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Designing More Effective Air Quality Advisories

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Masters of Environmental Management Thesis
FUSE Project

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Abstract

Background: There is increasing concern about the impact of air quality on human health in urban environments and how to best reduce impacts through public policies. An NSF Biocomplexity Project - "Feedbacks between Urban Systems and the Environment" (FUSE), led by Portland State University, studies the human feedbacks and responses to air quality and heat advisories through data collected in city-wide phone surveys in Portland, OR and Houston, TX. On days when ozone levels are predicted to exceed air quality standards, regulatory agencies issue air quality advisories which ask residents to reduce certain air polluting behaviors such as driving and lawn mowing. However, there have been very few studies of the effectiveness of these systems. Previous work documented that in both Portland and Houston, around ~10% of the population respond to voluntary advisories (Semenza et. al, 2008). In the testbed cities, the survey also asked respondents questions about their personal emissions-related behavior such as driving, mowing, use of household products, etc., as well as how that behavior was effected by an air quality advisory.

Objectives: In this project, the survey data is used to accomplish three major tasks. Firstly, to estimate emissions based on the survey responses. For example, estimating VOC emissions based on reported mowing behavior (size of lawn, frequency of mowing, and type of mower). Secondly, to compare reported behavior during normal days to behavior during air advisory days. And finally, to compare the emissions estimates to demographic data (such as population density) to find any trends. For example, can variations in emission patterns be predicted using a demographic characteristic such as housing density? Currently the EPA and the Oregon DEQ estimate many types of emissions on a per capita basis. These per capita emissions numbers are generally not adjusted for any local demographic information. One additional use of this research could be to improve current emissions estimation methods.

Methods: Survey responses to questions about emissions related behavior were used as activity factors in emissions calculations. The emission estimations were then tested against demographics such as housing density. For the purpose of graphical representation, housing density was broken into four quartiles to represent four different levels of density. For statistical analysis housing density was not categorized.

Results: Emissions behavior, in several cases, appears to be linked to demographic features such as housing density. Per capita lawn care hydrocarbon emissions, vehicle emissions, and several consumer product category emissions trend higher towards lower housing density in both Portland and Houston.

Conclusions: The results of this research project could be used to tailor air quality advisories to better target their audience with appropriate messages, thereby more effectively improving air quality during potentially hazardous air quality conditions. Understanding demographic elements to emissions estimation could be used by environmental agencies to produce better emission estimations.

Key words: air pollution, ozone, survey, emissions estimation, advisory, behavior, demographics

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Human Participant Protection: The institutional review board of Portland State University approved the protocol for this study. Oral informed consent that briefly described the study with all the procedures and activities was obtained from study participants prior to the completion of the phone surveys.

Abbreviations: DEQ: Department of Environmental Quality; TCEQ: Texas Commission on Environmental Quality; PSU: Portland State University; VOC: Volatile Organic Compounds.

Introduction

Adverse health effects of urban air pollution, a complex mixture of toxic gases and particulate matter, are now well documented. Elevated levels of urban air pollutants, such as ozone, have been linked to adverse health conditions. Additionally, there are interaction effects between multiple pollutants further increasing the magnitude and uncertainty of health effects (Samet and Krewski, 2007). The ultimate goal of reducing urban air pollution is to improve health by reducing human exposure to pollutants.

Sometimes air pollutant levels, usually in urban environments, exceeds standards set by government agencies. Levels exceeding these standards are considered unacceptable health risks and state agencies are required to take action to minimize their occurrences. Warning systems have been implemented that are designed to predict when meteorological and air quality conditions combine to exceed air quality standards. Methods for forecasting and triggering advisories have become increasingly sophisticated. However, there are few studies that examine the effectiveness of these advisories to reduce one's contribution to the adverse conditions.

Air quality advisories, issued by state or local agencies, are primarily used as a health warning of poor air quality and include advice to stay indoors or limit physical activity. In some cases, agencies ask residents to make voluntary changes to improve the air quality. In an August 14, 2008 Air Health Advisory press release, the Oregon DEQ makes the following recommendations to reduce smog during this particular period of hot and stagnant weather:

- Turn off your engine when your vehicle is parked or waiting in line.
- Refuel your vehicle during cooler evening hours.
- Wait until the heat wave breaks to use gas-powered mowers and yard equipment.
- Avoid painting and using aerosol sprays until it cools off.
- To the extent possible limit driving or use public transportation.

In the winter, the DEQ advisories shift to simply recommending a reduction in wood fires and driving most likely because it is assumed that the other behaviors are minimal during the winter.

The advisories are driven by an expectation that one or more criteria pollutants will soon rise or have risen above standards. It is important to study the effect of these advisories as this reactionary response to poor air quality could potentially be more damaging to the cause of air pollution reduction by scaring residents and decreasing economic productivity. The advisories may also send the message that the only time residents need to think about their emissions behavior is during air quality advisory periods. It is possible that the same resources spent on education, better emissions control methods, and efficient use of resources would produce a greater positive health impact.

The Oregon Department of Environmental Quality is responsible for estimating emission sources in Oregon. For the year 2002 they estimated VOCs from area sources in the tri-county area at 92,946 tons per year. On-road sources were estimated at 23,683 tons per year (DEQ Ozone Maintenance Plan, 13). In terms of VOC estimates, area sources contribute far more than vehicles. In fact, area sources are estimated as contributing more to VOC emissions than non-road, on-road, and point sources combined for the tri-county area. The Oregon DEQ estimates that nearly 80% of VOC emissions originate from area and non-road sources (DEQ, 2007). Most household emissions are considered area sources due to their small and dispersed nature.

Portland Area 2002 Attainment Inventory
Annual Emissions (tons/year)
Clackamas, Multnomah, Washington Counti

Source Type	2002 VOC	2002 NO_x	2002 CO
AREA	92,946	5,808	104,621
NON-ROAD	13,247	17,344	153,204
ON-ROAD	23,683	36,786	288,435
POINT	3,056	2,522	2,214
Total	132,931	62,461	548,474

Figure 1: Source: Portland-Vancouver Air Quality Maintenance Area Ozone Maintenance Plan. Oregon DEQ. 2007

Three area source types are identified by the DEQ as contributing the most to area emissions: fumes from surface coating, lawn care equipment, and residential wood combustion emissions. All three of these area sources, linked to individual behavior, are very difficult to quantify. According to the EPA, small, spark-ignited engines such as lawnmowers and weed-whackers contribute about 20% of hydrocarbon emissions in the U.S. Additionally, the DEQ includes these three sources along with vehicle emissions as the top contributors to air toxics which are generally unregulated and not part of the EPA's emission factors.

Through a literature review it was found that research is very limited on individual contribution to emissions from area sources such as grilling, painting, and personal care products and how these emissions are linked to public policy. If agencies are to recommend the reduction of any specific behavior, the costs and benefits of a reduction in that behavior should be quantified. Also, it should be known how the reduction might affect different demographic groups as well as physical regions. This research aims to quantify some of these possible emissions-to-demographic links.

In 2005 and 2006 a set of telephone surveys were carried out for the FUSE project. The project was designed to investigate the air quality – human response system. A subset of the questions in the survey ask about individual usage patterns of emissions related activities such as lawn mowing, aerosol spray can use, outdoor grilling, automobile use, and several other activities. In this paper, the survey data is analyzed to better understand the emissions from these sources. First, actual emission estimates are made from the responses, then the estimates are compared with demographic statistics such as housing density. Also, trends in behavior between advisory and non-advisory days are obtained.

Objectives

- Establish a methodology to convert survey responses to emission behavior
- Estimate the change in emissions related behavior due to an air quality advisory
- Identify demographic trends in emissions

Methodology

Emissions Estimation

Task: Derive emissions estimates from FUSE 2005 & 2006 survey responses.

Estimating area sources is often difficult as accurate data is not available for most types of sources. The EPA publishes a document, AP42, which attempts to quantify hundreds of types of area sources based on emissions factors. Factors are established for everything from dry cleaning solvent emissions to particulate matter from cheese making. Each emission factor relates a quantity of pollutant emitted with another factor such as number of people, quantity of substance burned, or quantity stored. In the document, each emission factor receives a rating from A through E. ‘A’ indicates the highest level of certainty in the accuracy of the emission factor. ‘E’ indicates that the emission factor is very uncertain and is based on just a few tests with variable results. An 'A' rating is rarely found and only when an emission can be directly related to, for example, a quantity of a fuel combusted.

Emissions can show up in unexpected places as well. In a 2001 report the investigators monitored the release of many VOCs both during and following lawn mowing (Karl et. al, 2001). Interestingly, the VOCs resulting from the grass clippings were on the same order of magnitude as the unburned hydrocarbons released during the mowing by the gas engine. This is an example of an unexpected source that is usually not accounted for when quantifying area sources.

Emissions from area sources are nearly always estimated using some type of mathematical scaling procedure. Direct measurement of area source emissions is almost never practical because of technical and cost considerations (EPA, Introduction to Area Source Emission Inventory Development, January 2001). The EPA prescribes four major approaches to estimating emissions:

- Extrapolation from a sample set of the sources (surveys, permit files, or other databases)
- Material balance method
- Mathematical models
- Emission factors applied to activity levels

To accomplish the task of estimating emissions from the FUSE survey responses, the method of applying established emission factors to activity levels is used. The activity levels are obtained from the survey responses. In some cases the activity level from the response is directly applied to an emissions factor, and in other cases the response is augmented with assumptions about activity (such as lawn mowing speed) in order to calculate emissions. The exact methods and all assumptions for each emission category are covered in the following sections.

Emissions Estimation Part 1: Lawn Care

Task: Derive an emissions estimate calculation from responses to questions 12-15.

Lawn Care Survey Questions

Q12: How much grass lawn do you have at your primary residence?

Q13: What type of lawn mower is primarily used to maintain your grass?

Q14: During the summer, how often is your grass cut?

Q15: During the summer, do you use other gas-powered garden equipment like weed whackers, edgers, or blowers?

To derive this calculation the EPA's Nonroad model technical documents were studied in an attempt to best emulate the methods used for this well established and widely used emissions modeling system.

The EPA's Nonroad model calculates small engine emissions based on a g/hp-hr emissions factor. For residential lawn mowers there are 9 different types of spark engines each with a different set of emissions factors.

Engine Tech Type	HC g/hp-hr	CO g/hp-hr	NO_x g/hp-hr	PM g/hp-hr	BSFC lb/hp-hr
G2N1 (gas 2-stroke nonhandheld Class I, baseline)	207.92	485.81	0.29	7.7	0.870
G4N1S (gas, side-valved, 4-stroke nonhandheld Class I, baseline)	38.99	430.84	2.00	0.06	1.365
G4N1O (gas, overhead-valved, 4-stroke nonhandheld Class I, baseline)	13.39	408.84	1.80	0.06	0.991
G2N11 (2-stroke, Phase 1)	120.06	449.66	4.00	7.7	0.870
G4N1S1 (Phase 1 side-valved, 4-stroke)	8.40	353.69	3.60	0.06	0.921
G4N1O1 (Phase 1 overhead valved 4-stroke)	8.40	351.16	3.24	0.06	0.781
G4N1SC1 (Phase 1 side-valved, 4-stroke with catalyst)	8.40	353.69	3.60	0.06	0.921
G4N1S2 (Phase 2 side-valved)	7.93	353.69	2.37	0.06	0.921
G4N1O2 (Phase 2 overhead valved)	6.13	351.16	1.83	0.06	0.781

* Assigned NONROAD hp range: 3-6 hp

Table 1: Sample Non-Road EPA Emissions Factors (EPA, 2005)

The Nonroad model also uses engine population estimates, average temperatures, fuel composition, activity factors, evaporation factors, and other estimates to calculate emissions at a county level. Some of these estimates are included in the model data (such as engine population) and some of the estimates must be provided by the user (such as fuel and temperature parameters).

Full technical documents on how the nonroad model calculates emissions can be found on the EPA's website:

http://www.epa.gov/omswww/nonrdmdl.htm#techrept

The FUSE survey questions obviously do not collect enough information to make an accurate lawn care emissions estimate. However, a simplified estimate should be adequate for the purpose of comparing emissions of groups of survey respondents.

To derive a mower emissions estimate the lawn size and frequency of mowing must be combined to provide a number of hours that the mower is used per time period. This calculation must include an estimate of the number of hours per area for mowing activity. The EPA's nonroad model uses the following emissions calculation:

$$\textbf{Emissions} = (Pop)(Power)(LF)(A)(EF)$$

where *Pop* = *Engine Population*
Power = *Average Power (hp)*
LF = *Load Factor (fraction of available power)*
A = *Activity (hrs/yr)*
EF = *Emission Factor (g/hp-hr)*

Figure 2: EPA Non-Road Engine Emissions Formula (EPA420-P-04-005)

Load factor = 0.33 for residential mowers (from EPA420-P-04-005).

EPA estimates 25 hours / year for residential mowers. However, in this case the survey response to Q14 will be used to estimate how many hours the mower is employed.

Population Estimates for Oregon 4-stroke residential mowers from the EPA Nonroad model data set:

2.55 avg hp – 7,982.7
4.1 avg hp – 396,730.2
6.24 avg hp – 130.8

Since specific information about the type of engine used is not available, an average emissions factor must be derived based on the population distribution of mower engines. In Oregon the residential mower population is dominated (98%) by 3-6hp mowers with an overall average horse power for all residential mowers at 4.07 hp (calculated from US EPA Nonroad model data). From the data it appears that all mower engines are assumed as 4-stroke.

Example:

A resident mows the lawn twice a month.

The lawn is 0.21 acres.

The type of mower is reported as a 'regular push mower'.

We will use an emissions factor of 13.39 g/hp-hr for hydrocarbons based on the EPA's G4N1S (gas, overhead-valved, 4-stroke nonhandheld Class I baseline) emissions factor.

An average power of 4.07 hp

A load factor of 0.33

The **activity** must be calculated. To calculate the activity an estimate must be made for the number of hours it takes, on average, to mow one acre.

Mowing speed calculation:

Acres/hr= (Width in ft) x (Speed in mph) / 8.25.

Residential mowers typically have a 19 inch blade. However, the full swath of the blade is rarely used when mowing as there must be an overlap of each successive mow line. We will consider the overlap to be 30%. Therefore the functional blade width would be 13.3" or 1.1 ft. Mowing speed is estimated at 2 mph. Therefore, average acres per hour would be about (1.1 ft) x (2 mph)/8.25 = 0.27 acres/hour or inversely 3.7 hours/acre.

(2 mows per month) X (0.21 acres) X (3.7 hours / acre) = 1.56 hours per month

Then, the emissions can be estimated:
(1.56 hours per month) X (13.39 g/hp-hr) X (4.07hp) X (0.33 load factor) = 28 g/month

Our estimate for this resident's mower emissions: 28 g/month of hydrocarbons. This is of course only for the mowing season.

Question 15 asks, "During the summer, do you use other gas-powered garden equipment like weed whackers, edgers, or blowers?".

An emission estimate relating to this question is difficult as more details about the type of equipment and the duration and frequency of use would be desirable. A somewhat safe assumption is that most of the "other gas powered garden equipment" consists of weed whackers. The small engine population statistics for Oregon support this assumption. The 1996 population estimate for residential "Trimmers/Edgers/Brush Cutters" is about 173,000. Leafblowers are second in population at about 80,000. For regulatory purposes, weed-whackers are also known as trimmers. Leaf blowers perform very similarly in terms of emissions and load factor to weed whackers. Residential weed whackers are primarily 2-stroke and 20 to 50 cc. Therefore the G2H4 emission factor could be used at 261 g/hp-hr for hydrocarbons. Contrary to the small size of these engines, the emissions are significantly higher than mowers. In general, two-stroke engines have high emissions due to simplicity of design and lower emission standards for small equipment. Therefore, hand held engines are an important addition to total lawn-care emissions.

However, in general, weed whackers are used for less duration than mowers. For the purpose of this estimation dividing the mowing time by 6 might be a safe way to estimate use of the weed whacker. This factor is based on personal experience. No established method of correlating weed whacker use to mower use was found in a literature search.

The load factor for trimmers is 0.91 (from EPA420-P-04-005).

From EPA Nonroad dataset:

2-Str Trimmers/Edgers/Brush Cutter (res) 0.81 avg hp 48255.4 population

2-Str Trimmers/Edgers/Brush Cutter (res) 1.4 avg hp 122205.1 population

The total average hp for all 2-stroke trimmers is 1.23 hp.

