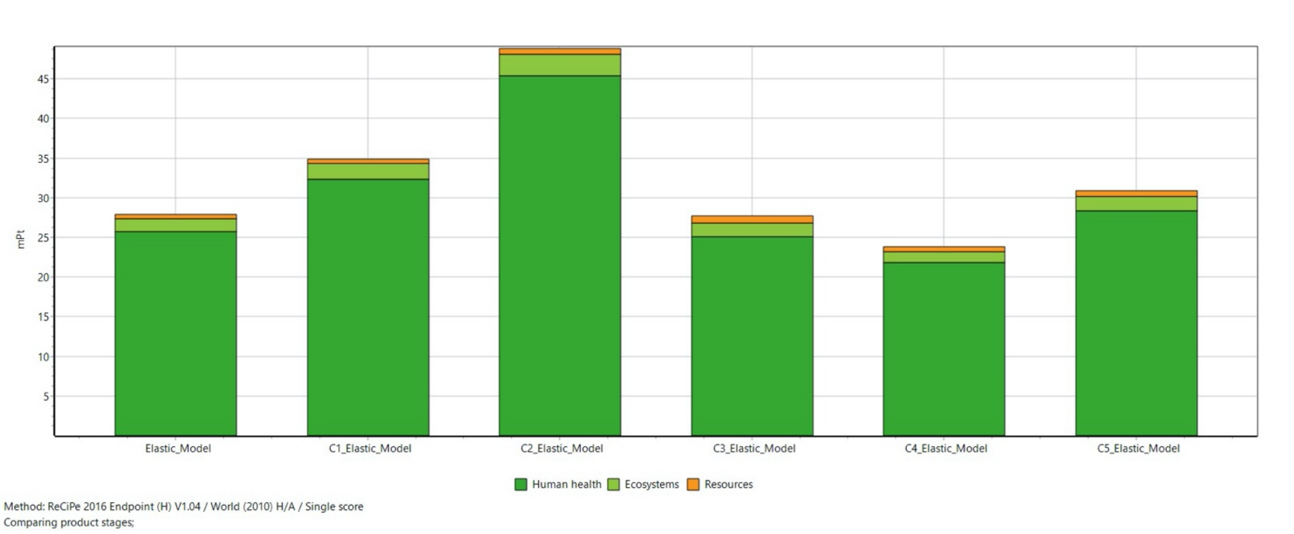
Graph 12: Normalised midpoint categories for LPG and eCook



