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Preliminary Analysis of the Distributions of Carbon and Energy Intensity for 27 Energy Intensive Trade Exposed Industrial Sectors

Gale Boyd*
Tatyana Kuzmenko*
Béla Személy*
Gang Zhang*

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* Department of Economics, Duke University

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PRELIMINARY ANALYSIS OF THE DISTRIBUTIONS OF CARBON AND ENERGY INTENSITY FOR 27 ENERGY INTENSIVE TRADE EXPOSED INDUSTRIAL SECTORS

GALE BOYD, TATYANA KUZMENKO, BÉLA SZEMÉLY, & GANG ZHANG

DEPARTMENT OF ECONOMICS, DUKE UNIVERSITY

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INTRODUCTION

It is well documented that different sectors of manufacturing, producing different products, require different amounts of energy. Primary materials conversion, e.g. iron ore and scrap into steel, limestone and sand into cement and glass, or wood and other fibers into paper, tend to be the most energy intensive in the production process, while final consumer products like electronics, clothing, etc require the least energy. This leads to something like the 80-20 rule, where a large portion of energy use is in a small number of industries. For example, the 2006 Manufacturing Energy Consumption Survey (MECS) reported that 75% of fuel use arises from only 5 of the 21 3-digit industries [1], using the North American Industry Classification System (NAICS)[2]. These five sectors are a small share of the total U.S. economy. The energy intensity, i.e. ratio of energy use to product produced, for different industrial sectors is easily measured using published government statistics. However, plants within these industries are not homogeneous entities. There are variations in productivity and energy use across plants even within a 6-digit NAICS industry, the most detailed level of data collected by government statistical agencies. The variation may be due to a variety of reasons, e.g., the energy efficiency of production, levels of vertical integration, and types of products produced. Measuring the extent of overall variability of energy use within different sectors is the first step to understanding the sources of variation.

This report measures the differences in energy use and associated CO_2 emissions as a first step to understanding the within-sector heterogeneity of energy use. This report does not try to attribute these differences to the specific drivers mentioned above. More detailed statistical analyses have been completed or are in progress for about a dozen sectors, at various levels of NAICS industry aggregation, to support the EPA Energy Star's program for industrial energy management and plant level recognition.[3] Those studies prepare "benchmarks" of energy efficiency that control for differences in products, materials, and other factors in the production process that affect energy use. This report's goal is more modest. It considers a group of energy intensive 6-digit NAICS industries that are also subject to relatively high levels of exposure to international trade and computes the variability of energy and CO_2 emissions within those sectors.

The reason to examine energy intensive industries is clear from the above discussion. The reason to look at trade exposed industries is related to the debate over policy approaches to control CO_2 for climate change mitigation. If manufacturing sectors in the US are subject to regulation that raises

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[1] The industries are Petroleum and Coal, Chemicals, Paper, Primary Metals, and Food. (source http://www.eia.gov/emeu/mecs/contents.html)

[2] NAICS is used by business and government to classify business establishments according to type of economic activity. NAICS is a two- through six-digit hierarchical classification system, offering five levels of detail. Each digit in the code is part of a series of progressively narrower categories, and the more digits in the code signify greater classification detail. The first two digits designate the economic sector, the third digit designates the subsector, the fourth digit designates the industry group, the fifth digit designates the NAICS industry, and the sixth digit designates the national industry. A complete and valid NAICS code contains six digits. (From Census Bureau NAICS FAQ, http://www.census.gov/eos/www/naics/faqs/faqs.html)

[3] Sector aggregation varies from the 6-digit NIACS to more detailed sub-sectors, See http://www.energystar.gov/epis, or for an overview see Boyd, G., E. Dutrow and W. Tunnesen, "The Evolution of the Energy Star Industrial Energy Performance Indicator for Benchmarking Plant Level Manufacturing Energy Use." Journal of Cleaner Production, Volume 16, Issue 6, pp 709-715, April 2008

their costs and some of these sectors have a high degree of competition from foreign plants that are not similarly regulated, then some are concerned that production may shift to the foreign plants. Not only would that damage the domestic economy in those sectors, but there would be "emission leakage" in terms of CO_2. The intent of regulation could thus be thwarted by the production and associated CO_2 emission moving to a country without the CO_2 limits. A study of distribution of energy and emissions intensity of these industries is useful in addressing a number of policy-relevant questions.