Using the same activity from the mowing example:

(1.56 hours / month) / (6) X (261 g/hp-hr) X (0.91 load factor) X (1.23 hp) = 76 g / month hydrocarbons

Therefore, this resident's total hydrocarbon output would be estimated at 28 g/month (mowing) + 76 g/month (trimming) = 104 g/month total.

= 0.23 pounds / month

= 1.38 pounds / years (assuming 6 month mowing season)

Table 2. Emissions and BSFCs for Class IV Handheld Small SI Engines (≥20cc and <50cc)*

Engine Tech Type	HC g/hp-hr	CO g/hp-hr	NO_x g/hp-hr	PM g/hp-hr	BSFC lb/hp-hr
G2H4 (gas 2-stroke handheld Class IV, baseline)	261.00	718.87	0.94	7.7	1.365
G2H41 (Phase 1)	179.72	407.38	0.51	7.7	1.184
G2H4C1 (Phase 1 with catalyst)	179.72	407.38	0.51	7.7	1.184
G4H41 (Phase 1 4-stroke)	22.37	533.42	1.79	0.06	0.847
G2H42 (Phase 2)	33.07	283.37	0.91	7.7	0.822
G2H4C2 (Phase 2 with catalysts)	26.87	141.69	1.49	7.7	0.822
G4H42 (Phase 2 4-stroke)	25.83	432.51	1.13	0.06	0.847

* Assigned NONROAD hp range: 1-3 hp

Table 2: Sample Hand-held Engine EPA Emission Factors, (EPA, 2005).

The Oregon DEQ has established per capita emissions factors for lawn care -

Oregon DEQ Emission Factor Examples:

Multnomah VOLATILE ORGANIC COMPOUNDS 2.96 lbs per capita 2002 Mobile Sources-Off-highway Vehicle Gasoline, 2-Stroke-Lawn and Garden Equipment-All

Multnomah VOLATILE ORGANIC COMPOUNDS 2.34 lbs per capita 2002 Mobile Sources-Off-highway Vehicle Gasoline, 4-Stroke-Lawn and Garden Equipment-All

5.3 pounds per capita per year is DEQ's estimate for all lawn care equipment (including commercial) emissions of VOCs in Portland's Multnomah county. If Joe cares for his lawn 6 months/year then even at about 1.4 pounds per year his emissions are quite a bit short of DEQ's estimate. This is possibly because the use of lawn care equipment for commercial and public purposes (nonresidential properties, parks, fields, etc) contribute to emissions more than residential lawn care.

Average lawn size calculated from survey:

Portland: 0.19 acres
Houston: 0.27 acres

The 0.21 acres of lawn used in the example is actually based on the average lawn size as reported in both years of the FUSE survey for Portland and Houston combined.

Given the above considerations and DEQ's estimate, 1.38 pounds per year of VOC for an average lawn mowed twice a month does not appear to be an unreasonable estimate.

Emissions Estimation Part 2: Household Products

Task: Derive an emissions estimate calculation from responses to questions 16 & 16a-f.

Household Products Survey Questions

2005

Q16: During the summer, how often do you use household products such as cleansers, aerosol air fresheners, glues, and rubbing alcohol?

Q27: Of the personal care products that you use, such as cosmetics, deodorants, perfume, and hairspray, how often during the summer do you use products that are in an aerosol can (as opposed to pumps)?

2006

Q16A: During the summer, how often do you use hair spray? - IWR prompt - Hair spray includes hair care products such as finishing hair sprays; finishing spritzers; styling sprays; styling spritzers and even mousses.

Q16B: During the summer, how often do you use aerosol air fresheners?

Q16C: During the summer, how often do you use weed killers, herbacides, or insecticides?

Q16D: During the summer, how often do you use a swimming pool disinfectant?

Q16E: During the summer, how often do you use sealants, glues, and spray paint?

Q16F: During the summer, how often do you use canned paints, wood stains, and solvents, like paint thinners?

EPA emissions factors for paint and adhesive products are based on the amount of product used by weight or volume. For example,

Petroleum and Solvent Evaporation > Surface Coating Operations > Surface Coating Application - General > Paint: Solvent-base > Volatile organic compounds (VOC)
1.120E3 Lb per Tons Coating Mix Applied

For every 2,000 pounds of solvent-base paint applied, the EPA estimates 1,120 pounds of VOCs are released into the atmosphere.

To use these EPA emissions factors to produce emissions estimates from the FUSE survey responses would be problematic. The survey responses would need to be converted from a known frequency of use of unknown amount to an amount per month quantity. Therefore difficult assumptions must be made about how much of each product is used on average per application. To generate these assumptions an additional survey or similar method would be needed to estimate average quantity used per application for all of these products. An additional survey is beyond the scope of this analysis. Therefore, a less direct method of estimation is used.

The Oregon DEQ already estimates average per capita emissions from many categories of consumer and commercial products. These emissions estimates are calculated using EPA prescribed methods and are used for policy and regulation decisions.

Emission Factor #	Emission Type	Emiss. Est. (lbs / yr)	Category	Products
2460100000	VOC	2.04	Consumer & Commercial	All Personal Care
2460200000	VOC	0.7	Consumer & Commercial	All Household
2460600000	VOC	0.52	Consumer & Commercial	All Adhesives and Sealants
2460800000	VOC	1.69	Consumer & Commercial	FIFRA Related (Pesticides)
2460900000	VOC	0.07	Consumer & Commercial	Miscellaneous
2460500000	VOC	0.95	Consumer & Commercial	All Coatings and Related
2460400000	VOC	1.24	Consumer & Commercial	All Automotive Aftermarket
TOTAL: Consumer and Commercial Products		7.21		

Table 3: Oregon DEQ Consumer & Commercial Product Emission Factors (in pounds per capita per year)

- Personal care items include hair care products, deodorants, fragrance products, nail care, facial and body treatments, and oral care products.
- Household products include hard surface cleaners, laundry products, fabric and carpet care products, dishwashing products, waxes and polishes, air fresheners, and shoe and leather care products.
- Adhesive and sealants are household glues, art and craft adhesives, and sealants such as spackling and caulking compounds.
- FIFRA pesticides include insecticides, fungicides, nematocide, and herbicides. This emission estimate covers all non-agricultural use including anything applied by a commercial company for any of the above conditions.
- The miscellaneous category includes those consumer products that are not covered elsewhere such as art and craft supplies, pressurized food products, and office supplies.
- Automotive aftermarket products include detailing products such as waxes and polishes, and maintenance and repair products such as antifreeze and windshield washer fluid.

To estimate household product emissions, the following method is used:

- Calculate average frequencies of product use for the entire survey data set

- Assign the EPA per capita emission factors to those average frequencies

- Linearly calculate individual respondent's emissions

Assumptions:

- The sample set is large enough to represent average emissions

- The EPA and DEQ's emission estimates are accurate

- There is a linear relationship between activity and emissions

Example:

Assume the total dataset average frequency of use for hair spray is 8 times per month. Then, assign 2.04 pounds per person of VOC emissions to that frequency. Therefore, if a survey respondent reported using hair spray 16 times per month, then they would have double the average emissions: 4.08 pounds per year.

It is interesting to note that the DEQ's total estimate of consumer and commercial product VOC emissions exceeds total lawn care emission estimates. Also very interesting to note is that the VOC emission estimate for personal care products is larger than any other consumer product category. This underscores the importance of consumer and personal care product VOC emissions.

The following activity averages from the survey dataset are used to establish a baseline emissions for the mean of all respondent's activity levels.

Dataset averages:

DEQ Category: Personal Care Products
Hairspray: 4.17 times / month
Air Fresheners: 3.39 times / month
Respondents averaged: 3.78 times / month for hairspray and air freshener use if treated as a single product.
DEQ per capita estimate: 2.04 pounds per year
Formula: 0.54 X (use per month) = pounds VOC per year

DEQ Category: FIFRA Related Products
Weed Killers
Respondents averaged: 0.54 times / month
DEQ per capita estimate: 1.69 pounds per year
Formula: 3.13 X (use per month) = pounds VOC per year

UNKNOWN CATEGORY
Swimming Pool Disinfectant: 0.58 times / month
This could be covered under the DEQ MISC products category. However, the estimation would most likely be meaningless without more detailed information.

DEQ Category: All Adhesives and Sealants:
Sealants, Glues, Sprays
Respondents averaged: 0.47 times / month
DEQ per capita estimate: 0.52 pounds VOC per year
Formula: 1.11 X (use per month) = pounds VOC per year

DEQ Category: All Coatings and Related Products
Paints, Stains, Solvents
Respondents averaged: 0.56 times / month
DEQ per capita estimate: 0.95 pounds VOC per year
Formula: 1.70 X (use per month) = pounds VOC per year

Emissions Estimation Part 3: Grilling

Task: Derive an emissions estimate calculation from responses to questions 28-31.

Grilling Survey Questions

Q28 Do you use an outdoor grill?

Q29 During the summer, how often do you use your grill?

Q30 How is this grill fueled?

Q31 Do you use lighter fluid to start it?

The EPA provides no emissions factors for residential grilling or cooking including the use of lighter fluid. However, there are emission factors for commercial charbroiling.

Example:

Industrial Processes > Food and Kindred Products: SIC 20 > Commercial Cooking - Charbroiling > Charbroiling Total
POLLUTANT Benzo (a) anthracene
Emission Factor -- 3.000E-1 mg per Kilograms Hamburger Charbroiled;

To apply these emission factors the frequency of grilling must be converted to kilograms of hamburger per time period. A fair estimate could be 0.5 kg of hamburger grilled per cook-out. So, if the respondent grilled once per week, this would be 2kg of hamburger grilled per month. Therefore, the emission of benzo anthracene would be 0.6mg per month.

(1 cook-out / week) X (4 weeks / month) X (0.5 kg hamburger / cook-out) X (0.3 mg benzo anthracene / kg hamburger) = 0.6 mg benzo anthracene per month

There is no EPA VOC emissions factor for charbroiling or charcoal grilling.

The Oregon DEQ does not estimate gas and charcoal grilling emissions.

Emissions Estimation Part 4: Off-Road Vehicles

Task: Derive an emissions estimate calculation from responses to question 32.

Off-Road Vehicle Survey Questions

2005

Q32: During the summer, for recreation how often do you use an off-road vehicle, jet-ski, motorboat, gas-powered go-cart, or RV?

Table 7. Emission Factors and BSFCs for Offroad Motorcycles, ATVs, and Snowmobiles

Equipment/Tech Type	**HC g/mile**	**CO g/mile**	**NO_x g/mile**	**PM g/mile**	**BSFC lb/mile**
Precontrol 2-stroke offroad motorcycles (R12S)	55.70	54.10	0.150	2.10	0.268 0.201*
Precontrol 4-stroke offroad motorcycles (R14S)	2.40	48.50	0.410	0.06	0.158
Phase 1 4-stroke offroad motorcycles (R14S1)	2.10	30.60	0.340	0.06	0.158
2-stroke all terrain vehicles (R12S)	53.90	54.10	0.150	2.10	0.213 0.160*
4-stroke all terrain vehicles (R14S)	2.40	48.50	0.410	0.06	0.167
Phase 1 4-stroke all terrain vehicles (R14S1)	1.60	30.60	0.260	0.06	0.167
	HC g/hp-hr	**CO g/hp-hr**	**NO_x g/hp-hr**	**PM g/hp-hr**	**BSFC lb/hp-hr**
Precontrol 2-stroke snowmobiles (R12S)	111.0	296.0	0.86	2.70	1.660
Modified 2-stroke snowmobiles (R12S1)	53.70	146.9	0.86	2.70	1.660
Direct Injection 2-stroke snowmobiles (R12S2)	21.80	90.0	2.80	0.57	1.245
4-stroke snowmobiles (R14S)	7.80	123.0	9.20	0.15	1.245

Table 4: Example EPA emission factors for offroad vehicles (EPA, 2005)

Table 11. Personal Watercraft Emission Factors [g/bhp-hr]

Pollutant	HP Bin	Technology Type						
		MP2C	MP2I	MP2D	MP2CA	MP4C	MP4I	MP4D
HC	0-3	271.92	205.35	60.78	106.70	25.84	31.75	30.09
	3-6	230.19	173.84	51.46	90.32	15.13	21.04	19.38
	6-11	188.47	142.33	42.13	73.95	4.43	10.33	8.67
	11-16	146.74	110.82	32.80	57.58	4.43	10.33	8.67
	16-25	105.02	79.31	23.48	41.21	4.43	10.33	8.67
	25-40	105.02	79.31	23.48	41.21	3.73	9.63	7.97
	40-50	105.02	79.31	23.48	41.21	3.73	9.63	7.97
	50-100	105.02	79.31	24.74	41.21	3.63	9.54	7.88
	100-175	105.02	79.31	24.37	41.21	3.63	9.54	7.88
	175+	105.02	79.31	15.76	41.21	3.63	9.54	7.88

Table 5: Example EPA emission factors for watercraft (EPA, 2005)

The EPA's document “**Exhaust Emission Factors for Nonroad Engine Modeling: Spark-Ignition**” includes emission factors for many types of off-road and marine engines. The emissions vary **widely** depending on the engine type. Mainly, motorboat emissions are very high compared with the other vehicles. Therefore, due to the simplicity of this survey question it is not recommended to make an emission estimation.

However, a frequency cut-off could be used to bump the respondent into a higher “emission category”. For example, if the respondent uses a recreational vehicle more than twice a month then perhaps their VOC emissions would move from “low” to “medium”.

Recreational vehicles are significant in their emissions due to relaxed standards as well as the prevalence of 2-stroke engine types. For comparison, the Oregon DEQ's estimation for lawn care VOC emissions is about 2.4 kg per person per year. A 2-stroke ATV would produce the same emissions in just 45 miles. One full day of ATV driving could equate to about a year of lawn care. Marine engines have much greater emissions, in many cases one order of magnitude higher.

Though an actual emission estimate based on this survey question is inadvisable, the answer should be used in some way as this category has the potential to produce a large emission.

Dataset Average:

2005 Offroad Vehicle use: 0.51 times/month (in summer)

Example:

Assume that each time the vehicle is used, it is operating for about 4 hours. Then, the average dataset use of 0.51 times/month would equate to about 2 hours per month. If the vehicle is an ATV then this amount of use over 4 months (summer) would equate to about a year of mowing emissions.

For the purpose of a rough emission estimate, it is assumed that the vehicle is a 2-stroke ATV that emits 53.70 g/mile of VOCs. Each use is estimated at 20 miles. There is little basis for these assumptions. Without an additional survey it is impossible to know what type of vehicle or craft is being used and for what duration.

Emissions Estimation Part 5: Driving

Task: Derive an emissions estimate calculation from responses to questions 2 - 7.

Driving Survey Questions

2005

Q2: During the summer, do you drive a vehicle at least once a week? Vehicles include all automobiles, trucks, vans and motorcycles.

Q3: For the primary vehicle you drive, approximately how many miles per gallon do you get in the city?

Q3A: Approximately how many miles per gallon does that vehicle get on the highway?

Q4: During the summer, approximately how many miles do you drive in your primary vehicle each week to get to and from work?

Q5: During the summer, approximately how many miles do you drive in your primary vehicle each week as part of your job, excluding the miles you drive to and from work?

Q6: During the summer, approximately how many miles do you drive in your primary vehicle each week for personal errands, appointments, recreation and entertainment activities?

2006

Q2: During the summer, do you drive a vehicle at least once a week? Vehicles include all automobiles, trucks, vans and motorcycles.

Q2A: Which of the following best describes your primary vehicle?

Q2B: What is the fuel type of your primary vehicle?

Q2C: What year was your primary vehicle manufactured?

Q3: For the primary vehicle you drive, what would you say are your typical miles per gallon?

Q4: On a typical summer weekday, how many miles do you drive your primary vehicle in and around the greater <CITY> metropolitan area? - IWR note - If R says number other than daily - please calculate and confirm daily number with them before moving on.

Q7: Do you typically use a car air conditioner on hot days?

The 2006 survey includes more detailed vehicle questions than in 2005 such as the vehicle type. However, for the purpose of combining 2005 and 2006 data, the data detail must be reduced. The survey asked fuel efficiency in both years. The efficiency combined with the miles traveled per week can produce total fuel consumed. Though vehicles do not necessarily produce the same amount of pollutant per gallon of gas, an average emission per gallon is used to work with this simplified data.

