SUMMARY

Domestic heating is one of the factors contributing to air pollution in the built environment. According to the World Health Organization, WHO, air pollution is one of the main causes of death in many countries, particularly emissions of particulates ($PM_{2.5}$). This pollution is particularly problematic in the built environment, where people live and work and are constantly inhaling polluted air. Besides damage to health, air pollution resulting from domestic heating also damages ecosystems and buildings, while burning fossil fuels contributes to climate change.

In economic science increasing efforts are being made to quantify this damage and express it monetarily. This damage manifests itself in a range of respiratory and cardiovascular disorders due to emissions of particulates and other pollutants, adverse effects on ecosystems and human health due to photochemical oxidant formation (smog), damage to buildings and heritage sites due to particulates and other pollutants, damage to nature due to the eutrophying effects of nitrogen deposition, and the costs of mitigating climate change. All these forms of pollution-related damage imply a loss of economic welfare. The present study estimates the environmental damage costs associated with domestic heating in Flanders, to improve understanding of this damage and of how these costs differ across the various technologies used for heating Flemish homes.

Calculating environmental damage costs is essentially a four-step process:

1 Emissions: what quantitative emissions are in fact associated with home heating, broken down by heating method and fuel type?
2 Dispersion: where do these emissions go?
3 Impacts: what effect do they have on humans, animals and ecosystems?
4 Valuation: how are these impacts to be valued?

A study encompassing all four of these steps is normally very labour-intensive, requiring elaboration of both dispersion and dose-response models. In most studies of environmental damage costs steps 2 to 4 are therefore collapsed into so-called '*Damage cost indices*': country-specific averages for the relationship between emissions at an average location, via dispersion through to valuation of impacts that are expressed in €/kg emission.

On the basis of the available literature on damage cost indices and the most recent WHO understanding on the damage caused by environmental pollution, this study calculates the most appropriate environmental damage costs for domestic heating in Flanders.

Table 3 reports the damage cost indices calculated on the basis of the present study. The damage costs of $PM_{2.5}$, PM_{10} and NO_x differ for the urban and rural environment, the former being higher because of the higher population density in towns and cities.

Table 3: damage cost indices calculated for emissions from domestic heating in Flanders (only for emissions causing > 0.1% of total environmental damage costs)

Atmospheric emission	Central value	Range**
CO_2	€ 0.057	€ 0.037-0.094
CH_4	€ 1.77	€ 0.47-2.92
Black carbon (>10% $PM_{2.5}$)*	€ 717	€ 512-1101
$PM_{2.5}$ space heating, urban*	€ 183	€ 131-281
$PM_{2.5}$ space heating, rural*	€ 84	€ 60-129
$PM_{2.5}$ unspecified*	€ 79.7	€ 56.9-122.4
PM_{10} space heating, urban*	€ 104	€ 74-161
PM_{10} space heating, rural*	€ 47	€ 33-73
PM_{10} unspecified*	€ 55.7	€ 39.8-86.1
NO_x space heating, urban	€ 32	€ 23-51
NO_x space heating, rural	€ 16	€ 11-25
NO_x unspecified	€ 22.8	€ 15.7-36.6
SO_2	€ 20.9	€ 14.8-32.8
NH_3	€ 34.8	€ 23.1-58.6
NMVOC	€ 2.8	€ 2.1-4.2
CO	€ 0.13	€ 0.09-0.20
Pb	€ 5908	€ 3967-6596

Note: Figures are rounded to three floating-point decimals, apart from space-heating emissions of $PM_{2.5}$, PM_{10} and NO_x, which are rounded to an integer because of the wide uncertainty margins.

* To avoid double-counting, in the calculations PM_{10} was broken down into three fractions: (a) elementary carbon, if this fraction was > 10% of $PM_{2.5}$ emissions; (b) $PM_{2.5}$ minus the black carbon fraction if the latter was >10%; (c) the PM_{10} fraction not included in $PM_{2.5}$.

