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Charcoal versus LPG grilling: A carbon-footprint comparison

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ABSTRACT

Undoubtedly, grilling is popular. Britons fire up their barbeques some 60 million times a year, consuming many thousands of tonnes of fuel. In milder climates consumption is even higher, and in the developing world, charcoal continues to be an essential cooking fuel. So it is worth comparing the carbon footprints of the two major grill types, charcoal and LPG, and that was the purpose of the study this paper documents. Charcoal and LPG grill systems were defined, and their carbon footprints were calculated for a base case and for some plausible variations to that base case. In the base case, the charcoal grilling footprint of 998 kg CO_2e is almost three times as large as that for LPG grilling, 349 kg CO_2e. The relationship is robust under all plausible sensitivities. The overwhelming factors are that as a fuel, LPG is dramatically more efficient than charcoal in its production and considerably more efficient in cooking. Secondary factors are: use of firelighters, which LPG does not need; LPG's use of a heavier, more complicated grill; and LPG's use of cylinders that charcoal does not need.

1. Introduction

This report documents a study of the carbon footprints of charcoal and LPG grills.

1.1. What was studied?

The study looked at conventional, outdoor-barbeque grills that number in the millions in the developed world. Our notional location was the UK, but the results could apply to many other locations. Two types of grills were examined: charcoal and LPG fired. Except for this fuel-type difference, the grills are very similar.

1.2. Why is this study important?

There are three main reasons: to inform consumers and policy-makers; to test the presumed biofuel advantage over petrofuels; and to show the value of footprinting.

1.2.1. To inform consumers

Grill usage is popular in the developed world. Many of the users would like to know how grilling's environmental impacts can be minimised or reduced (SF Chronicle, 2007), and policy-makers probably would like to know this as well.

Grill usage is also very widespread in the developing world (Bailis, 2005). Their grills are not identical to leisure barbeques used in the West, but there are plenty of similarities. Researchers and policy-makers are interested in the impacts of fuel-switching on carbon footprints and other indicators[1] (Natiyal and Kaechele, in press).

1.2.2. To test the presumed biofuels' advantage over petrofuels

Several standards for carbon footprinting, and most published carbon footprints or LCAs, presume that biomass heating fuels are carbon neutral. However, it is recognised increasingly that this is incorrect: biomass fuels are not always carbon neutral. Indeed, they can in some cases be far more carbon positive than fossil fuels.

For liquid biofuels (mainly biodiesel and bioethanol), this false presumption of carbon neutrality has been corrected by numerous studies (for example, RTFO, 2008) in recent years. Today it is widely accepted that land-use change must be accounted in liquid biofuel footprints. For solid biofuels (wood and woody fuels), land-use change may be significant, as may land-use (e.g. increasing the harvest intensity of a forest) — so these factors need to work their way into standards and studies. (Johnson, 2009)

1.2.3. To show the value of footprinting

From initial calculations prior to undertaking the study, it was posited that this study would generate a counterintuitive answer, i.e. one at odds with conventional wisdom yet still robust. Footprinting's ability to generate non-obvious, important answers is of value to society.

2. Context and method

The following subsections briefly review the approach to footprinting, sources of data and the study's accuracy and precision.

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[1] For instance, indoor-air quality.

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Table 1
Properties of charcoal and wood, approximate values (Biomass Handbook, 2007).

Property	Units	Lump charcoal	Air-dried wood	Fresh harvested wood
Density	kg/m3	250	700–800	800–1,300
Moisture content	wt.%	Nil	20	NA
Carbon content	Wt.%	85–98	50	NA
Lower heating value	MJ/kg	32	20	15

2.1. Footprinting approach

Carbon footprints are a summation of the greenhouse-gas emissions of a product or service across its lifetime (or life cycle). A carbon footprint is a subset of a life-cycle assessment (LCA), which is a summation of all emissions of a product or service. The approach to footprinting is identical to that for LCA; the only difference is that in a carbon footprint, a smaller scope of emissions is covered.

The approach used in this study is believed to be in line with current, global best-practice, and it is broadly compliant with LCA standards ISO 14040 and ISO 14044. Most of the inputs for the study were tabulated in Excel. The footprints were then calculated and analysed in SimaPro 7, a commercial software package for LCA.

2.2. Sources of process data

A major source of process data[2] for this study was the EcoInvent 2.0 database. This database was published in 2007; it is based on 15–20 years of research by a group of researchers funded by Switzerland's government and led by Switzerland's materials testing institute, EMPA. It is probably the most authoritative databases for LCA and footprinting.

Process data not sourced from EcoInvent and BUWAL were for LPG production. These came from previous work on UK LPG by Atlantic Consulting. A few other factors were used in the calculations — these are cited in the text.

2.3. Accuracy and precision

Footprint estimates of the type conducted for this study are generally understood to be accurate within a range of ±10–20%. By definition they are somewhat imprecise, because they express a representation of an entire industry.

Comparing footprints as measured by different studies or researchers is often problematic. Because methods and assumptions can vary widely, so can answers. However, by using EcoInvent — probably the most widely-used and authoritative databases — to the extent possible, we are most likely to generate results consistent with those of other researchers.

3. Definitions of the grilling systems

Two grilling systems were defined: a charcoal and a LPG one. Both are located in the UK for the period 2000–2010. The following subsections present definitions of subsystems: production of charcoal; production of LPG; use and disposal of charcoal; use and disposal of LPG; and production, use and disposal of the grill and the LPG cylinder.