The U.S. Government Interagency report, *The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade-Exposed Industries,* identifies 44 out of nearly 500 6-digit North American Industry Classification System (NAICS) manufacturing sectors that would be deemed "presumptively eligible" for allowance rebates under proposed climate legislation. The analysis in the report relies on published industry level data to measure energy intensity, defined as the ratio of energy costs to total value of shipments, and trade exposure, defined as the sum of the value of a sector's imports and exports divided by the sum of its value of shipments and imports. However, the interagency report does not address the range of performance across establishments within any individual sector. In this report, we examine the distribution of relative energy consumption and CO_2 emissions across these "presumptively eligible" manufacturing industries. Due to data limitations with respect to confidentiality, this report is able to conduct this analysis for a subset of the 44 sectors, for a total of 27. We construct four measures: two measures of energy intensity (fuels and fuels plus electricity) and two measures of CO_2 emissions intensity (direct CO_2 emissions from fuels combustion and direct and indirect CO_2 emissions from all energy sources). Our measure of intensity differs from the interagency report; this report uses the ratio of btu per dollar value of shipments rather than energy costs as the numerator. While energy costs are relevant to identifying the industries that are most susceptible to emission leakage, differences in costs are less relevant to the measuring of the potential impact of various policies on industry performance. For each of these four measures, we report detailed summary statistics (mean, standard deviation, skewness, and kurtosis) at the 6-digit NAICS industry level. In addition, we provide kernel density plots that characterize the distributions of these measures for each industry.

DATA AND METHODS

This analysis uses confidential plant-level data from two sources: the 2002 Census of Manufacturers (CM) and the 2002 Manufacturing Energy Consumption Survey (MECS) maintained by the Center for Economic Studies (CES), U.S. Bureau of the Census (Census). The CM includes the non-public, plant-level data that are the basis of government-published statistics on manufacturing. The CM includes economic activity — for example, labor, plant and equipment, materials costs, and total shipment value of output for all plants during the years of the Economic Census (those ending in "2" and "7"). The MECS is a detailed survey of energy use, e.g. energy use in physical units by type of fuel, for a sample of plants in the CM.

Under Title 13 of the U.S. Code, these data are confidential; however, CES allows academic and government researchers with Special Sworn Status to access these confidential micro-data under its research associate program at one of eleven designated Census Research Data Centers. The confidentiality restrictions prevent the disclosure of any information that would allow for the identification of a specific plant's or firm's activities. Aggregate figures or statistical coefficients that do not reveal the identity of individual establishments or firms can be released publicly. The ability to use plant-level data, rather than aggregate data, significantly enhances the information that can be obtained about economic performance, particularly when examining the issue of energy efficiency.

SAMPLE CONSTRUCTION AND CUTS

Our sample starts with a list of 44 industries identified as likely to be deemed as "presumptively eligible" for allocations under H.R. 2454 based on EPA's updated preliminary assessment[4] (in this report, we also denote these 44 industries as EITE: Energy Intensive Trade Exposed industries). We select all establishments from these 44 industries that are included both in the Census of Manufacturing and 2002 Manufacturing Energy Consumption Survey (MECS is a subsample of the ASM). We then conduct a number of cuts, intended to (a) eliminate all observations that have missing values for any of the key variables, (b) eliminate all observations that appear to have reporting errors, and (c) identify and exclude all industries that do not meet disclosure criteria due to small sample size. The rest of this subsection describes these cuts in more detail.