Annual Emissions and Fuel Consumption for an "Average" Passenger Car[1]

Pollutant	Problem	Amount[2] per mile (mi)	Miles[3]	Calculation	Pollution/Fuel Consumption[4]
Hydrocarbons	Urban ozone (smog) Air toxics	2.9 grams (g)	12,500	2.9 g/mi X 12,500 mi X 1 lb/454 g	**= 80 pounds of hydrocarbons**
Carbon Monoxide	Poisonous gas	22 grams	12,500	22 g/mi X 12,500 mi X 1 lb/454 g	**= 606 pounds of carbon monoxide**
Nitrogen Oxides	Urban ozone (smog) Acid rain	1.5 grams	12,500	1.5 g/mi X 12,500 mi X 1 lb/454 g	**= 41 pounds of nitrogen oxides**
Carbon Dioxide	Global warming	0.8 pound (lb)	12,500	0.8 lb/mi X 12,500 mi	**= 10,000 pounds of carbon dioxide**
Gasoline	Imported oil	0.044 gallon	12,500	0.044gallon/mi X 12,500 mi	**= 550 gallons of gasoline**

Annual Emissions and Fuel Consumption for an "Average" Light Truck[1]

** "Light trucks" include popular passenger vehicles such as pickups, vans, minivans, and sports-utility vehicles **

Pollutant	Problem	Amount[2] per mile (mi)	Miles[3]	Calculation	Pollution/Fuel Consumption[4]
Hydrocarbons	Urban ozone (smog) Air toxics	3.7 grams(g)	14,000	3.7 g/mi X 14,000 mi X 1 lb/454 g	**= 114 pounds of hydrocarbons**
Carbon Monoxide	Poisonous gas	29 grams	14,000	29 g/mi X 14,000 mi X 1 lb/454 g	**= 894 pounds of carbon monoxide**
Nitrogen Oxides	Urban ozone (smog) Acid rain	1.9 grams	14,000	1.9 g/mi X 14,000 mi X 1 lb/454 g	**= 59 pounds of nitrogen oxides**
Carbon Dioxide	Global warming	1.2 pound (lb)	14,000	1.2 lb/mi X 14,000 mi	**= 16,800 pounds of carbon dioxide**
Gasoline	Imported oil	0.065 gallon	14,000	0.065 gallon/mi X 14,000 mi	**= 915 gallons of gasoline**

Figure 3: U.S. EPA Estimated Average Vehicle Emissions

Vehicle Type:	LDGV	LDGT12	LDGT34	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
GVWR:		<6000	>6000	(All)						
VMT Distribution:	0.4361	0.3190	0.1209		0.0388	0.0011	0.0020	0.0775	0.0046	1.0000
Fuel Economy (mpg):	23.9	18.7	14.4	17.3	9.6	27.7	17.6	7.1	50.0	17.0
Composite Emission Factors (g/mi):										
Composite VOC :	1.468	1.557	1.733	1.605	1.492	0.806	1.100	0.628	2.77	1.469
Composite CO :	19.60	24.86	24.97	24.89	15.60	1.923	1.880	3.526	14.07	20.446
Composite NOX :	1.294	1.651	2.019	1.752	4.839	1.912	1.718	14.106	1.98	2.631
Composite CO2 :	371.7	473.6	616.3	512.8	923.8	367.0	577.0	1435.6	177.4	537.11

Table 6: Oregon DEQ estimated average fuel economy and emissions, EPA Mobile 6.2 Output

For all vehicles categories combined, the DEQ estimates an average fuel economy of 17mpg and an average VOC emission of 1.469 g/mi. Multiplying the economy and emission produces about 25 g of VOC per gallon on average for all vehicles. This composite emission factor is used to estimate each respondent's emissions from their computed gallons of fuel consumed per month. This simplified estimation method is necessary to combine 2005 and 2006 data as in 2005 the vehicle type was not asked.

Source	VOC Emissions in pounds per vehicle mile traveled
Diesel-Light Duty Diesel Trucks 1 thru 4 (M6) (LDDT)	9.647566E-07
Diesel-Heavy Duty Diesel Buses (School & Transit)	6.032774E-07
Gasoline-Light Duty Gasoline Vehicles (LDGV)	1.264221E-06
Gasoline-Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5)	1.479264E-06
Gasoline-Heavy Duty Gasoline Vehicles 2B thru 8B & Buses (HDGV)	3.921415E-06
Gasoline-Motorcycles (MC)	3.925355E-06
Diesel-Heavy Duty Diesel Vehicles (HDDV)-Class 3, 4, & 5	2.963419E-07
Diesel-Light Duty Diesel Vehicles (LDDV)	1.06205E-06
Diesel-Heavy Duty Diesel Vehicles (HDDV)-Class 2B	4.391973E-07
Diesel-Heavy Duty Diesel Vehicles (HDDV)-Class 3, 4, & 5	4.918212E-07
Highway Vehicles-Diesel-Heavy Duty Diesel Vehicles (HDDV)-Class 6 & 7	9.315025E-07
Diesel-Heavy Duty Diesel Vehicles (HDDV)-Class 8A & 8B	1.200244E-06
Highway Vehicles-Diesel-Heavy Duty Diesel Buses (School & Transit)	9.507116E-07

Table 7: Oregon DEQ Vehicle VOC Emission Factors for Multnomah County

Data Analysis

The survey dataset was cleaned of incomplete responses. “Don't know” responses were not included in the analysis. Emissions estimation methods were applied to the individual responses. Then the emission estimate data was graphed against housing density information obtained by dividing per zipcode housing numbers by zipcode area. Housing density was divided into four quartiles as used in a previous study, Linking land use with household vehicle emissions in the central Puget Sound (Frank et. al, 2000). The quartile statistics feature of SPSS was applied to the range of housing densities in Portland and Houston combined to generated the four housing density quartiles. The quartiles were numbered 1 through 4 with 1 being the lowest density and 4 being the highest.

Quartile	Min Housing Density (Dwellings per square mile)	Max Housing Density (Dwellings per square mile)
1	0	815.7
2	815.7	1521.2
3	1521.2	2623.5
4	2623.5	Infinity

Table 8: Housing Density Quartiles

The following formulas were used to estimate emissions:

Lawn Care:

IF (Q13 mower type = Gas or Diesel)

Mower Hydrocarbon Emissions (in pounds per month) = (number of mows per month) x (lawn size in acres) x (3.7 hours / acre) x (13.39 g/hp-hr) x (4.07 hp) x (0.33 load factor)

IF (Q15 “Do you use other gas powered garden equipment” = TRUE)

“**Trimmer” Hydrocarbon Emissions** (in pounds per month) = [(number of mows per month) / 6] x (261 g/hp-hr) x (0.91 load factor) x (1.23 hp)

Total lawn care emissions per year = (6 months) x (mower emissions + trimmer emissions)

Household Products:

Personal Care Product VOC pounds per year = 0.54 x (number of uses per month)

FIFRA Related Products VOC pounds per year = 3.13 x (number of uses per month)

Adhesives & Sealants VOC pounds per year = 1.11 x (number of uses per month)

Coatings and Related Products VOC pounds per year = 1.70 x (number of uses per month)

Grilling:

(number of cook-outs / week) X (4 weeks / month) X (0.5 kg hamburger / cook-out) X (0.3 mg benzo anthracene / kg hamburger) = mg benzo anthracene per month

Off-road Vehicles:

(number of uses per month) X (20 miles per use) X (53.70 g/mile hydrocarbons) = Hydrocarbon emissions in grams per month

Driving:

gallons per month = (4.3 weeks per month x miles per week) / (miles per gallon)

emissions = (per gallon emission factor) x (number of gallons)

Results

Behavior and Demographic Patterns of Emissions

GIS analysis of Portland survey data by zipcode initially showed some possible trends in per-capita emissions. For example, behavior associated with lawn-care emissions (Figure 4) appeared to be more concentrated outside of population dense areas. The same appeared true of grilling (Figure 5) as well as the use of aerosol spray cans (Figure 6). The maps generated an interest in exploring relationships between demographics and emissions. However, the maps are not quantitative. Data analysis of emissions estimates was performed in order to better quantify possible trends.