3.1. Production of charcoal

Charcoal is a dried, carbon-concentrated form of wood[3]. Compared to wood (Table 1), it is easier to store and to use, and because of its higher heating value, it is more efficient to transport.

Table 2
UK imports of charcoal, 2008 (UK Trade Info, 2009).

		% of total			
	Quantity tones	All imports	EU and developed countries	Africa	Developing countries
Country					
South Africa	15,979	30%		30%	30%
Argentina	9,323	18%			18%
Spain	7,369	14%	14%		
Namibia	6,297	12%		12%	12%
Nigeria	3,590	7%		7%	7%
Brazil	2,149	4%			4%
China	1,625	3%			3%
Poland	1,209	2%	2%		
Paraguay	1,162	2%			2%
Italy	750	1%	1%		
Indonesia	708	1%			1%
Uruguay	542	1%			1%
Netherlands	470	1%	1%		
Germany	435	1%	1%		
Malaysia	289	1%			1%
Other	1,243	2%			2%
Total	53,140	100%	19%	49%	81%

3.1.1. Usage and sources of UK charcoal

In 2006 the UK consumed 50,000 tonnes of charcoal. Domestic production was 5000 tonnes, imports were 55,000 tonnes, and 10,000 tonnes were exported or re-exported (UK Forestry Commission, 2008). At least two-thirds (Royal Botanic Gardens, 2008) or perhaps even most of UK charcoal (Friends of the Earth, 2004) is consumed in barbeque grills, but this is not captured in official statistics (UK Forestry Commission, 2008). Consumption and trade have changed modestly over the past decade; 2006 can be considered a typical year of the present.

Where do UK charcoal imports come from? Royal Botanic Gardens (2008) and Friends of the Earth (2004) say that leading exporters to the UK are countries such as Indonesia, Brazil, Ghana, and Nigeria. The European Parliament (2008) disagrees, claiming that “Trade in charcoal from Africa to the EU is not significant, however. The largest importers of charcoal in the EU (Germany, Poland, Spain, Bulgaria and UK) source charcoal mainly from other countries inside the EU (the largest exporters of charcoal are Poland, France and Germany).”

For the UK at least, the European Parliament has the facts completely wrong, while Royal Botanic Garden and Friends of the Earth are broadly right. According to UK statistics (UK Trade Info, 2009) for 2008, half of

Table 3
Changes in forest stock of leading charcoal exporting countries (FAO, 2005).

	Change in forest growing stock, 2000–2005	Change in extent of forest and wooded land, 2000–2005	
Leading charcoal exporters to the UK	thousand m^3/year	thousand ha/year	% per year
South Africa	0	0	0.0
Argentina	−21,200	−150	−0.4
Spain	19,600	296	1.7
Namibia	−1,800	−74	−0.9
Nigeria	−45,000	−410	−3.3
Brazil	−698,892	−3,103	−0.6
China	181,400	4058	2.2
Poland	25,660	27	0.3
Paraguay	NA	−179	−0.9
Italy	31,560	106	1.1
Indonesia	−561,200	−1,871	−2.0
Uruguay	NA	19	1.3
Netherlands	800	1	0.3
Germany	NA	0	0.0
Malaysia	6,800	−140	−0.7
Total, for leading exporters of charcoal to the UK	−1,062,272	−1,420	NA
Total world	Not reported	−7,317	−0.18

[2] By process data, we mean GHG emissions for a process, for example the amount of GHGs emitted in production of a UK-average kWh of electricity.

[3] Or other biomass. For convenience's sake, hereafter we shall refer simply to wood.

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UK charcoal imports came from Africa, 80% from developing countries and only 20% from the EU. The largest single importer is South Africa, with a 30% import share (Table 2).

Some UK charcoal imports are certified or controlled by the Forest Stewardship Council (FSC). The FSC itself does not know what fraction of imports this constitutes (FSC, 2008).

3.1.2. Wood production and depletion

Most charcoal is produced from wood harvested from forests (US EPA, 1999, Clean Fuels, 2002). Unlike Europe or North America, where they are increasing, forest stocks are declining among many of the charcoal exporting countries and also globally (Table 3).

The decline in forest growing stock (column 2 in Table 3) suggests that UK imports are depleting carbon stocks among the charcoal exporters. This holds true even for FSC controlled or certified charcoal, because FSC does not control or certify changes in forest growing stock (FSC, 2007).

Harvesting trees for charcoal also displaces their use in non-fuel applications. As FSC explains (SGS Qualifor, 2003) about one of its certified operations in Brazil: “Harvest for charcoal production is conducted in a 6-year cycle. For sawn timber, the cycle is 12 years, and for logs for the production of poles, 6 years.” In other words, wood processed into charcoal could alternatively be processed into poles, or left to mature another 6 years and then processed into sawn timber.

3.1.3. Wood harvesting process

Trees are felled, air dried in the forest, split and transported to the charcoal kiln. We have defined this as the EcoInvent process module for ‘Logs, hardwood at forest’, that is used as an input to EcoInvent's charcoal production module.

3.1.4. Charcoal production process

Charcoal is made by pyrolising[4] wood at 300–500 °C, usually in a kiln, to flash off all volatiles, leaving behind mostly dry carbon. The process can be rather simple. In the developing world, “much of its (charcoal) production occurs on a small scale, typically involving no more than covering a stack of burning wood with dirt and leaving it to smoulder for a week.” (OECD, 2005) To aid and speed up the process, most commercial kilns add fuel to the process: some use wood, others use fossil fuels. (EcoInvent, 2007)

Yields vary depending on type of wood, kiln and process conditions. Commercial yields (charcoal:wood at 20% moisture) are in the 20–35% range (Biomass Handbook, 2007, OECD, 2005), yet open pits or rural kilns may yield as little as 10–15% (Clean Fuels, 2002).