First, we eliminated all observations that have missing values for any of the key variables: total fuel use, total energy use, total value of shipments (obtained from the Census of Manufacturing data[5]). Also we dropped observations that have zero or negative values for any of these variables, as they are likely to be reporting errors[6]. Next, we eliminate extreme outliers that are most likely caused by reporting or NAICS classification errors. More precisely, we calculate two measures of energy intensity and two measures of CO_2 emissions intensity and examine their distributions within each NAICS 6-digit industry. Within each industry, we drop the observations with the largest (smallest) value if it is more than 10 times larger (smaller) than the second largest (smallest) value. The choice of the 10X threshold is based on visual inspection of the data and clustering of the observations. Finally, we counted the number of firms in each 6-digit industry (one firm might include several establishments) and eliminated the industries in which the effective sample size is too small to pass the Census RDC disclosure thresholds. The final research sample contains 27 NAICS 6-digit industries.

Even though both our analysis and publicly available MECS tabulations[7] are based on the same MECS micro data set, our results and summary statistics cannot be directly compared (in most

[4] "The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade-Exposed Industries": An Interagency Report Responding to a Request from Senators Bayh, Specter, Stabenow, McCaskill, and Brown, December 2, 2009,2009, http://www.epa.gov/climatechange/economics/pdfs/InteragencyReport_Competitiveness-EmissionLeakage.pdf

[5] MECS itself does not collect information about total value of shipments and cost of materials, so we merged MECS with the Census of Manufacturing data in order to obtain them.

[6] Among all cuts, the most observations were lost because of zero or missing values for fuels consumption; that is, we dropped all establishments that report electricity as their sole energy source. While it is possible for a manufacturing establishment to be all-electric, we believe it is unlikely for an establishment in energy-intensive industry.

[7] Available at http://www.eia.doe.gov/emeu/mecs/contents.html

cases) with the MECS tabulations, due to important differences in sample selection and data processing:

- **Reporting cells:** For each of 27 industries in our final sample, we report all applicable results at the NAICS 6-digit level (see Footnote 1 for information on level of detail in NAICS). In contrast, the level of detail varies in MECS published tabulations: for 21 of these 27 industries public data are available at the 6-digit industry level; for the remaining 6 industries, publicly available estimates are grouped at 4-digit or 3-digit level. Our estimates for the industries that do not have 6-digit data available are likely to be less reliable, as data collected for these industries is not supposed to be representative at 6-digit level. However, in this report we aimed to provide as much industry-level detail as possible, even if MECS does not report energy use estimates at this level of detail.
- **Use of sample weights:** unless noted otherwise, our results and findings are based on the unweighted MECS sample (that is, each observation receiving equal weight). In the section titled "Returns to scale analysis", we present some evidence suggesting that our findings would not have changed qualitatively if these weights were used. In contrast, publicly available MECS tabulations were calculated with the use of sample weights.
- **Sample cuts and imputations:** According to the MECS Methodology report, as a part of data processing for the MECS tabulations, imputations were used to fill in missing values and to account for small establishments. These imputed values are not available in the MECS micro data, so we had to drop some observations due to missing data or suspected errors.

Sample size:

Our reported summary statistics do not include the number of observations in each industry. The sample size information was withheld in order to avoid possible individual information disclosure issues. However, one can utilize publicly available MECS tabulations to get a sense of number of observations in each industry. Table 1 reports establishment counts (obtained from the MECS tabulations) for the 27 (NAICS 6-digit) industries included in our final sample; the estimated establishment count ranges from 21 to 709[8]. It should be noted that in most industries, not all establishments were included in the MECS sample; also, we had to drop some observations due to missing data or suspected errors. Thus, as a rule, our sample size is smaller than the number of industries reported in Table 1. Given this information, one should exercise more caution when drawing inference about an industry with small establishment count.

[8] See Note 2 under Table 1 for a discussion about the establishment count in MECS vs. in the Census of Manufacturing.

