LPG's Carbon Footprint Relative to Other Fuels

A Scientific Review

Atlantic **Consulting**

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1 Foreword: The Case for LPG

This document, on LPG's carbon footprint relative to other fuels, is one of a series of summaries for policy makers about LPG in Europe.

Other summaries set out the position of LPG in relation to other important policy challenges for the European Union, including: improving local air quality, enhancing the security of its energy supply, and promoting the safe use of energy.

The summaries are intended to provide policy-makers, other stakeholders in energy and environment policy and the LPG industry itself with an authoritative, quantified, and independent assessment of LPG's position.

This document presents conclusions from a comprehensive literature search and synthesis of relevant studies of LPG's carbon footprint and those of other fuels, drawing on the most credible and recent sources available.

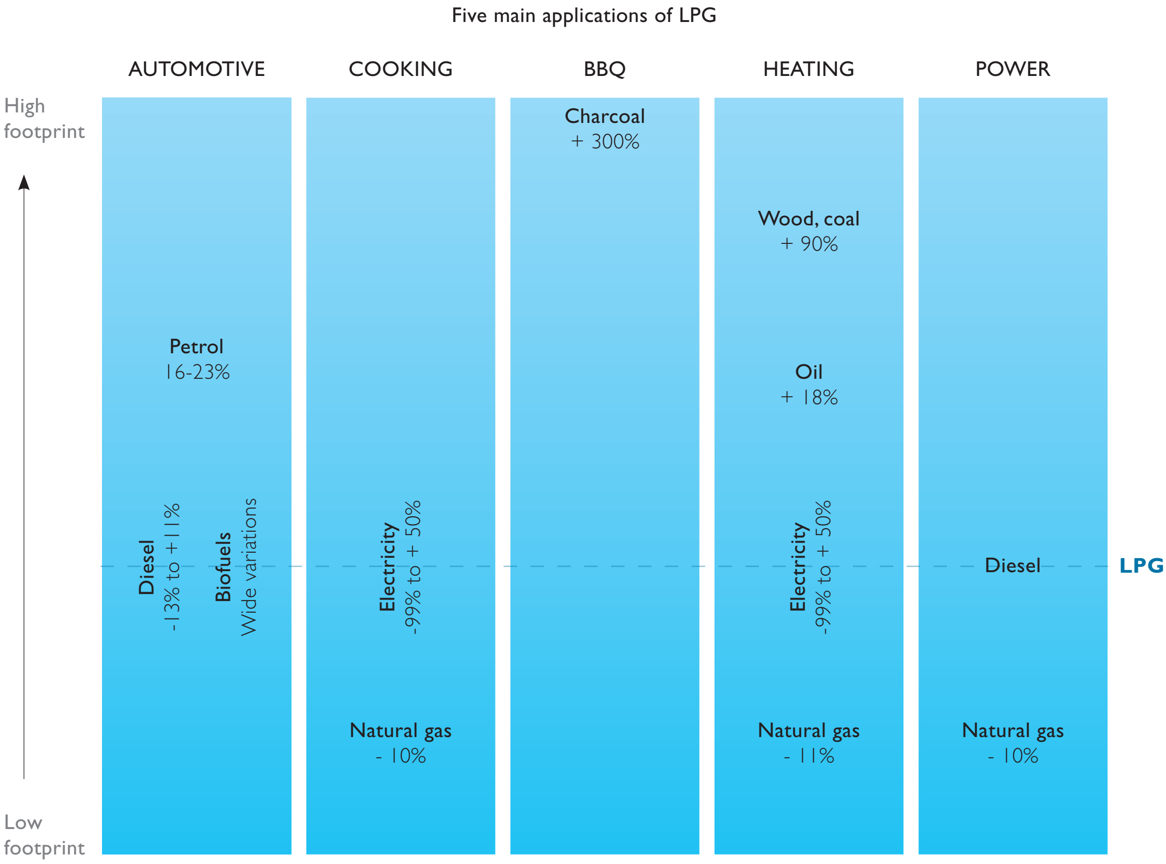
LPG, a mixture of gaseous hydrocarbons produced from natural gas and oil extraction as well as oil refining, has three physical properties that are particularly relevant to its carbon footprint:

- In comparison to most hydrocarbons, LPG has a low carbon to hydrogen ratio, which means that it generates lower amounts of carbon dioxide per amount of heat produced.
- While there is a degree of natural variation in heating values due to the specific proportions of butane and propane within a particular sample of LPG, it nevertheless has a comparably high heating value, meaning it contains more energy per kilogramme than most competing fuels.
- According to the United Nations International Panel on Climate Change (IPCC), LPG is not a greenhouse gas, meaning it is assigned a global warming potential (GWP) factor of zero. The IPCC lists the GWP factor of CO_2 as 1 and methane as 25.

