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Socioeconomic distribution of emissions and resource use in Ireland

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ABSTRACT

This paper aims to determine emissions polluted directly and indirectly by an average person, for each household type, across a wide range of emissions. There are five household type categories: location, income decile, household composition, size and number of disabled residents. Ireland's Sustainable Development Model (ISus) is used which allows the analysis of direct and indirect sources of pollution per household as the model is based on an input–output methodology. Four sets of results are presented: first for greenhouse gas emissions, second for air pollutants, third for persistent organic pollutants and lastly for metals. An analysis section shows how the picture changes when one controls for the size and income of households. All results analysed are for the year 2006. Most greenhouse gas and metal emissions are polluted via indirect means, although direct sources of emissions play a role for CO_2, SO_2 and CO. The results suggest that the richest decile is the biggest emitter and poorer and larger households are seen to emit the least per person. It is also shown that household income has a stronger relationship with pollution than household size per person.

1. Introduction

Households differ, both in idiosyncratic ways and in the form of systematic differences between household types. One effect of these variations is that different household types exert different pressures on the environment through their varying behaviour. For example, people in rural areas tend to use their cars more often and people who are out of work have a reason to heat their home in the day time. It is important to be able to quantify these distributional differences as they may have implications for environmental policy making (Lee and Tansel, 2012). For example, energy is a necessary good and thus policies that increase the cost of energy tend to be regressive; that is, poorer households spend proportionately more of their income on household energy than richer households. Additional policies may therefore be needed to offset the equity impact of regressive environmental policies. This paper attempts to assess whether different household characteristics matter for the amount of pollution emitted by the residential sector; for example do richer households emit more than poorer households, urban households emit more than rural or do households with children pollute more than those without? Although this paper does not draw formal policy conclusions, it does show that there are differences in household emissions due to different household characteristics and this should be borne in mind by policymakers. The paper thus adds to the environmental justice literature (e.g., Krieg and Faber, 2004), which has primarily focussed on the USA.

This paper is part of a broader literature on distributional analysis at the household level. Stokes et al. (1994) use a survey analysis for Melbourne (Australia) asking residents about their understanding of the greenhouse gas effect and their contributions to reducing the amount of carbon dioxide emitted. The author's analysis focuses on whether the understanding of climate change issues has resulted in fewer CO_2 emissions from four different household types: location, composition, size and economic resources. This paper expands on the household distributional analysis of Stokes et al. (1994) twofold; firstly by including income deciles and the number of disabled residents in household types and secondly by analysing the distribution of household pollution

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for forty-three[1] emissions. Our study also differs given its focus on Ireland for the year 2006.

Most distributional analysis undertaken in the literature estimates the effects of a carbon tax on different types of households and studies have been done for several countries including Ireland (Verde and Tol, 2009), Spain (Labandeira and Labeaga, 1999), the USA (Hassett et al., 2007) and the UK (Symons et al., 1994). All papers find that a carbon tax is regressive, indeed Hassett et al. (2007) find that the lowest income burden can be up to four times that of the richest decile. When Hassett et al. (2007) use consumption as a proxy for income, however, the authors find that a carbon tax is less regressive. The introduction of a carbon tax in the UK and Ireland is also found to be highly regressive, however less so for Spain. The studies use an input–output methodology which not only allows the study of the whole economy rather than just one specific sector but also it highlights the significance of indirect emissions from final consumption (Labandeira and Labeaga, 1999) and thus a decomposition of the importance of direct and indirect emission sources for each household type.

This paper aims to determine direct and indirect emissions for an average person by household type, across a wide range of emissions. Direct emissions are those generated when a household pollutes from personal consumption and over which it has direct control, such as petrol use from driving a car or fuels burned for home heating. Indirect emissions are emitted during production processes over which a household does not have direct control; for example pollution from power stations used to provide energy to households. The household type categories we use are location (urban and rural), income decile, household size, household composition and number of disabled residents. To do this Ireland's Sustainable Development Model (ISus) is used which allows the analysis of direct and indirect sources of pollution per household. Four sets of results are presented: first for greenhouse gas emissions, second for air pollutants, third for persistent organic pollutants and lastly for metals. An analysis section shows how the picture changes when one controls for the size and income of households. All results analysed are for the year 2006.

The main conclusions are that indirect emission sources are the main contributor of pollution for most emissions; direct emissions play different roles for each emission, and income is a more important factor than household size for the quantities of pollution emitted. The paper is set up as follows; Section 2 presents the methodology, Section 3 describes the data, Section 4 analyses the results,[2] Section 5 offers some analysis and Section 6 concludes.

2. Methodology

The first step is to run an input–output model to determine emissions from production attributed to twenty final demand sectors (shown in Table 1). The ISus model uses the input–output table for 2000 (CSO, 2006) updated to 2006 using the RAS method (Parikh, 1979). The standard input–output model is set-up as (1) where X is a vector of production, Y is a vector of final demand, A is a matrix of production coefficients, I is the identity matrix and L is the Leontief inverse.

Table 1
The 20 final demand sectors used (NACE19 plus the residential sector).

Agriculture, fishery and forestry	Rubber and plastic production
Coal, peat, petroleum, metal ores and quarrying	Residential
Food, beverage and tobacco	Transport
Textiles, clothing, leather and footwear	Services excluding transport
Wood and wood products	Construction
Pulp, paper and print production	Fuel, power and water
Chemical production	Other manufacturing
Non-metallic mineral production	Transport equipment
Metal production excluding machinery and transport equipment	Electrical goods
Agriculture and industry machinery	Office and data processing machines

$$X = AX + Y \Leftrightarrow (I - A)X = Y \Leftrightarrow X = (I - A)^{-1}Y = LY \tag{1}$$

Let R denote emissions and B the matrix of emission intensities of production. Then

$$R = BX = BLY \tag{2}$$

As a next step, we split final demand Y into its components, those being households, charities, government, investment, inventories and exports:

$$R = BLY = BL(E + C + G + K + I + X) \tag{3}$$

Finally, household expenditure E is split into the expenditure by household type:

$$R = BL\left(\sum_t E_t + C + G + K + I + X\right) \tag{4}$$

The indirect emissions from household type t are thus defined as

$$R_t = BLE_t \tag{5}$$

The distribution of direct emissions by type of household[3] are estimated for pollutants produced by fuel use. They are calculated by using the data on the quantity of household fuel used from the CSO anonymised Household Budget Survey data file (CSO, 2007). For each household type, the emission shares add to unity. For example, for CO_2 from fossil fuels the share emitted per person in an urban household is 0.585 and the share for a rural household is 0.415. These figures are calculated by using the emissions factor database (EFDB) which converts the fuel use data into common units. Fuel use is then multiplied by the appropriate emission factor from the EFDB to find each individual household's (of the 6884 in the survey) contribution to total emissions. These households are then aggregated by household type and total emissions for each type is then multiplied by a population grossing factor which yields the national share of each emission produced by each household category for each emission. Direct emissions are found by multiplying the residential total emissions for each pollutant by the household-type share for each pollutant. Household types are aggregated and compared against each other, for example urban versus rural households, richer against poorer households and alternative household compositions (single, with or without children for example). Hypotheses relating to household type that we

[1] Given the large number of emissions only the most important are analysed in this paper. The remaining household emission distribution results are available on request.

[2] Results for HFC's, ammonia and nitrogen oxide can be found in the Appendix due to the large number of emissions in the model.

[3] Household type categories being: location (urban or rural), income decile (1, poorest to richest, 10), household size (1 person to 7 + people), household composition (single adults working and retired, a couple, a couple with 1, 2 3 or 4 + children and a single parent) and number of disabled residents (none to 3 or more).

attempt to analyse are given in Table 2 below. In addition, this paper also examines whether households pollute more through direct or indirect channels. This could potentially be an important issue as households would be able to curb emissions from direct sources more easily, if a tax was introduced for example, than those via indirect means.

