Emissions of (bio)LPG and other energy carriers in domestic heating, BBQs and forklift trucks

Country-specific report Belgium

CE Delft

Committed to the Environment

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Delft, CE Delft, March 2021

Publication code: 21.200209.033

Fuels / Biofuels / LCA / Air pollution / Impact

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Abbreviations

CO	Carbon monoxide
CO_2	Carbon dioxide
CPO	Crude palm oil
GHG	Greenhouse gas
LCA	Life cycle assessment
LPG	Liquid petroleum gas
NOx	Nitrogen oxides
PM	Particulate matter
RBD (palm oil)	Refined, bleached and deodorized (palm oil)
SO_x	Sulphur oxides
TTW	Tank-to-wheel
VOC(s)	Volatile organic compound(s)
WTT	Well-to-tank
WTW	Well-to-wheel

Summary

This report for Belgium presents the carbon footprint and air pollutant emissions related to the use of (bio)LPG in comparison to alternative energy carriers for three applications in Belgium: domestic heating, BBQ and forklift trucks.

Methodology

We have taken a life cycle assessment (LCA) approach to compare the use of (bio)LPG to the use of alternative energy carriers. To compare carbon footprints, we have taken into account the production, transport and end-use of the energy carrier and the production of the end-use technology. For air pollutant emissions, only the end-use emissions have been included in the analysis. Six air pollutants are included: CO, VOC, NO_x, SO_x, $PM_{2.5}$ and PM_{10}. To enable the comparison of energy carriers, a single but different functional unit is used for each of the applications.

Regarding domestic heating, we have compared the average heating installation for each of the energy carriers that are currently used in Belgian households, taking into account that older installations have a lower energy efficiency. Given the availability of data, we have used data of the situation in Flanders for this, and have assumed that these data apply to the whole of Belgium. However, the situation in Wallonia and Belgium in general might differ from Flanders.

Domestic heating

Switching to LPG is perceived especially as an alternative for off-grid domestic heating options. The shift from LPG to bioLPG is perceived as a second step to further reduce the carbon footprint. Therefore, the outcomes are presented for both the switch from other energy carriers to LPG as well as to bioLPG.

Carbon footprint

- In case of replacement of **an average heating oil boiler** with a **new condensing (bio)LPG boiler using LPG,** the carbon footprint reduces by 39%.
- The **least efficient oil boiler** and a **new oil boiler** represent the minimum and maximum of the carbon footprint reduction that can be realised when switching from heating oil to LPG. This range is calculated at **22 to 55%**.
- A carbon footprint reduction of 77% is reached in case **an average heating oil boiler** is replaced by **a new condensing (bio)LPG boiler using bioLPG**.
- When **an average coal stove** is being replaced by **a new condensing (bio)LPG boiler**, **using LPG**, the carbon footprint is reduced by **69%**. A reduction of **89%** will be reached when the LPG boiler uses **bioLPG**.
- Replacing a boiler using **wood logs or wood pellets** with a boiler using LPG results in around 6.4-8.4 times higher carbon emissions. In case bioLPG is used instead of wood logs and wood pellets, the carbon footprint is between 2.4 and 3.6 times higher.

Air pollutant emissions

LPG and bioLPG are assumed to have the same air pollution level, because they have the same chemical composition. When switching from heating oil to (bio)LPG, the NO_x emissions decrease by 9%, the PM emissions by 87% and the SO_x emissions by 100%, but the CO emissions are 5.8 times higher and the VOC emissions 10.3 times higher. When switching from wood logs or wood pellets to (bio)LPG, the emissions are reduced for all six included air pollutants: by 37% for NO_x and by 78 to 99.9% for the other pollutants.

BBQ

Carbon footprint

The carbon footprint of a BBQ on LPG is 44% higher than the carbon footprint of a BBQ on charcoal. This outcome relates to the biogenic nature of charcoal, assuming it is produced from sustainable wood. There is however no full consensus among scientists on the calculation methodology for carbon emissions from charcoal. When switching from charcoal to bioLPG, the carbon footprint reduces (improves) by 18 to 24%; when switching from LPG to bioLPG, it improves by 43 to 47%.

Air pollutant emissions

The analysis results clearly show that charcoal will produce much more end-use air pollutants than (bio)LPG, except in the case of NO_x. When switching from charcoal to (bio)LPG, the CO, VOC and PM emissions decrease by about 99%.

Forklift trucks

Carbon footprint

A forklift truck on LPG has a 6% lower carbon footprint compared to diesel, but this footprint is almost six times higher (473% higher) than for battery electric forklift trucks. In case of an additional shift to bioLPG, the carbon emissions are reduced a further 52-57% (the immediate shift from diesel to bioLPG results in a 55-60% carbon footprint reduction). Also the difference with battery electric forklift trucks becomes smaller: the carbon emissions of bioLPG are 2.4-2.7 times higher than those of battery electric forklift trucks.

Air pollutant emissions

When switching from a diesel forklift truck to a (bio)LPG forklift truck, the emissions of the following air pollutants decrease: CO (53%), NO_x (9%), and PM (89%). (Bio)LPG fuelled forklift trucks will emit 108% more VOCs than diesel trucks. Battery electric forklift trucks do not have end-use air pollution emissions. No data on SO_x emissions were found.

1 Introduction

This country-specific report for Belgium presents the carbon footprint and air pollutant emissions related to the use of (bio)LPG in comparison to alternative energy carriers for three applications: domestic heating, BBQ and forklift trucks.

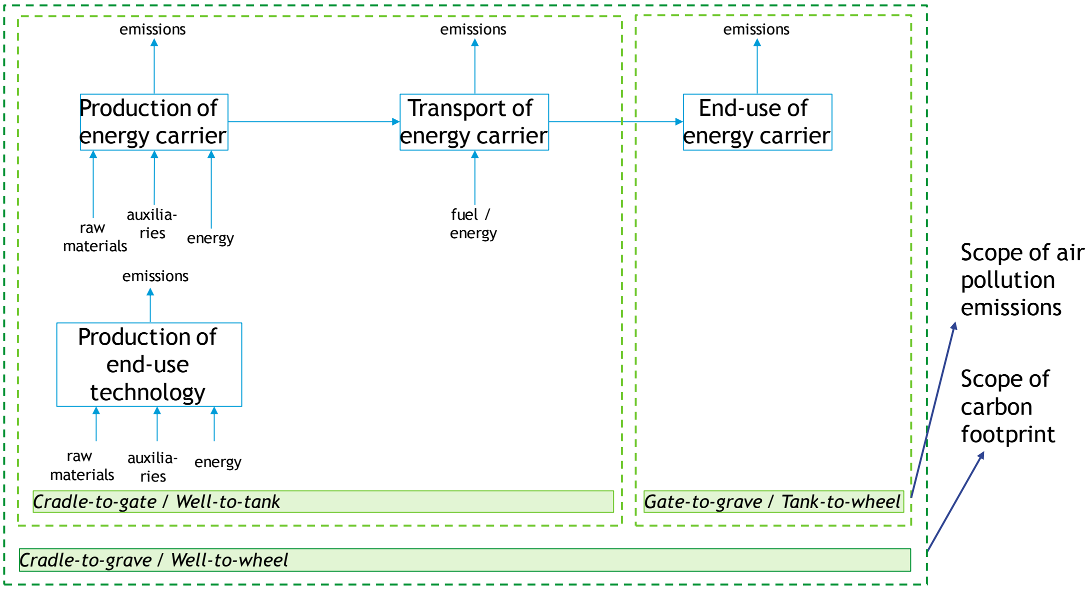
2 Methodology

We have taken a life cycle assessment (LCA) approach to compare the use of (bio)LPG to the use of alternative energy carriers in different applications in Belgium. Where possible, we have used data on the Belgian situation. It is important to note that the results of each comparison should be taken as indicative, as the data comes from different sources, which are not always dedicated to the country of Belgium.

For the carbon footprint, the following life cycle stages are taken into account:
- production of the energy carrier;
- transport and distribution of the energy carrier;
- end-use of the energy carrier;
- production of the end-use technology (i.e., the BBQ unit, forklift truck, or boiler).

For the air pollution emissions, only end-use emissions are taken into account.
The difference in scope is shown in Figure 1.

Figure 1 - Scope of carbon footprint and air pollution emissions



Bron: CE Delft.

It is important to note that the scope of the carbon footprint includes both the carbon footprint of the life cycle of the energy carriers and the carbon footprint of the production of the end-use technology. However, only in those cases where substantially different end-use technologies are required for different energy carriers, different carbon footprint values of production of the end-use technology will be used in the analysis. Note that capital goods (e.g. factories and machinery) and infrastructure are considered out of scope, as no significant changes between the cases are expected and their contribution to the overall environmental impacts of fuel are typically minor. Note that this approach also aligns with GHG emissions calculations in the Renewable Energy Directive.

In order to be able to make a good comparison, a functional unit is used in LCAs. The carbon footprint is calculated per functional unit. In this way the impact of each of the life cycle stages can be added up to a total carbon footprint.