2 Summary: LPG is a lower-carbon fuel

Based on the most authoritative, consistent data available, LPG in Europe is a lower-carbon fuel.In its five main applications, LPG's carbon footprint consistently appears at the lower end of the range (Figure 1).

Figure 1: Competing fuels' footprints vs LPG's footprint, Europe



3 Carbon footprints by application

Carbon-footprint studies in Europe and the US on the five major applications of LPG were reviewed in detail.

3.1 AUTOMOTIVE

Road transport is responsible for approximately 17% of EU Greenhouse Gas emissions.[A] LPG is currently Europe's most widely used alternative fuel, accounting for roughly 2% of the road transport fuel mix in the European Union. Studies consistently demonstrate that LPG generates fewer carbon emissions than gasoline (petrol) and broadly equivalent emissions to diesel.

Seven major studies of automotive carbon footprints - summarised in Table 1 – have been conducted in the past five years.[B] Five of these have compared automotive footprints in Europe. While similar studies have compared automotive footprints in the US, the potential significance of regional differences means that these are of lesser value to policy decisions in Europe.

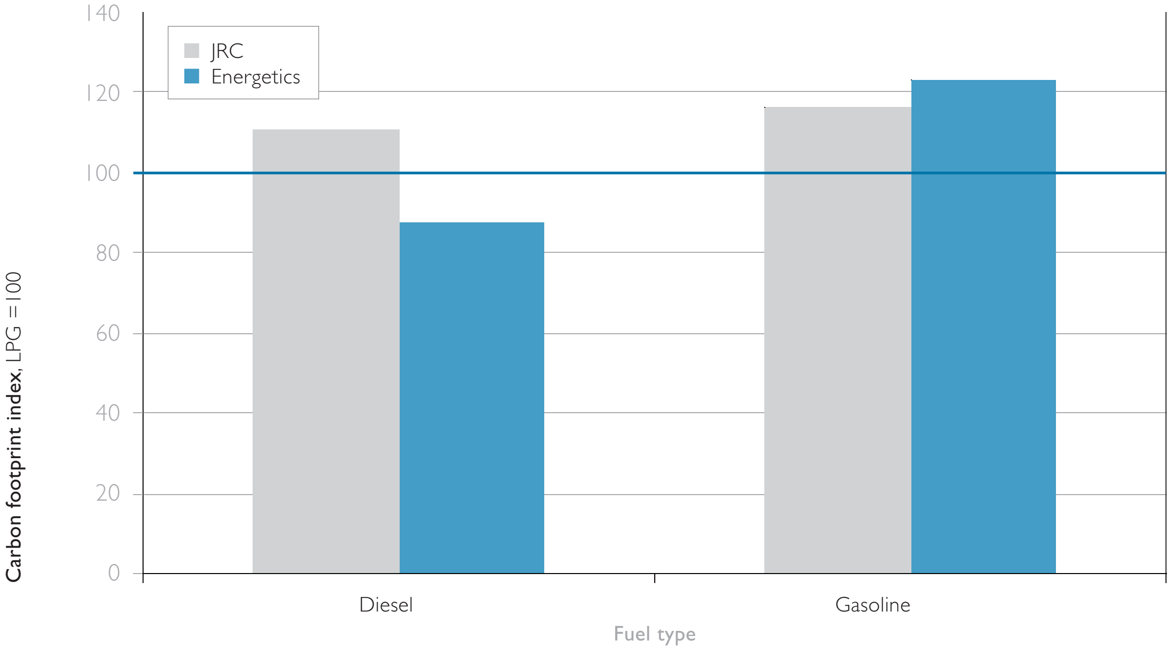
[A] 2009 EU Energy in Figures handbook: figure from 2006, the most recent available.
[B] The ANL/GREET study began in the mid-1990s, but is still ongoing.