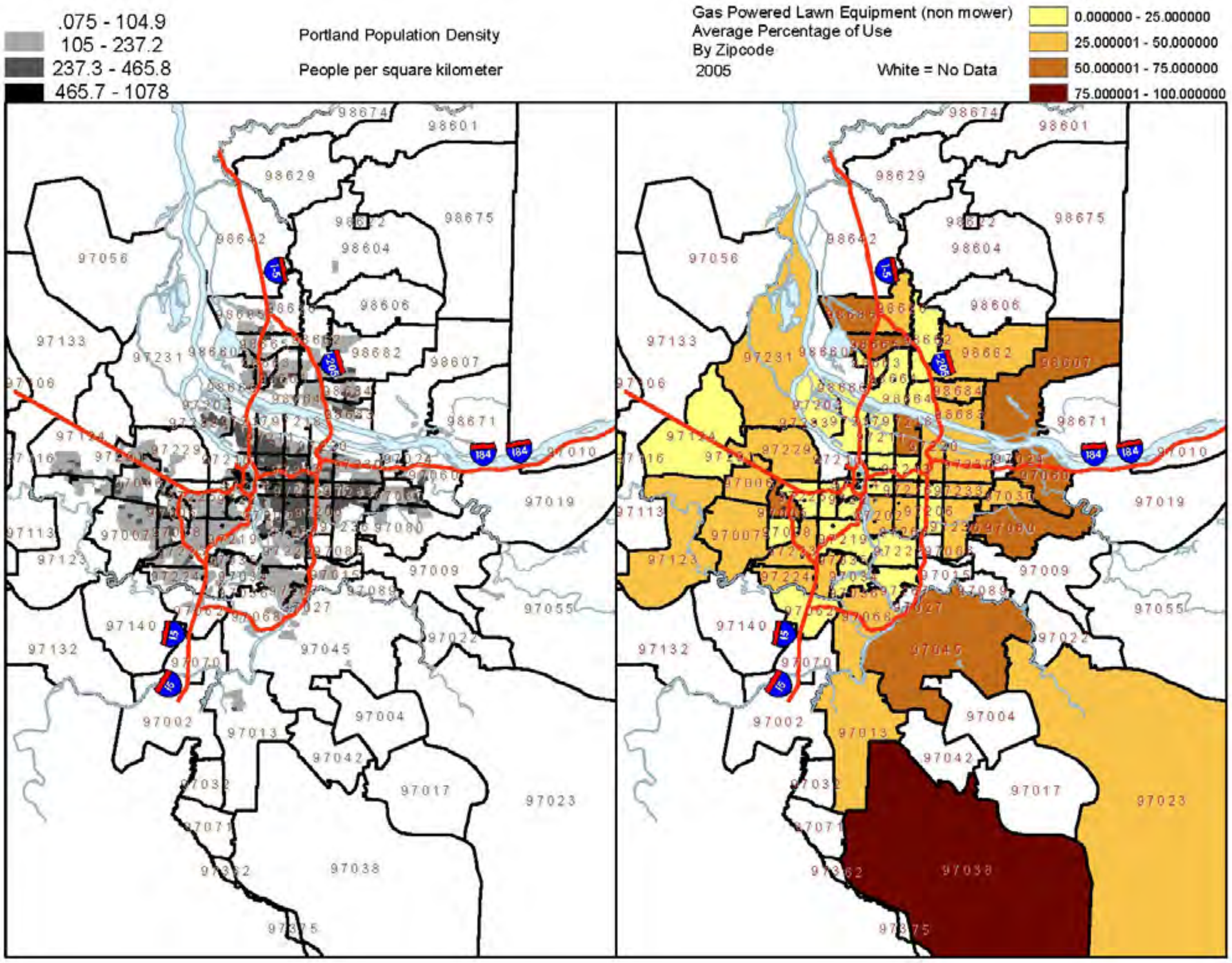

Figure 4: Population density and Non-mower gas powered lawn equipment use

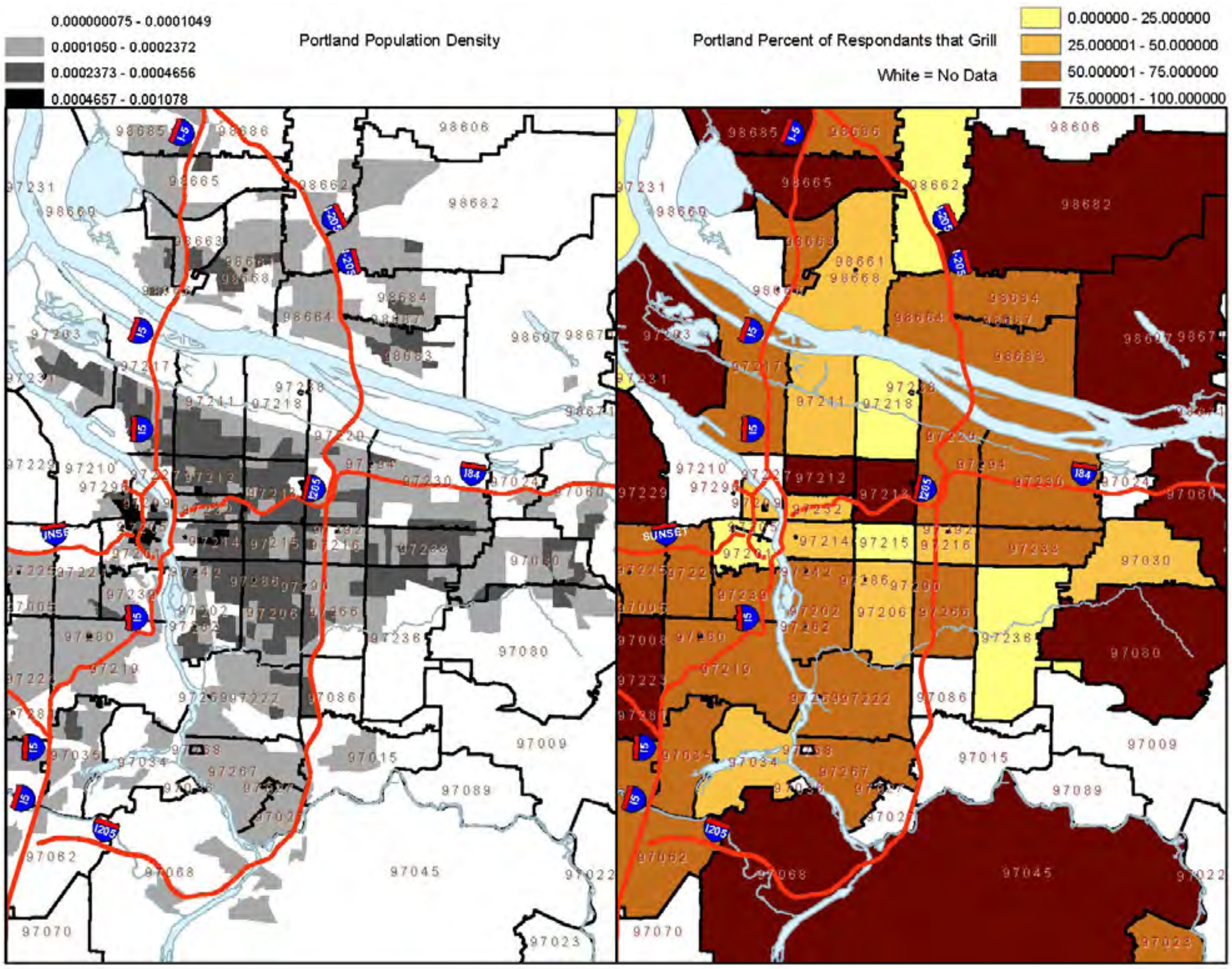

Figure 5: Population density and grill use

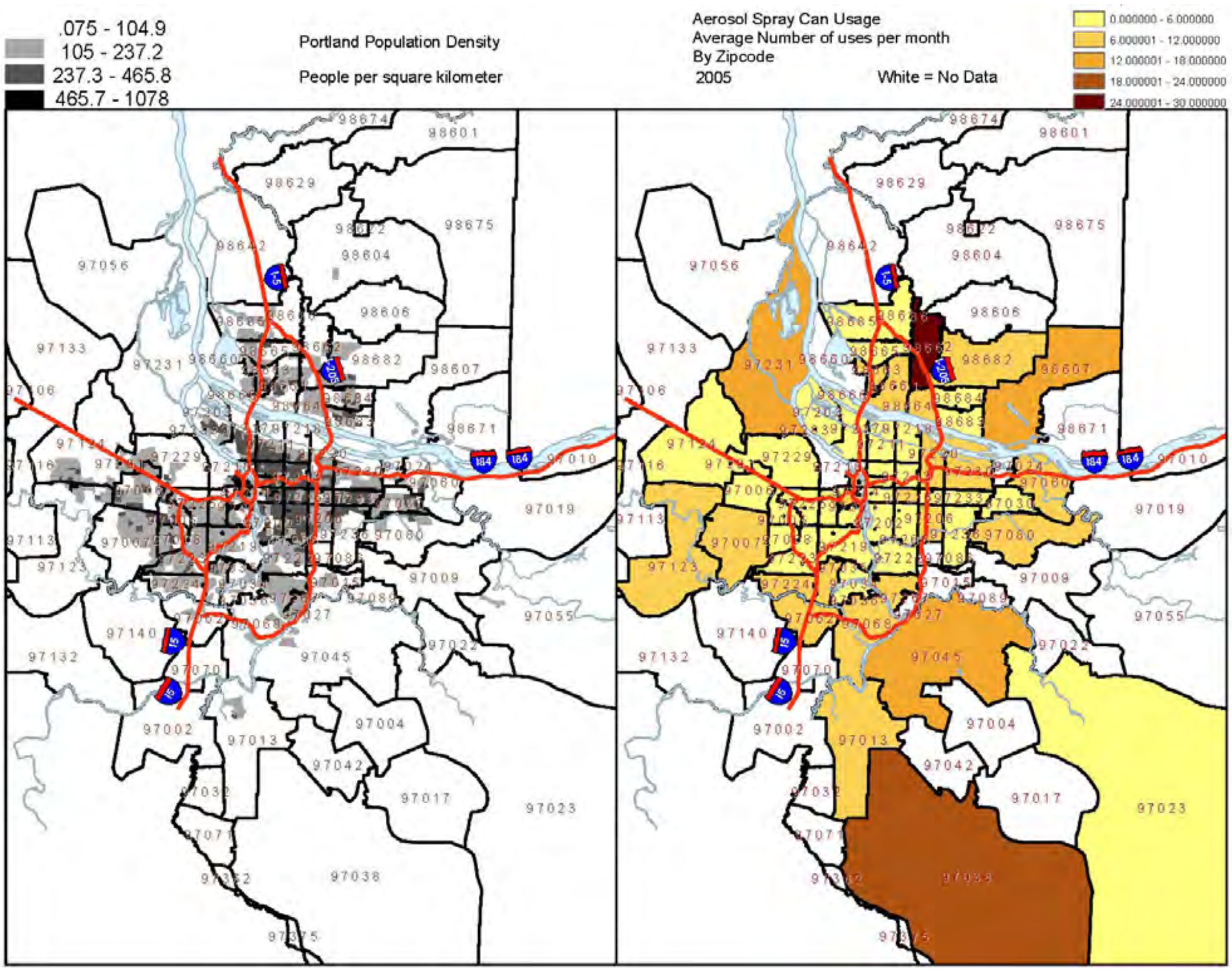

Figure 6: Population density and spray-can use

The main demographic indicator studied was housing density. Portland surveyed areas have a higher average density than areas surveyed in Houston. Both cities show a similar mean income level for individuals surveyed. An income level of 1 indicates up to $10K, 2 indicates $10K to $30K, 3 indicates $30K to $50K, 4 indicates $50K to $100K, and 5 indicates more than $100K. So, a mean income level of 3.4 would correspond to a mean income of about $38K.

	Mean Housing Density	Mean Income Level
Portland	1936 units / sq-mi (+/- 70)	3.4 (+/- 0.8)
Houston	1462 units / sq-mi (+/- 83)	3.38 (+/- 0.1)

Table 1: Comparing housing density and income level between both cities. (Error 95% CI)

When data from both cities is combined, there is a relatively even distribution of respondents among the four housing density quartiles. Individually, however, the two cities have a somewhat uneven distribution of respondents among different housing densities.

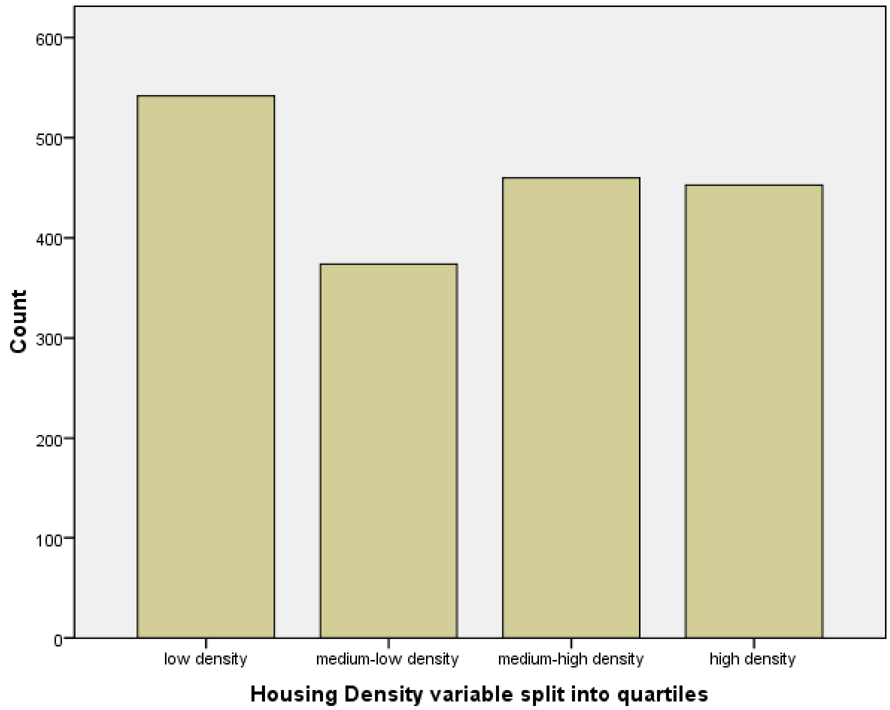

Figure 7: Number of responses vs. housing density

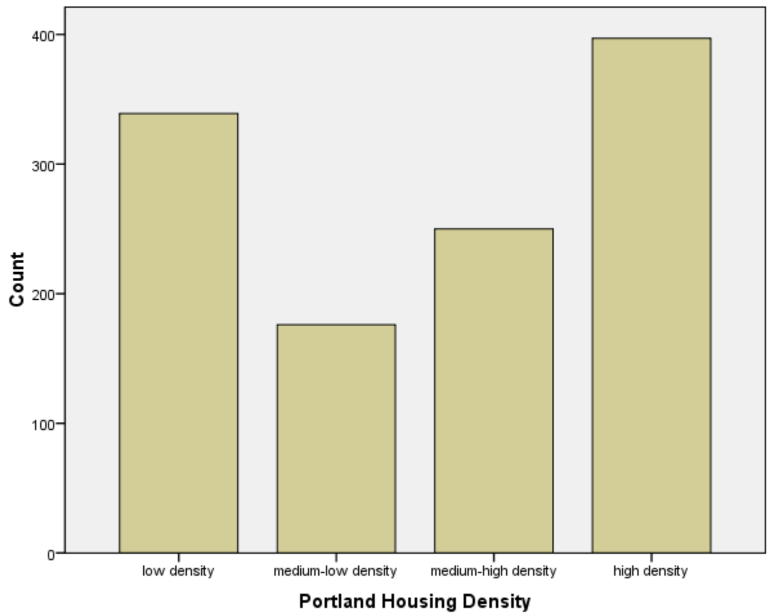

Figure 8: Number of responses vs. Portland housing density

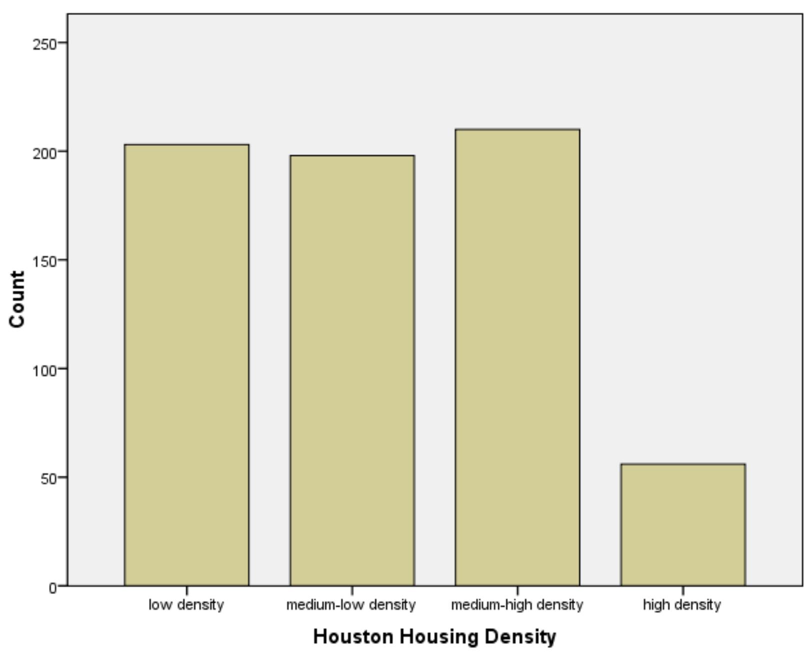

Figure 9: Number of responses vs. Houston housing density

Lawn Care Emissions and Housing Density

For both Houston and Portland, lawn care hydrocarbon emissions estimations are higher for areas of lower housing density. In fact, the difference between the high and lowest quartile emissions is a factor of about 3 for Houston and a factor of about 6 for Portland. Portland's average per-capita lawn care emissions are much lower than Houston's in all density quartiles. Houses, townhouses, and condominiums have the highest lawn care emissions while apartments, single rooms, and “other” have the lowest emissions.

A Spearman bivariate correlation shows a significant correlation between housing density and lawncare emissions.

Case	City	N	Correlation Coefficient	Significance
Lawncare vs. Housing Density	Houston	667	-0.228**	0.000
Lawncare vs. Housing Density	Portland	1163	-0.285**	0.000
Lawncare vs. Housing Density	Both	1830	-0.305**	0.000