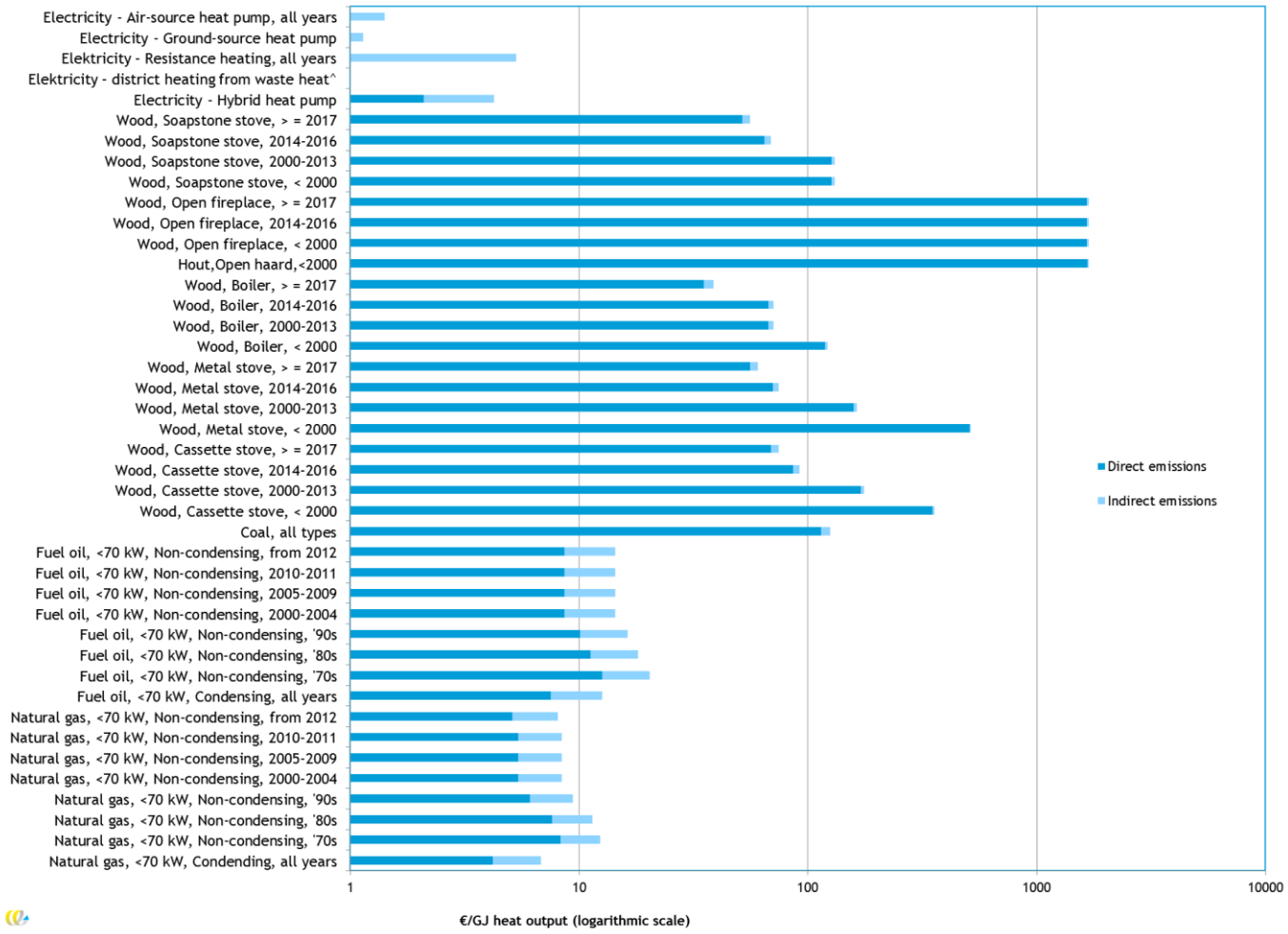
** Range gives the uncertainty in the valuation of environmental impacts.

Domestic heating emissions were calculated for each individual heating method and for Flanders as a whole. Direct and indirect emissions were distinguished. Direct emissions are those leaving rooftop chimneys and thus occurring in Flanders. Indirect emissions are those occurring during the production of energy carriers, such as methane emissions from natural gas extraction, and will often also lead to damage outside Flanders. Indoor emissions due to unenclosed space-heating systems are not included in this study.

Multiplying quantitative emissions by damage cost indices yields figures for environmental damage costs. Figure 5, with a *logarithmic* scale, summarizes the damage costs associated with the various kinds of space heating, broken down by technology and age class. Wood-burning heating systems generally have far higher environmental damage costs than systems using natural gas or fuel oil. The figure also shows that there are enormous differences in damage costs across the various technologies and fuels. Open fireplaces are by far the most polluting form of domestic space heating – about 250 times worse than a modern condensing gas-fired appliance. Figure 6, with a *normal* scale, provides a similar breakdown, but now restricted to the latest models of appliance for each respective fuel. As can be seen, heat-pump systems

have the lowest environmental damage costs. The figure also shows that even the most advanced wood-burning stoves and boilers still have 5-12 times higher damage costs than the cleanest gas-burning alternatives (condensing boilers).