Table 1: Automotive footprints, key European and US studies

Researcher	Coverage	Comment
	European studies	
EcoInvent	Diesel, gasoline, some bio- and alternative fuels, but not LPG.	No LPG, so limited meaning for this study of studies. However, work could be extended to LPG.
Energetics, on behalf of WLPGA	In Europe, diesel, gasoline & LPG.	
IPCC, UN Intergovernmental Panel on Climate Change		Automotive efficiencies not included, so outputs not applicable in this comparison.
JRC, Joint Research Centre of the EU	Commercial and experimental fuels.	Wide range of scenarios and outputs.
Silva et al	Diesel and natural gas only.	
	United States' studies	
ANL, Argonne National Laboratories	Wide range of commercial and experimental fuels, including LPG.	Standard reference for most US comparisons.
CEC, California Air Energy Commission	Gasoline, diesel, LPG, natural gas and some alternatives.	Significant inputs appear to come from ANL/GREET.

Of these, two studies – those by JRC and Energetics – are the most relevant to LPG in Europe. They are also authoritative and current, and have therefore been used as the basis for comparing fuel carbon footprints.

Figure 2: Automotive carbon footprints of LPG, gasoline and diesel



Compared to its primary commercial competitors, the European carbon footprint rankings from lowest to highest are (Figure 1):

- LPG and diesel
- gasoline

The differences between LPG and diesel are relatively modest, and their precise ordering is not identical in all studies. Gasoline shows a consistently higher footprint than the other two.

3.2 COOKING AND BARBEQUING

A major European application of LPG is in cooking, primarily in indoor kitchens but also in outdoor grills. LPG's main alternatives as an indoor cooking fuel are electricity and natural gas. As an outdoor cooking fuel, the main alternatives are charcoal, electricity.

For indoor cooking, one significant study of carbon footprints in Europe has been conducted. It compares stove-top cooking (i.e. it excludes ovens) and reports electricity footprints for western and eastern Europe. The study shows natural gas cooking to have a marginally lower footprint than LPG's throughout Europe. The same study shows electricity's footprint to be significantly higher than LPG's in Eastern Europe and significantly lower in Western Europe.

Depending on its location, the electricity footprint can be greater, less than or roughly equal to that of LPG (as shown in Table 2). Electricity's footprint will be lowest in countries such as Norway, Sweden or Switzerland, which rely heavily on low-carbon hydropower. It will be highest in countries such as Germany and Poland, which rely much more on high-carbon coal power for electricity generation.

Table 2: Cooking footprints, Europe (Source: Energetics)

Fuel	Burner type	Efficiency	Cooking footprint g CO_2e
Natural gas, European mix	High-efficiency	42.0%	53.7
Electric	Induction	84.0%	56.1
Natural gas, European mix	Standard	39.9%	56.6
LPG	High-efficiency	42.0%	59.0
LPG	Standard	39.9%	62.2
Electric	Smooth	74.2%	63.5
Electric	Coil	73.7%	63.9

Indeed, electricity's cooking footprint will vary dramatically, depending on the region in which it is produced. Within Europe, this varies from as low as 1.0 g CO_2e in Norway to as high as 83.6 g CO_2e in Germany. The average footprint for the Union for Co-ordination of Transmission of Electricity (the UCTE - the closest regional approximation to the EU) is 63.9 g CO_2e – which is roughly equal to LPG's footprint.

For outdoor cooking – i.e. barbequing – one study has compared charcoal to LPG grilling. It shows LPG's footprint to be one-third that of charcoal's.

3.3 HEATING (SPACE AND WATER)

A further important European application of LPG is in space heating via a dedicated boiler and radiator network. LPG, oil and natural gas are the primary heating fuels in Europe, with coal, electricity, heat pumps and wood weighing in with minor contributions.