Graph 13: Relative damage to endpoint categories for kerosene and eCook



Graph 14: Normalised endpoint impact for kerosene and eCook



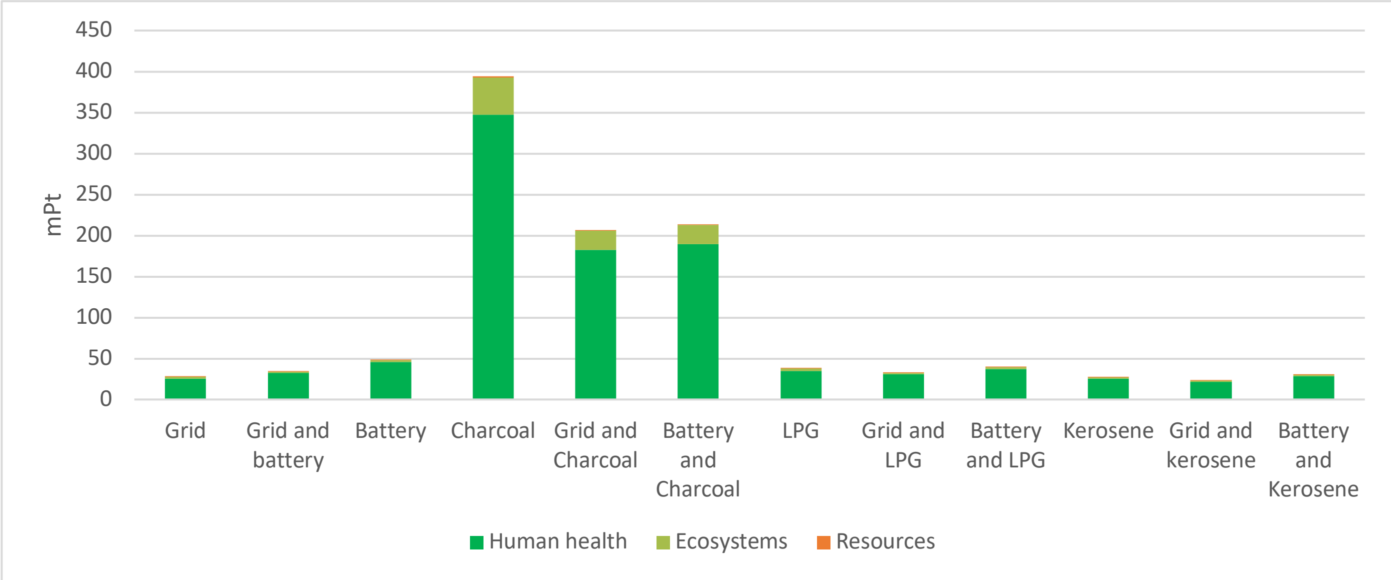
Graph 15: Single Score endpoint impact for kerosene and eCook

The results for kerosene are similar to those for LPG, 100% battery is the worst option with Kerosene in combination with the grid as the best option. This is not surprising as the root for both LPG and Kerosene fuel is the refining of petroleum products. One potential route to further reducing the impact from LPG/kerosene is to consider the production of liquid and gaseous fuels from biomass or food/biomass waste systems.

d) Summary

Graph 16 below brings all the endpoint single scores together, to show how each of the cooking options compares. Charcoal comes out worst in all of its scenarios than any other cooking scenario by several orders of magnitude, for all endpoint impact categories. Cooking on battery power, trickle charged by the grid is the next worst option. However, here is little difference between electric cooking from the grid, LPG and kerosene and further investigation is need to refine these systems, but the results suggest a combination of LPG/kerosene with electric cooking would deliver an appropriate cooking system with lower environmental impact than using charcoal. For weak grid systems where the grid is backed up by a battery, this incurs additional impacts. As a result, the relative environmental cost of upgrading a grid system to provide stable electrical delivery versus supplying all users with a battery backup would require investigation on a case by case basis.

Clearly these results are highly dependent on the mix of fuels used to generate the grid electricity and will change on a country by country basis.