Table 9: Lawncare vs. Housing Density Statistical Results

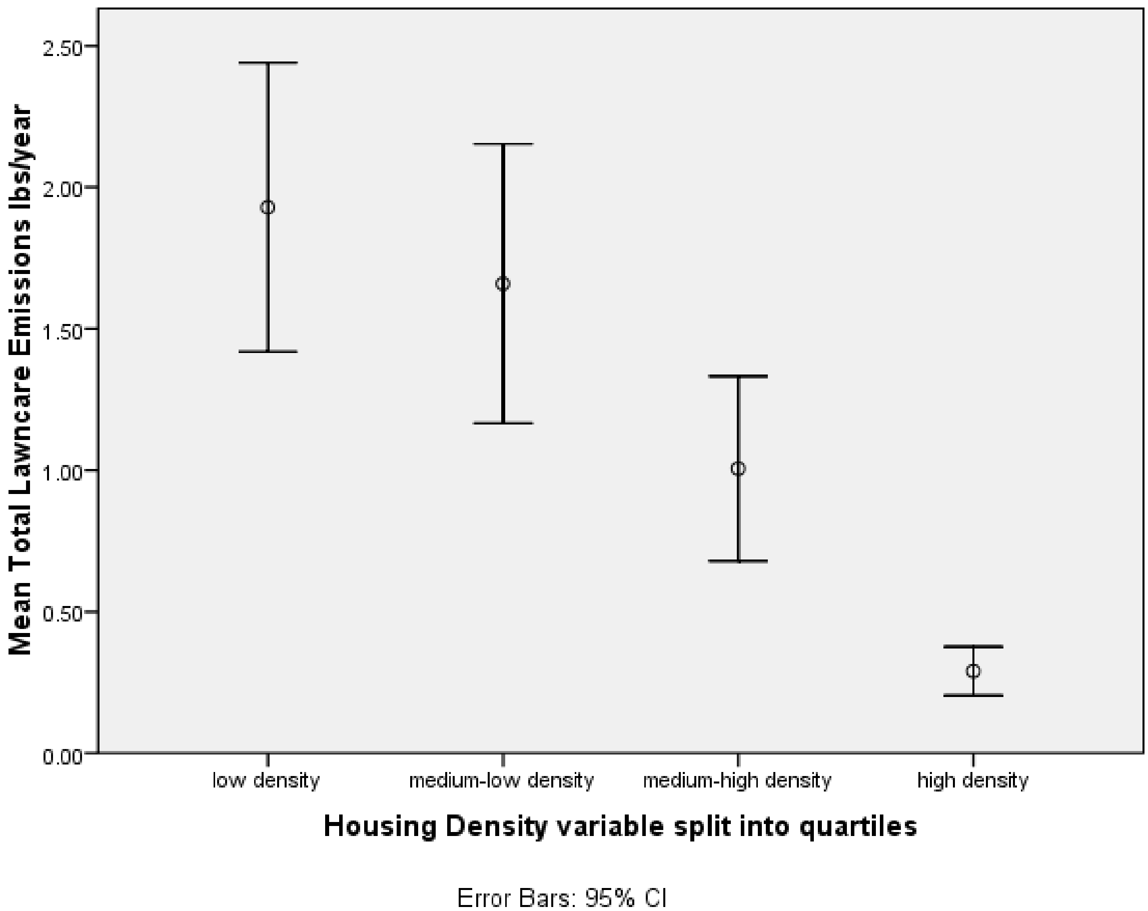

Figure 10: Lawncare vs. Housing Density

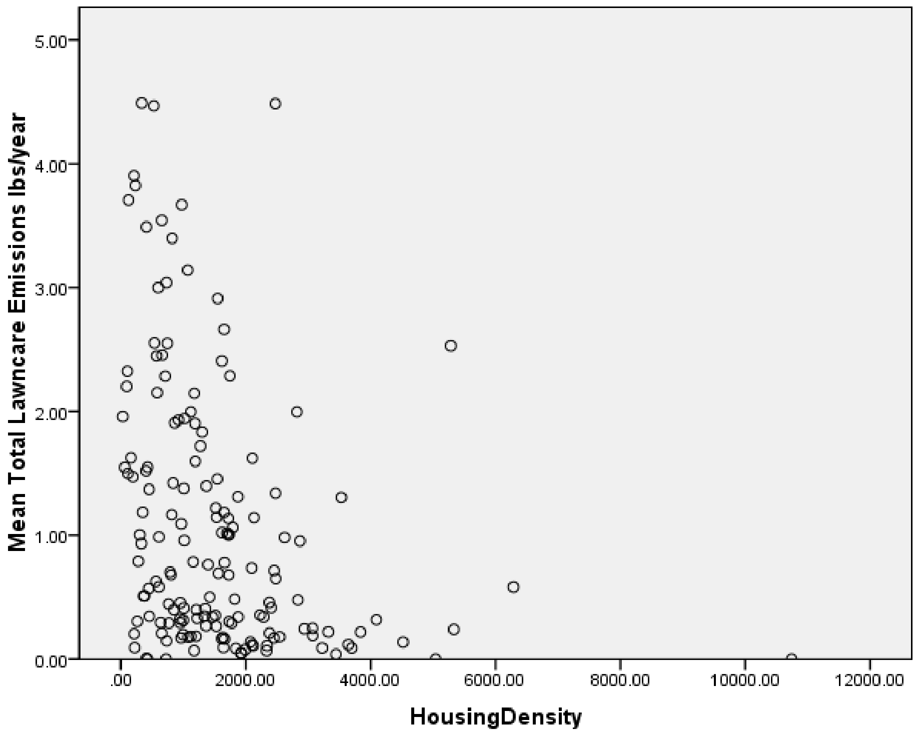

Figure 11: Lawncare vs. housing density

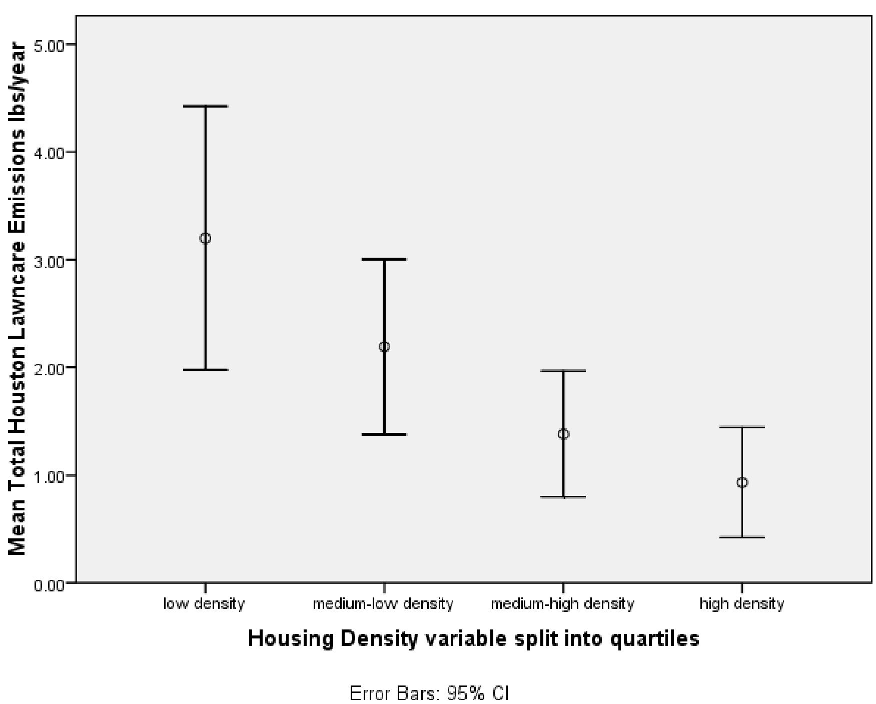

Figure 12: Houston lawn care emissions vs. housing density

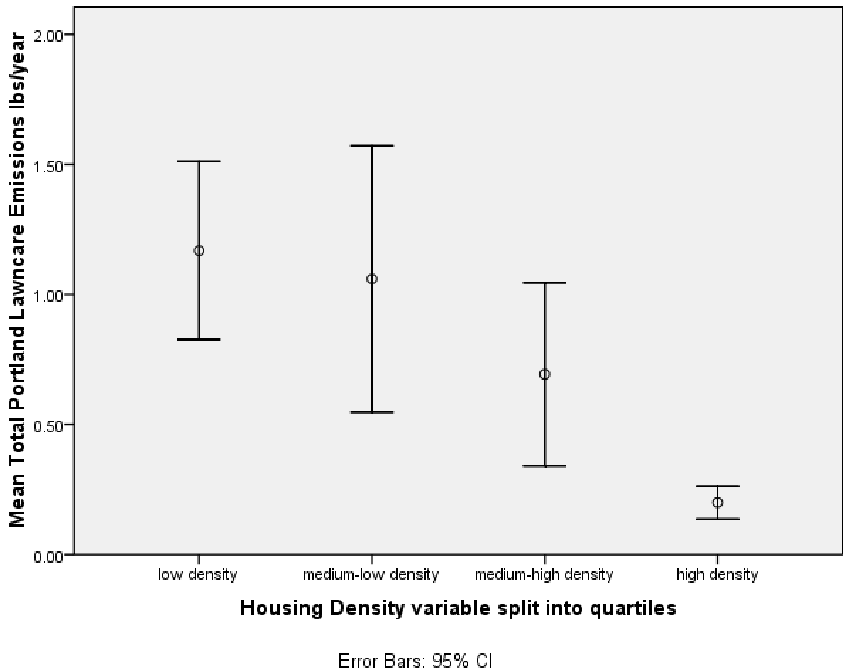

Figure 13: Portland lawn care emissions vs. housing density

Portland	0.71 (+/- 0.15) lbs / year
Houston	2.13 (+/- 0.48) lbs / year

Table 10: Portland and Houston mean lawncare emissions (error 95% Cl)

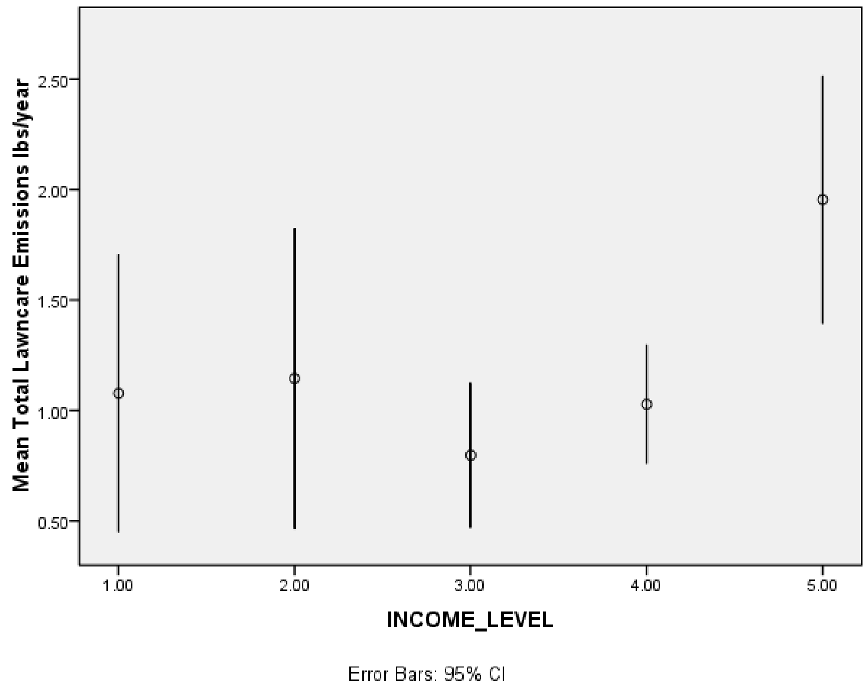

Figure 14: Lawncare emissions vs. income

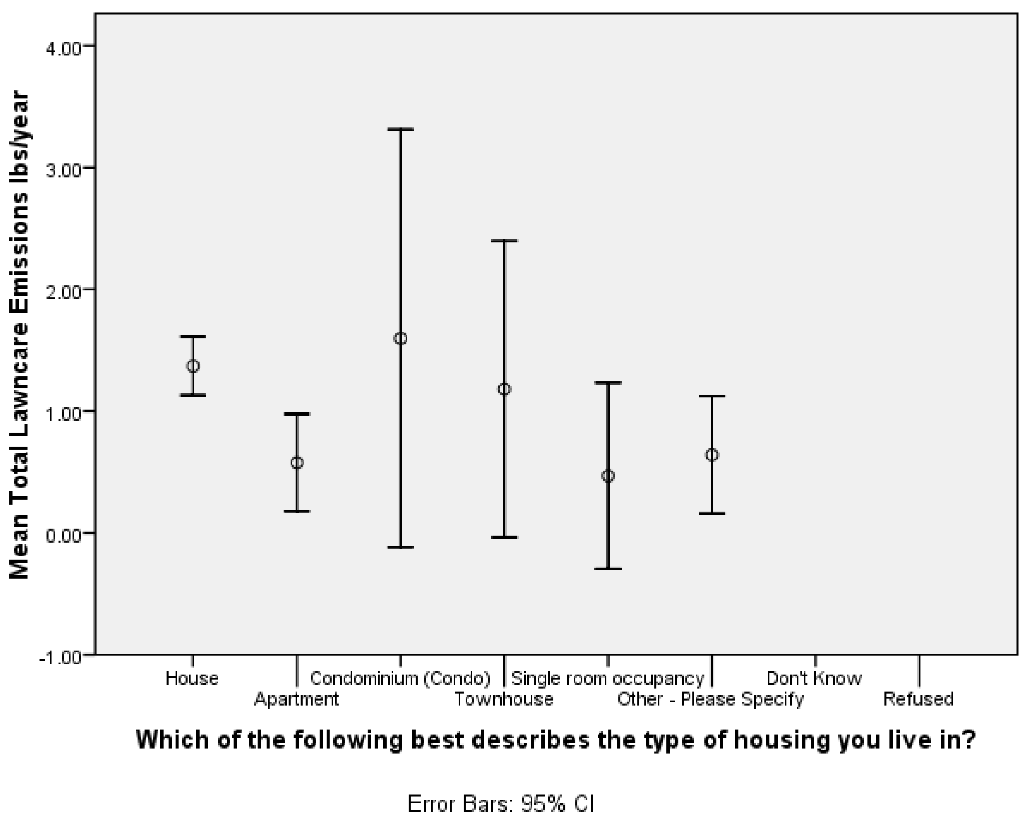

Figure 15: Lawncare emissions vs. housing type

<u>Personal Care Products</u>

A relationship between housing density and personal care product emissions is less clear and shows almost opposite behavior between Houston and Portland. However, for combined results, three out of 4 of the quartiles exhibit a general trend of lower per capita emissions in higher density areas. Females surveyed have average total emission estimates about twice as high as males. The lowest income group exhibited the highest emissions estimates. Houston's total average personal care product emissions were much higher than Portland's. A bivariate Spearman analysis shows correlation for Portland and combined city emissions with housing density. However, the is no significant correlation for Houston alone.

Case	City	N	Correlation Coefficient	Significance
Personal Care Products vs. Housing Density	Houston	458	-0.003	0.948
Personal Care Products vs. Housing Density	Portland	757	-0.192**	0.000
Personal Care Products vs. Housing Density	Both	1215	-0.190**	0.000

Table 11: Personal Care Producs vs. Housing Density Statistical Results

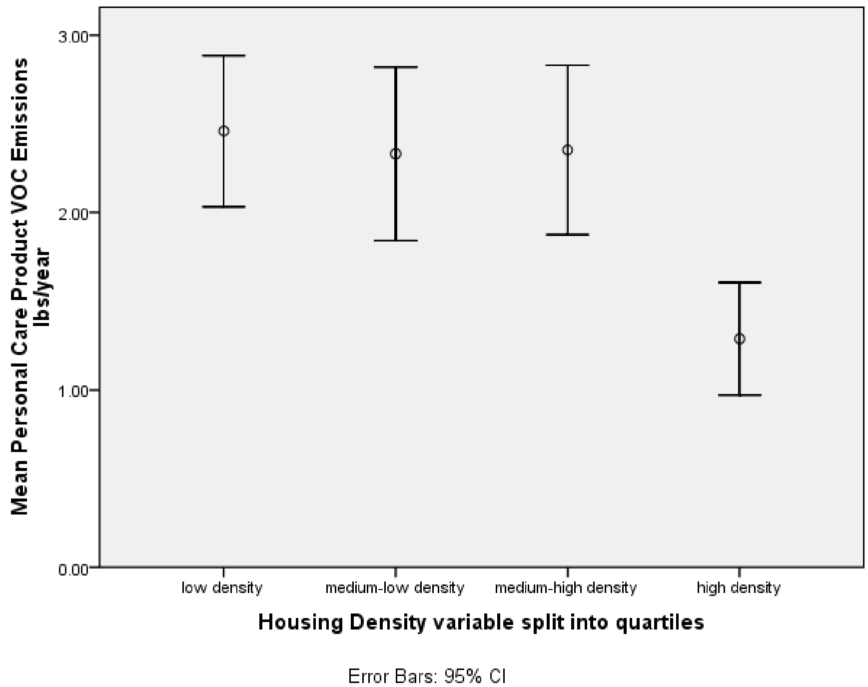

Figure 16: Combined personal care product emissions vs. housing density

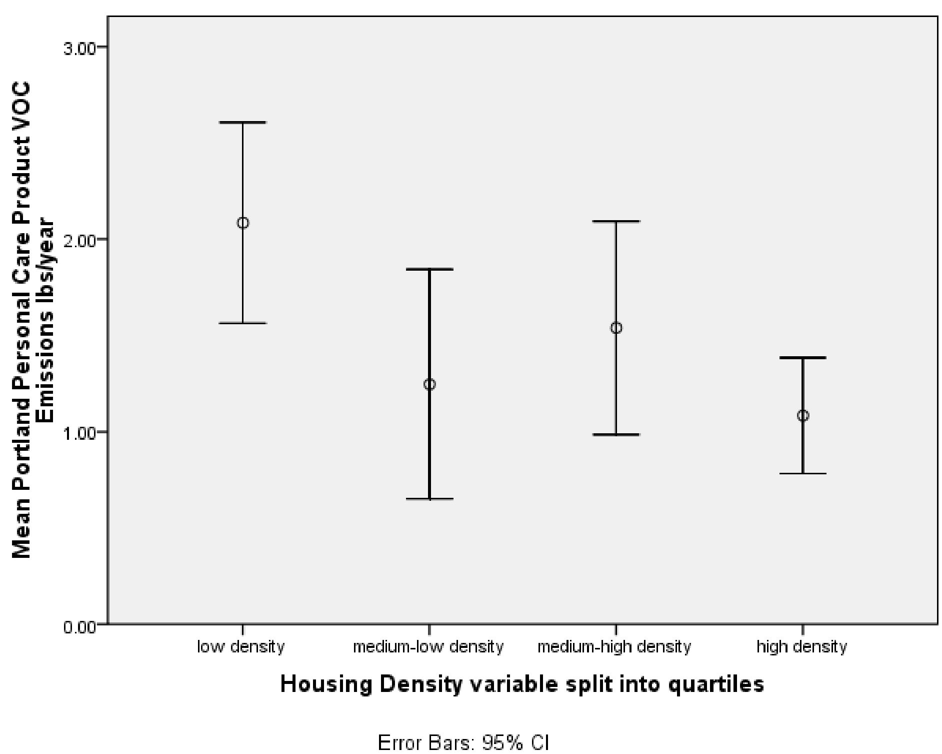

Figure 17: Portland personal care product emissions vs. housing density

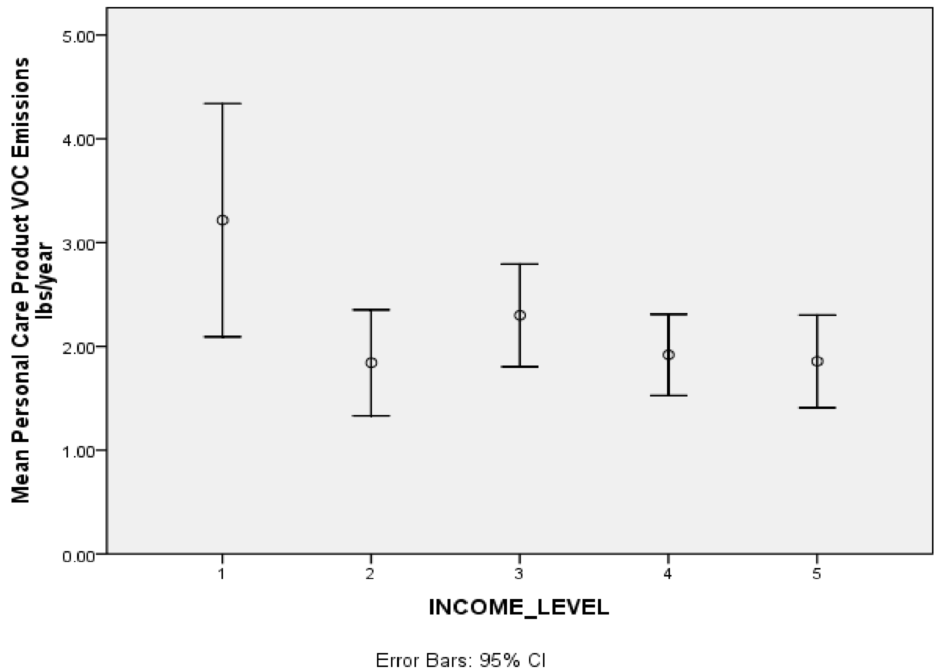

Figure 18: Personal Care Product Emissions vs. Income Level

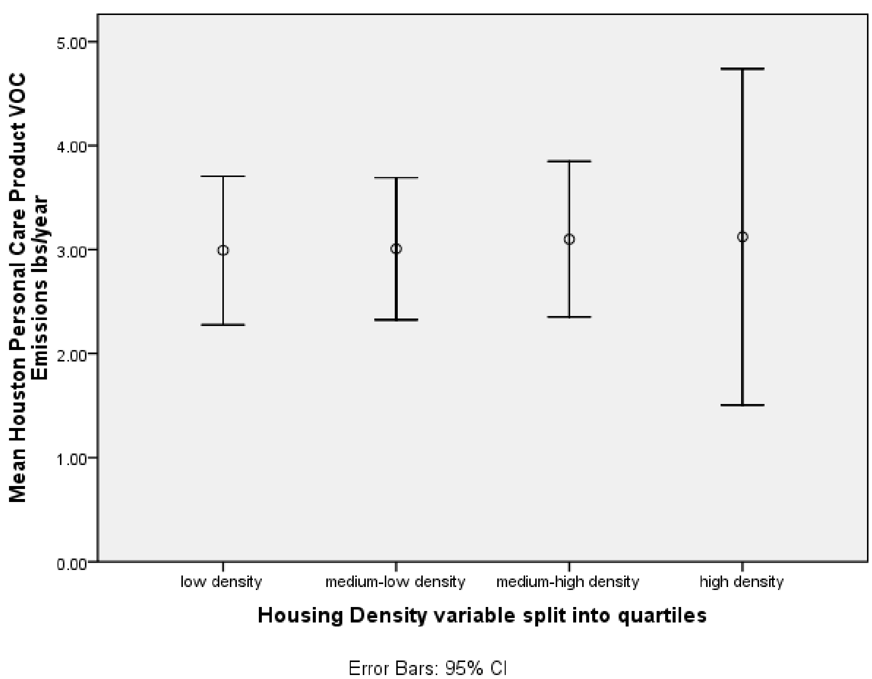

Figure 19: Houston personal care product emissions vs. housing density

Female	2.59 (+/- 0.3) lbs / year
Male	1.15 (+/- 0.25) lbs / year

Table 12: Female and Male Personal Care Product emissions (error 95% Cl)

Portland	1.44 (+/- 0.23) lbs / year
Houston	3.05 (+/- 0.4) lbs / year

Table 13: Portland and Houston Personal Care Product emissions (error 95% Cl)

<u>Pesticides</u>

For Houston and combined city data, trend emerges for pesticide VOC emissions. However, when Portland is graphed alone, the trend is unclear. A bivariate Spearman analysis shows correlation between emissions and housing density for the cities individually as well as combined cities.