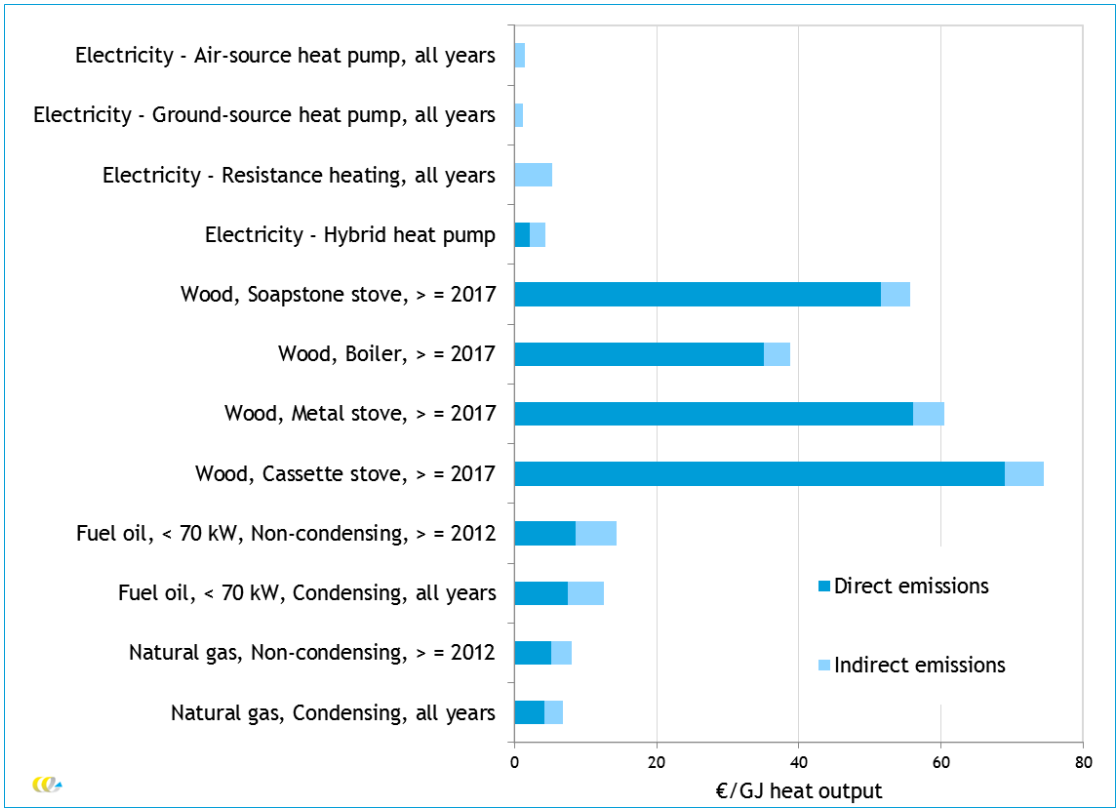
figure 5: environmental damage costs of space-heating technologies by type and age class (€/GJ heat output, logarithmic scale)



Notes: * For wood-fired boilers, the average was taken of fuels with highest and lowest emissions. The impacts of wood-fired appliances include those of CO_2 emissions.
^ The electricity consumption of a heat network relates to the electricity needed to supply geothermal or residual heat to households. No loss factor has been taken into account for any efficiency losses at the installation that supplies residual heat.

Combining these figures and statistics on use of the various heating appliances by Flemish households, total environmental damage costs were estimated. In 2015 the damage costs associated with domestic space heating in Flanders totalled 2.6 billion euro, of which 2.1 billion euro are due to direct emissions and around 0.5 billion euro to the indirect emissions included in the present study.

figure 6: environmental damage costs of space-heating technologies: most advanced appliances (€/GJ heat output, normal scale)



Note: for wood-fired boilers, the average was taken of fuels with highest and lowest emissions. The impacts of wood-fired appliances include those of CO_2 emissions.

Figure 7 shows the respective contributions of the various pollutants to total costs, while figure 8 provides a breakdown by energy carrier. Particulate emissions ($PM_{2.5}$) are the single largest factor in environmental damage costs, contributing about 38% with respect to total emissions. In second place come CO_2 emissions, accounting for around 27% of total environmental costs. Wood-burning for space heating in its various forms accounts for about 50% of total damage costs (and 60% of environmental damage due to direct emissions). This is despite wood-burning being used by a mere 1.6% of Flemish households as the main form of heating and by 19.1% of households as supplementary heating or 'mood heating'. If the CO_2 emissions of wood-burning are excluded (because the same amount of CO_2 was absorbed from the atmosphere during tree growth) the environmental damage costs decline by about 3.0% (€ 80 mln./year). The damage costs are therefore essentially unaffected by how the CO_2 emissions of biomass are calculated.