Graph 16: Endpoint single score for all Case Study 1 scenarios

5.2 Case Study 5

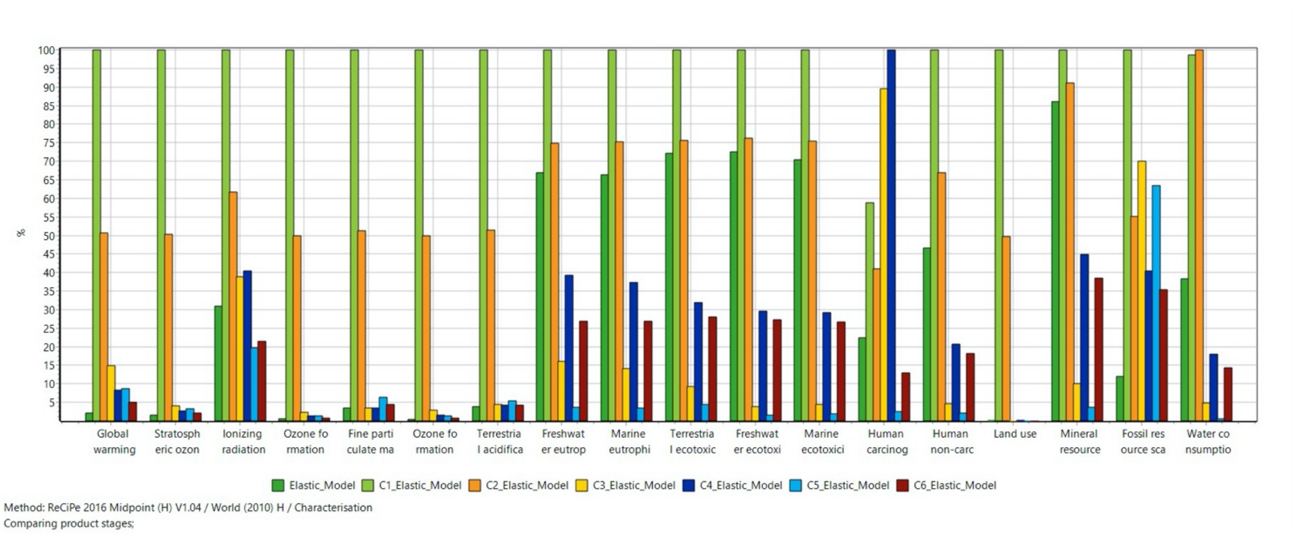
Case Study 5 is based in rural Kenya (Echariria), and investigates the options for electric cooking for those not connected to the grid. Table 8 provides the details and model references for the various scenarios investigated.

Echariria, Kenya									
Offgrid solar-battery cooking									
			%		Original energy source		Battery Size	Pv panel size	Device
	Model Reference	Fuel	Grid	Battery	Charcoal/LPG/kerosene	Electricity from panel		m3	
PV/ Battery	Elastic Model	**	**	100	**	1.92	2.22	3.94	PV/LFP/sEPC/HP
Traditional CH	C1 Elastic Model	100	**	**	1.75	**	**	**	sCHB
PV/Battery and charcoal	C2 Elastic Model	50	**	50	0.87	0.64	0.74	1.32	PV/LFP/sEPC/sCHB
Traditional LPG	C3 Elastic Model	100	**	**	0.23	**	**	**	LPBG
PV/Battery and LPG	C4 Elastic Model	50	**	50	0.11	0.64	0.74	1.32	PV/LFP/sEPC/LPGB
Traditional Kerosene	C5 Elastic Model	100	**	**	0.25	**	**	**	KB
PV/Battery and Kerosene	C6 Elastic Model	50	**	50	0.12	0.64	0.74	1.32	PV/LFP/sEPC/KB

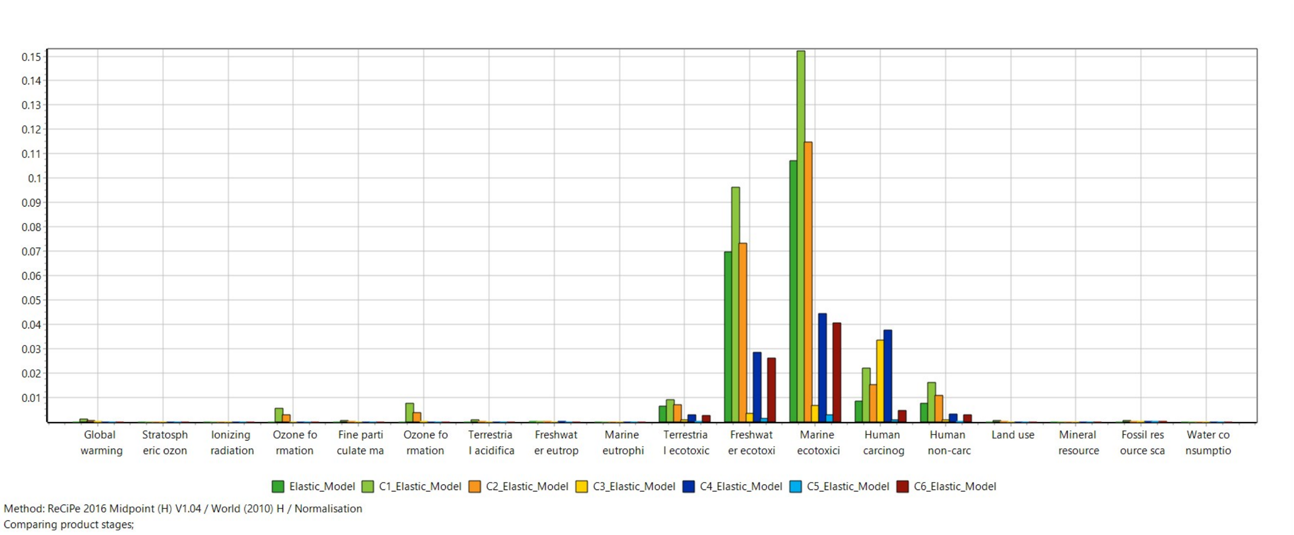
Table 8: Detail and model reference for off-grid scenario