Case	City	N	Correlation Coefficient	Significance
Pesticides vs. Housing Density	Houston	451	-0.200**	0.000
Pesticides vs. Housing Density	Portland	754	-0.218**	0.000
Pesticides vs. Housing Density	Both	1205	-0.250**	0.000

Table 14: Pesticides vs. Housing Density Statistical Results

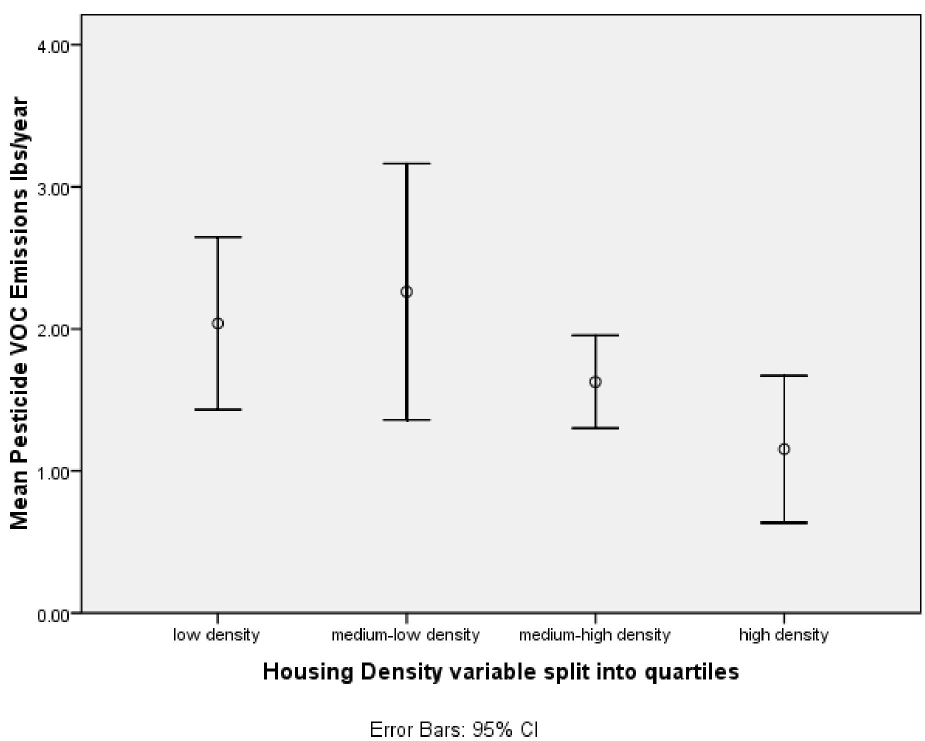

Figure 20: Pesticide emissions vs. housing density

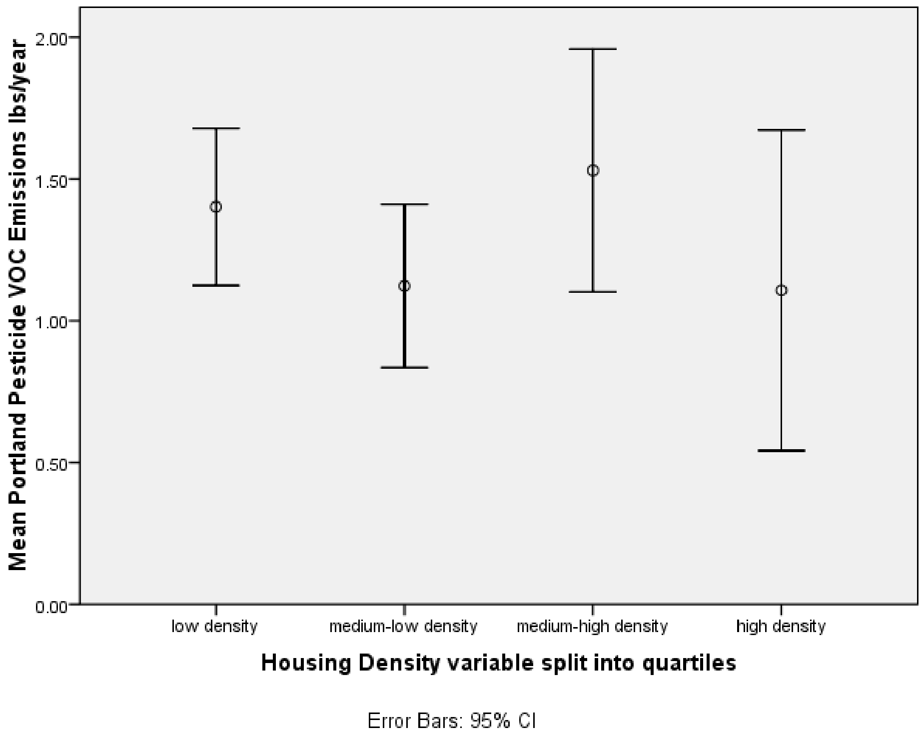

Figure 21: Portland pesticide emissions vs. housing density

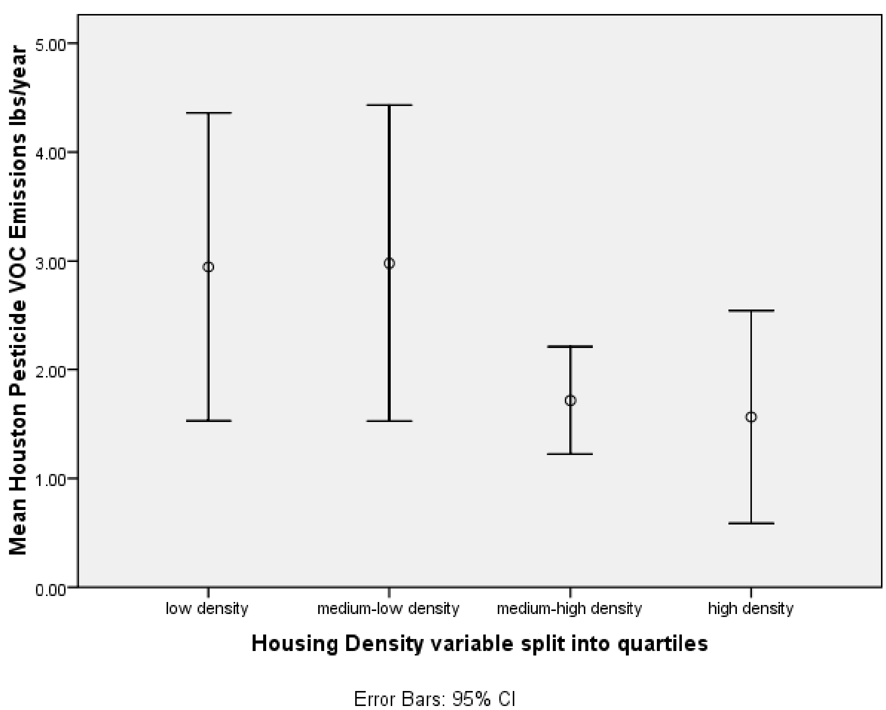

Figure 22: Houston pesticide emissions vs. housing density

Sealants, Glues, Sprays

Sealants, glues, and spray paint emissions show conflicting results making it difficult to produce a conclusion for this emissions category. A bivariate Spearman analysis shows no significant correlation between this emission category and housing density.

Case	City	N	Correlation Coefficient	Significance
Sealants, Glues, Sprays vs. Housing Density	Houston	458	-0.067	0.151
Sealants, Glues, Sprays vs. Housing Density	Portland	757	0.065	0.072
Sealants, Glues, Sprays vs. Housing Density	Both	1215	0.005	0.848

Table 15: Sealants, Glues, Sprays vs. Housing Density Statistical Results

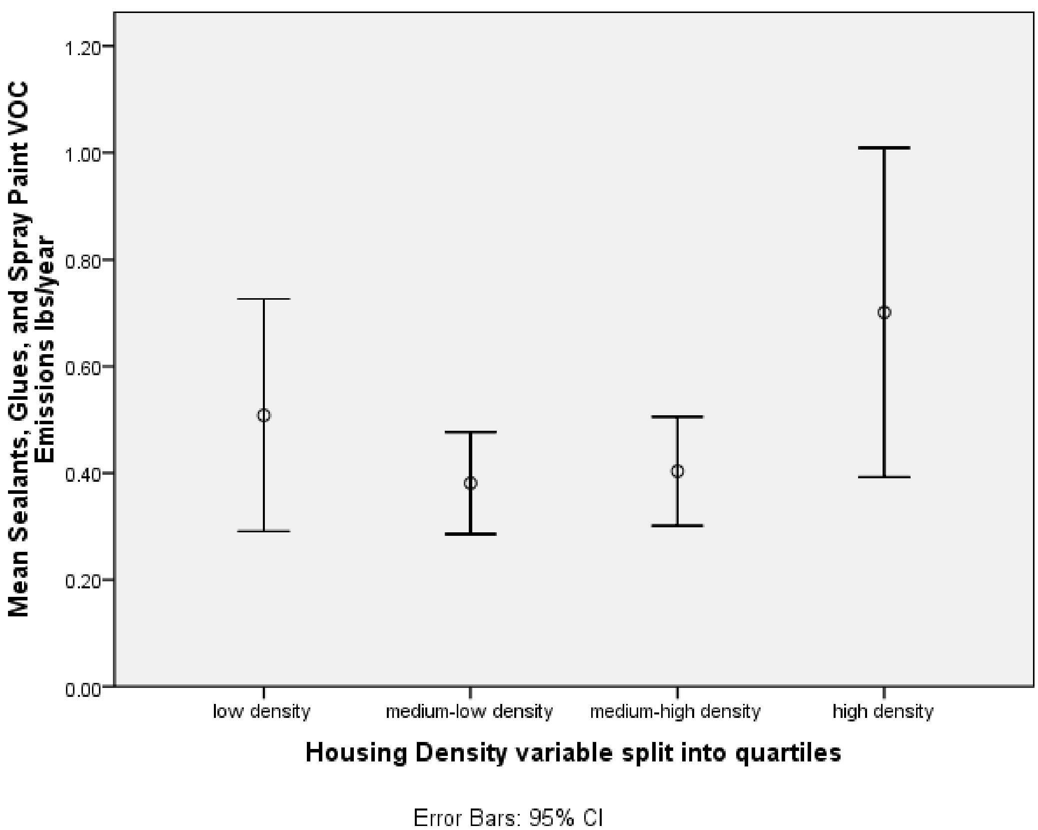

Figure 23: Sealants, glues, spray paint emissions vs. housing density

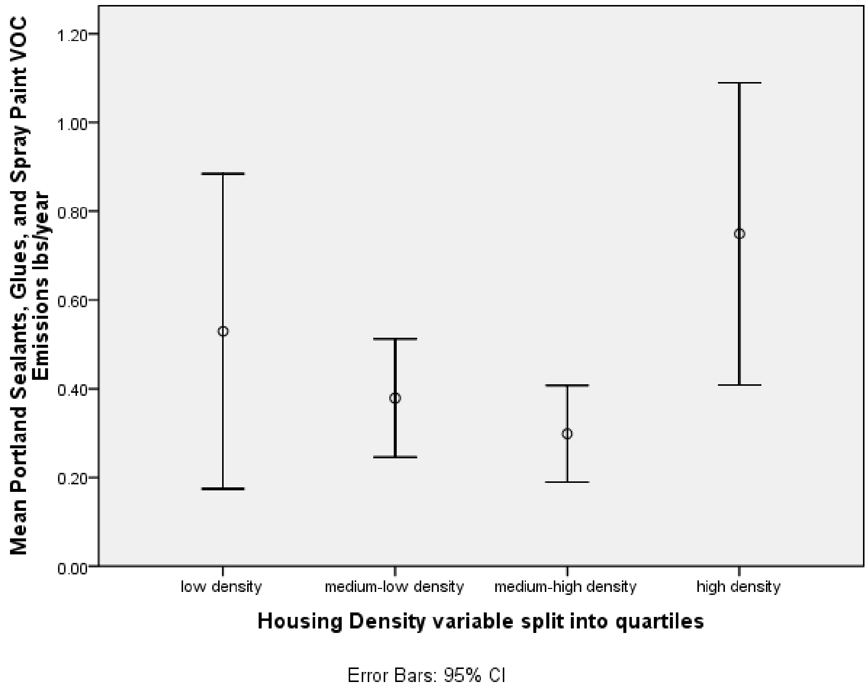

Figure 24: Portland Sealants, glues, spray paint emissions vs. housing density

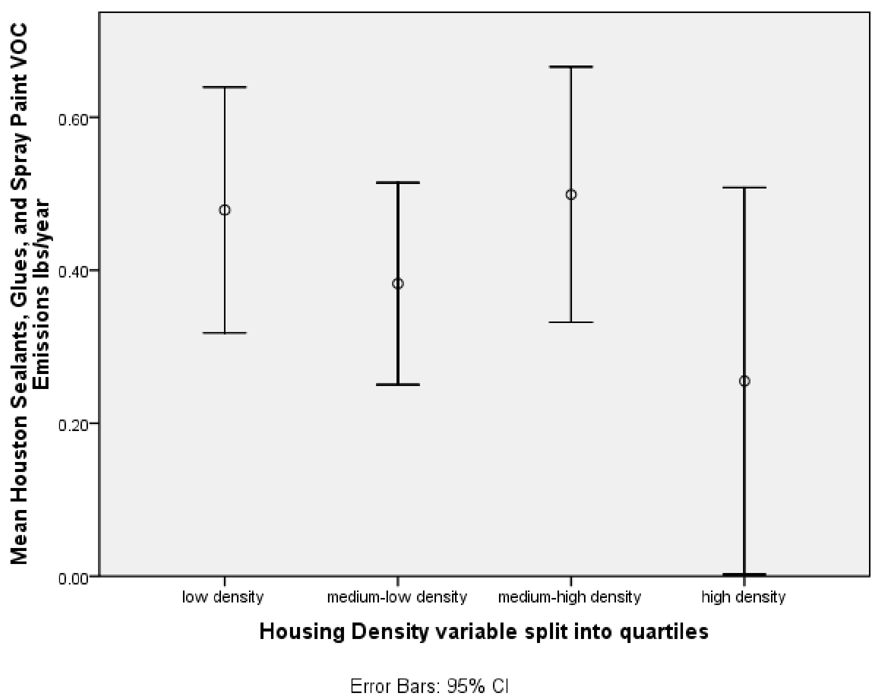

Figure 25: Houston sealants, glues, spray paint emissions vs. housing density

Paints, Stains, Solvents

Paints, stains, and solvents also show conflicting results and almost opposite behavior for Portland and Houston. A bivariate Spearman analysis shows a significant correlation for Houston emissions in this category with housing density. A correlation is not observed for Portland or combined city data.