3. Data employed

The ISus model is based on both environmental and economic data and for this study, emissions are broken down into direct and indirect emissions. The source used for information on direct emissions is the anonymised data file for the Irish Household Budget Survey (HBS) which is a random sample of representative households in Ireland. The main aim of this survey is to quantify how much the average household (by household type) spends on each basket of goods (milk and boys clothes, for example) for the weighting of the CPI index and is carried out by the Central Statistics Office (CSO, 2007). In the most recent 2004/2005 survey 6884 private households in Ireland participated (a 47% response rate). In this cross-sectional micro dataset detailed information is also provided on income and household facilities, for example it is possible to examine which household characteristics, which appliances and which heating and cooking methods significantly influence the amount of energy used in the home. In addition, households are asked to report expenditure on, as well as quantity used, of different fuel types in the past year.

Table 2
Hypotheses to be examined.

Household type	Hypothesis / research question
Location	Do rural households emit more than urban ones? Rural households may use private transport more often and have longer journeys leading to higher emissions. Urban areas tend to be far busier than rural areas and thus usage of constant public transport, for example, may induce urban households to have higher pollution levels. The split between direct and indirect emissions may play a large part relative to location where rural households are hypothesised to pollute more directly but urban households are hypothesised to have higher indirect emissions.
Income decile	Do richer households emit more than poorer ones? Richer households would be able to afford a higher energy use than poorer households leading to higher emissions. Poorer households however may not be able to afford 'greener technology' such as extra insulation or more efficient heating systems thus leading to higher emissions.
Household size	Do larger households emit more than smaller ones? If economies of scale in consumption are present then households with more people in would, per capita, emit less than those with fewer residents. With more residents usage is higher however, which may lead to higher emissions for a larger household.
Household composition	How does household composition affect emissions? Do those with children emit less (per head) if economies of scale in consumption are present? Retired households may emit more than a working household as they are potentially at home more during the day. A single parent may not be able to afford as much energy consumption as a household where two working adults reside leading to fewer household emissions.
Number of disabled residents	Does the number of disabled residents matter for household emissions? For example, emissions may differ due to the share of time spent in the home, requirements for extra heating or specialised electrical equipment.

The emissions data are taken from a range of sources found in Table 3 along with variable descriptions. The Environmental Protection Agency (EPA) data sources for the air emissions in this paper have been used previously for Ireland by Ferreira and Moro (2011); however, with a focus on environmental accounting rather than distributional analysis.

Table 3
Variable descriptions.

Variable	Description (years available, source, measurement unit)
CO_2 from fossil fuel	Carbon dioxide emissions from fossil fuels 1990–2009, (Duffy et al., 2011) thousand tonnes
CO_2 other	Carbon dioxide emissions from non fossil fuels 1990–2009 (Duffy et al., 2011) thousand tonnes
CH_4	Methane emissions 1990–2009 (Duffy et al., 2011) thousand tonnes
N_2O	Nitrous oxide emissions 1990–2009 (Duffy et al., 2011) thousand tonnes
HFC23 HFC32 HFC134a HFC125 HFC143a HFC152a HFC227ea	Halofluorocarbon emissions 1990–2095 (Duffy et al., 2011) tonnes of CO_2 equivalent
CF_4 C_2F_6 C_4F_8	Perfluorocarbon emissions 1990–2009 (Duffy et al., 2011) tonnes of CO_2 equivalent
SF_6	Sulphurhexafluoride emissions 1990–2009 (Duffy et al., 2011) tonnes CO_2 equivalent
SO_2	Sulphur dioxide emissions 1990–2009 (Duffy et al., 2011) thousand tonnes
NO_x	Oxides of nitrogen 1990–2009 (Duffy et al., 2011) thousand tonnes
CO	Carbon monoxide 1990–2009 (Duffy et al., 2011) thousand tonnes
NMVOC	Non-methane volatile organic compounds 1990–2005 (Duffy et al., 2011) thousand tonnes
NH_3	Ammonia 1990–2009 (CSO Environmental Accounts, 2010) thousand tonnes
BOD	Organic water pollution emissions 1990–2009 (Scott, 1999) thousand tonnes
Dioxin (water)	Dioxin emissions to water 1990–2009 (Hayes and Murnane, 2002) g TEC
Dioxin (air)	Dioxin emissions to air 1990–2009 (Hayes and Murnane, 2002) g TEC
Dioxin(land)	Dioxin emissions to land 1990–2009 (Hayes and Murnane, 2002) g TEC
PCB (air)	Polychlorinated biphenyl emissions to air 1990–2009 (Creedon et al., 2010) kg
PCB (land)	Polychlorinated biphenyl emissions to land 1990–2009 (Creedon et al., 2010) kg
HCB (air)	Hexachlorobenzene emissions to air 1990–2009 (Creedon et al., 2010) kg
HCB (land)	Hexachlorobenzene emissions to land 1990–2009 (Creedon et al., 2010) kg
HCB (water)	Hexachlorobenzene emissions to water 1990–2009 (Creedon et al., 2010) kg
Benzo(a)pyrene	Emissions 1990–2009 (Creedon et al., 2010) kg
Benzo(b)fluoranthene	Emissions 1990–2009 (Creedon et al., 2010) kg
Benzo(k)fluoranthene	Emissions 1990–2009 (Creedon et al., 2010) kg
Indeno(1,2,3)pyrene	Emissions 1990–2009 (Creedon et al., 2010) kg
Mercury	Emissions 2001–2009 (Integrated Pollution Prevention Control (IPPC)) kg
Cadmium	Emissions 1996–2009 (IPPC, 2011) kg
Lead	Emissions 1996–2009 (IPPC, 2011) kg
Chromium	Emissions 1996–2009 (IPPC, 2011) kg
Arsenic	Emissions 1996–2009 (IPPC, 2011) kg
Zinc	Emissions 1996–2009 (IPPC, 2011) kg
Copper	Emissions 1996–2009 (IPPC, 2011) kg
Nickel	Emissions 1996–2009 (IPPC, 2011) kg
Population	1990–2009 (ESRI's databank) thousands of people
Output	1990–2009 (ESRI's databank) million euro constant 2004 gross output