For the base case, we have used the charcoal process model from EcoInvent, which yields 25% charcoal. The module (Table 4) is based on actual operations in Brazil, and is seen as a proxy for commercial operations in developing countries. (EcoInvent, 2007)

3.1.5. Packaging and transport

Charcoal is shipped, bagged, distributed, sold and transported by the end-consumer (Table 5). Using data from EcoInvent, we have put these processes into the system model.

3.2. Production of LPG

Liquified petroleum gas is a mixture of the hydrocarbons propane and butane that are gaseous in ambient conditions. For use as a fuel, LPG is compressed and contained; in the case of grills it is contained in a portable, refillable cylinder (Table 6).

Table 4
Charcoal production, process definition.

Output	Quantity	Unit
Charcoal, at plant	1000	kg
Inputs		
Water, cooling	50	m^3
Logs, hardwood, at forest (5.128 m^3)	4000	kg
Electricity, medium voltage, production UCTE, at grid	75	kW h
Wood chips, from forest, hardwood, burned in furnace 50 kW	900	MJ
Transport, lorry >16t, fleet average	0.000394	tkm
Emissions to air	0	
Heat, waste	11,603	MJ
Carbon dioxide, biogenic	2695	kg
Carbon monoxide, biogenic	190	kg
Methane, biogenic	40.33	kg
Ethene	2.33	kg
Ethane	7	kg
Particulates, <2.5 um	0.45	kg
Particulates, >2.5 um, and <10 um	0.05	kg
Particulates, >10 um	0.055	kg

3.2.1. Sources of UK LPG

LPG is a byproduct of two energy-production processes: petroleum refining and gas processing. In the UK today (Table 7), about two-thirds of LPG comes from associated gas, while the rest comes from refining.

3.2.2. LPG production and distribution processes

LPG is produced in the 2/3:1/3 ratio of associated gas and petroleum refining, and is transported by tank truck to a cylinder filling plant. From there, cylinders are distributed to retailers. Inputs to this and associated GHG emissions (Table 8) were taken over from a previous study of UK LPG production (Atlantic Consulting, 2007).

For car transport to the end consumer, we have defined the same distance and mode as for charcoal, 5 km by passenger car.

3.3. Consumption of charcoal and LPG

To use a grill consists of loading fuel, ignition, warmup, cooking and cooldown. Data on these steps are not available from EcoInvent or other LCA databases, and an extensive literature search identified only one other similar study (West, 2008)[5]. For LPG grills, fuel consumption can be estimated from a grill's power rating, but charcoal grills have no such power ratings.

Two methods to estimate fuel consumption were considered: 1) the approach taken by the other study (West, 2008), which was to use theoretical heating values, or 2) to conduct a testing programme using volunteer grillers. The first method was rejected and the second adopted, as explained in the following subsections.

3.3.1. Theoretical heating values

A comparison of charcoal, LPG, natural gas and electric barbeque grills by a researcher at Oak Ridge Laboratory (West, 2008) comes to some broadly similar relationships as this study (compare Table 9 to Section 4.6), yet by a different approach to estimating fuel or power consumption. Oak Ridge estimates fuel or power consumption based on theoretical, one-hour usage of each grill.

This approach could be used to estimate LPG consumption, because LPG grills have power ratings, so power rating times one hour equals energy consumed in a one-hour grilling session. However, as our testing showed (Section 3.3.2.2), there still will be variance among grillers. Moreover, for charcoal, this approach is too difficult to apply. Charcoal has a warm-up and a cool-off phase that can consume considerable fuel, and there is neither a power rating on the grill nor an obvious way to

[4] Heating with an absence or deficit of oxygen. Heating with oxygen leads to combustion, i.e. fire.

[5] Two other related, but not really similar, studies may be of value to other researchers: Jungbluth (1997) and Jungbluth et al. (1997).

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Table 5
Charcoal's packaging and transport inputs.

Input	Quantity	Unit	Comment
Paper sack (for 3 kg charcoal)	74	g	Estimate, based on measuring actual sacks
Ship transport, Brazil-UK	9000	km	
UK distribution, by lorry	100	km	
Car transport to end consumer, UK	5	km	

Table 6
Properties of LPG[a].

Property	Unit	Quantity
Lower heating value	MJ/kg	46.4
Density (in cylinder)	kg/l	0.541
Cylinder weight, tare	kg	14.5
Cylinder weight, full	kg	27.5

[a] Cylinder weights are standard for the UK, taken from the previous work on LPG by the author.

Table 7
Production/Consumption of LPG, UK (Johnson, 2003).

	1999	2010
	thousand tonnes/year	
Production	6450	4708
Of which		
Refined	1500	1500
Associated gas	4950	3208
Consumption	3140	4700

Table 8
Carbon footprint of LPG production and distribution.

Process	Carbon footprint kg CO_2e/t LPG
Production	177
Transport to cylinder filling	4
Cylinder filling	11
Transport to retailer	38
Total	230

measure it. Consequently, we did not apply this method to estimate fuel consumption; instead, we conducted grill testing.