Case	City	N	Correlation Coefficient	Significance
Paints, Stains, Solvents vs. Housing Density	Houston	459	-0.135**	0.004
Paints, Stains, Solvents vs. Housing Density	Portland	757	0.031	0.390
Paints, Stains, Solvents vs. Housing Density	Both	1216	0.017	0.546

Table 16: Paints, Stains, Solvents vs. Housing Density Statistical Results

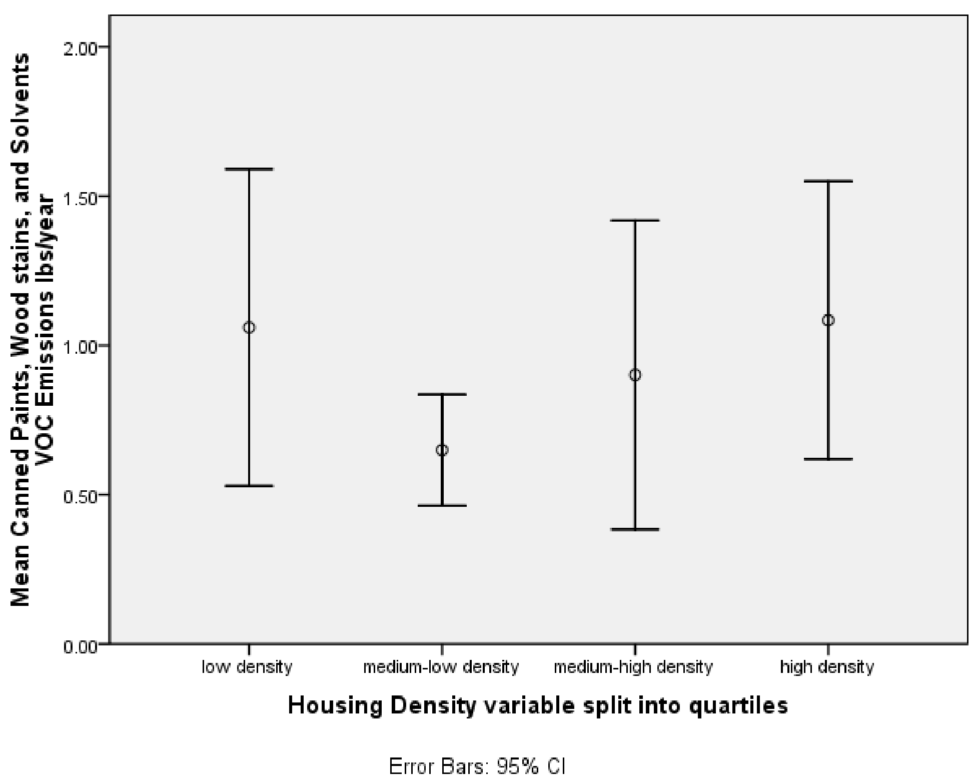

Figure 26: Paints, stains, solvent emissions vs. housing density

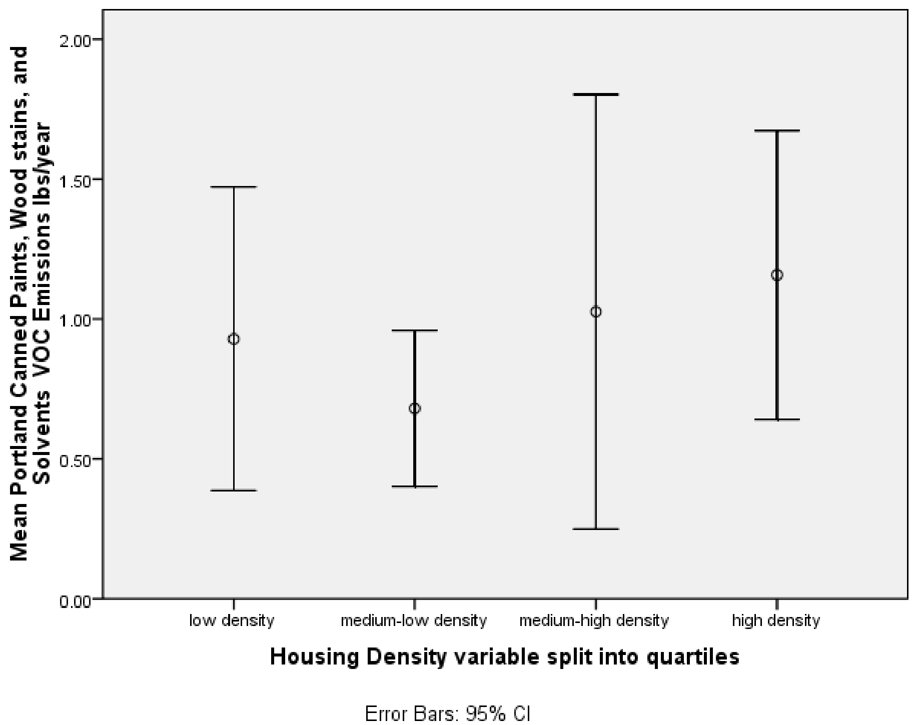

Figure 27: Portland paints, stains, solvent emissions vs. housing density

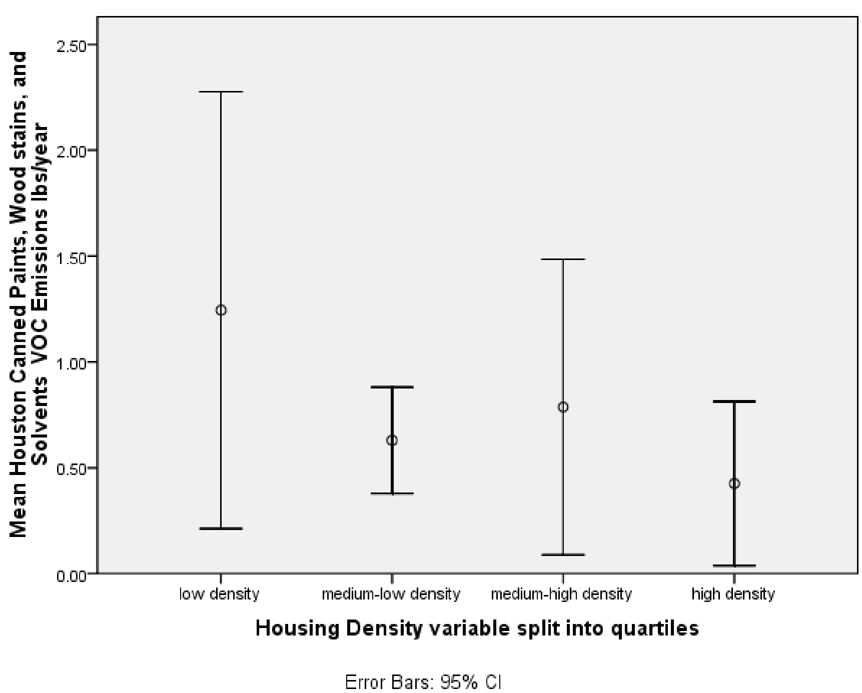

Figure 28: Houston paints, stains, solvent emissions vs. housing density

Grilling

There is a general trend of about 10% reduced grilling in the two more dense quartiles as compared to the two less dense quartiles. An actual emission estimate of this category is not made due to the difficulty in establishing an emissions factor. A bivariate Spearman analysis shows no significant correlation between grill use and housing density.

Case	City	N	Correlation Coefficient	Significance
Grilling Use vs. Housing Density	Houston	424	-0.113*	0.020
Grilling Use vs. Housing Density	Portland	743	-0.040	0.281
Grilling Use vs. Housing Density	Both	1167	-0.016	0.593

Table 17: Grilling Use vs. Housing Density Statistical Results

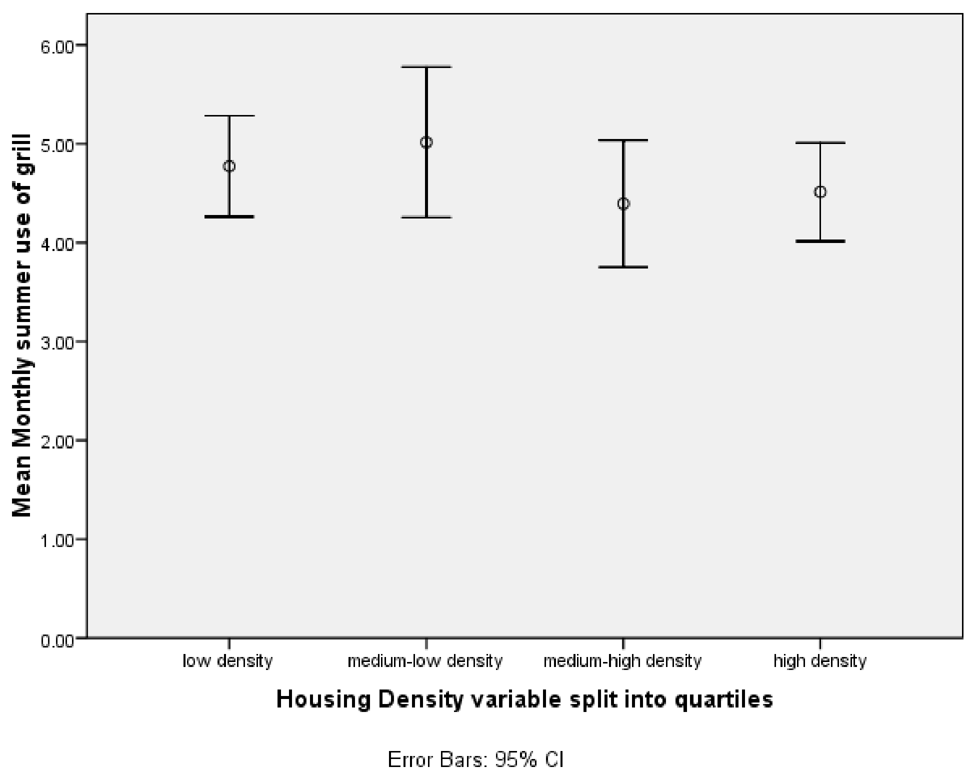

Figure 29: Grill use vs. housing density

Off-Road Vehicle

Off-road vehicle use seems to show a relationship to housing density with a higher average per capita use in low density areas. The emission estimate pattern is identical as specific information about the vehicle or craft is unavailable. However, a bivariate Spearman analysis shows no significant correlation between off-road emissions and housing density.

Case	City	N	Correlation Coefficient	Significance
Off-road use vs. Housing Density	Houston	207	-0.012	0.860
Off-road use vs. Housing Density	Portland	404	-0.093	0.063
Off-road use vs. Housing Density	Both	611	-0.067	0.097

Table 18: Off-road use vs. Housing Density Statistical Results

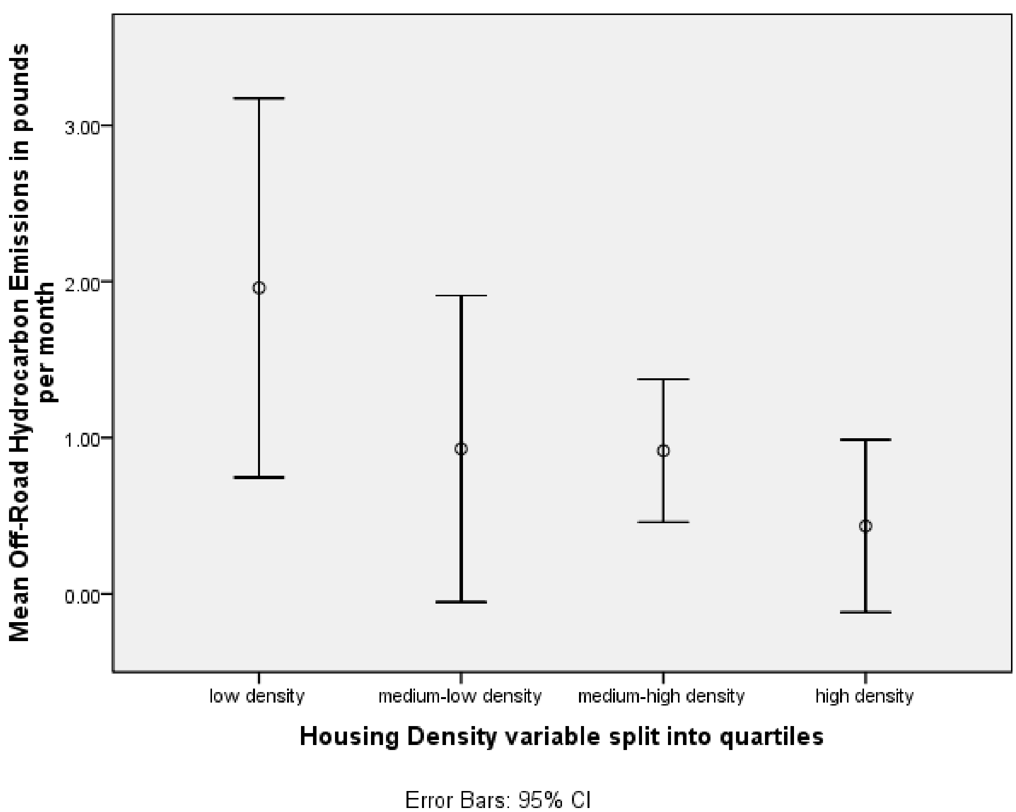

Figure 30: Off-road emissions vs. housing density

<u>Driving</u>

Monthly automobile fuel consumption appears to decrease as housing density increases. The lowest density quartile consumes an average of almost four times as much fuel compared with the highest density quartile. This indicates that emissions would behave similarly. A bivariate Spearman analysis shows a significant correlation between vehicle emissions and housing density for Houston and combined city data, but not for Portland alone.

Case	City	N	Correlation Coefficient	Significance
Vehicle vs. Housing Density	Houston	573	-0.148**	0.000
Vehicle vs. Housing Density	Portland	1069	-0.325**	0.000
Vehicle vs. Housing Density	Both	1643	-0.305**	0.000

Table 19: Vehicle Emissions vs. Housing Density Statistical Results

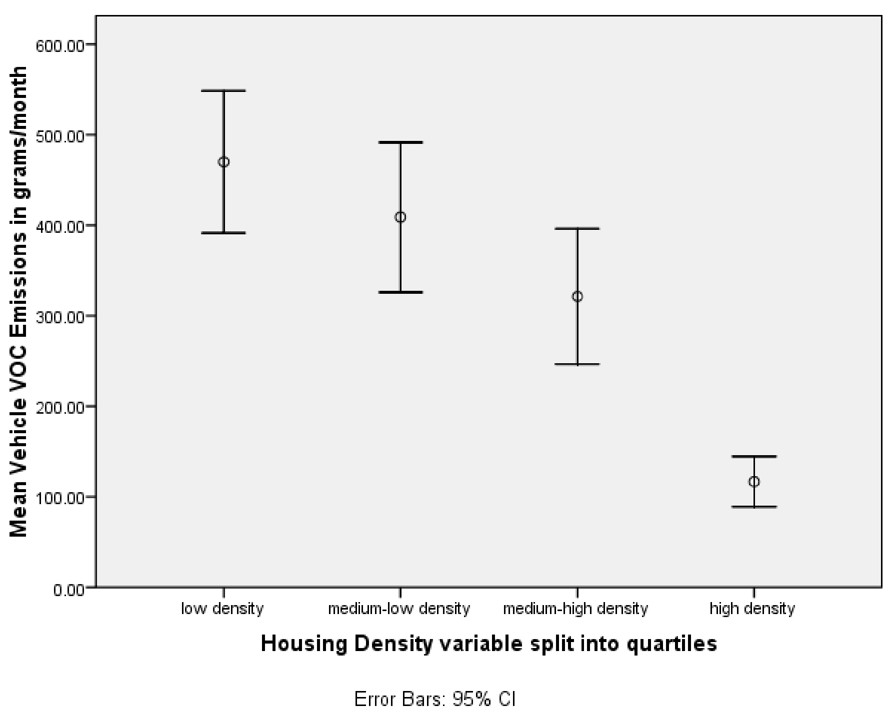

Figure 31: Vehicle emissions vs. housing density

<u>Combined Results</u>

When consumer product VOC emissions are combined, a general trend of lower emissions in higher density areas is observed. There is an increase of about 50% in emissions estimates from the highest to lowest density quartiles. A bivariate Spearman analysis shows a significant correlation between combined consumer product emissions and housing density.