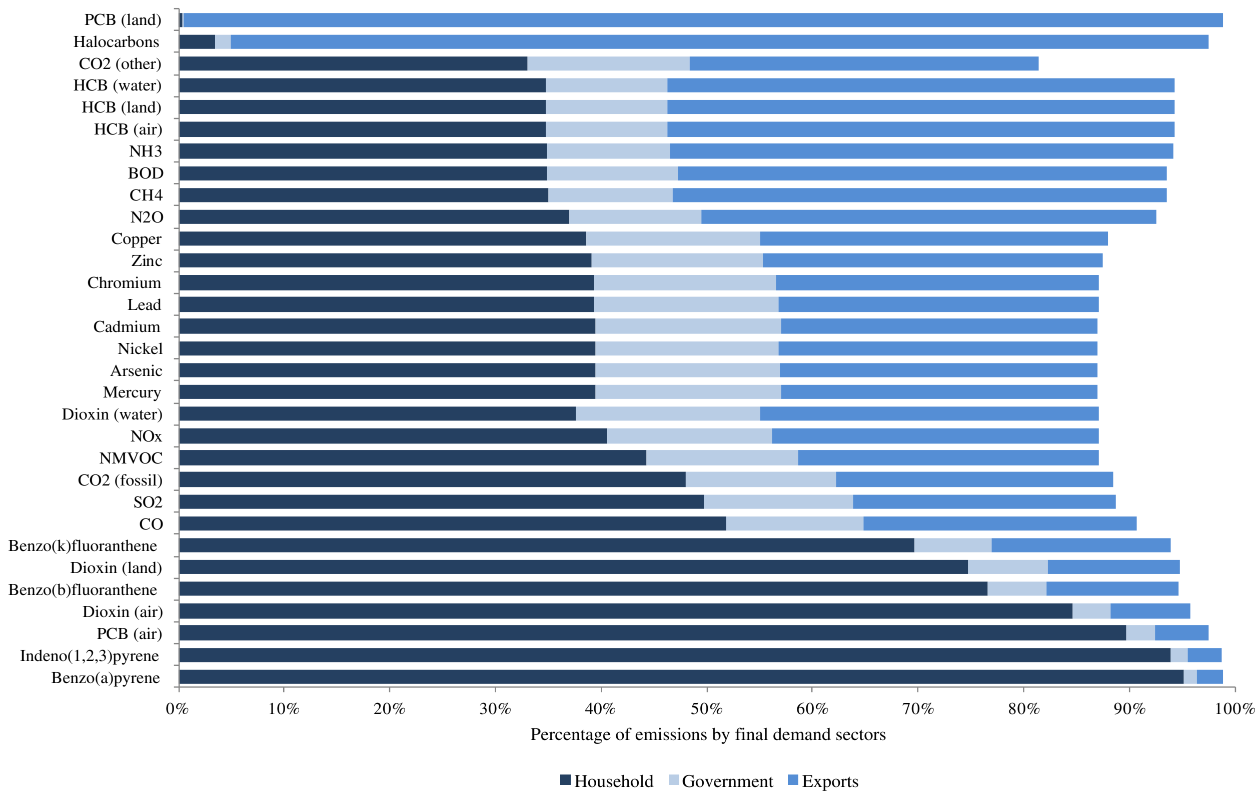

Fig. 1. Total (direct and indirect) emissions by final demand sectors (%).

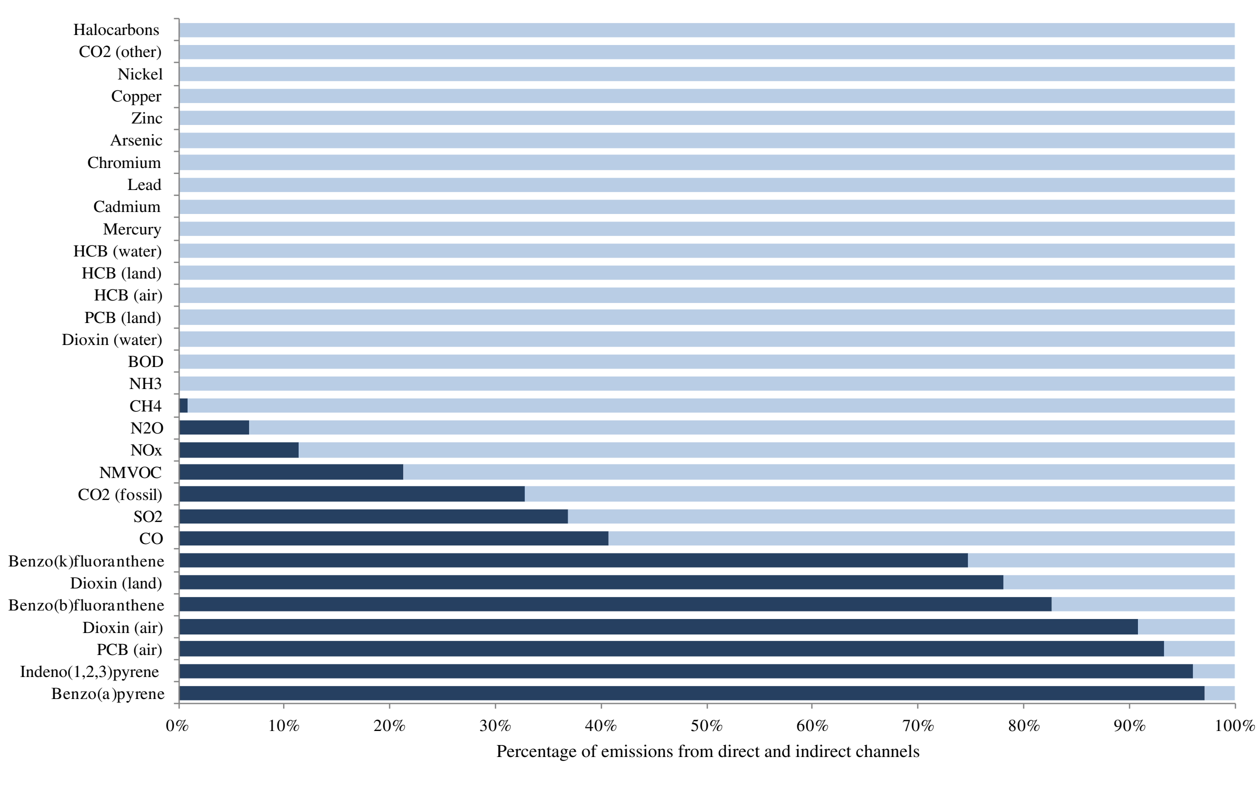

Fig. 2. Emissions from households by direct and indirect channels (%).

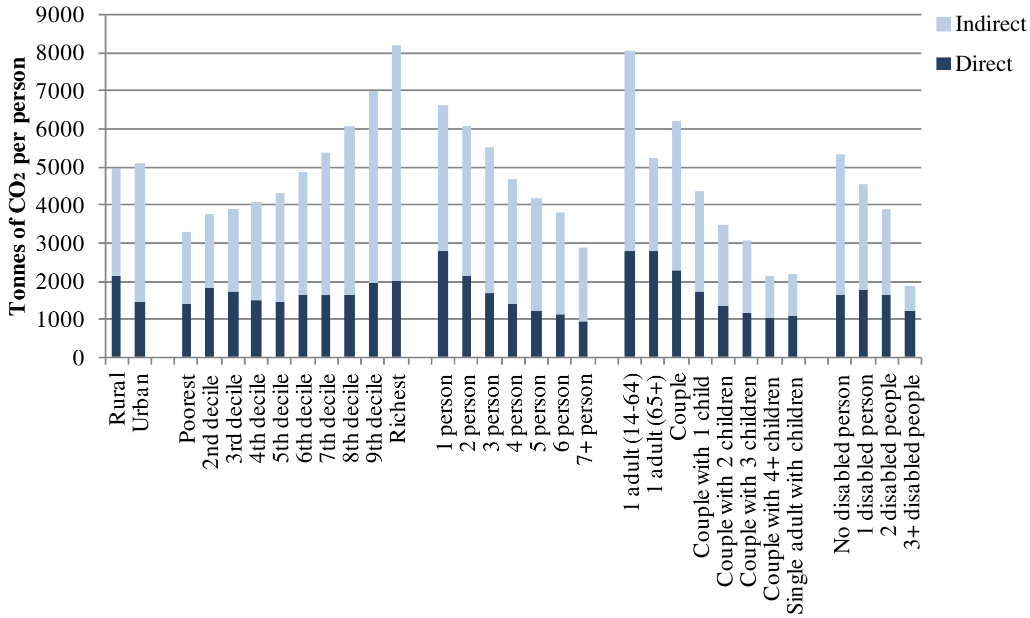

Fig. 3. Direct and indirect emissions of Carbon Dioxide (CO_2) per person by household type.

Fig. 1, for each pollutant, shows a breakdown of percentages for the three final demand sectors which have the highest total (direct and indirect) emissions. A full table of percentages which includes all six final demand sectors can be found in Table A1 in the Appendix (only three sectors are shown graphically for clarity and hence the graph percentages do not sum to 100).

CO_2 from fossil fuels is emitted mainly on behalf of households (just less than 50%) whereas CO_2 other (non-greenhouse gas emissions) can be attributed more to exports (33%) and investment (17%) as well as households (30%). Households cause 95% of benzo(a)pyrene emissions, whereas PCB emissions to land are mainly due to exports (97%). The biggest emission for the government sector is pollution of dioxins into water followed closely by copper; the government contributes roughly 20% of these pollutants. Households emit the majority of sulphur dioxide (SO_2), contributing 50% of emissions. Greenhouse gas emissions of nitrous oxide (N_2O) and methane (CH_4) are emitted mainly from exports; however households emit a large share of roughly 35% with households emitting slightly more nitrous oxide than methane.