Graph 17 shows the midpoint category impact results for off-grid cooking scenarios. Once again, charcoal can be seen to have the highest relative impact across almost all of the categories, with the exception of Human carcinogen. For Human carcinogen, the high impact for LGP is due to the chromium plated components in the LPG burner. An interesting result is the fossil resource consumption for charcoal; given that the base for charcoal is wood, the high value for fossil resource seems erroneous. In this case, it can be traced back to the production of sustainable wood in a plantation, the fossil driven activities that are used to maintain and harvest the wood. Further investigation of the main driver for the GWP impacts shows;

- For 100%PV and battery (Elastic Model), it is the use of coal in energy production (bearing in mind that the PV and battery are manufactured in China)
- For 100% charcoal and 50% charcoal with 50% PV and battery (C1 and C2 elastic models), it is the manufacture of charcoal
- For all combinations of LPG, Kerosene and PV and Battery (C3, C4, C5 and C6 elastic models), it is the burning of the fuel at point of use.



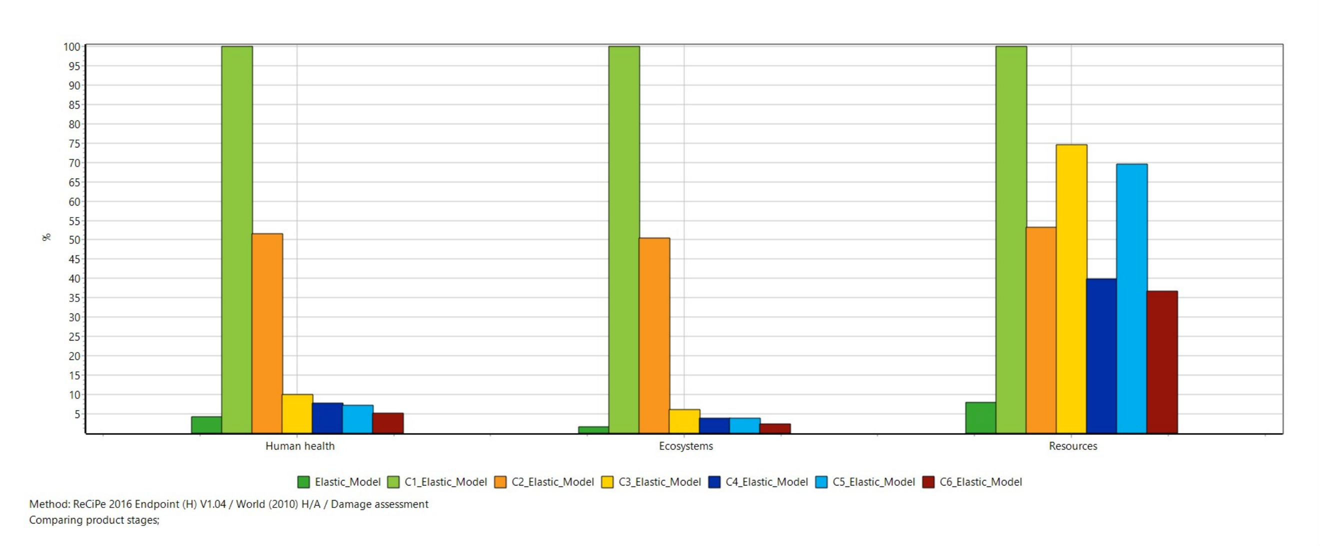
Graph 17: Midpoint categories for off-grid cooking scenarios