The following functional units are used in the analysis:
- domestic heating: MJ of heat delivered;
- BBQ: BBQ session;
- forklift truck: hour of operation.

The functional units for BBQ and forklift trucks are explained in Section 3.

The used data for the analysis are listed in Appendix A.

3 Results and discussion of results

In this section we show the results of the analysis for the case of Belgium. We discuss the results for domestic heating, BBQ and forklift trucks in different paragraphs.

3.1 Domestic heating

For heating, we compare one MJ of heat delivered when using coal, heating oil, wood logs, wood pellets, electricity (heat pump), LPG and bioLPG as an energy carrier. The carbon and air pollutants emissions were calculated applying the average energy efficiency of currently used heating installations in Belgium based on data from CE Delft (2019) except in the cases of heat pumps (which do not have end-use emissions) and wood log and wood pellet boilers (for which no information was found on installation ages and differences in efficiencies). The data from CE Delft (2019) concern the region of Flanders, but we assume that these are valid for Belgium as a whole. The average installation efficiencies are weighted averages, which have been calculated taking into account the age distribution of the currently used installations. The efficiencies are presented in Table 1.

For information purposes, we have also included in Table 1 an estimation of the fuel consumption shares for main domestic heating in Flanders , based on figures from 2015. In Belgium as a whole, 47% of the energy used for residential heating comes from natural gas, 37% from heating oil, 1% from coal, 2% from (bio)LPG, 10% from biomass, and 3% from electricity (FOD Economie, 2019). It must be noted that these shares concern the amount of energy used, not the shares of households. However, FOD Economie (2019) does mention that households in Brussels and Flanders predominantly use natural gas for heating, whereas Walloon households rather use heating oil, as some cities in Wallonia do not have a natural gas distribution grid. The shares of households using a specific heating installation type in Flanders can be found in Appendix B.

Table 1 – Average energy efficiencies of domestic heating installations in Flanders in 2015 based on CE Delft (2019), which are applied to the analysis for Belgium as a whole

	Average energy efficiency in Flanders	*Fuel consumption share in Belgium*	Remarks
Coal	42%	*1%*	
Heating oil	67%	*37%*	
Natural gas	76%	*47%*	
(Bio)LPG	69%	*2%*	
Heat pump	270%		
Wood boiler	83%		The efficiency has been applied to both wood log boilers and wood pellet boilers.
Biomass installations		*10%*	The analysis only includes the wood boiler used for main heating. The share of 10% also includes other wood-burning installations (also the ones used for additional heating).
Electricity		*3%*	Includes both resistance heaters and heat pumps. In the analysis, only the heat pump is included.

Note: The energy efficiencies are weighted averages, which have been calculated in CE Delft (2019) taking into account the age distribution of installations. The fuel consumption shares (as a percentage of the total energy value of energy carriers used for domestic heating) in Belgium are not used in the analysis, but are shown for information purposes.

In the analysis, we have not made a distinction between condensing and non-condensing boilers, because the available data on energy efficiencies and age distribution of the installations did not specify this[1]. We note however that a large part of the heating installations in Belgium is more than fifteen year old (when non-condensing boilers were prevalent), and that 71% of the natural gas boilers in Flanders are non-condensing (CE Delft, 2019).

Regarding the use of wood, we have looked at the wood boiler, which is the most energy-efficient type of wood-burning installation. In Flanders, about 20% of the wood-burning installations used for main domestic heating is a wood boiler (CE Delft, 2019). The use of wood stoves and other types of wood-burning installations leads to higher emissions than presented here, as these have a lower energy efficiency.
Biomethane is not included in the analysis. This renewable fuel could be supplied to households using the existing national natural gas network. A comparison with (bio)LPG is less relevant, because (bio)LPG is typically a fuel option for households not connected to the natural gas network.
Bio-oil is not included either, because bio-oil boilers are not used in households yet.[2] As a result, emission factors based on real-life measurement values are not yet available.

1 Except for natural gas, but we have chosen to not distinguish between condensing and non-condensing natural gas boilers, in order to make a more consistent and straightforward comparison.

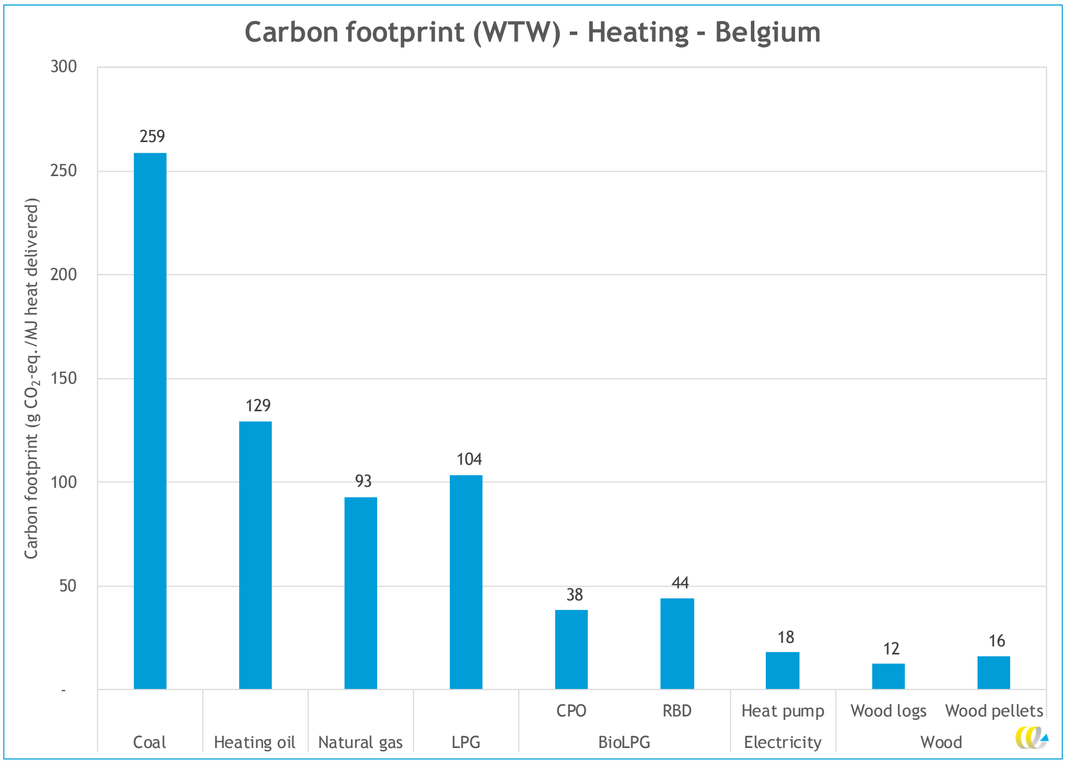
2 A main goal of the Horizon 2020 project 'Residue2Heat' is to develop an efficient small-scale fast-pyrolysis bio-oil (FPBO) residential heating boiler (20-200 kW_{th}). There are still a number of technical challenges that must be met before FPBO can be used in residential boilers (NNFCC, 2019).

Carbon footprint

An overview of the carbon footprint of different energy carriers is given in Figure 2 . The relative reduction of the carbon footprint of bioLPG compared to alternative energy carriers is shown in Table 2. A minus sign means there is no reduction, but an increase of the carbon footprint when switching to bioLPG.

The bioLPG delivered by Neste to the Belgian market has a lower (better) carbon footprint when using it in heating compared to the use of coal, natural gas, LPG and heating oil. This is true for both bioLPG made from crude palm oil (CPO) and bioLPG made from refined, bleached and deodorised (RBD) palm oil.[3] The difference in carbon footprint between CPO-based bioLPG and RBD-based bioLPG is much smaller than the difference between bioLPG and other energy carriers.
Wood logs and wood pellets have a lower carbon footprint than bioLPG, resulting in lower greenhouse gas emissions. Heat pumps use electricity to extract heat from the atmosphere to heat domestic buildings, which is very energy efficient. This is an important contributing factor in the lower carbon footprint of heat pumps compared to bioLPG boilers. Considering the fossil fuels, LPG and natural gas are more favourable fossil options than coal and heating oil.

Figure 2 - Carbon footprint (WTW) of different energy carriers in heating in Belgium, based on average energy efficiencies of currently used installations



3 The emission reduction of feedstocks, such as crude palm oil (CPO), are based on the Proof of Sustainability certificates as delivered by the client. The carbon footprint calculations within this study are in line with the calculation methodology of the RED. However, the broader policy discussion on palm oil such as the discussion on additional emissions as result of indirect land use change and various caps within the context of the RED have not been part of the scope of this study. As result of policy developments HVO production is likely to shift away from palm oil to waste and residues, which will also consequently improve the sustainability of bioLPG.