Table 1 MECS Establishment Counts

NAICS	Industry	Establishment count
311221	Wet Corn Milling [1]	49
321219	Reconstituted Wood Product Manufacturing	Reported at 4 digit level
322110	Pulp Mills[1]	34
322121	Paper Mills, except Newsprint	323
322122	Newsprint Mills [1]	21
322130	Paperboard Mills	210
325110	Petrochemicals [1]	37
325181	Alkalies and Chlorine [1]	33
325188	Other Basic Inorganic Chemicals	515
325192	Cyclic Crudes and Intermediates [1]	37
325199	Other Basic Organic Chemicals [1]	578
325211	Plastics Materials and Resins	709
325212	Synthetic Rubber	125
325222	Noncellulosic Organic Fibers [1]	64
325311	Nitrogenous Fertilizers [1]	56
327211	Flat Glass [1]	38
327212	Other Pressed and Blown Glass and Glassware Manufacturing	Reported at 4 digit level
327310	Cements	195
327410	Lime [1]	65
327992	Ground or Treated Mineral and Earth Manufacturing	Reported at 4 digit level
327993	Mineral Wool	207
331111	Iron and Steel Mills	771
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	Reported at 4 digit level
331312	Primary Aluminum [1]	41
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	Reported at 4 digit level
331511	Iron Foundries	453
335991	Carbon and Graphite Product Manufacturing	Reported at 3 digit level

Source: 2002 Manufacturing Energy Consumption Survey (MECS), Table 1.4. Number of Establishments Using Energy Consumed for All Purpose. http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/pdf/table1.4_02.pdf

Notes:

1. Denoted with "1" are industries where ALL eligible establishments were selected for MECS participation ("certainty industries").
2. Note that the establishment counts can differ between 2002 MECS and Census of Manufacturing. Reasons for that: First, even though these two surveys use the same frame, their respective populations of interest and coverage are not exactly the same (e.g. MECS does not cover small establishments; see the MECS Methodology report at http://www.eia.doe.gov/emeu/mecs/mecs2002/methodology_02/meth_02.html for more details).
Second, the establishment counts shown in Table 1 are in fact the estimates for the number of establishments consuming any energy (from Table 1.4 of the MECS data release at http://www.eia.doe.gov/emeu/mecs/mecs2006/2006tables.html). According to the MECS Methodology report, these estimates were calculated using poststratified sample weights (see subsection "Estimator for Number of Establishments in Population Totals" of the MECS Methodology report). Depending on the sampling and weighting procedures, survey count estimates might differ from the population counts, especially in small samples.

Industries in the sample: economic characteristics

In order to give a sense for the relative importance of the 27 industries in our research sample, we report their basic economic characteristics (number of establishments, employment and payroll, total value of shipments, fuel and electricity expenditures), as compared to all Energy-Intensive Trade Exposed industries (EITE, 44 NAICS codes), and all manufacturing sector. These characteristics are reported in Table 2. As can be seen from this table, our research sample covers over 90% of all EITE industries in terms of output (total value of shipment) and fuel and electricity expenditures, and over 85% in terms of employment and payroll.

Next, focusing on the last two rows of Table 2, one can see that while the EITE industries represent a relatively small share of all manufacturing output and employment (9.3% and 6.1%, respectively), they account for 46% of all expenditures on fuel and 31% expenditures on electricity in the manufacturing sector.