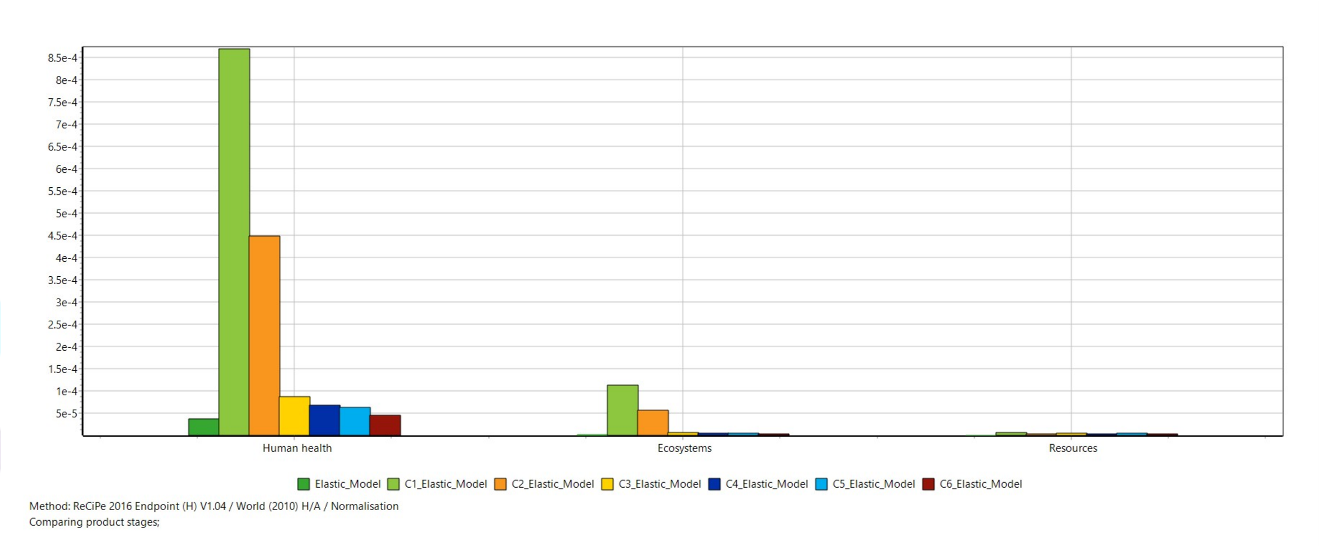
Graph 18: Normalised midpoint categories for off-grid cooking scenarios

Graph 18 show the normalised midpoint impact categories. Once again, the impact on freshwater and marine ecotoxicity are seen to be the categories of greatest concern.