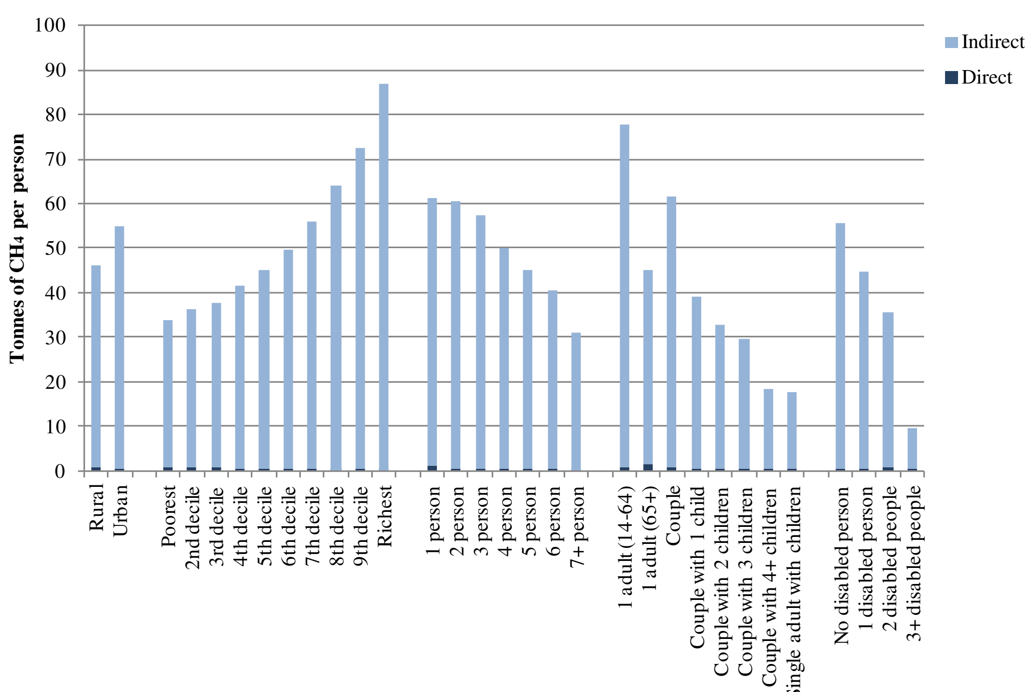

Fig. 4. Direct and indirect emissions of Methane (CH_4) per person by household type.

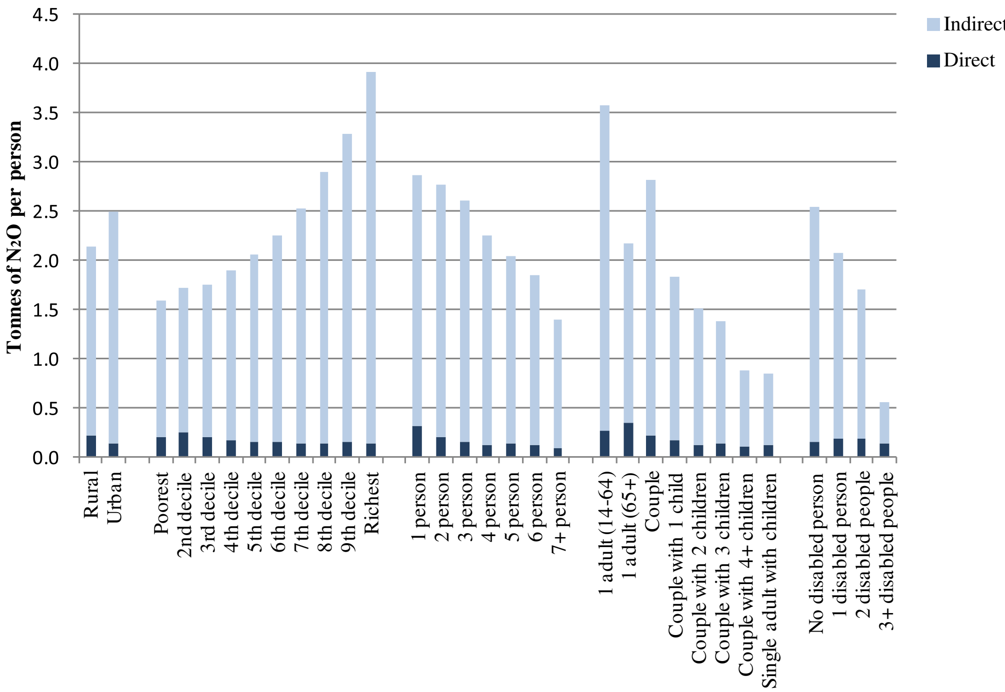

Fig. 5. Direct and indirect emissions of Nitrous Oxide (N_2O) per person by household type.

Fig. 2 shows the split of direct and indirect emission sources for households. The majority of emissions are emitted indirectly; however, the most important greenhouse gasses are also emitted directly. For example roughly 1% of methane comes from direct sources; 8% of nitrous oxide is contributed by direct sources, 38% for sulphur dioxide and roughly 33% for carbon dioxide from fossil fuel. Emissions of dioxins to air, PCB pollution to air, indeno(1,2,3)pyrene and benzo(a)pyrene are mainly emitted directly with direct emissions contributing to over 90% of these pollutants. CO_2 (other), HCB's and halocarbons are all emitted 100% indirectly, as a consequence of production.

4. Results

4.1. Greenhouse gas emissions per person by household type

The first set of results presented here are for the year 2006 and show greenhouse gas emissions per average person for a range of household types. The figures compare emissions within household types, for example urban against rural households, larger against smaller households and richer against poorer households. Fig. 3 depicts the per person emissions by household type for carbon dioxide from fossil fuels.

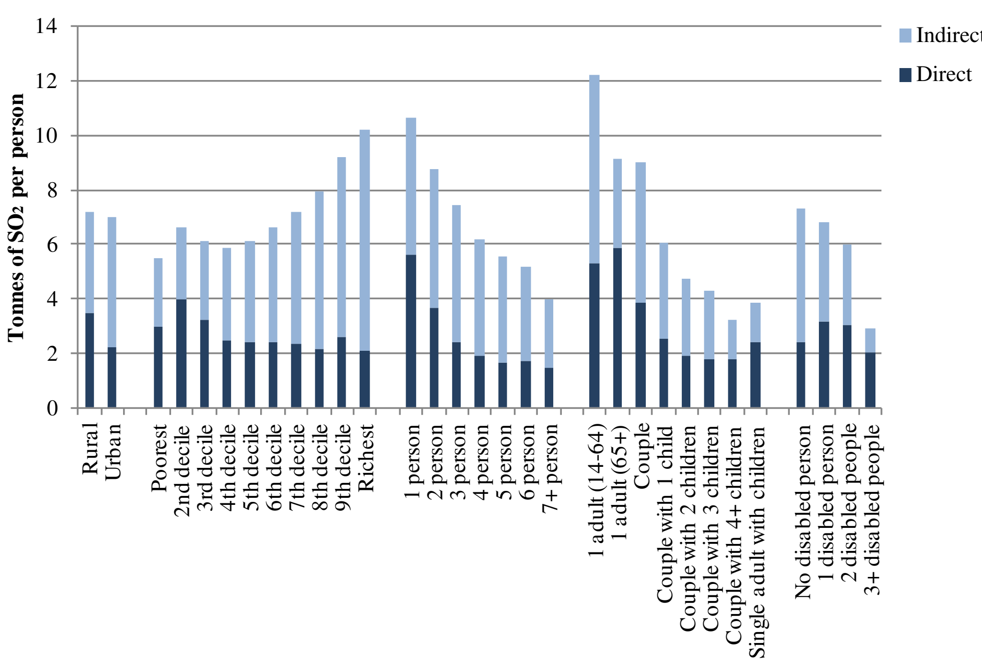

Fig. 6. Direct and indirect emissions of Sulphur Dioxide (SO_2) per person by household type.