Table 2 - Relative reduction of carbon footprint when switching to LPG or bioLPG for domestic heating in Belgium, based on average energy efficiencies of currently used installations

Old energy carrier	New energy carrier		
	LPG	bioLPG	
		RBD	CPO
Coal	60%	83%	85%
Heating oil	20%	66%	70%
Natural gas	-11%	53%	59%
LPG	-	57%	63%
Electricity	-477%	-146%	-114%
Wood logs	-739%	-257%	-211%
Wood pellets	-538%	-172%	-137%

Replacement of existing oil and coal installations with a new (bio)LPG boiler

The above results are based on average installation efficiencies. Here we look at the effect of replacing average fossil installations with a new (biol)LPG boiler. The average fossil fuelled heating installation currently used in Belgian households has a relatively low energy efficiency, as a large share of installations is more than fifteen years old.[4] By replacing such an installation with a new condensing (bio)LPG boiler, the carbon footprint of heating can be reduced. This is shown in Table 3. If an average coal stove is replaced with a new (bio)LPG boiler, the carbon footprint reduction is highest: 69% if fossil LPG is used, and 89% if bioLPG is used. The carbon footprint reduction is higher when using bioLPG instead of fossil LPG, as the end-use CO_2 emissions of bioLPG are biogenic and are therefore not taken into account.

Table 3 - Carbon footprint reduction when replacing fossil-burning installations in Belgium with a new condensing (bio)LPG boiler

Replaced installation	New installation	Carbon footprint reduction	New installation	Carbon footprint reduction
Average heating oil boiler	New (bio)LPG boiler, using LPG	39%	New (bio)LPG boiler, using bioLPG	77%
Average coal stove		69%		89%

Scenarios for replacement of oil boilers with a new bio(LPG) boiler

Heating oil boilers that are used in Belgian households have a relatively low energy efficiency. More than 72% of the oil boilers that were used in Flanders in 2015 was more than fifteen years old (Verbeeck & Ceulemans, 2015). The least efficient oil boilers in use have an efficiency of 49%, whereas the most efficient boilers have an efficiency of 85% (CE Delft, 2019). To examine the individual effects of switching to a newer boiler and switching to another fuel, we compare here different specific replacement scenarios. If one of the least efficient oil boilers is replaced by a new oil boiler, the carbon footprint drops by 42%. If that new oil boiler is in turn replaced by a new condensing (bio)LPG boiler with

[4] More than 38% of the natural gas boilers and more than 72% of the oil boilers in Flanders in 2015 were more than fifteen years old (Verbeeck & Ceulemans, 2015).

an efficiency of 90% [5], the carbon footprint drops by 22% if fossil LPG is used and by 71% if bioLPG is used (see Table 4). The results show that the switch from a heating oil boiler to a (bio)LPG boiler always improves the carbon footprint of heating, which can become as high as 83%. The carbon footprint reduction is considerable when LPG is used instead of heating oil, and increases even further when switching to bioLPG.

A similar analysis for coal stoves would paint the same picture: the replacement of coal stoves with (bio)LPG boilers always leads to a reduction of the carbon footprint. Compared to the replacement of heating oil boilers, the reduction is higher. However, the fact that only 1.0% of the Flemish households had a coal stove in 2015, compared to 25.8% which had a heating oil boiler (CE Delft, 2019), makes this analysis less relevant.

Table 4 – Carbon footprint reduction when replacing oil boilers in Belgium with a new condensing (bio)LPG boiler with an energy efficiency of 90%

Old installation	New installation	Carbon footprint reduction
Least efficient oil boiler	New oil boiler	42%
New oil boiler	New (bio)LPG boiler, using LPG	22%
Least efficient oil boiler	New (bio)LPG boiler, using LPG	55%
New oil boiler	New (bio)LPG boiler, using bioLPG	71%
Least efficient oil boiler	New (bio)LPG boiler, using bioLPG	83%

Air pollution

The relative reduction of air pollutant emissions when using LPG or bioLPG instead of alternative energy carriers in heating is shown in Table 5. A minus sign means there is no reduction, but an increase of the air pollutant emission level when switching to (bio)LPG. The emissions for all air pollutants per energy carrier are shown in Figure 3. A comparison between energy carriers of individual air pollutants is made in Figure 4 to Figure 9, accompanied by a short description of the results per air pollutant.

Different energy carriers used for heating lead to different air pollution levels. In our analysis, these differences originate from the different emission factors and energy efficiencies, which we collected from literature (see Appendix A). We do not have insight in the underlying variables that influence the emissions factors, but general variables that have an effect on the emission factor value are the nature of the combustion process, the chemical composition of the fuel, and the configuration of the heating installation.

LPG and bioLPG are assumed to have the same air pollution level, because they have the same chemical composition. Heat pumps do not have end-use air pollution emissions.

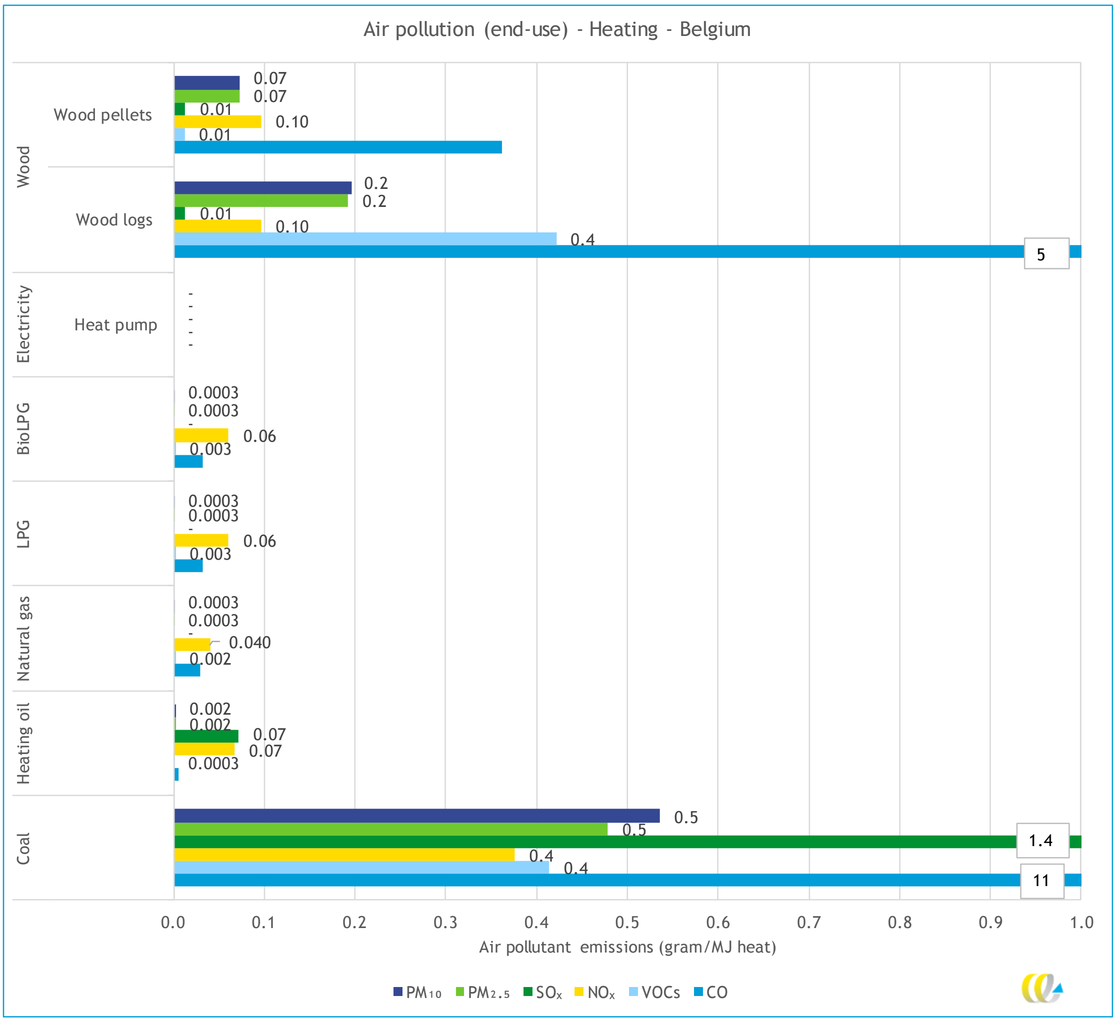
A first observation that we can make when looking at Figure 3 is that an average coal stove leads to the highest air pollutants emissions, followed by a boiler fuelled by wood logs and a boiler fuelled by wood pellets.