Four major studies since 2001 compare footprints of LPG or gas to other heating fuels in Europe (Table 3). LPG shows a footprint about 20% lower than that of fuel oil. Heat pumps generally show a lower footprint, but this varies with heat pump type, and for one type the footprint is equal to LPG's. Coal has a much higher footprint than LPG, as does wood, if it is not presumed to be carbon neutral. Conventional electric heating (not with a heat pump) is reported in only one of the studies. Although in that specific case, electricity's footprint is much higher than LPG's or that of gas, in some European countries the footprint would be much lower.

Table 3: Heating footprints, European studies

Researcher	Coverage	Comment
EcoInvent	Gas, not LPG, oil, coal and wood	Unclear whether water heating is included or not.
Energetics	Gas, LPG, oil and wood.	Space heating only.
IER Stuttgart	Gas, not LPG, oil, wood and heat pumps.	Space and water heating. Comparison in Germany only.
VHK [C]	Gas, LPG, oil, electricity, heat pump and wood.	Appears to include both space and water heating. Comparable figures for all fuels presented on a fuel-only basis, i.e. not the entire life cycle.

For space heating, (Figure 3), the European carbon footprint rankings for the main heating fuels from lowest to highest are:

- natural gas and LPG
- heating oil

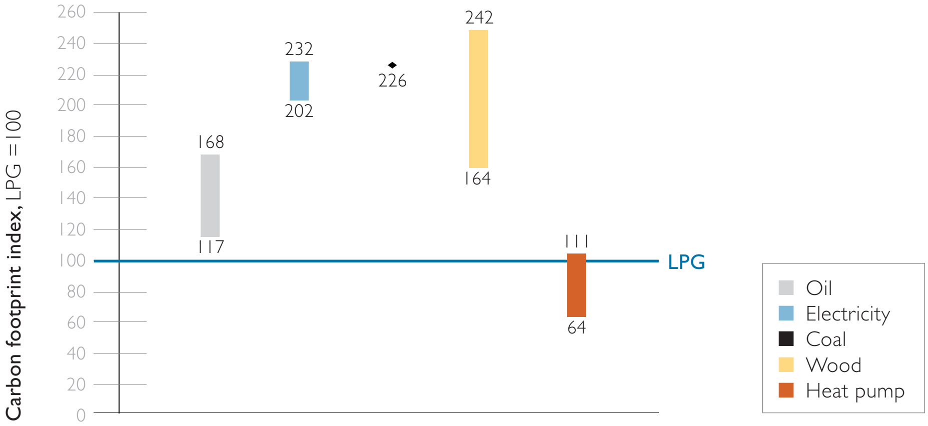
The difference from one group to the other is significant; the gaseous fuels' footprints are some 20% lower than those of heating oil. This broad conclusion rests on a critical assumption – that the footprints of natural gas and LPG in this application are identical – an assumption accepted under the Energy Using Products Directive.

LPG's footprint is significantly lower than coal's. For the other, minor fuels, general comparisons are more difficult. Electricity footprints are significantly higher than that of LPG on European average, yet in some countries they will be lower. The footprint of wood can be higher or lower than LPG's and will vary by its source. For heat pumps, in three studies that look broadly at them, two find their footprints significantly lower than natural gas's or LPG's. The most detailed study (by IER Stuttgart, see References p 10), however, finds that air-water heat pumps generate a footprint about equal to that of natural gas.

Water heating in Europe is supplied by two main types of systems: combination systems that heat space as well as water; and separate heaters for water.

For combination heaters, the footprint relationships of fuels for space heating will be the same for water heating. For separate water-heaters, the footprint relationship between fuels is less clear-cut. One study has looked specifically at water heating systems in Europe. In it, natural gas water-heating shows a marginally lower footprint than LPG's throughout Europe. The study also shows electricity's footprint to be significantly higher than LPG's in Eastern Europe and significantly lower in Western Europe. Again (see *Cooking and Barbequing*), electricity footprints will vary within those regions.

Figure 3: Heating carbon-footprint ranges, as reported by the four major European studies



3.4 POWER GENERATION

One carbon footprint comparison of generator sets[D] is available; this covers all global regions including Europe. Natural gas's footprint comes out marginally lower than LPG's, although the difference borders on insignificance. LPG's footprint is also lower than that of diesel in smaller-sized gensets.