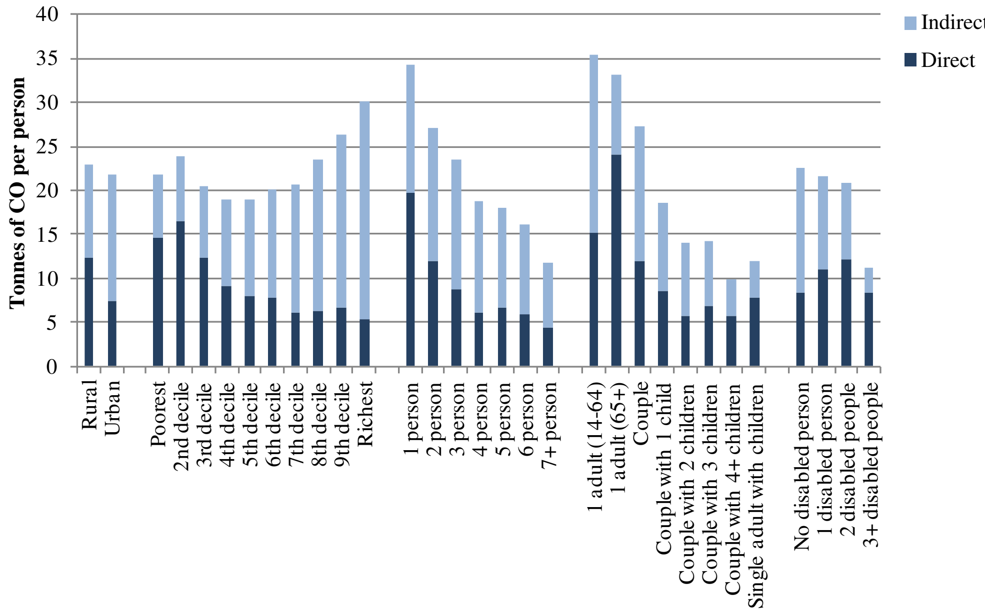

Fig. 7. Direct and indirect emissions of Carbon Monoxide (CO) per person by household type.

The average person in a rural household emits more CO_2 directly than an average person in an urban household; however an average urban household emits more CO_2 indirectly and also more in total than an average person in a rural household. Direct emissions in rural areas could be due to transport for example as cars are used more in rural areas whereas public transport is used more in urban areas. The definition of 'rural' used here includes much of the commuter belt. Indirect emissions could result from the production of household energy by power plants.

The poorest households emit the least CO_2 both directly and indirectly with nearly 1400 tonnes and 1900 tonnes per person respectively, and the richest households emit the most CO_2 both directly (1985 tonnes) and indirectly (6224 tonnes) per person and thus the richest decile emits 4900 tonnes more in total than the poorest decile. The increase in each decile for indirect emissions seems to be more an exponential growth than a linear one. The larger the household the less CO_2 is produced per person, with decreases in indirect, direct and thus total emissions as households get bigger. This is consistent with the presence of economies of scale in consumption; where household activities, for example cooking, are undertaken for the whole household rather than by each individual and thus emissions per person are less for households with more people. The only anomaly is for a retired aged single adult; for a single adult it is expected that total emissions would higher than a for a couple, however this is not the case and results suggest a couple emits 999 tonnes more

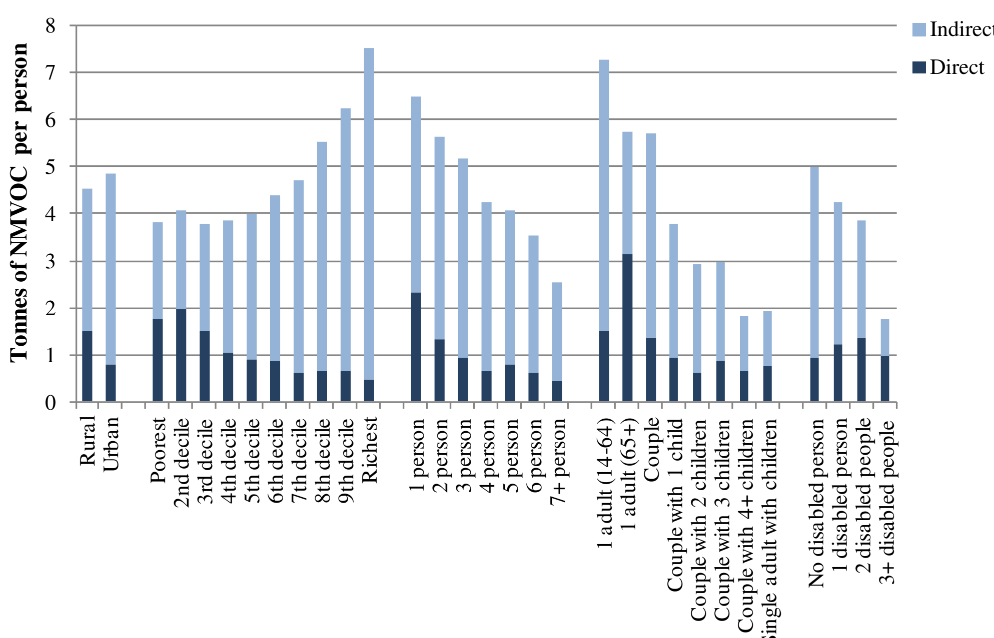

Fig. 8. Direct and indirect emissions of Non-methane VOC per person by household type.

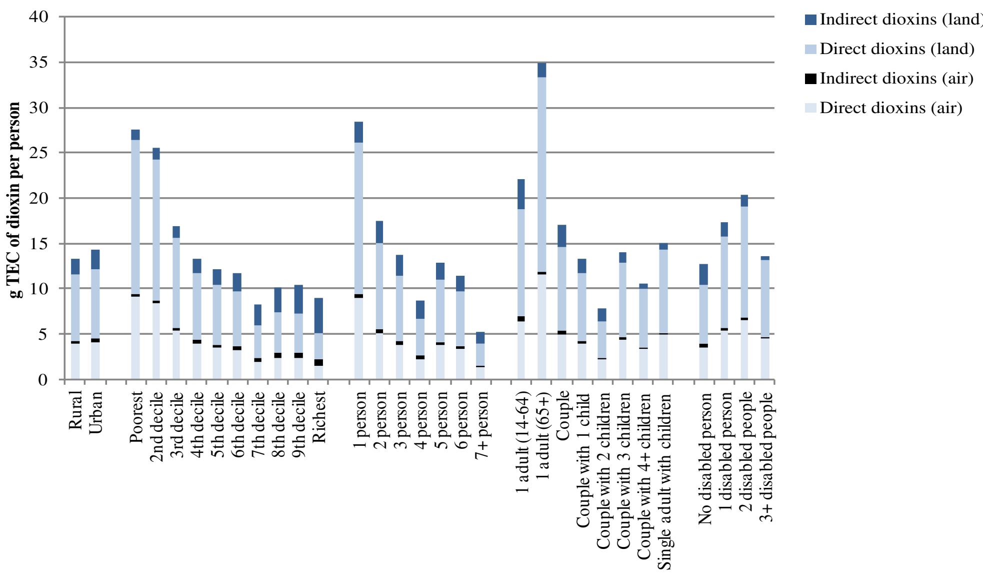

Fig. 9. Direct and indirect emissions of Dioxins per person by household type.

than an average retired adult. This could be due to an average couple having a higher income than an average single retired person.

Fig. 4 shows per average person emissions for methane (CH_4) where almost all household emissions of this gas are indirect.

Direct household methane emissions originate mainly from household waste and compost and sources of indirect methane emissions are landfill sites, for example. It is clear that, indirectly, urban households emit more per person than rural households by 10 tonnes but rural households emit more per person than urban households by 0.2 tonnes from direct sources. The richer the average person becomes the higher the indirect emissions (and the lower the direct emissions), and this increase seems to be more exponential rather than linear. The difference between indirect and direct emissions for the richest decile is 85 tonnes.