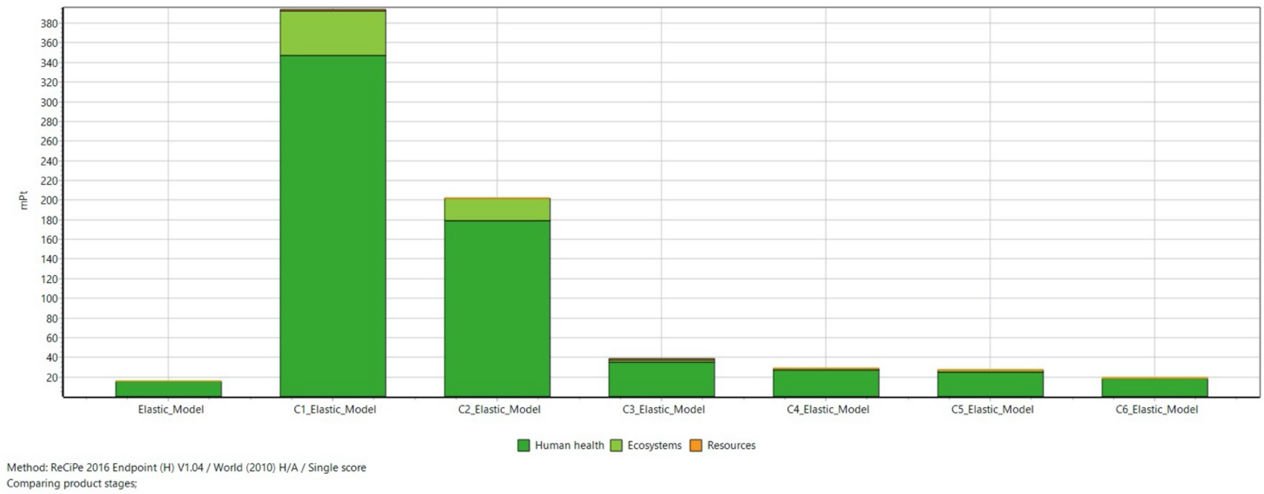
Graphs 19,20 and 21 show the results of the endpoint analysis. As to be expected, Graph 19 shows that charcoal contributes the most to each end point category, with the PV and LPG battery combination contributing the least. The normalised results, graph 20, shows once again that human health is the endpoint of most concern with both combinations using charcoal with the highest impact. Graph 21 shows the single score result. Here it can eb clearly seen the difference between the cooking scenarios with charcoal, and the rest. As for the urban scenario, the best option appears to be 100% electric cooking using PV and LPF battery combination, or LPG/Kerosene with electric cooking.



Graph 19: Relative damage to endpoint categories for off-grid cooking



Graph 20: Normalised endpoint impact for off-grid cooking



Graph 21: Endpoint single score for off-grid scenarios

6) Conclusions

The results for both urban and rural applications show comparability in that charcoal shows the worst environmental impacts for all cases where it is used. There is little difference between LPG and kerosene impacts, kerosene appears a little lower but the model does not yet include the impacts resulting from the manufacture of a kerosene burner. It should also be recognised that rural communities are less likely to have a twin ring LPG burner, and that the use of this model for this scenario is inflating the impacts that would otherwise be seen with a single ring burner that might be simply attached to the LPG gas bottle.

Notwithstanding the above caveats, it is clear that electric cooking, either through the grid or PV and LFP battery where a grid service is not available, demonstrates significant environmental benefits over traditional charcoal use. An uncertainty assessment is required to fully assess if there are significant benefits over the use of LPG or kerosene. In addition, the cooking energy requirements have been assumed to be identical for the two locations, this requires review to assess the different foods cooked in the different locations, as the proportion of heavy foods (that favour electric cooking) may vary which will affect the energy required.

One option that has not been assessed in these scenarios is the option of HotBoxes, a highly insulated box into which semi cooked food is placed to continue cooking without addition of extra power/fuel. These could be considered an alternative to the pressure cookers, and the relative environmental impact of an insulated box may (or may not) be better than an electric combination of grid/PV/battery and EPC.

7) Recommendations for future analysis

This analysis has highlighted some areas where further study may be useful:

a) Impact of biomass derived LPG or liquid fuel on environmental assessment for modern energy cooking systems
b) Comparison of HotBox food delivery with sEPC food delivery systems
c) Uncertainty assessment for LPG and kerosene food delivery systems against grid and PV/battery system

d) Review of cooking energy needs between rural and urban location in Kenya to see if 'heavy food' (with high cooking energy needs) proportion varies significantly.
e) External review of model and results to allow publishing of comparative results into the public domain