5 Source: www.directheatingsupplies.co.uk/news/pros-cons-lpg-boiler/

Table 5 - Relative reduction in air pollution emissions achieved when using LPG or bioLPG instead of alternative energy carriers in Belgium, based on average energy efficiencies of currently used installations

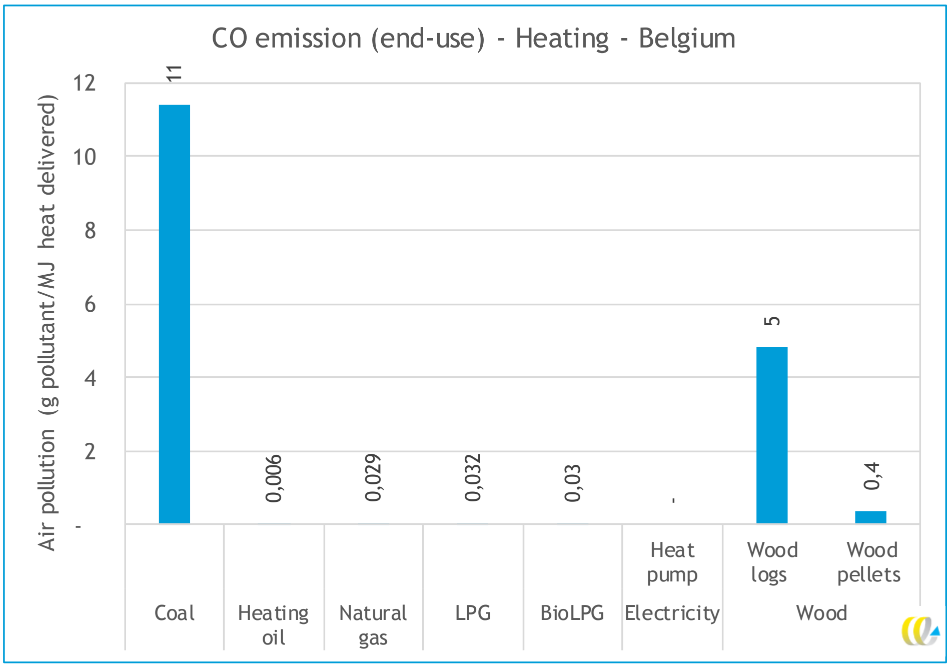
	Coal	Heating oil	Natural gas	Electricity	Wood logs	Wood pellets
CO	99.7%	-477%	-9%	Not applicable	99%	91%
VOCs	99%	-928%	-9%	Not applicable	99%	78%
NO_x	84%	9%	-52%	Not applicable	37%	37%
SO_x	100%	100%	Not applicable	Not applicable	100%	100%
$PM_{2.5}$	99.9%	87%	-9%	Not applicable	99.8%	99.6%
PM_{10}	99.9%	87%	-9%	Not applicable	99.9%	99.6%

Figure 3 - Air pollution emissions (end-use) of different energy carriers in heating in Belgium, based on average energy efficiencies of currently used installations



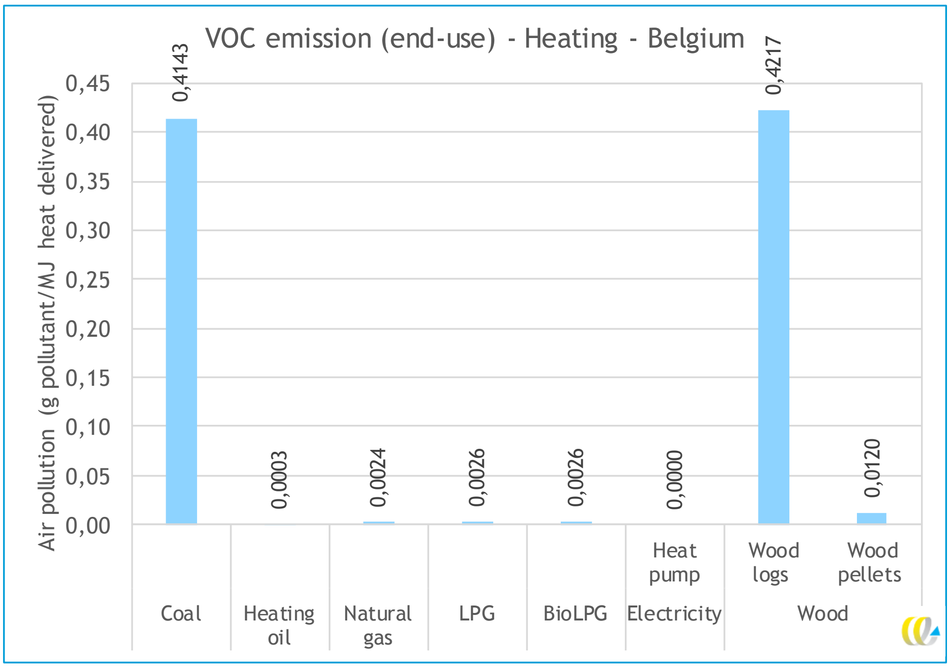
Note: The x-axis has been capped to improve readability.

Figure 4 - CO emission (end-use) of different energy carriers in heating in Belgium, based on average energy efficiencies of currently used installations



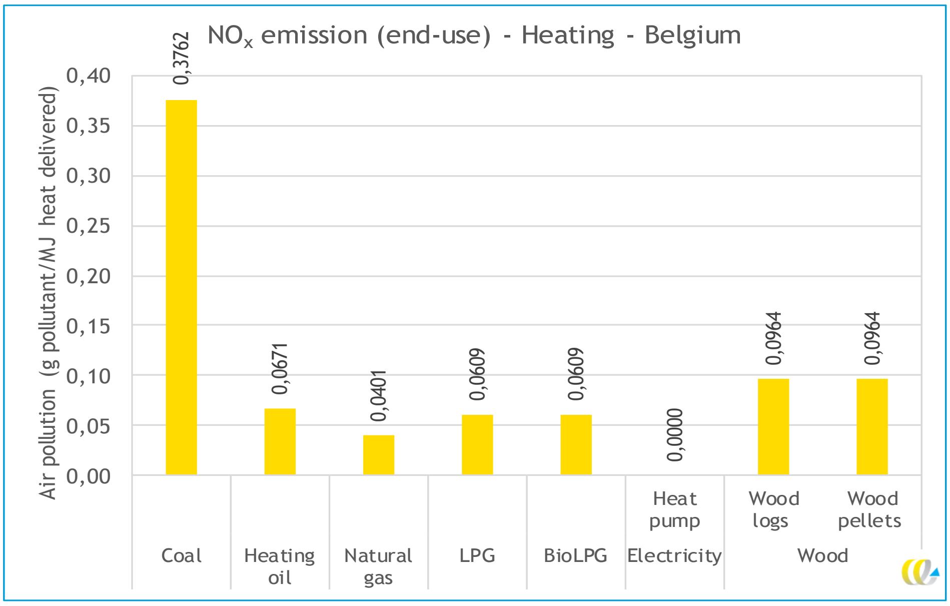
The comparison of the CO emissions for different energy carriers in Figure 4 shows that coal has the highest emission level, followed by wood logs and wood pellets. The CO emissions of heating oil are 83% lower than those of (bio)LPG, but compared to coal and wood the differences are minor.

Figure 5 - VOC emission (end-use) of different energy carriers in heating in Belgium, based on average energy efficiencies of currently used installations



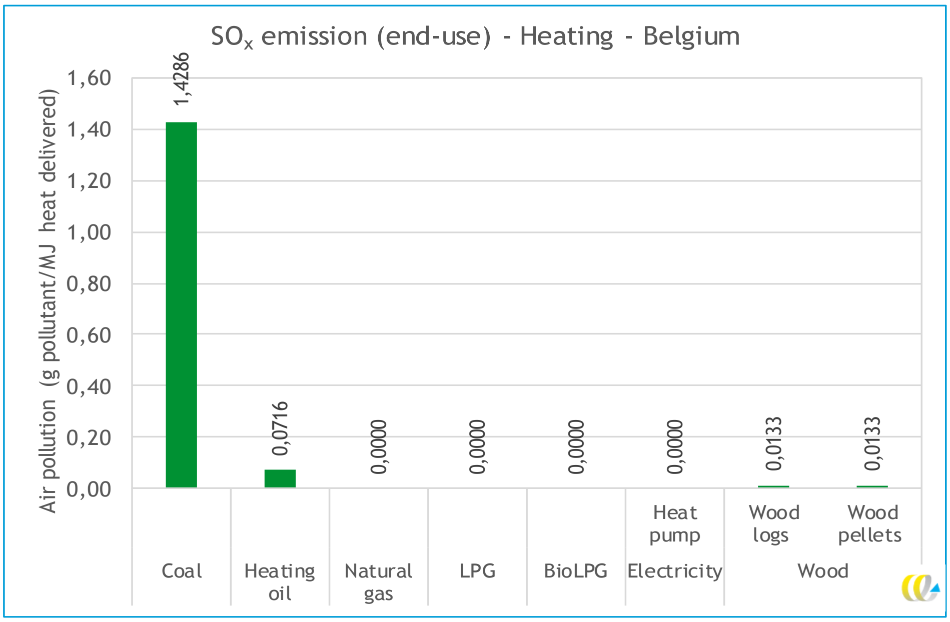
The comparison of the VOC emissions for different energy carriers in Figure 5 shows that coal and wood logs have the highest emission level. The VOC emissions of heating oil are 90% lower than those of (bio)LPG, but compared to coal and wood logs the differences are minor.