One and two person households emit roughly the same quantity of methane per person indirectly, however a one person household emits more than any other household size by direct sources (a one person household emits 1 tonne directly whereas a two person household emits 0.6 tonnes and a seven or more person household emits 0.2 tonnes from direct sources). The larger the household the

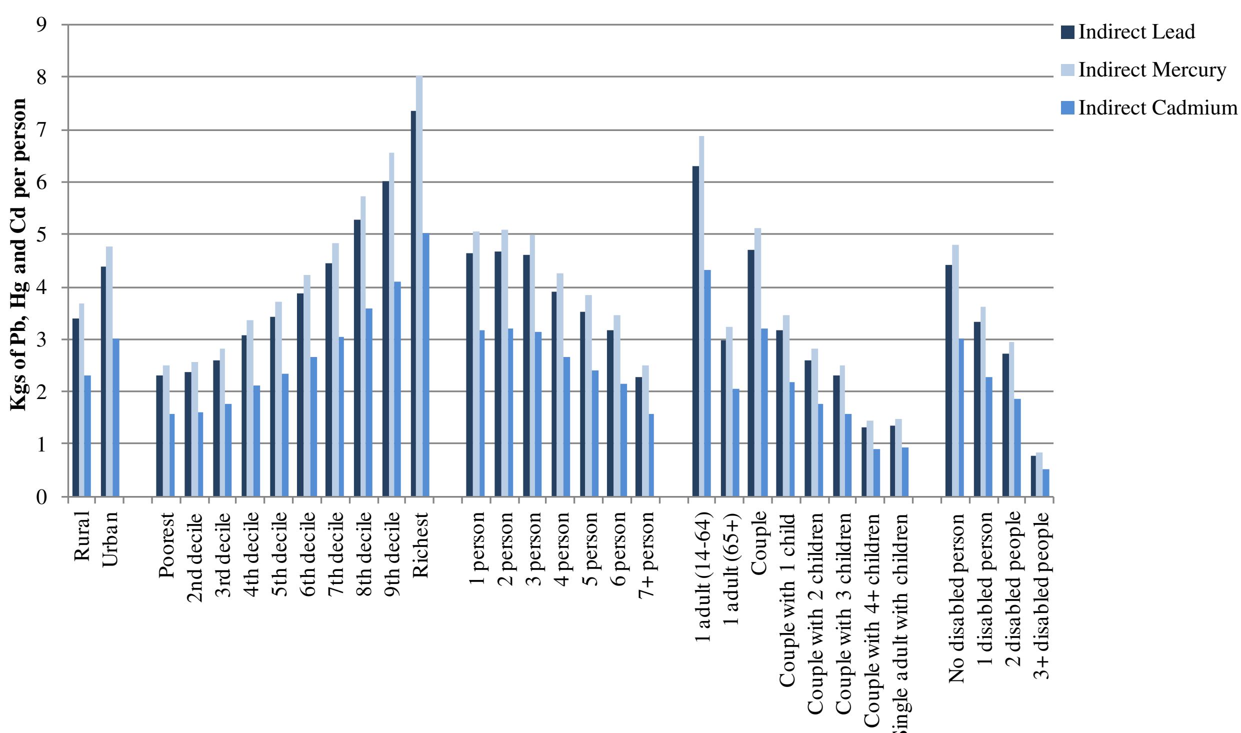

Fig. 10. Indirect emissions of Lead (Pb), Mercury (Hg) and Cadmium (Cd) per person by household type.

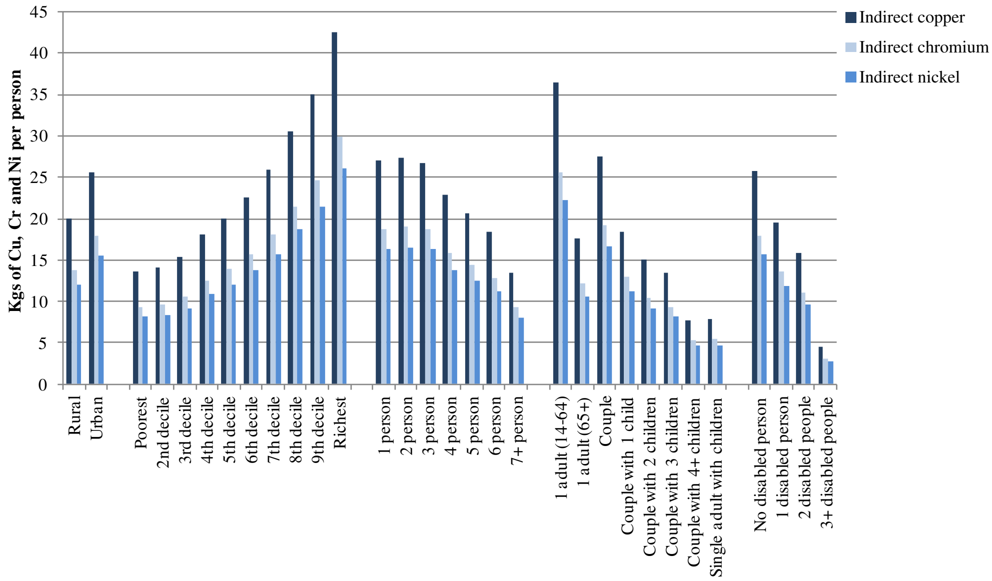

Fig. 11. Indirect emissions of Copper (Cu), Chromium (Cr) and Nickel (Ni) per person by household type.

less is emitted per person both from indirect and direct sources, making smaller households bigger emitters. A similar pattern holds for household composition for both direct and indirect emissions; single adults and couples are the largest emitters per person and emissions fall the more children are in the household. A working aged adult emits the most indirectly with 76 tonnes and a retired adult emits the most directly at 1.3 tonnes. Again the pattern is similar for the number of disabled people in a household; the more disabled people the less emissions per person from indirect sources. This, however, is not the same for direct emissions; emissions from direct sources increase with the number of disabled people, amounting to 0.6 tonnes for two disabled people whereas with no disabled person in a household the average per person emission of methane is 0.4 tonnes. Emissions do fall, however, when there are at least three disabled people in a household to just over 0.4 tonnes. A detailed graph of direct emissions of methane (and other emissions) can be found in the Appendix (Fig. A1), although roughly 99% of methane emissions come from indirect sources as shown by Fig. 2.

Fig. 5 depicts emissions of nitrous oxide per person by household type. Direct household emissions of N_2O could be a consequence of fossil fuel use from driving and indirect emissions could arise from the use of fertilisers or the incineration of household waste, for example. Nitrous oxide emissions are mostly emitted indirectly, with the richest income decile emitting the most (the difference between direct and indirect emissions is roughly 3.5 tonnes for the richest decile). The more people in the household, the less emissions per person both indirectly and directly; for one and two person households the average person emits similar amounts indirectly (2.37 and 2.35 tonnes respectively), however

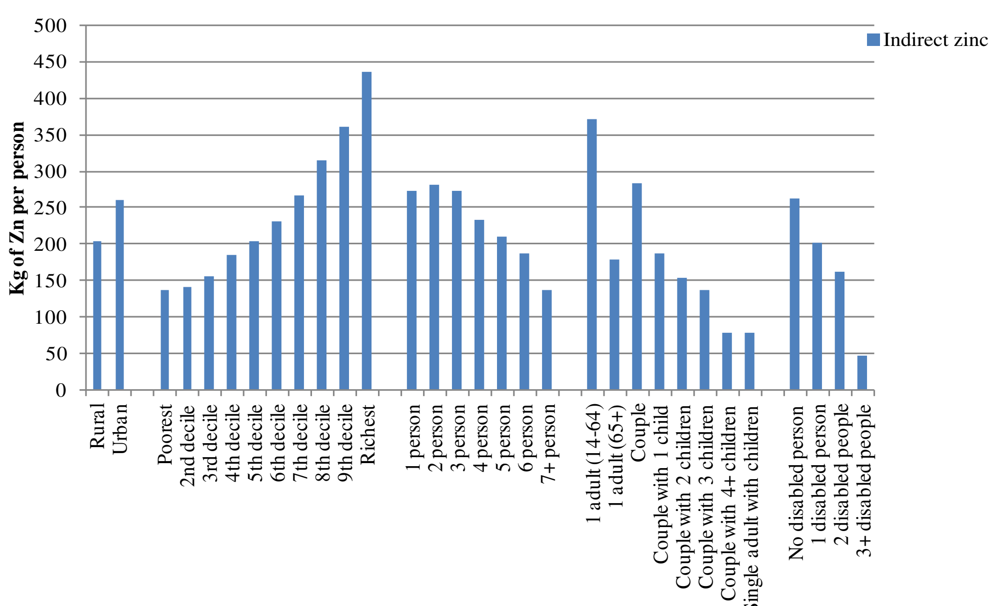

Fig. 12. Indirect emissions of Zinc (Zn) per person by household type.

a two person household emits less directly than a one person household.