3.3.2. Grill testing for this study

To determine fuel consumption, a grilling test-programme was organised to support this study. Eight volunteers (including the author) were recruited; all were experienced, amateur grillers, representing typical barbeque grill users. They conducted 50 individual grill ‘sessions’, where they grilled as usual, yet documented the relevant quantities of times and weights of fuel and food usage.

3.3.2.1. How much charcoal (and lighter) do grillers use? Charcoal grilling differs from most types of western-style cooking in that there is no ‘on/off’ switch, and fuel consumption is not easily regulated with a dial. Key factors in determining fuel consumption are: size of the grill, design of the grill, amount of food to be cooked, cooking style and the griller's loading (i.e. how much charcoal does he or she put on, what sort of starting-aid does he use and how much). The primary factor is the griller's loading (Table 10).

Table 9
Oak Ridge footprints of grilling fuels.

Fuel (or power source)	Footprint, kg C/h
Electricity	1846
Charcoal, briquettes	1391
Charcoal, lump	1366
LPG	690
Natural gas	537

Table 10
Charcoal consumption varies far less than food quantity or cooking time.

		Variation in consumption, at 95% confidence			
		Charcoal	Food	Cooking time	Comment
Griller	Grill type	g	g	min	
JB	Kettle	±1%	±17%	±11%	
NE	Kettle	±7%	±13%	±0%	
EJ	Pan	±12%	±15%	±28%	Using a new, unfamiliar grill
EJ	Kettle	±7%	±92%	±49%	
MR	Kettle	±3%	±30%	±36%	
Average variation (at 95% confidence)		6%±2%	34%±12	25%±9%	

Our volunteers used charcoal grills of nearly identical size (cooking area). Four of the grills were kettle type, of nearly identical design, while one was a pan type without vents. Their loadings varied by only 4–8% from session to session, while the quantity of food cooked varied by 22–46% and the cooking time varied from 16–34% (Table 10). In other words, charcoal grillers tend to use a similar load of fuel from one session to the next, although the amount of food to be cooked and the cooking time may vary considerably. They fill the grill and then they cook; they compensate a bit for the amount and type of food, but not much.

Not surprisingly, there is variation in what each griller considers to be a loaded grill (Table 11). At the minimum, griller NE consumed an average of 490 g charcoal per session; at the maximum, griller JB consumed 918 g. Average consumption, at 95% confidence, was in the range of 667–799 g per session. Fire-lighter consumption was fairly consistent (except for griller NE), with a 95% confidence range of 94–136 g per session.

To improve efficiency of the pan grill, a pan-sized sheet of aluminium foil was applied to the bottom of the grill before charcoal was loaded. This foil was changed out for every session.

3.3.2.2. How much LPG do grillers use? LPG grilling is similar to most types of western-style cooking — and unlike charcoal grilling — in that there is an ‘on/off’ switch, and fuel consumption is easily regulated with a dial. This suggests that, compared to charcoal grilling, fuel consumption is more closely related to the amount of food to be cooked.

Our testing showed this to be the case: LPG consumption at 95% confidence stayed within the 25–45% range, by weight, of the food being cooked. (By contrast, charcoal consumption ranged far more broadly, from a minimum of around 30% to a maximum of 140% per session.) Quantities of food cooked and cooking time were broadly

Table 11
Charcoal consumption varies according to the griller's loading.

			Mean charcoal consumption per session	Mean fire lighter consumption per session
Griller	Grill type	Charcoal type	g	g
JB	Kettle	Lump	918	158
NE	Kettle	Lump	490	30
EJ	Pan	Lump	645	150
EJ	Kettle	Lump	708	120
MR	Kettle	Briquette	905	Lighter is built-into the pre-treated bag
Mean average[a] (at 95% confidence)			733±66	115±21

[a] The mean of the means, 733 g/session, was nearly identical to the absolute mean (all charcoal consumed/total number of sessions) of 735 g.

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Table 12
Composition of grills and LPG cylinder.

Materials	Units	Grill		LPG Cylinder
		Charcoal	LPG	
Carbon steel	kg	15	15	14.5
Stainless steel	kg		4	

Table 13
Functional unit, base case.

Factor	Quantity	Comment
Functional unit	150 grill sessions	15/year × 10 years, or 10/year × 15 years
Food cooked	1.5 kg/session	Inferred from grill testing
LPG consumption	525 g/session	35% of food weight, see Section 3.3.2.2
Charcoal consumption	733 g	see Table 11
Firelighter consumption	115 g	see Table 11

similar for both grill types: about an hour of grilling to prepare about 2 kg of food.

3.4. Disposal of charcoal and LPG

For the base case, we have presumed that cooled ash from the charcoal and the charcoal bag are disposed to municipal solid waste. LPG is combusted, so it is 'disposed' to the atmosphere. Disposal of the LPG cylinder is defined below in Section 3.5.2.

3.5. Production, use and disposal of the grill and the LPG cylinder

With help from a grill manufacturer (O'Connell, 2008), compositions of two equivalent grills were defined for usage in the UK; with the help of a UK LPG distributor, compositions of grill–gas cylinders were also defined (Table 12).

Grills are manufactured in the Far East, cylinders in Europe. Transport for both is included. We used generic EcoInvent processes to define these.

3.5.1. Production and disposal of the grill

Carbon steel production is defined by EcoInvent as a 'production mix' of 63% virgin (or primary) plus 37% recycled metal. We have treated this as a so-called closed-loop/open-loop system. This approach complies with the ISO standard[6] for recycling allocation.