Figure 6 - NO_x emission (end-use) of different energy carriers in heating in Belgium, based on average energy efficiencies of currently used installations



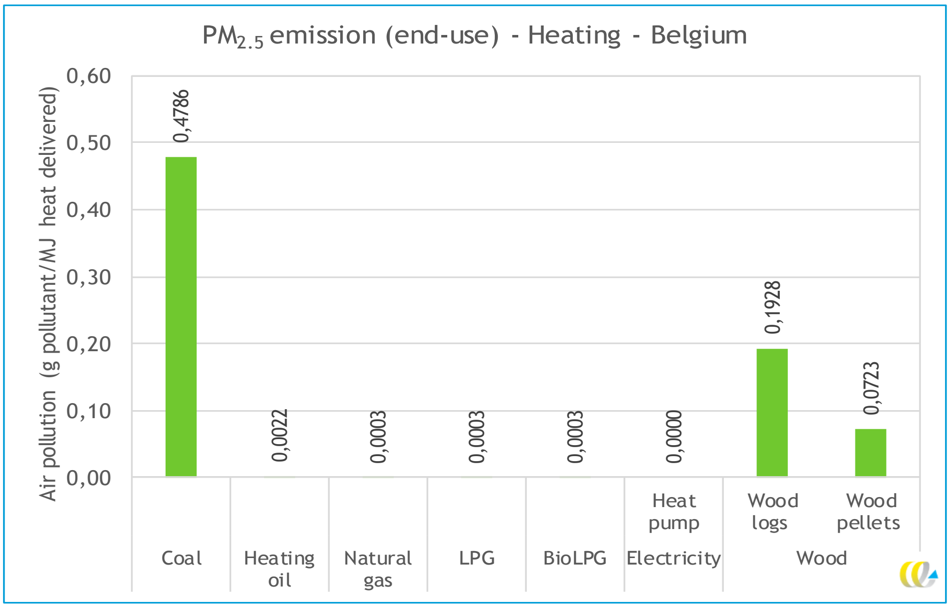
The comparison of the NO_x emissions for different energy carriers in Figure 6 shows that coal has the highest emission level. The NO_x emissions of (bio)LPG are 9% lower than those of heating oil. Wood logs and wood pellets generate 58% higher emissions than (bio)LPG.

Figure 7 - SO_x emission (end-use) of different energy carriers in heating in Belgium, based on average energy efficiencies of currently used installations



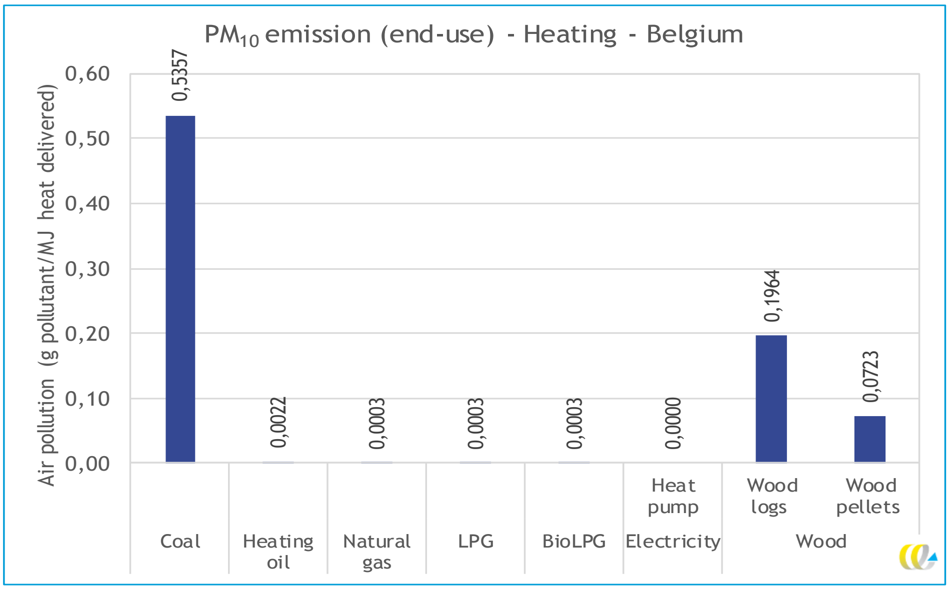
The comparison of the SO_x emissions for different energy carriers in Figure 7 shows that coal has the highest emission level, followed by heating oil. (Bio)LPG does not generate any SO_x emissions. Wood logs and wood pellets have lower emissions than heating oil.

Figure 8 - $PM_{2.5}$ emission (end-use) of different energy carriers in heating in Belgium, based on average energy efficiencies of currently used installations



The comparison of the $PM_{2.5}$ emissions for different energy carriers in Figure 8 shows that coal has the highest emission level, followed by wood logs and wood pellets. The $PM_{2.5}$ emissions of (bio)LPG are 87% lower than those of heating oil. Compared to coal and wood, the $PM_{2.5}$ emissions of (bio)LPG are even reduced by almost 100%.

Figure 9 - PM_{10} emission (end-use) of different energy carriers in heating in Belgium, based on average energy efficiencies of currently used installations



The comparison of the PM_{10} emissions for different energy carriers in Figure 9 shows that coal has the highest emission level, followed by wood logs and wood pellets. The PM_{10} emissions of (bio)LPG are 87% lower than those of heating oil. Compared to coal and wood, the PM_{10} emissions of (bio)LPG are even reduced by almost 100%.

3.2 BBQ

For BBQ, we are comparing a BBQ session in which charcoal, LPG or BioLPG is used. It is difficult to determine the carbon and air pollutants emissions related to an average BBQ session as there are many different types of BBQ on the market and the use of fuel is very dependent on the user and specific circumstances in which it is used. Here, we have based the functional unit on an existing LCA study about LPG versus charcoal BBQs (Johnson, 2009). It was determined that during one BBQ session in which 1.5 kg of food was cooked, 525 grams of (bio)LPG was used or 733 grams of charcoal. This is how 'BBQ session' is defined for each of the fuels (only (bio)LPG and charcoal are considered here).

Carbon footprint

The relative reduction of the carbon footprint by using bioLPG instead of LPG or charcoal is shown in Table 6. The carbon footprints of the fuels are presented in Figure 10.

BioLPG has a lower carbon footprint than fossil LPG, because the end-use CO_2 emissions of bioLPG are biogenic and are therefore not taken into account. Also, bioLPG produced from crude palm oil (CPO) has a lower carbon footprint than bioLPG produced from refined, bleached and deodorized palm oil (RBD), because the carbon emissions related to the processing of crude palm oil are included in the carbon footprint of RBD.

Furthermore, our analysis shows that the carbon footprint of charcoal[6] is higher than that of bioLPG, but lower than the carbon footprint of fossil LPG. This last outcome is the opposite from the one in Atlantic Consulting (2018), where fossil LPG is found to cause lower well-to-wheel (WTW) greenhouse gas emissions per BBQ session than charcoal. The difference is caused by the used well-to-tank (WTT) emission factor for charcoal, which is more than twice as high in Atlantic Consulting (2018). The latter has used the life cycle analysis results from Johnson (2009) which was based on the Ecoinvent 2.0 database from 2007, whereas we used the Ecoinvent 3.6 database from 2019. Thus, the well-to-tank emission factor of charcoal has been adjusted downward in newer versions of the Ecoinvent database.
The WTW carbon footprint of LPG and the tank-to-wheel (TTW) carbon footprint of charcoal[7] in our analysis and Atlantic Consulting, (2018) are similar.

It must be remarked that the assumption of a near-zero TTW emission factor for charcoal is linked to the assumption that the charcoal is produced from wood from sustainably managed forests. However, WWF Belgium found in their market research that charcoal on the Belgium market often includes wood from tropical forests without proper sustainability certification, and that a large part of the charcoal originates from countries with endangered forests (WWF-BE, 2018). Unfortunately, it is hard to quantify the corresponding risk of deforestation in terms of additional CO_2 emissions. Therefore, this could not be incorporated into the analysis.