Urban households emit more nitrous oxide indirectly by 0.3 tonnes. Rural households emit more directly, although this difference is a lot smaller. For a household with three or more disabled people, the average person per household emits less nitrous oxide than other other household type (the difference between direct and indirect emissions is also the smallest). A more detailed graph of direct emissions of N_2O can be found in the Appendix (Fig. A2).

4.2. Air pollutants per person by household type

Fig. 6 shows emissions from both direct and indirect sources of sulphur dioxide (SO_2) for an average person in each household type. The largest source of indirect SO_2 pollution is from fossil fuel combustion in power plants (for example burning coal to provide electricity). Direct emission sources of SO_2 include car emissions from fuel combustion.

Direct emissions per person fall gradually as household income increases, whereas indirect emissions increase sharply with income. The average person in an urban household emits more by indirect means than an average rural residing person; however this pattern is reversed with direct emissions. In contrast, indirect emissions are roughly constant across household sizes, while direct emissions per person are lower for larger households. Similar total emissions for urban and rural households mask differing composition, with rural households having relatively more direct emissions.

In Fig. 7 we show the distribution of carbon monoxide emissions per average person for different household types. Direct emissions could result from car exhausts and lawn mowers with internal combustion engines; an indirect source is the burning of fossil fuels in power plants.

A working aged single person generates the most carbon monoxide and a couple with at least four children emits the least carbon monoxide. Again direct emissions play a significant role although for most households per person emissions are mainly from indirect sources. The patterns are similar to those analysed before; the richest decile is the biggest emitter quantified as 30 tonnes and the more people per household, the lower emissions per person become. For rural households, the poorest three income deciles, a one person household, a retired single adult, a couple with 4 children, a single parent and households with at least two disabled people, per person emissions are greater from direct sources than indirect sources. The highest emission per person from direct sources is for a retired adult (23 tonnes) and the smallest for a seven person household at just under 5 tonnes. This is similar to the results for sulphur dioxide and carbon dioxide but substantially different from the other gas emissions.

Fig. 8 shows direct and indirect sources of emissions for NMVOC; the former resulting from the vapour emitted from car exhausts and solvent use and the latter as a consequence of extraction and distribution of fossil fuels. A retired adult and an average household with at least three disabled residents in emit more NMVOC directly than indirectly. The rich emit more indirectly and in total than the poor, however, the poor emit more directly than the rich. For both indirect and direct channels of emissions, the larger the household the lower emissions per person. This is consistent with household composition where the more children there are in a household, the lower emissions per person.

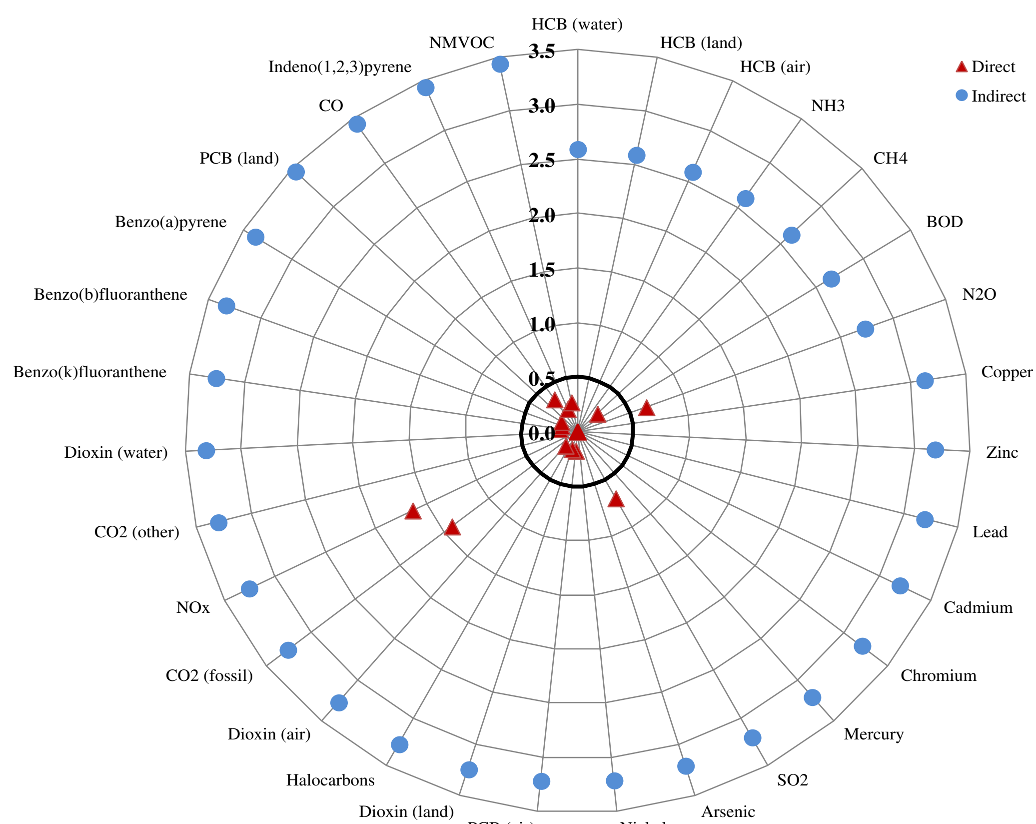

Fig. 13. Income intensity of emissions: ratio of household emissions per person for those in the highest income decile to those in the lowest decile by substance.