TABLE 2 ECONOMIC CHARACTERISTICS

NAICS	Industry	Establishment count	Employees (thousand)	Annual payroll ($B)	Total value of shipment ($B)	Cost of purchased fuels ($B)	Purchased electricity ($B)
311221	Wet Corn Milling	61	9.0	0.48	7.9	0.47	0.27
321219	Reconstituted Wood Product Manufacturing	278	22.3	0.82	5.8	0.15	0.25
322110	Pulp Mills	32	7.7	0.47	3.5	W	0.08
322121	Paper Mills, except Newsprint	307	96.5	5.31	42.5	1.49	1.02
322122	Newsprint Mills	22	8.4	0.54	3.6	0.17	0.40
322130	Paperboard Mills	199	46.2	2.56	20.9	1.30	0.81
325110	Petrochemicals	55	9.2	0.64	20.3	1.53	0.22
325181	Alkalies and Chlorine	40	6.0	0.37	2.7	0.34	0.39
325188	Other Basic Inorganic Chemicals	617	46.0	2.78	14.8	0.30	0.79
325192	Cyclic Crudes and Intermediates	39	6.3	0.42	4.5	0.15	0.08
325199	Other Basic Organic Chemicals	688	77.0	4.71	48.2	2.00	0.81
325211	Plastics Materials and Resins	688	67.6	3.86	47.9	1.19	1.01
325212	Synthetic Rubber	157	9.6	0.52	5.8	0.16	0.09
325222	Noncellulosic Organic Fibers	94	20.8	0.85	7.2	0.16	0.16
325311	Nitrogenous Fertilizers	143	4.5	0.27	3.2	0.37	0.12
327211	Flat Glass	36	10.7	0.47	2.8	0.23	0.09
327212	Other Pressed and Blown Glass and Glassware Mfg	525	29.3	1.14	4.8	0.21	0.16
327310	Cements	246	17.9	0.90	7.5	0.57	0.55
327410	Lime	77	4.0	0.17	1.0	0.16	0.06
327992	Ground or Treated Mineral and Earth Mfg	291	6.8	0.28	2.1	0.07	0.06
327993	Mineral Wool	304	19.3	0.81	4.9	0.18	0.16
331111	Iron and Steel Mills	373	118.8	6.23	47.2	1.94	1.80
331210	Iron and Steel Pipe and Tube Mfg from Purch. Steel	183	22.7	0.92	6.6	0.04	0.08
331312	Primary Aluminum	41	13.1	0.70	5.4	0.18	1.05
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	170	7.6	0.36	2.2	0.05	0.10
331511	Iron Foundries	619	66.5	2.71	10.2	0.21	0.37
335991	Carbon and Graphite Product Manufacturing	129	8.4	0.34	1.7	0.03	0.05
	Total for 27 industries in the sample	6414	762.2	39.6	335.0	13.7	11.0
	All EITE industries	8584	895.5	44.3	364.6	14.6	11.9
	All manufacturing	350054	14692.8	573.8	3906.0	31.7	38.6

Source: 2002 Economic Census.

Notes:

W: Withheld by Census Bureau to avoid disclosing data for individual establishments.

The same number of establishments (688) in two different industries (325199 and 325211) shown in the adjacent cells – might be an error, but this is what is reported in the Economic Census data.

Also, See Note 2 under Table 1 for a discussion about the establishment count in MECS vs. in the Census of Manufacturing

VARIABLE CONSTRUCTION

Our four measures of interest are two measures of energy intensity (all fuels and all energy sources-including electricity) and two measures of CO_2 emissions intensity (CO_2 emissions from fuels consumed and CO_2 emissions from all energy sources). Process and non-CO2 emissions are not included in the CO2 emissions intensity estimates.

The establishment-level direct energy consumption from all fuels (in MBtu) was calculated as a sum of all fuels consumption in physical units multiplied by corresponding MBtu conversion factors:

$$DirectFuel = \sum_j Fuel_j \; MBtu_j \;,$$

Where *j* indexes various fuel types (energy sources), for example coal, natural gas, propane, fuel oil, wood, waste materials, etc.; $Fuel_j$ is the quantity of the fuel (energy source) j used by the establishment in physical units (tons, barrels, gallons, cubic feet, etc.), and $MBtu_j$ is a conversion factor used to convert physical units of fuel *j* into MBtu (Million British thermal units). The MBtu conversion factors for fuels were obtained from 2002 MECS Survey forms[9].