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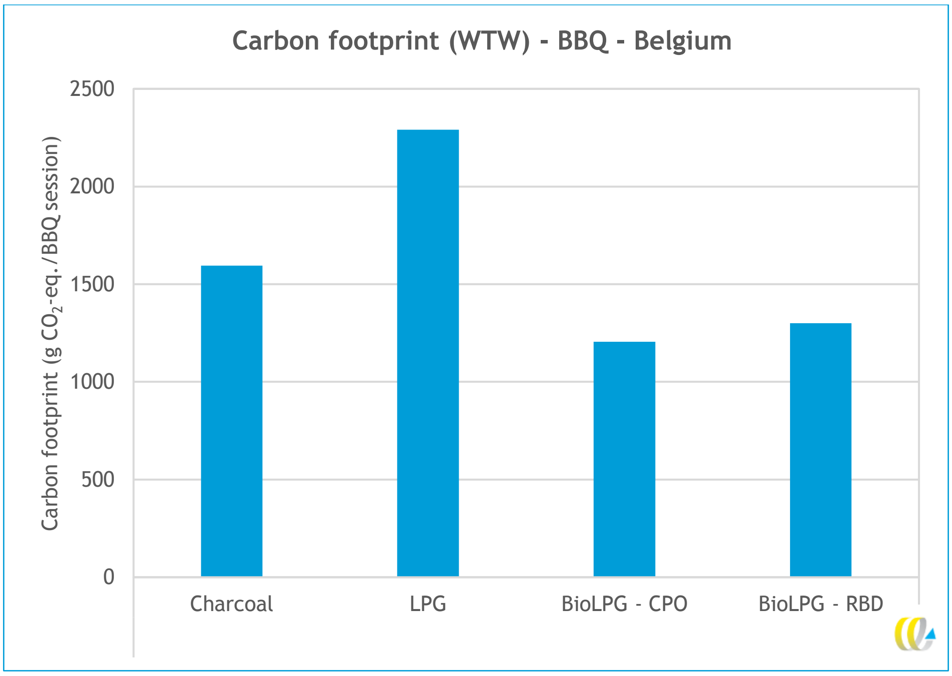
6 The carbon footprint of charcoal is determined using global emission data, and thus applies to imported charcoal.

7 In our analysis we adopted the TTW value of 5.2 g CO_2-eq./MJ of charcoal used by Atlantic Consulting (2018). We could not find the origin of these emissions, but these are much lower than the actual combustion emissions, which are 128 g CO_2-eq./MJ (Johnson, 2009). This shows that the TTW CO_2 emissions of charcoal are considered biogenic and have not been incorporated in the carbon footprint in both analyses.

Table 6 - Relative reduction of carbon footprint when switching to LPG or bioLPG from different feedstocks in BBQ in Belgium

	LPG	BioLPG - CPO	BioLPG - RBD
LPG	-	47%	43%
Charcoal	-44%	24%	18%

Figure 10 - Carbon footprint (WTW) of different fuels in BBQ in Belgium



Air pollution

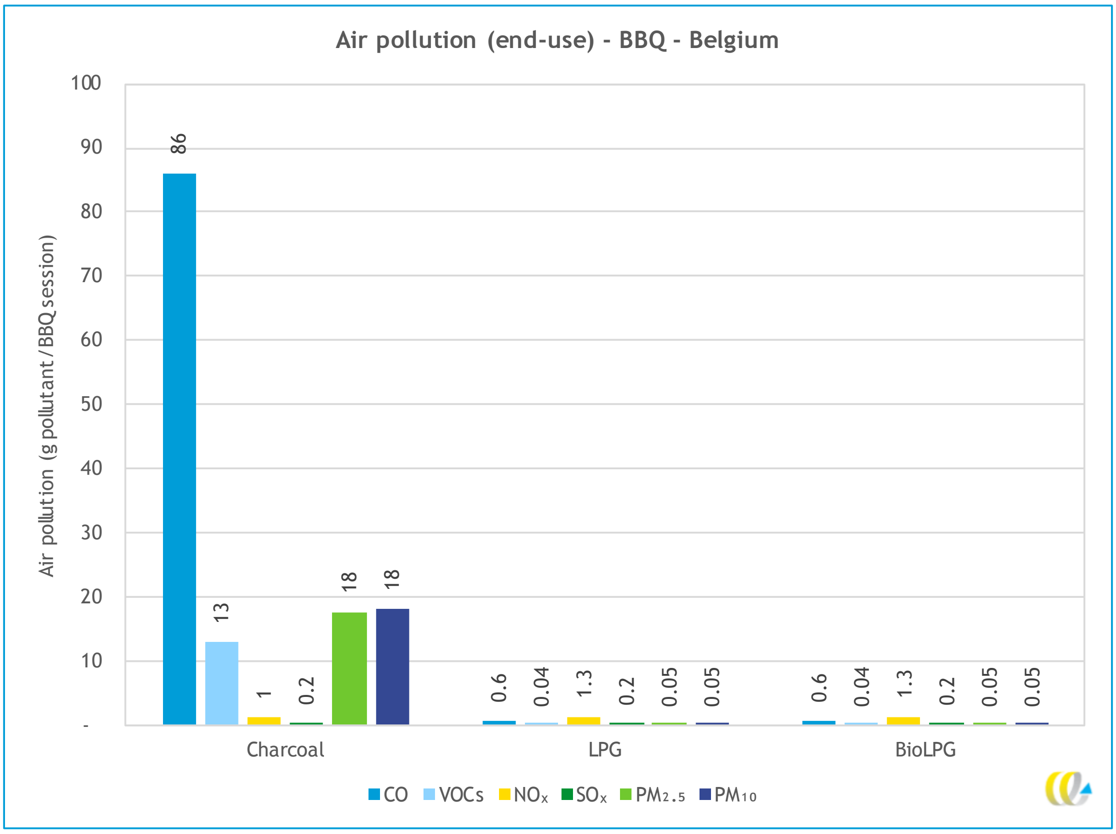
The relative reduction of air pollutant emissions when using LPG or bioLPG instead of charcoal is shown in Table 7. The emission values are shown in Figure 11. A minus sign means there is no reduction, but an increase of the air pollutant emission level when switching to (bio)LPG.

LPG and bioLPG are assumed to have the same air pollution level, because they have the same chemical composition. The analysis results clearly show that, when barbequing, charcoal will produce much more end-use air pollutants, except for NO_x.

Table 7 - Relative reduction in air pollution emissions achieved when using LPG or bioLPG instead of charcoal in Belgium

Air pollutant	Charcoal
CO	99%
VOCs	99.7%
NO_x	-20%
SO_x	32%
$PM_{2.5}$	99.7%
PM_{10}	99.7%

Figure 11 - Air pollution emissions (end-use) of different fuels in BBQ in Belgium



3.3 Forklift trucks

For forklift trucks, we are comparing a typical work hour of a forklift truck in which diesel, electricity (battery electric), LPG or bioLPG is used. Because forklift trucks carry out a variety of tasks (driving with and without load, lifting, etc.) which can vary from hour to hour, it is challenging to couple a single energy use value to a typical work hour. We have made use of the study by Atlantic Consulting (2018), in which for each type of fuel/energy carrier an energy usage per typical 'hour' is defined.

Carbon footprint

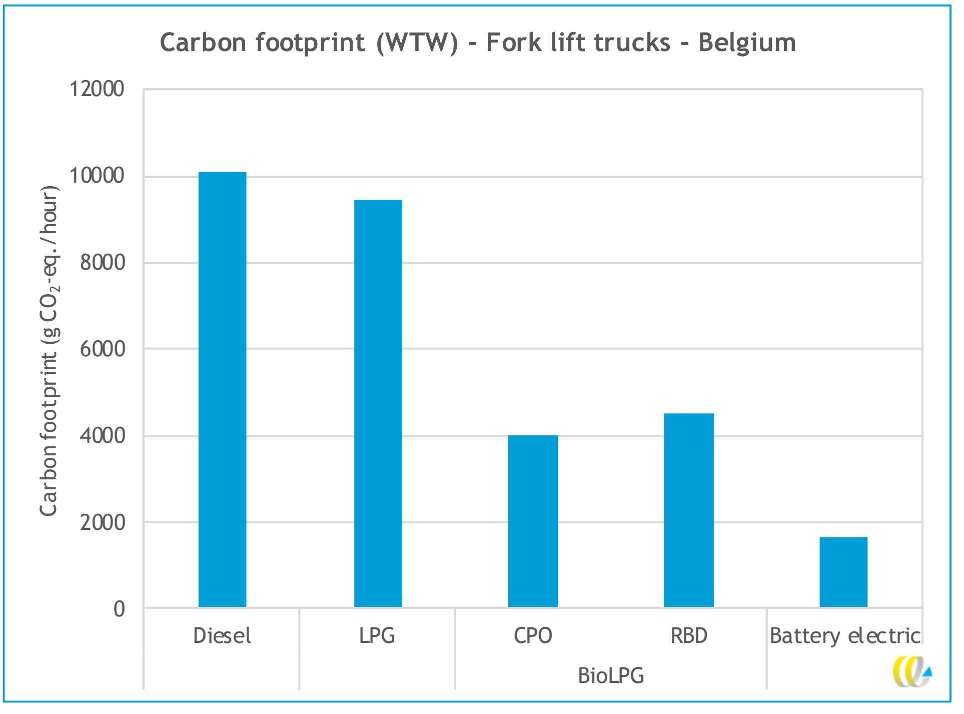
Figure 12 shows the carbon footprint of different fuels for forklift trucks. The relative reduction of the carbon footprint of bioLPG (for different feedstocks) is shown in Table 8. A minus sign means there is no reduction, but an increase of the carbon footprint when switching to bioLPG.