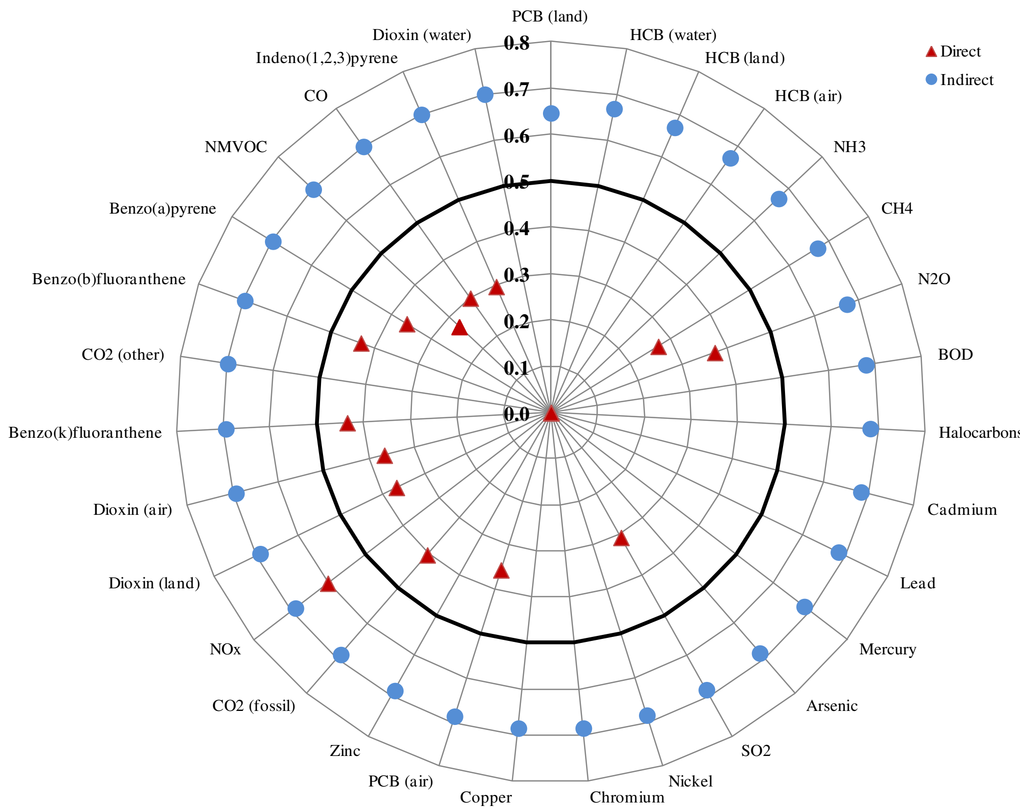

Fig. 14. Household intensity of emissions: ratio of household emissions per person the largest households (6 persons) to those in the smallest (one person) by substance.

4.3. Persistent organic pollutant emissions per person by household type

Fig. 9 shows direct and indirect emissions of dioxins which go into land and air. Emissions of dioxins into water, which are negligible in quantity, can be found in the Appendix (A6).

Urban and rural households emit roughly the same of each type of dioxins. The richer deciles emit less than poorer deciles in total, which stands in contrast to every other emission we studied. Poorer households emit larger quantities directly, perhaps due to greater use of open fireplaces, wood stoves and coal fired utility boilers. The richest deciles do, however, emit more indirectly into land than the poorer deciles. An indirect source of dioxin pollution is through the production of chemical and pesticides. Bigger households pollute less than smaller households per person, as found for other emissions. If up to two disabled people reside in the household, emissions are higher than for three or more disabled people which is also different from the gas emissions previously analysed where emissions fall for each additional disabled resident.

4.4. Metal emissions per person by household type

We have data only for metal emissions via indirect channels by households and thus we do not show any direct pollution from households for the metal pollutants examined. Indirect metal emissions mainly are a result of municipal waste incineration, fossil fuel combustion for example pollution from power stations, and industrial processes such as pulp and paper manufacturing.

Fig. 10 depicts the indirect emissions per person by household type for three metals, namely lead, mercury and cadmium. The patterns of the results are essentially the same for these emissions, so we analyse them together.

Urban households emit more than rural households, the richest deciles emit more than the poorer deciles and the larger the household the lower emissions are per person. Households with up to three residents emits roughly the same quantities per person of lead, mercury and cadmium, which is slightly different from the pattern observed for gas emissions where two and three person households emitted visibly less than one person households. Of the three metals, the least cadmium and the most mercury are emitted by households. Cadmium is emitted is the manufacturing of electrical equipment, and it is also found in cigarettes. Most mercury pollution form households is from production (of non-ferrous metal and cement for example), but it is also from waste disposal.

Fig. 11 shows the indirect emissions by household type for copper, chromium and nickel. Once again, we group these metals together because their patterns are similar.

Urban households emit more than rural households, the richer income deciles emit more than the poorer deciles and the larger the household size the fewer emissions per person. For all emissions the richest decile is the biggest emitter and a household with at least three disabled residents are the smallest emitters with the difference being 38 kg, 26 kg and 24 kg for copper, chromium and nickel respectively.

In Fig. 12 we show the indirect emissions by household type for zinc. Urban households emit more than rural households, the richer deciles emit more than the poorer deciles and the larger the household the less are emissions per person. The richest decile emits the most (436 kg) and a household with at least three disabled residents emits the least (46 kg). The difference between the richest and the poorest is 300 kg. The difference between per person emissions of a single adult with children and a single adult of working age without children is on a similar scale: 292 kg.

5. Analysis

In this section we consider how household income and size are associated with emissions of the substances covered in the paper. Household income and size are analysed as these household types have a clearer policy focus than location or household composition.[4] Fig. 13 depicts the relationships that direct and indirect emissions have with income: the emissions ratio of the richest decile to the poorest decile. For each emission, this is per person pollution emitted directly (indirectly) for the richest household income decile divided by per person pollution emitted directly (indirectly) for the poorest income decile. Thus an emission with a high ratio is one where emissions are strongly related to income, whereas low ratios indicate emissions with little association with income.

HCB (emitted to water) is shown to have the lowest ratio both indirectly and directly. Top earning households cause only 2.6 times the per capita indirect emissions that low earning households do. Non-methane volatile organic compounds (NMVOC) have the highest ratio for indirect emissions (almost 3.5) and oxides of nitrogen (NO_x) have the highest for direct emissions. Only NO_x and CO_2 from fossil fuels have a ratio of more than 1 for direct emissions. *Ceteris paribus*, policies that affect the cost of direct emissions are likely to be much more regressive than those affecting indirect emissions.

Fig. 14 illustrates the association between household size and emissions: the emissions ratio of the largest household size to the smallest household size. This is calculated as the per person pollution of direct (indirect) emissions for a six person household divided by the per person pollution of direct (indirect) emissions for a one person household, for each emission.

Pollutants show a very similar pattern, with an average ratio of 0.68. Again oxides of nitrogen (NO_x) have the highest direct emissions ratio and PCB (pollution to land) has the lowest. Size ratios are generally lower than the income ratios discussed above; in Fig. 14 no emission has a ratio over 0.7; however in Fig. 13 all indirect emissions ratios and two of the direct emissions ratios are over 1. Income has a much stronger association with household emissions per person than household size does.

6. Conclusion

This paper has reported estimates of Ireland's direct and indirect emissions per capita by household type for a range of pollutants. Households are split in five ways, by location, income decile, composition, size and the number of disabled residents. This was done for indirect emissions using input–output modelling and for direct emissions (where relevant) by applying emission factors to microdata from an expenditure survey.

The results show that most pollution comes from indirect sources; in fact for the greenhouse gases, direct sources never make up more than 35% of household emissions per person. In general, richer deciles tend to pollute more than poorer deciles; however dioxins seem to be an exception to this pattern. Another common feature is that the larger the household the less pollution per person. Urban households tend to pollute more than rural households except for emissions of carbon monoxide and sulphur dioxide, which probably has to do with differences in the average household fuel mix. For emissions of CO_2, N_2O and CH_4, indirect sources play a more important role than direct sources of emissions, whereas for emissions CO and SO_2, direct emission sources are relatively more important.

For metals we have estimated emissions only for the indirect channel. Zinc is emitted the most by households of all the metals followed by copper. Cadmium is emitted the least. The patterns by household type are similar across the various metals, and they are not dissimilar to those found for the gases. There are some subtle differences; for example, for the metal emissions a household of up to three residents emit a fairly equal share, however, for the gas emissions a two person household emits visibly less than a one person household and a three person household again visibly emits less than a two person household.

We also noted that household size has a weaker association with both direct and indirect emissions than household income does. Variations in indirect emissions are much more strongly associated with income than direct emissions, implying that a similar proportional change in the cost of emissions would be more regressive if applied to direct emissions than to indirect emissions.

The impact of environmental policy will tend to have differing incidence across households, to the extent that household types have differing emission patterns. This non-homogeneity has implications for environmental policy, because measures that raise the cost of emitting a pollutant (e.g., a tax or regulatory restriction) will fall more heavily on some households than others. If this significantly affects vulnerable households or changes the distribution of taxation in a material way, it may be necessary to offset the impact through appropriate tax or benefit measures. Further work would be to estimate a regression equation in order to predict emission levels of the different household types and to determine the relative contribution of household types for emissions.

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Appendix A. Supplementary data

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.jenvman.2012.07.019.

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