figure 7: environmental damage costs of total emissions from domestic space heating in Flanders in 2015, calculated using central damage-cost value: breakdown by pollutant

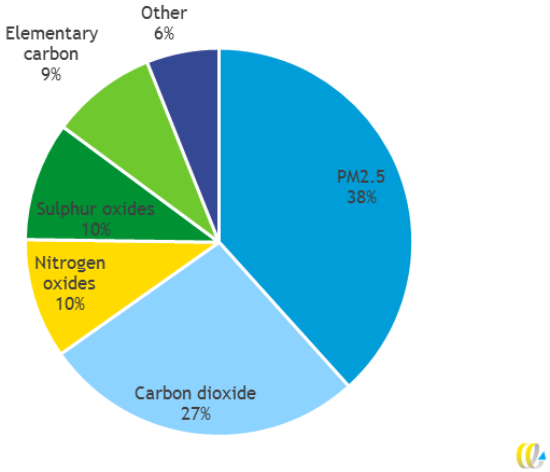
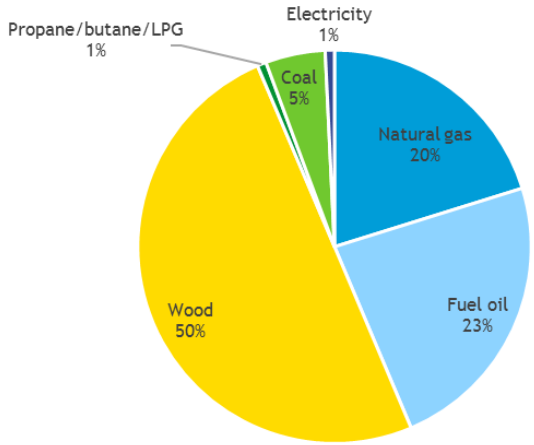


figure 8: environmental damage costs of total emissions from domestic space heating in Flanders in 2015, calculated using central damage-cost value: breakdown by energy carrier



Open fireplaces are by far the most polluting form of wood-burning: one GJ of heat supplied by an open fireplace causes over 1,600 times higher environmental damage costs than one GJ of heat from a ground source heat pump. Open fireplaces are used above all as 'mood heating', however. Overall , their use in Flanders accounts for about 5% of aggregate environmental damage costs: € 130 mln./year.

There is a certain amount of difference depending on the kind of wood fuel used for domestic space heating. Wood pellets generally have the lowest environmental damage costs, except with the latest boilers, where waste wood has the lowest costs: € 33.71/ GJ heat output, the very lowest for any kind of wood-burning. Even so, these damage costs still exceed those of a modern condensing gas-fired appliance by a factor 5. The difference between locally produced pellets and those imported from Canada or the US

derives from the indirect emissions, which make the damage costs of imported pellets burned in any of the latest appliances (apart from open hearths) around 10% higher.

Under various scenarios and projections, the impact of modelling adjustments was also examined. These may be relevant for further study. Table 4 summarizes these scenarios and projections and reports their impact on the total environmental damage costs.

Table 4: trends in environmental damage costs (M€/a) due to domestic space heating in alternative variants compared with current estimates

	Direct emissions	Total emissions	Reduction in total emissions rel. to 2015
Current situation, 2015	2.131	2.644	
Current situation, 2015, excl. CO_2 costs of wood-burning	2.051	n.a.	-4%*
2030, after roll-out of National Energy Plan	1.691	2.131	-19%
2030, replacement rate to 10%	1.097	1.536	-42%/-28%^
2015, only pellets in wood-burning appliances	1.729	2.242	-15%
2015, all wood-burning appliances with catalytic converter	1.932	2.444	-8%
2015, zero open fireplaces plus across-the-board replacement by latest appliances	1.137	1.647	-38%

n.a. = not applicable in this study

* Reduction relative to direct emissions.

^ -28% compared to the situation in 2030, after the roll-out of the National Energy Plan.

In the 2030 scenario, the annual environmental damage costs associated with the sum total of emissions are about 19% less than they are today. This improvement is due partly to the natural replacement of heating appliances and partly to roll-out of the National Energy Plan, with the rate of replacement probably the dominant factor. With the replacement rate raised by a factor 2-4 to 10% per annum, damage costs would decline by around 42% compared with the current situation. If all wood-burning appliances were to burn only pellets, damage costs would be about 15% lower. If all today's wood-burning appliances were fitted with a catalytic converter, damage costs would drop by 8%.

The most significant reduction would be achieved by replacing every domestic heating appliance by the latest variant for the fuel concerned and at the same time discontinuing use of open fireplaces altogether. This variant would reduce the environmental damage costs by 38% compared with the current situation (33% due to replacement of outmoded appliances, 5% to phase-out of open hearths).