At the end of their useful lives, the grills are disposed of to municipal solid waste. Because scrap steel is unusually valuable today, we have presumed that all steel will ultimately be sold or collected for recycling.

3.5.2. Production and disposal of the LPG cylinder

Again, carbon steel production is defined by EcoInvent as a 'production mix' of 63% virgin (or primary) plus 37% recycled metal. We have treated this as a so-called closed-loop/open-loop system. This approach complies with the ISO standard[7] for recycling allocation.

Cylinders have a lifetime of 40 uses. At the end of this life, 95% of scrapped cylinders are reconditioned and put back into life for another 40 uses. The 5% remaining are recycled. In summary, cylinder disposal is: 97.5% reuse; 2.38% reconditioning; and 0.12% recycling.

4. Base case footprints

This chapter presents the base case footprints for both grill types and compares the two. Before that, we present the functional unit, the impact assessment (characterisation) method and the combustion emission factors.

[6] Paragraph 4.3.4.3.3 of ISO's LCA standard 14044.
[7] Paragraph 4.3.4.3.3 of ISO's LCA standard 14044.

Table 14
Combustion emission factors, from IPCC (IPCC, 2006).

Fuel	kg CO2e per tonne			
	CO2	CH4	N2O	Sum, GHG
Charcoal	3,584	147	9	3,741
LPG	2,928	5	1	2,935
Wood[a]	2,240	138	24	2,402

[a] Wood's emission factors are provided for reference.

4.1. Functional unit

Based on the collected consumption data (see Section 3.3) a base case functional unit (Table 13) was defined for the grills.

Charcoal and LPG are deemed to be equally functional, i.e. fit-for-purpose of cooking the food.

4.2. Impact assessment method

Global warming potentials (GWPs) for atmospheric gases have been defined and redefined over time by the Intergovernmental Panel on Climate Change (IPCC) as part of the UN Framework Conventional on Climate Change (UNFCCC). These 100-year GWPs are commonly used in LCAs and footprints, and they are recommended in footprint guidelines issued by UK authorities (DEFRA, 2003; PAS 2050, 2008) and the World Business Council for Sustainable Development (WBCSD, 2004). We have used the IPCC's most recent 100-year factors, published in 2007.

Biofuels are not presumed to be inherently carbon neutral. This presumption was common until recently, when it was refuted first for transport biofuels (RTFO, 2008) and then for solid fuels such as wood and charcoal (Johnson, 2009; Eliasch Review, 2008).

4.3. Combustion emission factors

To calculate greenhouse gases emitted in combustion of the fuels, we used emission factors published by the IPCC (Table 14).

4.4. Charcoal grilling footprint

The footprint of charcoal grilling, for 150 grill sessions, comes out at 998 kg of CO_2e, or 6.7 kg CO_2e per grill session (Fig. 2). So each charcoal grilling session has a footprint similar to that of driving an average European passenger car, as defined by EcoInvent, for about 35 km.

As might be expected, most of the footprint, about 87%, comes from CO_2, and the rest comes from methane. Nitrous oxide and other greenhouse gases make a negligible contribution to the footprint.

The footprint is dominated by charcoal production, about 45%, and charcoal combustion, about 40%. The rest of the footprint comes from firelighter combustion and production of the grill — each contributing around 7%.

4.5. LPG grilling footprint

The footprint of LPG grilling, for 150 grill sessions, comes out at 349 kg of CO_2e, or 2.3 kg CO_2e per grill session (Fig. 1). So each LPG grilling session has a footprint similar to that of driving an average European passenger car[8] for about 13 km.

As might be expected, almost all the footprint, nearly 99%, comes from CO_2, and the rest comes mainly from methane. Nitrous oxide and other greenhouse gases make a negligible contribution to the footprint.

The dominant process in the footprint is LPG combustion, which accounts for two-thirds of the total. Production of the grill accounts for another one-quarter, and the remaining one-tenth is split almost equally between LPG production and cylinder production and use.

[8] As defined by EcoInvent.