Both bioLPG variations delivered by Neste to the Belgian market have a lower (=better) carbon footprint when using it in forklift trucks compared to the use of diesel or LPG. Battery electric forklift trucks are scoring better when it comes to carbon footprint than the other fuels. When the electricity mix in Belgium becomes more renewable, battery electric forklift trucks will have an even lower carbon footprint. LPG use is comparable to diesel use, although LPG is slightly more favourable than diesel: The carbon footprint reduction when switching from diesel to LPG is 6%.

Table 8 - Relative reduction of carbon footprint when switching to LPG or bioLPG from different feedstocks in forklift trucks in Belgium

	LPG	BioLPG - CPO	BioLPG - RBD
LPG	-	57%	52%
Diesel	6%	60%	55%
Battery electric	-473%	-144%	-173%

Figure 12 - Carbon footprint (WTW) of different fuels in forklift trucks in Belgium



Air pollution

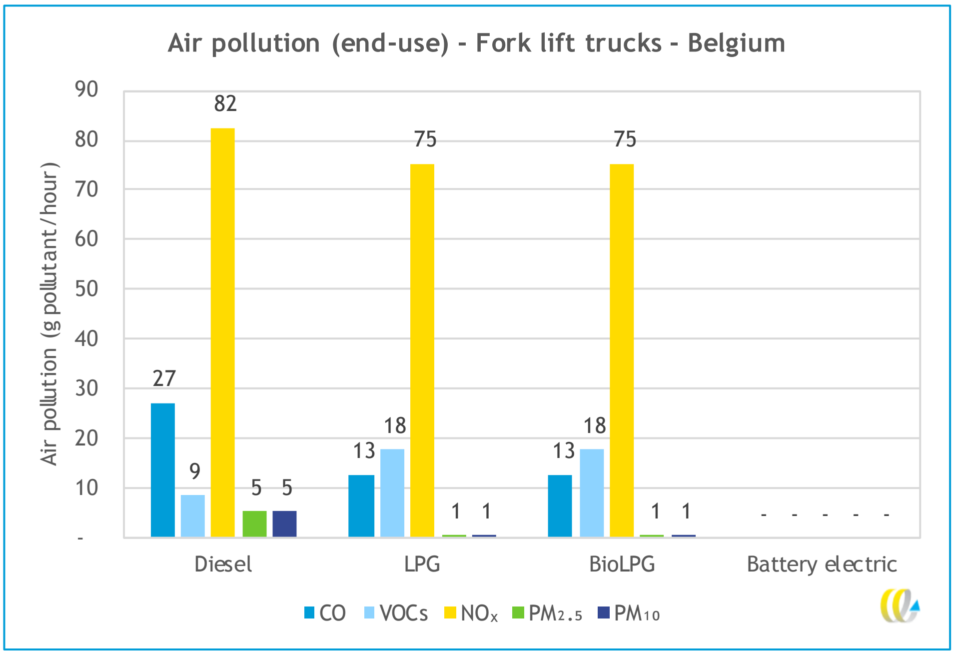
The relative reduction of air pollutant emissions when using LPG or bioLPG instead of diesel or battery electric forklift trucks is shown in Table 9. All results are shown in Figure 13. A minus sign means there is no reduction, but an increase of the air pollutant emission level when switching to (bio)LPG.

LPG and bioLPG are assumed to have the same air pollution level, because they have the same chemical composition. Battery electric forklift trucks do not have end-use air pollution emissions. When using a forklift truck, diesel will produce more end-use CO, NO_x. $PM_{2.5}$ and PM_{10} emissions compared to (bio)LPG. (Bio)LPG fuelled forklift trucks will emit more VOC than diesel trucks. No data on SO_x emissions was found.

Table 9 - Relative reduction in air pollution emissions achieved when using LPG or bioLPG instead of alternative in Belgium

Air pollutant	Diesel	Battery electric
CO	53%	Not applicable
VOCs	-108%	Not applicable
NO_x	9%	Not applicable
$PM_{2.5}$	89%	Not applicable
PM_{10}	89%	Not applicable

Figure 13 - Air pollution emissions (end-use) of different fuels in forklift trucks in Belgium



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A Data used and assumptions

A.1 General

Production of energy carriers - Carbon footprint (g CO_2-eq./MJ)			
What	**Value**	**Data source**	**Note**
BioLPG-CPO	22.73	Weighted average of CPO batches of Proof of Sustainability Belgium from Neste with dispatch dates April 2018 (2x, as 'HVO renewable propane made with crude palm oil', Jan. 2019, Feb 2019 (2x), June 2019 (4x)	Eec, El, Ep [8].
BioLPG-RBD	26.84	Proof of Sustainability Belgium from Neste RBD palm oil batch, dispatch date December 2019	Eec, El, Ep.
Coal	11.93	Ecoinvent v3.6: Market for hard coal (Europe, without Russia and Turkey)	10% T&D subtracted[9].
Electricity	47.11	(EEA, 2019)	2016
Heating oil	11.26	Ecoinvent v3.6: Market for light fuel oil (Europe without Switzerland)	5% T&D subtracted.
LPG	6.2	(JRC, 2020) (production from natural gas)	
Natural gas	12.37	Ecoinvent v3.6: Market for natural gas, high pressure {BE}	10% T&D subtracted.
Wood logs	9.27	Ecoinvent v3.6: Market for residual wood, dry {GLO}	6% T&D subtracted.
Wood pellets	9.04	Ecoinvent v3.6: Market for wood pellet, measured as dry mass {RER}	8% T&D subtracted. European value.
Charcoal	51.05	Ecoinvent v3.6: Market for charcoal {GLO}	1% T&D subtracted. Global value.

8 Eec = GHG emissions from the extraction or cultivation of raw materials; El = Annualised (over 20 years) GHG emissions from carbon stock change due to land use change; Ep = GHG emissions from processing.

9 For Ecoinvent data points with this note, transport and distribution (T&D) is part of the Ecoinvent process. The network diagram given in SimaPro, shows which share of the GHG footprint is caused by T&D. This part of the footprint was manually subtracted by CE Delft in order to show production and T&D separately in the results.

Transport & distribution of energy carriers - Carbon footprint (g CO_2-eq./MJ)			
What	Value	Data source	Note
BioLPG-CPO	3.44	Weighted average of CPO batches of Proof of Sustainability (POS) Belgium from Neste with dispatch dates April 2018 (2x, as 'HVO renewable propane made with crude palm oil', Jan. 2019, Feb 2019 (2x), June 2019 (4x)	Etd.
BioLPG-RBD	3.25	Proof of Sustainability Belgium from Neste RBD palm oil batch, dispatch date December 2019	Etd.
Coal	1.31	Ecoinvent v3.6: Market for hard coal {Europe, without Russia and Turkey}	10% of total is transport & distribution (T&D)[10].
Electricity	0	(EEA, 2019)	2016.
Heating oil	0.64	Ecoinvent v3.6: Market for light fuel oil {Europe without Switzerland}	5% of total is T&D.
LPG	1.6	(JRC, 2020a)	European value.
Natural gas	0.64	Ecoinvent v3.6: Market group for natural gas, high pressure {Europe without Switzerland}	5% of total is T&D.
Wood logs	0.54	Ecoinvent v3.6: Market for residual wood, dry {GLO}	6% of total is T&D.
Wood pellets	0.72	Ecoinvent v3.6: Market for wood pellet, measured as dry mass {RER} CO2 emissiefactoren: Lijst emissiefactoren - European	8% of total is T&D. European value.
Charcoal	0.63	Ecoinvent v3.6: Market for charcoal {GLO}	1% of total is T&D. Global value.

End-use of energy carriers - Carbon footprint (g CO_2/MJ)			
What	Value	Data source	Note
BioLPG	0	Not applicable	Biogenic CO_2.
Charcoal	5.2	(Atlantic Consulting, 2018)	
Coal	95.3	(CE Delft, 2019)	
Electricity	0	Not applicable	No tailpipe emissions.
Heating oil	74.5	(Atlantic Consulting, 2018)	
LPG	63.3	(Atlantic Consulting, 2018)	
Natural gas	56.3	(Atlantic Consulting, 2018)	
Wood logs	0.011	Not included in Belgian source, based on UK Government, (2020)	
Wood pellets	3.3	(Atlantic Consulting, 2018)	

10 The Ecoinvent processes used include both the GHG footprint of production and transport and distribution (T&D) of the product. CE Delft has determined which share of the footprint is caused by T&D, by looking at the network diagram presented in SimaPro, so we can present production and T&D separately.