[C] Commissioned by DG ENTR, as part of the EU Eco-Design Programme
[D] Generating sets, or gensets, are small, self-contained power generators used as back-up supplies for critical services (for example, in hospitals) and in locations not accessible to the grid (in construction sites, for example).

4 Appendix: Carbon footprinting

A carbon footprint is the sum of greenhouse-gas (GHG) emissions of a product or service. It is a measure of that product's or service's contribution to global warming, often referred to as climate change.

Because carbon dioxide is the most significant GHG, 'carbon footprint' is often used as a catch-all term to cover GHGs as a whole. 'Global warming footprint' or 'climate change footprint' would be more precise and appropriate terms, as they would incorporate the other GHGs, notably methane, which also contribute to global warming.

4.1 GLOBAL WARMING POTENTIAL OF HYDROCARBONS

Emissions of GHGs cause potential global warming.[E] 'Carbon footprint' is a term commonly used to describe the global warming potential (GWP) for a given product. Footprints are expressed usually in kg or t CO_2e (carbon dioxide equivalent): t $CO_2e = a \times b$, where (a) is tonnes of gas emitted and (b) is the gas's GWP. A gas's GWP is its global warming impact relative to an equivalent unit of carbon dioxide over a given period of time (usually 100 years).

By definition, carbon dioxide is assigned a GWP of 1, meaning that a product emitting five tonnes of CO_2 produces a footprint of five tonnes × GWP 1 CO_2e, or five tonnes CO_2e. Similarly, a product emitting two tonnes of methane (which has a GWP of 25 CO_2e) yields a footprint equal to two tonnes × GWP 25 CO_2e or 50 tonnes CO_2e.

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). IPCC 100-year GWPs are commonly used for the purposes of lifecycle and footprint analysis, and they are recommended for use in footprint guidelines.

4.2 GLOBAL WARMING POTENTIALS OF GREENHOUSE GASES OTHER THAN CO_2

It is generally accepted that CO_2 accounts for 80% of all GHG. The other two main greenhouse gases are methane and nitrous oxide. GWPs for both of these have changed slightly over time (due to redefinitions by the IPCC). IPCC defines GWPs for LPG as zero. In other words, direct emissions of LPG do not contribute to climate change.

4.3 COMPARATIVE PRODUCTION/DISTRIBUTION FOOTPRINTS[F] OF LPG AND OTHER FUELS

Footprints for the production and distribution (i.e. not the combustion) of LPG and its competitors differ in precision and in range. Fossil fuels, including LPG, have relatively definable footprints. Biofuels have widely varying footprints. Electricity's footprint varies widely, but is well defined, by region or by generation type.

4.3.1 Fossil fuels

The footprints of diesel, gasoline, LPG and natural gas can all be established with a relatively high degree of precision. Variances for diesel, gasoline and LPG generally are modest. Footprints for natural gas vary marginally more.

4.3.2 Biofuels

The lifecycle carbon benefits of today's biofuels vary considerably, due to factors such as choice of feedstock, sources of energy used in production and fate of co-products. Some have low footprints; some do not.

[E] The technical term for this is 'radiative forcing'.
[F] Published footprints of products are known to vary widely. This is mainly due to 1) relative inaccuracy, caused by application of different calculation methods, especially different allocation rules, from one study to the next; and 2) imprecision, caused by comparison of two different systems (e.g, a soybean farm in Brazil vs one in the Midwestern US).

4.3.3 Electricity (and electric heat pumps)

Among commercial power plants, electricity generation footprints can vary dramatically, depending on the fuel and process technology used. To compensate for this variability, researchers generally express the electricity footprint as an average for a regional power grid.

Figure 4: Sampling of electricity footprints (Source: EcoInvent)

Country or region	Footprint	
	g CO_2e per MJ	g CO_2e per kWh
Finland	122	439
Germany	184	662
Norway	2	8
Sweden	10.8	38.9
Switzerland	5	19
UCTE	141	506
UK	165	594
USA	209	752

The broadest grid for Europe is the UCTE (Union for Co-ordination of Transmission of Electricity), a 24-nation group roughly parallel to the European Union (plus Switzerland and some Balkan countries, minus the British Isles, Finland and Sweden).

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