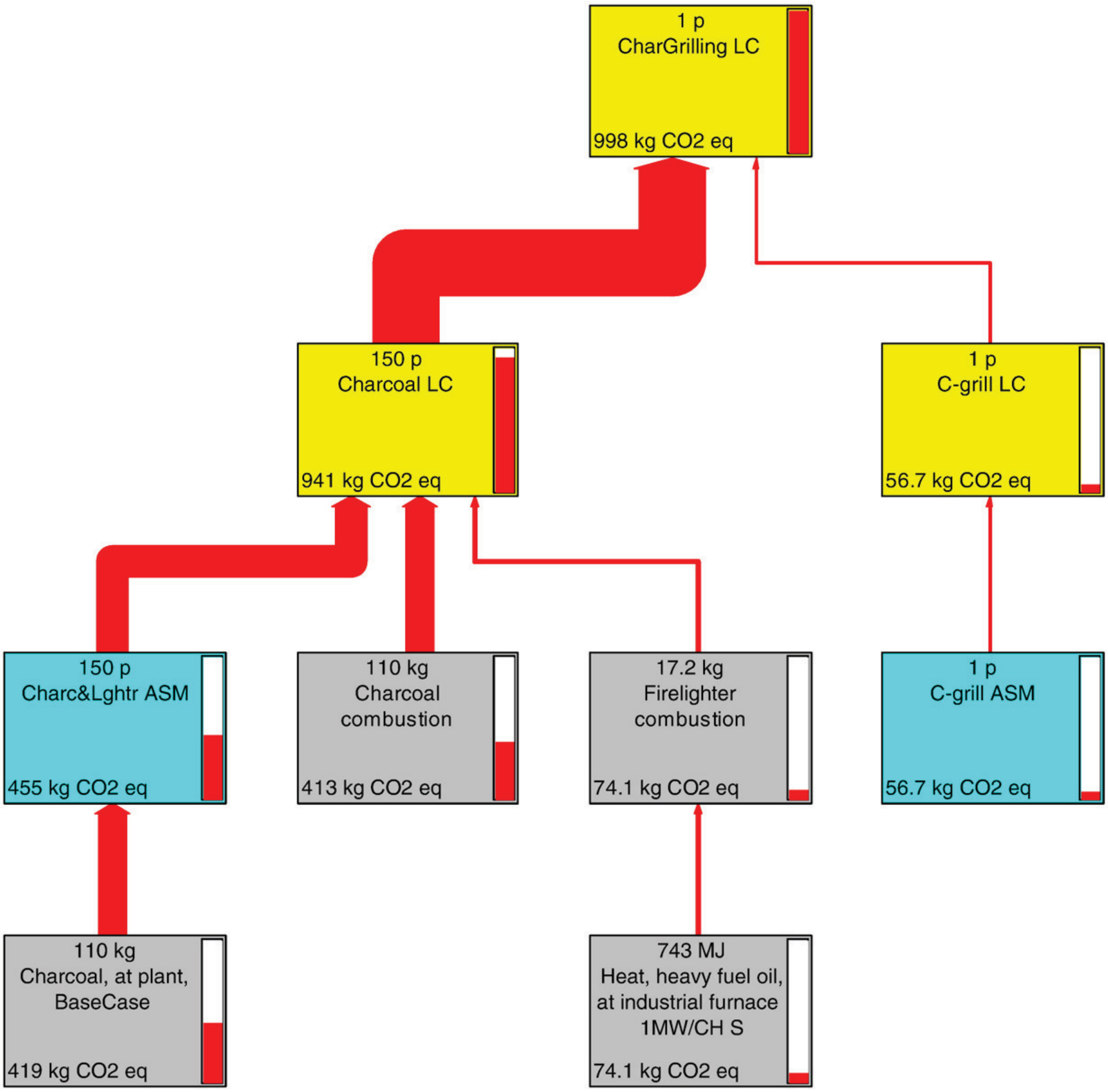

Fig. 1. Charcoal grilling footprint, base case. LC = life cycle, ASM = assembly, C-grill = charcoal grill, Charc&Lghtr ASM = the combined charcoal and lighter consumed in grilling. Heat, heavy fuel oil is used as a proxy for firelighter production and combustion, because paraffin's footprint is pretty similar to that of heavy fuel oil.

4.6. Comparison of charcoal and LPG footprints

The charcoal grilling footprint of 998 kg CO_2e is almost three times as large as that for LPG grilling, 349 kg CO_2e.

The difference can be understood through a comparison of the two by component (Table 15, Fig. 3). The overwhelming factors are that as a fuel, LPG is dramatically more efficient than charcoal in its production and considerably more efficient in cooking.

Secondary factors are: use of firelighters, which LPG does not need; LPG's use of a heavier, more complicated grill; and LPG's use of cylinders that charcoal does not need.

5. Sensitivities of the footprints

To test the robustness of the footprint comparison (see previous chapter), a series of sensitivities[9] were identified and tested (Table 16). The sensitivity cases are presented in the first section of this chapter; their results are presented and discussed in the second. Two other potential sensitivities — one less plausible and another one difficult to define precisely — are presented and discussed in the third and fourth sections.

5.1. Sensitivity cases

Based on inspection and experience, four potential sensitivities were identified as plausible: relative fuel consumption; charcoal yield; cylinder disposal; and use of fossil fuel in charcoal production. These are presented in the following subsections.

5.1.1. Relative fuel consumption (functional unit)

Fuel consumption is inherently variable (see Section 3.3), mainly depending on how an individual griller loads `and uses the grill. We looked at this with two sensitivity cases, a maximum and a minimum fuel use, based on grill test data.

5.1.1.1. Maxima and minima, from test data. Sensitivities for both were run for charcoal and for LPG.

5.1.1.1.1. Charcoal. For the base case footprint, we used 773 g of charcoal per grilling session, which was the average for all test

[9] Sensitivity analysis means testing how assumptions or input variables affect the results.