Heating values of energy carriers				
What	**Value**	**Unit**	**Data source**	**Note**
Charcoal	29.30	MJ/kg	(VMM, et al., 2020)	
Coal	28.43	MJ/kg	(VMM, et al., 2020); Anthracite	
Diesel	42.60	MJ/kg	(VMM, et al., 2020); Gasoil	
Battery electric	3.60	MJ/kWh		
Heating oil	40.00	MJ/kg	(VMM, et al., 2020); Residential fuel oil	
Bio(LPG)	46.00	MJ/kg	(VMM, et al., 2020)	
Natural gas	34.18	MJ/m^3	(VMM, et al., 2020)	
Wood logs	5515.76	MJ/kg	(AEBIOM, 2008) Table 2.9.1, average of stacked wood logs	Based on European value
Wood pellets	17.10	MJ/kg	(AEBIOM, 2008), Table 2.9.1, wood pellets	Based on European value

Note: For some of the energy carriers, no heating value was needed to calculate the emissions.

Density of energy carriers[11]				
What	**Value**	**Unit**	**Data source**	**Note**
Diesel	1.20	L/kg	EU: Fuels: Reference Diesel Fuel	
Bio(LPG)	0.54	kg/L	European LPG Sector : Overview 2016	
Wood logs	398	kg/m^3	(AEBIOM, 2008), Table 2.9.1, average of stacked wood logs	

Note: For some of the energy carriers, no density value was needed to calculate the emissions.

A.2 BBQ

Air pollution

Air pollution emissions of end-use technology: BBQ (kg/session)			
What	**Value**	**Data source**	**Note**
LPG	CO: 0.00064 VOC: 0.000043 NO_x: 0.0013 SO_x: 0.00016 $PM_{2.5}$: 0.000047 PM_{10}: 0.000047	(CEIP, 2020)	LPG decentralized. No values given for worst- and best case.
Charcoal	CO: 0.085 VOC: 0.013 NO_x: 0.0011 SO_x: 0.00024 $PM_{2.5}$: 0.018 PM_{10}: 0.018	(CEIP, 2020)	Wood in open fireplace (all types of wood give the same emission factors). In this source, only an average value is given , so no distinction can be made between Average, best- and worst case.

Energy use per session

Energy use of end-use technology: BBQ (MJ used/session)			
What	**Value**	**Data source**	**Note**
LPG	24.15	(Johnson, 2009)	Calculated using a lower heating value of 46 MJ/kg.
Charcoal	21.48	(Johnson, 2009)	Calculated using a lower heating value of 29.3 MJ/kg.

11 Only necessary for those energy carriers of which the unit of the heating values did not match the unit of the end-use GHG emission factor. When a range is possible, the average is picked.

End-use technology

Carbon footprint of end-use technology: BBQ (g CO_2-eq./session)			
What	Value	Data source	Note
LPG	573	(Johnson, 2009)	
Charcoal	373	(Johnson, 2009)	

A.3 Forklift trucks

Performance

Energy needed per functional unit (MJ / hour)			
What	Value	Data source	Note
Gas engine	121.2	(Atlantic Consulting, 2018)	Table 19
Diesel engine	107.6	(Atlantic Consulting, 2018)	Table 19
Battery electric	23	(Atlantic Consulting, 2018)	Table 19

Air pollution

Air pollution emissions of end-use technology: Forklift trucks (kg/hour)			
What	Value	Data source	Note
Gas engine	CO: 0.013 VOC: 0.018 NO_x: 0.075 SO_x: 0 $PM_{2.5}$: 0.00059 PM_{10}: 0.00059	(EMEP/EEA, 2019)	Tier 3, Table 3-9, Only one value available for each of the pollutants included: NO_x, VOC, CO. SO_2, $PM_{2.5}$ and PM_{10} are not included in the source, data is not available.
Diesel engine	CO: 0.027 VOC: 0.0085 NO_x: 0.082 SO_x: 0 $PM_{2.5}$: 0.0053 PM_{10}: 0.0053	(EMEP/EEA, 2019)	Tier 3, Table 3-6, 56-75 kW engines. Best: Stage V, Worst: Stage I, Average: average of each Stage emission factor between Stage I and Stage V (I, II, IIIA, IIIB, IV, V). SO_2 is not included.
Battery electric	0	Not applicable	No end-use emissions.

A.4 Heating

Efficiency

Efficiency of end-use technology: Heating			
What	**Value**	**Data source**	**Note**
Natural gas boiler	76%	(CE Delft, 2019)	Table 16, in combination with research data about the age distribution of the installations in Flanders.
LPG gas boiler	69%	(CE Delft, 2019), (Thibaut) year not specified	Average installation: CE Delft (2019), Table 16, in combination with project data about the age distribution of the installations in Flanders. Most efficient installation: (Thibaut, sd), product information from various boiler suppliers.
Coal stove	42%	(CE Delft, 2019)	Table 16, in combination with research data about the age distribution of the installations in Flanders.
Heat pump	270%	(Fraunhofer-ISI et al., 2016)	Table 26, Table 24 and 25: Best case is highest COP of geothermal heat pump, worst case is lowest COP of aerothermal heat pump. Per geography a weighted average is determined using the best and worst COP, and the amount of each type of heat pump indicated in Tables 24 + 25.
Oil boiler	67%	(CE Delft, 2019)	Table 16, in combination with research data about the age distribution of the installations in Flanders.
Wood boiler	83%	(CE Delft, 2019)	Expert consultation in the course of the study.
Wood pellet boiler	83%	(CE Delft, 2019)	Expert consultation in the course of the study.

Note: The listed energy efficiencies are the ‘average’ values for Belgium used in the analysis.

Air pollution

Air pollution emission factors of end-use technology: Heating (kg/MJ fuel)[12,13]			
What	**Value**	**Data source**	**Note**
Natural gas boiler	CO: 2.2E-05 VOC: 1.8E-06 NO_x: 2.9E-05 SO_x: 0 $PM_{2.5}$: 2.0E-07 PM_{10}: 2.0E-07	(CEIP, 2020), (Fraunhofer-ISI et al., 2016), (CE Delft, 2019)	Shown are a weighted average of the emission factors for condensing and non-condensing boilers, taking into account the installation age distribution and frequency of occurrence in Flanders.
LPG gas boiler	CO: 2.2E-05 VOC: 1.8E-06 NO_x: 4.2E-05 SO_x: 0 $PM_{2.5}$: 2.0E-07 PM_{10}: 2.0E-07	(CEIP, 2020)	Central. No distinction between different years.
Coal stove	CO: 0.0048 VOC: 0.00017 NO_x: 0.00016 SO_x: 0.00060 $PM_{2.5}$: 0.00020 PM_{10}: 0.00023	(CEIP, 2020)	Central.
Heat pump	0	Not applicable	No end-use emissions.
Oil boiler	CO: 3.7E-06 VOC: 1.7E-07 NO_x: 4.5E-05 SO_x: 4.8E-05 $PM_{2.5}$: 1.5E-06 PM_{10}: 1.5E-06	(CEIP, 2020)	Central, < 70 kW – only non-condensing considered because of 98% share. Difference by age only given for NO_x, the other pollutants stay the same over time. Best case is values '2000-2004', '2005-2009', '2010-2011' and 'from 2012', worst case is value '70s', '80s' and '90s'. Average value based on age distribution from Figure 7 in (Fraunhofer-ISI, et al., 2016): 3/6th before 1990, 2/6th 90s and 1/6th after 2000.
Wood boiler	CO: 0.0040 VOC: 0.00035 NO_x: 8.0E-05 SO_x: 1.1E-05 $PM_{2.5}$: 0.00016 PM_{10}: 0.00016	(CEIP, 2020)	Boiler, pruning wood/piece of wood. Differences over time indicated for PM_{10} and $PM_{2.5}$. Other pollutant do not change over time.
Wood pellet boiler	CO: 0.00030 VOC: 1.0E-05 NO_x: 8.0E-05 SO_x: 1.1E-05 $PM_{2.5}$: 6.0E-05 PM_{10}: 6.0E-05	(CEIP, 2020)	Pellets.

12 In some cases, air pollution emission factors per MJ energy carrier of more recent years are higher than those in the past. The reason for this is mostly that more recent insights show that emission factors are higher than what was thought before, either due to better detection equipment or because real-life measurements show higher emissions than what was assumed in test measurements.

13 Air pollution emission factors are used in conjunction with the energy efficiency of the boilers to calculate the emissions per MJ of heat delivered.

B Household shares of heating installations in Flanders

Table 10 – Household share and average energy efficiency per energy carrier for Flanders in 2015, based on CE Delft (2019). The energy efficiencies been applied to the analysis for Belgium as a whole

Installation type	Share of households in Flanders using installation type	Weighted average energy efficiency in Flanders	Remarks
Coal stove	1.0%	42%	
Heating oil boiler	25.8%	67%	
Natural gas boiler	62.5%	76%	
(Bio)LPG boiler	1.0%	69%	
Heat pump	0.6%	270%	
Wood boiler	0.3%	83%	The efficiency has been applied to both wood log boilers and wood pellet boilers.
Other wood installation type	1.3%		Not included in the analysis.
Resistance heater	7.1%		Not included in the analysis.
Heat network	0.4%		Not included in the analysis.

Note: The household shares have not been used in this study, but are shown for information purposes.