Case	City	N	Correlation Coefficient	Significance
Consumer Products, Vehicle, Lawncare combined vs. Housing Density	Houston	390	-0.226**	0.000
Consumer Products, Vehicle, Lawncare combined vs. Housing Density	Portland	698	-0.327**	0.000
Consumer Products, Vehicle, Lawncare combined vs. Housing Density	Both	1088	-0.361**	0.000

Table 20: Combined emissions vs. Housing Density Statistical Results

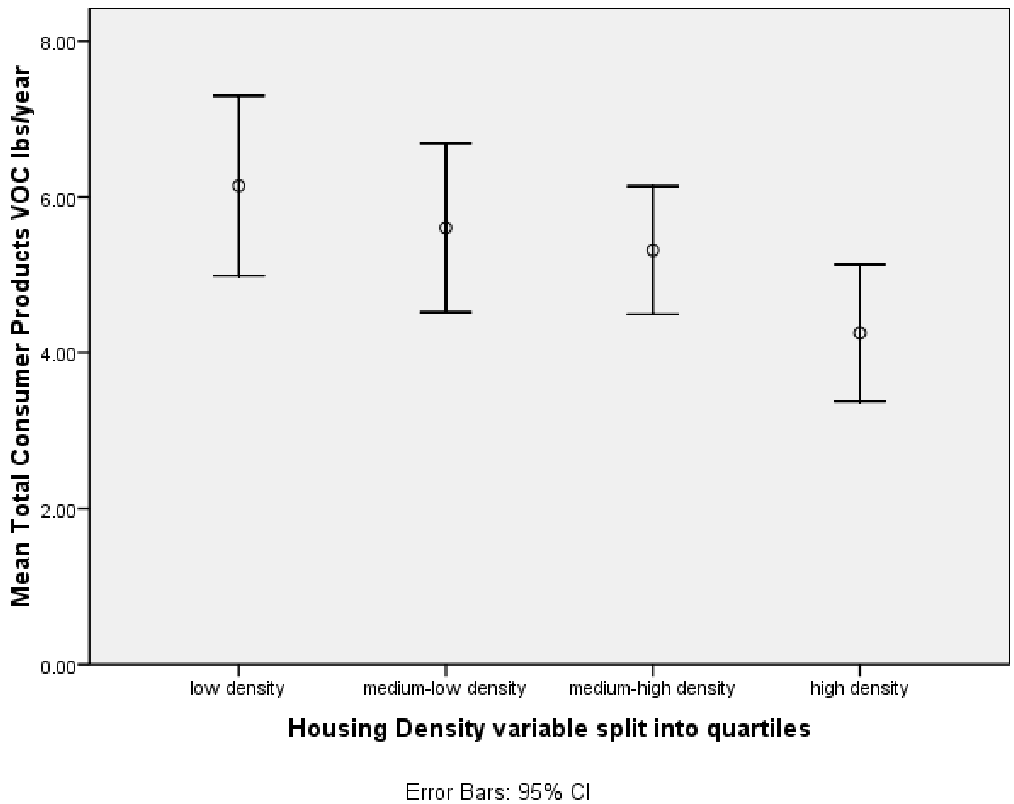

Figure 32: Consumer product emissions vs. housing density

After combining several emissions and graphing against housing density, a fairly clear pattern emerges. Per capita VOC emissions for these categories combined are inversely related to housing density. A bivariate Spearman analysis shows a significant correlation between combined emissions and housing density.

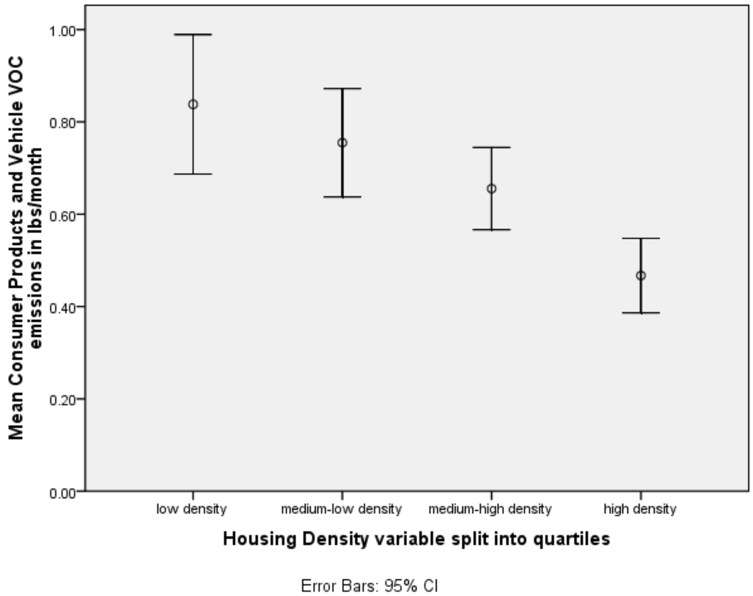

Figure 33: Consumer products and vehicle emissions vs. housing density

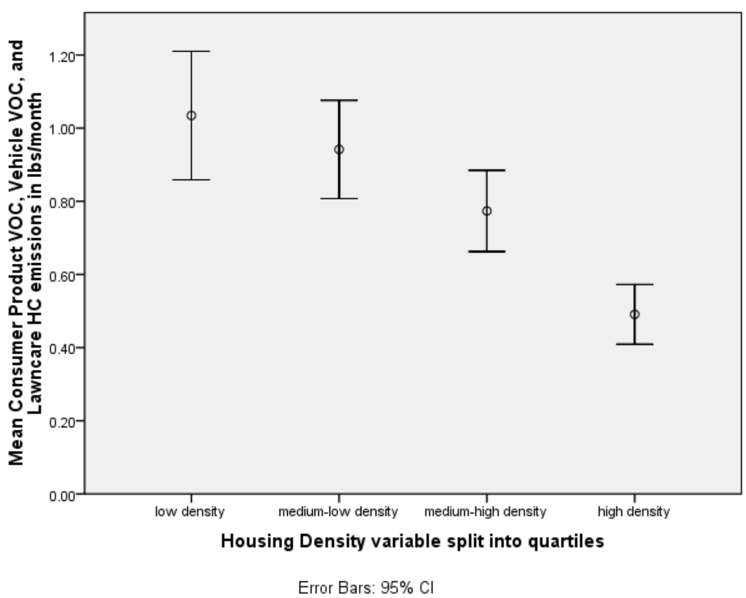

Figure 34: Consumer products, vehicle, and lawncare emissions vs. housing density

Summarized below are the results of a bivariate Spearman coorelation statistical test between all the emission types analyzed and housing density. The test showed significant corelation in at least one city for many of the emission types including lawncare, personal care products, pesticides, paints stains and solvents, grilling, and vehicle emissions.

Case	City	N	Correlation Coefficient	Significance
Lawncare vs. Housing Density	Houston	667	-0.228**	0.000
Lawncare vs. Housing Density	Portland	1163	-0.285**	0.000
Lawncare vs. Housing Density	Both	1830	-0.305**	0.000
Personal Care Products vs. Housing Density	Houston	458	-0.003	0.948
Personal Care Products vs. Housing Density	Portland	757	-0.192**	0.000
Personal Care Products vs. Housing Density	Both	1215	-0.190**	0.000
Pesticides vs. Housing Density	Houston	451	-0.200**	0.000
Pesticides vs. Housing Density	Portland	754	-0.218**	0.000
Pesticides vs. Housing Density	Both	1205	-0.250**	0.000
Sealants, Glues, Sprays vs. Housing Density	Houston	458	-0.067	0.151
Sealants, Glues, Sprays vs. Housing Density	Portland	757	0.065	0.072
Sealants, Glues, Sprays vs. Housing Density	Both	1215	0.005	0.848
Paints, Stains, Solvents vs. Housing Density	Houston	459	-0.135**	0.004
Paints, Stains, Solvents vs. Housing Density	Portland	757	0.031	0.390
Paints, Stains, Solvents vs. Housing Density	Both	1216	0.017	0.546
Grilling Use vs. Housing Density	Houston	424	-0.113*	0.020
Grilling Use vs. Housing Density	Portland	743	-0.040	0.281
Grilling Use vs. Housing Density	Both	1167	-0.016	0.593
Off-road use vs. Housing Density	Houston	207	-0.012	0.860
Off-road use vs. Housing Density	Portland	404	-0.093	0.063
Off-road use vs. Housing Density	Both	611	-0.067	0.097

Vehicle vs. Housing Density	Houston	573	-0.148**	0.000
Vehicle vs. Housing Density	Portland	1069	-0.325**	0.000
Vehicle vs. Housing Density	Both	1643	-0.305**	0.000
Consumer Products, Vehicle, Lawncare combined vs. Housing Density	Houston	390	-0.226**	0.000
Consumer Products, Vehicle, Lawncare combined vs. Housing Density	Portland	698	-0.327**	0.000
Consumer Products, Vehicle, Lawncare combined vs. Housing Density	Both	1088	-0.361**	0.000

Table 21: Summary of bivariate Spearman correlation statistical results

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Behavior Change Related to Advisories

The survey only asks if certain activities were reduced in response to an air quality advisory. The survey does not ask by how much the activities were reduced. Therefore, only results relating to the percentage of people who reduced certain types of activities can be calculated. No actual estimate of emissions reduction can be made from these simple yes/no responses. However, the results could be useful in showing which types of activities are most likely to be reduced during an air quality advisory. The results below represent a subset of the survey respondents who responded positively to changing at least one behavior in response to an air quality advisory.

	City	Yes	No	Other
Did you avoid or postpone refueling your vehicle during the advisory day?	Both	147	428	
	Houston	51	214	
	Portland	96	214	
Did you postpone mowing your lawn?	Both	42	101	23 (I don't determine when the lawn is mowed)
	Houston	14	58	13
	Portland	28	43	10
Did you reduce, avoid, or postpone your use of an outdoor grill or barbecue?	Both	146	278	
	Houston	54	147	
	Portland	92	131	
Did you decrease the amount you drove on the advisory day?	Both	161	416	
	Houston	44	222	
	Portland	117	194	

Table 22: Behavior change in response to air quality advisory

Discussion

Lawn Care Emissions

It was found that lawn care emissions were much higher in lower density zipcodes. A significant correlation was found between lawncare emissions and housing density. Though a somewhat obvious result due to larger lawns in lower density areas, the result is useful. The EPA Nonroad model calculates lawn care and other non-road emissions on a county level using engine population estimates. To create a more accurate model, housing density at the zipcode level could augment the engine population estimates to produce a more spatially accurate lawn care emissions estimate. Spatially accurate emissions can be used in small scale urban atmosphere models to better predict pollutant concentrations.

Emissions estimates for residential lawn care based on this survey estimation method show that per capita residential emissions are fairly small compared with the DEQ's per capita lawn care emissions estimate. This might be evidence that residential lawn care accounts for only a fraction of total lawn care emissions. Therefore, air quality advisories or regulations targeting commercial lawn care services could be much more effective at reducing pollutant concentrations.

Consumer Product Emissions

A significant correlation was found between personal care product emissions and housing density for Portland and combined city data, but not Houston alone. Pesticides with housing density showed a significant correlation for both cities. Sealants, glues, and spray paints did not show any significant correlation between emissions and housing density. Emissions from paints, stains, and solvents showed a significant correlation with housing density only in Houston as did grill use.

Observing a relationship between consumer product emissions and housing density is significant for the following reason. Currently, agencies estimate county wide consumer product emissions based an per-capita emissions factors. These emissions factors are multiplied by the population regardless of the density or other demographic features. This result would imply that agencies are over-estimating consumer product emissions in high density areas and under-estimating the emissions in low density areas. In this analysis, the emissions difference between the highest and lowest density quartiles is about 50%.

Grilling Emissions

A relatively small reduction in per-capita grilling behavior was calculated between the two low and two high density quartiles. The emissions graph does not show a consistent trend across housing densities. It is possible that grilling behavior is fairly constant across different housing densities. A significant correlation was found between grill use and housing density in Houston only.

Off road vehicles

Off road vehicles, on average, had higher per-capita use in areas of lower population density. This is most likely due to the availability of space and the proximity to land where these vehicles are permitted. However, no significant correlation between off-road emissions and housing density was found.

Driving

Vehicles, probably the most obvious contributer to urban air pollution, exhibit a similar trend to lawn care emissions estimates. Fuel consumed increased as housing density decreased. This is most likely a result of decreased proximity to centers of employment and commerce in low density areas. Though an obvious result, this is further evidence that areas of increased density have reduced per-capita vehicle emissions. A significant correlation between vehicle emissions and housing density was found in both cities.

Summary

Overall, the results of this behavior and emission analysis point to a a general increase in per-capita emissions in lower housing density for the areas and several of the emission types studied. The patterns observed could be helpful in designing more effective air quality advisories by identifying which types of behavior have been successfully reduced in the past as well as which types of behavior are most important to limit and in what areas.

This study also identifies just some of the difficulties in estimating emissions, especially those that are associated with residential behavior. Better methods of residential emission estimation can be just as important as quantifying emissions for a type of industry, for example.

A more effective air quality advisory should incorporate estimates of emissions reduction due to voluntary behavior. If citizens understand that perhaps reducing their use of a two-stroke lawn trimmer might be just as important as putting-off cutting their lawn, then they might be more willing to make a small sacrifice. But for advisories to be effective, residents must be able to understand what the outcome of their reductions will be. This information could be provided by the organizations making the advisory. Just as standards set acceptable levels of air quality, there should also be standards for evaluating the effectiveness of an air quality policy.

Limitations

Though the evidence for demographic relationships to individual emission patterns seems conclusive, it should be noted that there are many limitations to these results. The first obvious limitation is that the the data comes from a survey and includes all the issues with survey data including but not limited to inconsistencies in issuing surveys, misinterpreting questions, and misreporting by both the surveyed and surveying. Secondly, the survey was done in two phases; one in 2005 and another in 2006. Some of the original questions from 2005 were modified for 2006 and some questions were removed or added. Therefore, some of the data comes from only one year's dataset, which limits the data set size. For example, results relating to Houston in 2005 would be limited to just 207 survey responses. When split again by housing density quartiles, the number of responses becomes a limitation. Therefore, results that relate to both cities for both years should have the highest significance due to the large number of total responses. Lawn care and vehicle results, for example, draw on data for both cities in both years. However, individual consumer product questions were only asked in 2006 which limits the dataset for these emissions estimations.

Year	**Portland Respondents**	**Houston Respondents**	**Total Respondents**
2005	411	207	618
2006	759	460	1219
2005 + 2006	1170	667	1837

Table 23: Number of Survey Respondents

References

Eastern Research Group, Inc. "Introduction to Area Source Emission Inventory Development." (Jan 2001)

Provides approaches to estimating emissions from area sources.

EPA. 2005. Exhaust Emission Factors for Nonroad Engine Modeling: Spark-Ignition. U.S. Environmental Protection Agency, Office of Transportation and Air Quality.

EPA. 2004. Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling. U.S. Environmental Protection Agency, Office of Transportation and Air Quality. EPA420-P-04-005.

Frank, Lawrence D., Stone, Brian Jr., Bachman, William. 2000. Linking land use with household vehicle emissions in the central puget sound: methodological framework and findings. Transportation Research. Part D 5. 173-196

Karl, T., Fall, R., Jordan, A., and Lindinger, W.R. "On-Line Analysis of Reactive VOCs from Urban Lawn Mowing." Environmental Science & Technology. Vol. 35, no. 14 (Jul 2001): 2926-2931.

The authors monitored the release of many VOCs both during and following lawn mowing. Interestingly, the VOCs resulting from the grass clippings were on the same order of magnitude as the unburned hydrocarbons released during the mowing by the gas engine. This is an example of an unexpected source that is usually not accounted for when quantifying area sources.

Oregon Department of Environmental Quality. "Portland-Vancouver Air Quality Maintenance Area (Oregon Portion) and Salem-Keizer Area Ozone Maintenance Plan." Feb. 5, 2007.

This document outlines a plan for maintaining levels of ozone below benchmark levels for the Portland area. Strategies pertaining to area sources include: lowering VOC content of spray paints, better painting methods requirements, and public outreach encouraging voluntary reduction of pollution related activities on air pollution advisory days. An inventory of area emissions of various types is also provided.

Oregon Department of Environmental Quality. "Oregon Open Burning Guide." Oct., 2006.

Guidelines and regulations pertaining to open burning. "Backyard burning" is prohibited in and around the Portland area.

Samet, J, Krewski, D., (2007) Health effects associated with exposure to ambient air pollution, Journal of Toxicology and Environmental Health, Part A, 70, 227-242.

Semenza, Jan C., Wilson, Daniel J., Parra, Jeremy., Bontempo Brian D., Hart, Melissa., Sailor David J., George, Linda A. 2008. Public perception and behavior change in relationship to hot weather and air pollution. Environmental Research. 107, 401-411

Outreach response is found to be low in regards to individual voluntary reduction in emissions. Only 10-15% of surveyed claimed to have changed their behavior in response to an air quality advisory.

U.S. Environmental Protection Agency. “AP 42, Fifth Edition, Compilation of Air Pollution Emission Factors.” (Jan 1995).

Official report of emissions factors for hundreds of types of area emissions.