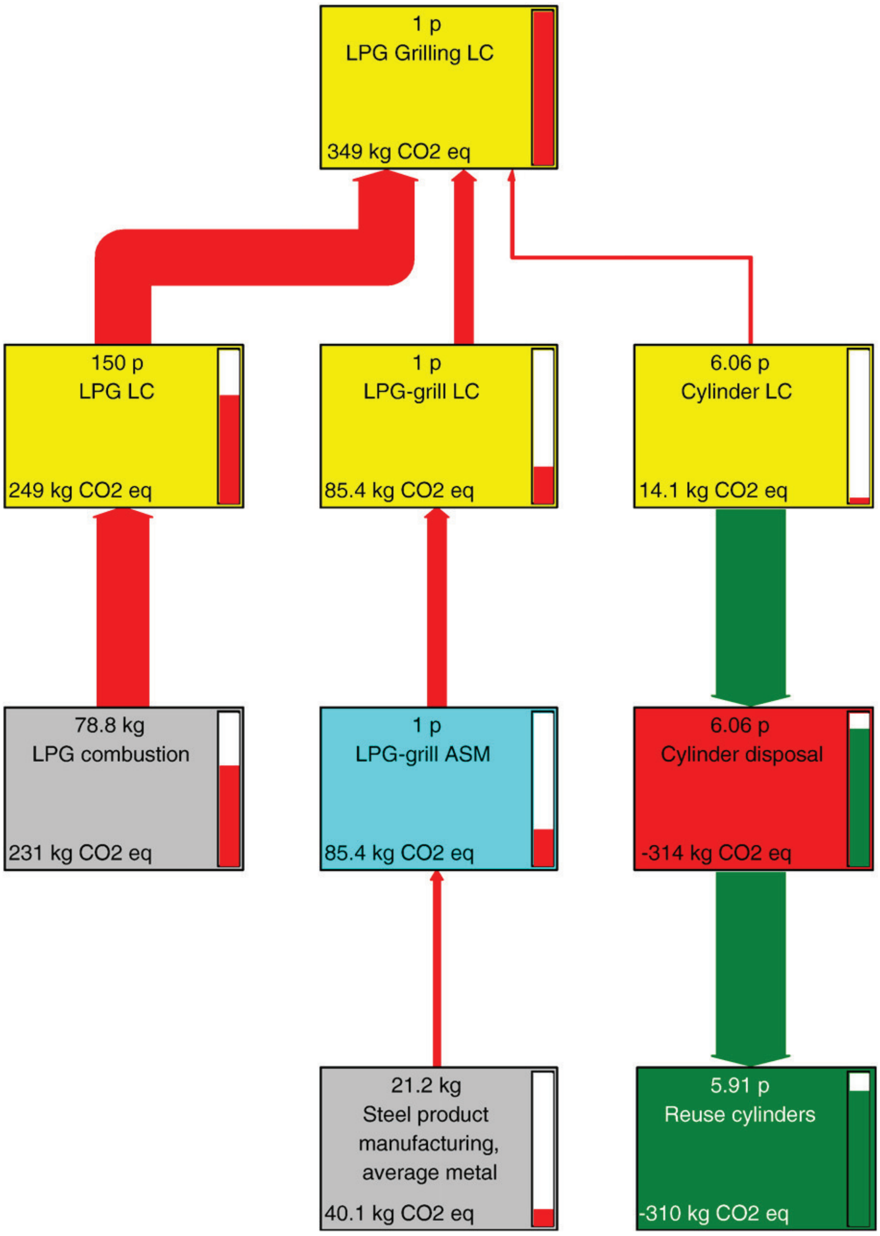

Fig. 2. LPG grilling footprint, base case. LC = life cycle, ASM = assembly, LPG ASM = the LPG consumed in grilling.

sessions. The individual averages for the testers, however, ranged from a minimum of 490 g to a maximum of 918 g; so both these amounts were run as sensitivities.

5.1.1.1.2. LPG. For the base case footprint, we used 35% of the food weight for the amount of LPG consumed, i.e. 525 g of LPG. The individual averages for the testers, however, ranged from a minimum of 25% to a maximum of 45%; so both these amounts were run as sensitivities.

5.1.2. Charcoal yield, or CO_2 emissions in charcoal making

In the base case footprint we used a charcoal yield (i.e. weight of charcoal produced relative to weight of wood input to the charcoal kiln) defined by EcoInvent of 25%. As discussed in Section 3.1.4, this can range from 10–35%, so we tested both of these options as sensitivities.

5.1.3. Disposal of cylinders

In the base case footprint, it was assumed that cylinders have a lifetime of 40 uses. As a sensitivity case, we ran the model with a cylinder lifetime of only 20 uses.

5.1.4. Using a fossil fuel in charcoal production

In the base case, we used the EcoInvent presumption that wood chips are used to fire the charcoal kiln (see Section 3.1.4) and that these are waste wood (see Section 5.3). As a sensitivity case, we ran the model using heating oil as an alternative fuel source (because many charcoal kilns are fuelled by fossil fuels rather than wood).

Table 15
Size comparison of the two base case footprints, by component.

Component	Footprint (kg CO_2e/150 grilling sessions) Charcoal	LPG
Production of fuel	455	18
Combustion of fuel (i.e. cooking)	413	231
Combustion of firelighter	74	0
Production of grill	56	86
Production, use of cylinders	0	14
Total	998	349

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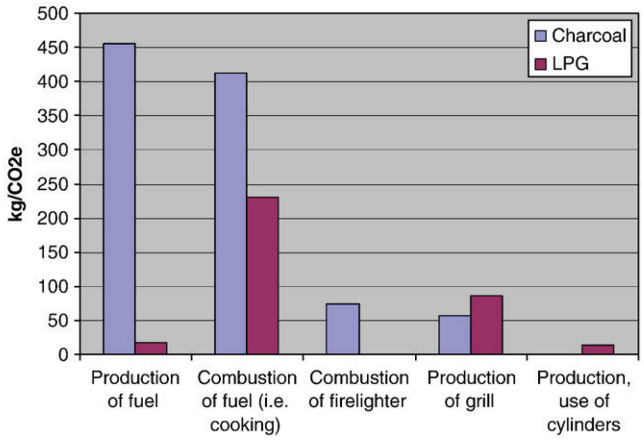

Fig. 3. Size comparison of the two base case footprints, by component.

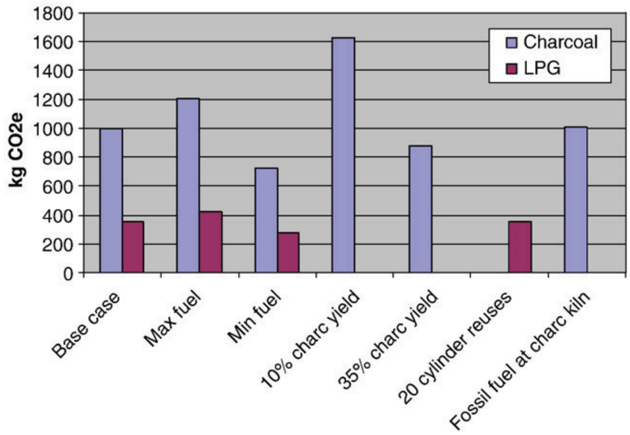

Fig. 4. Footprint sensitivities.

5.2. Sensitivity results

The sensitivities (Table 16, Fig. 4) show the base case to be robust: charcoal grilling generates a significantly higher carbon footprint than does LPG grilling.

Although the sensitivities show some considerable variation, in none of the sensitivities are the footprints of the two grill types even close.

5.3. A less plausible sensitivity: charcoal sourced from waste wood

From the review of charcoal markets and production conducted for this study (Section 3.1), it is clear that charcoal supplied to the UK market in particular and global markets in general is produced from harvested wood, i.e. wood harvested expressly for the purpose of producing charcoal. By definition, this is not waste wood.

Waste wood is wood not usable anywhere else, including other energy generation processes. If the wood could be used in some other process than charcoal making, then it is not a waste. For instance, sawdust generated by a saw mill or paper mill is not necessarily a waste if it could be used some other way. A good example of genuine waste wood is a disused pallet that otherwise would be sent to landfill.

Charcoal can (and sometimes is) made from waste wood or other biomass wastes. If waste wood in a forest were not converted to charcoal, then the alternative would be to leave it in the forest floor, where it will decompose. In decomposing, some carbon would be emitted to atmosphere, some to the soil.

For this sensitivity, we have used a 95:5 atmosphere:soil ratio based on a literature value (Börjesson and Gustavsson, 2000) that is itself recognised as a rough approximation. It is presumed that 95% of the direct CO_2 emissions in producing and cooking with charcoal would have happened anyway, so they are removed from the grilling footprint. Other indirect emissions CO_2 from equipment, transport and so on are still included. The result is a charcoal grilling footprint of 342 kg CO_2e, about two-thirds lower than the base case and roughly equal to that of the LPG base case.

5.4. What about land-use change?

In compiling the charcoal footprint, the idea of land-use change — i.e. destroying forest to harvest charcoal — was not analysed for two reasons: 1) no data on land-use change specifically for charcoal production appear to be available; and 2) the result would be fairly obvious — an increase in the charcoal footprint. Nonetheless, the relationship of charcoal production and land-use change would be a good topic for further research.

5.5. A difficult-to-define sensitivity: Lifetime of the grill

In the base case, the lifetime of the grill was defined as 150 grill sessions: either 10 years × 15 sessions/year or 15 years × 10 sessions/year. In the British climate, this seems plausible, but there are no statistics available to prove or disprove it. In any case, reducing or increasing the grill lifetime does not change the fundamental result of the comparison (Fig. 5).

Table 16
Footprint sensitivities and significance.

	Charcoal			LPG		
	Footprint	Delta to base case	% change, to base case	Footprint	Delta to base case	% change, to base case
Scenario	kg CO_2e			kg CO_2e		
Base case	998	NA	NA	349	NA	NA
Sensitivity						
Maximum fuel	1208	210	21%	420	71	20%
Minimum fuel	722	−276	−28%	278	−71	−20%
10% charcoal yield	1627	629	63%	NA	NA	NA
35% charcoal yield	878	−120	−12%	NA	NA	NA
20 cylinder reuses	NA	NA	NA	353	4	1%
Fossil fuel at charcoal kiln	1007	9	1%	NA	NA	NA

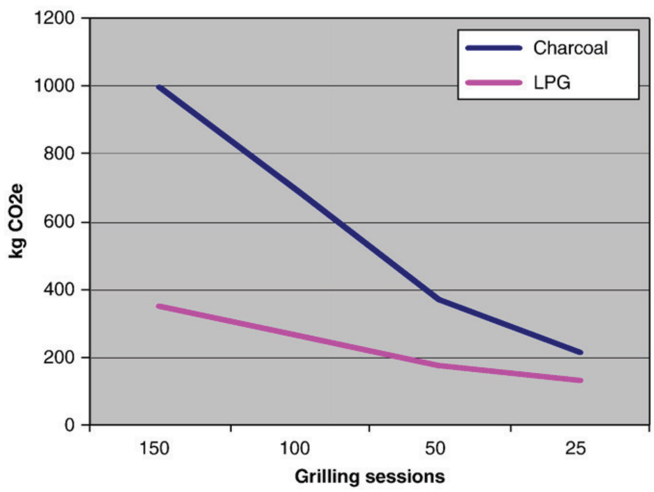

Fig. 5. Grilling less means lower footprints.

But what if the grills have different lifetimes? Again, there are no data available on grill lifetimes, but based on inspection of numerous grills during the course of this study, it is suspected that LPG grills probably last longer than charcoal ones, because they are both more robust and more expensive. If they do last longer, this too will not change the fundamental result of the comparison; indeed, it would widen the gap.

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