MECS has several definitions of "fuel use." We use "energy consumed as fuel," excluding feedstock uses of energy, e.g. natural gas in the petrochemical industry. Since we use the MECS conversion factors our measure of energy should correspond to those in the MECS table 3.2. The establishment-level total energy consumption (in MBtu) from all sources was calculated as a sum of the direct energy consumption from all fuels (otherwise called direct fuel use in this report) and the electricity consumption (in kilowatt hours) multiplied by the MBtu conversion rate for electricity (obtained from the same MECS survey forms) and by the coefficient that accounts for losses incurred in the electricity production, transmission, and delivery to the site[10].

$$TotalEnergy = DirectEnergy + Electr \cdot MBtu_{Electr} \cdot Loss_{Elect}$$

The establishment-level direct CO_2 emission (from all fuels, but not including electricity) was calculated as a sum of the amounts of the consumed energy from each fuel type multiplied by the onsite emission factors[11]:

$$DirectCO_2 = \sum_j Fuel_j \; MBtu_j \; Emission_j \;,$$

Where $Emission_j$ denotes an emission factor that converts energy from fuel *j* into mass of CO_2 emissions.

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[9] http://www.eia.doe.gov/emeu/mecs/mecs2002/forms2002/mecs_forms.html

[10] This coefficient, called source-site ratio, was obtained from the EPA report "ENERGY STAR Performance Ratings Methodology for Incorporating Source Energy Use" that can be found at http://www.energystar.gov/ia/business/evaluate_performance/site_source.pdf

[11] The emission factors were obtained from the following EPA reports: Inventory of U.S Greenhouse Gas Emissions and Sinks: 1990-2005, EPA430-R-07-002, U.S. EPA, Washington, DC, April 2007; and Direct Emissions from Stationary Combustion Sources, May 2008.

The establishment-level total (direct and indirect) CO_2 emissions (from all energy sources, including electricity) was calculated as a sum of the CO_2 emissions from direct fuel combustion and CO_2 emissions arising from the electricity consumed by the establishment:

$$TotalCO_2 = DirectCO_2 + Electr \cdot MBtu_{Electr} \cdot Emission_{Electr}$$

It should be noted that both the heat rate and CO_2 emission rate applied to electricity is based on the U.S. national average. Some energy and CO_2 accounting schemes apply region specific indirect factors for electricity derived from the U.S. EPA's Emissions & Generation Resource Integrated Database (eGRID). This report does not account for this location specific effect, but the Census data used here would allow for this refinement to the analysis. Use of regional factors would tend to increase the variability for total energy and CO_2 emission intensity presented here, so the estimates provided here should be viewed as a lower bound[12].

All four measures listed above (direct energy consumption, total energy consumption, direct emissions, total emissions) have been divided by the establishment's total value of shipments (measure of plant size). The resulting ratios are two energy intensity ratios (for direct energy from all fuels and for total energy, both measured in thousand BTU per dollar) and two emission intensity ratios (also for direct energy from all fuels and for total energy, measured in kilograms per thousand dollars). These four measures are the main object of interest in this report. It is important to note these measures reflect energy consumption and carbon emissions *per dollar of output*; these measures are not included in MECS tabulations, as MECS focuses on *total* energy consumption estimates.

SUMMARY STATISTICS AND KERNEL DENSITY PLOTS

We use two tools for our analysis:

First, we calculate detailed summary statistics (mean, standard deviation, skewness, and kurtosis) for the two energy intensity ratios (for direct energy from all fuels and for total energy) and two emission intensity ratios (also for direct energy from all fuels and for total energy) described in the previous subsection. Second, we provide kernel density plots that characterize the distributions of these measures in each industry.

Since the main focus of this analysis is on variability (rather than total or average) of the energy intensity and emission intensity within each industry, and on the comparison of that variability across different manufacturing industries, the density plots reflect the distributions of the mean-normalized counterparts of the four energy/emission intensity measures. That is, for each of the intensity measures, we calculate sample means in each industry, and then divide the establishment-level intensity measures by the corresponding mean. For example, mean-normalized total energy intensity for an establishment *i* from industry *I* with *N* establishments in it is given by:

[12] This would be true unless the indirect electric emission factor was negatively correlated with the average direct fuel emission factor in manufacturing in the region. It is more likely that the factors are positively correlated, e.g. if coal use is more common in a region for electric generation it may be cheaper and therefore used more frequently by manufacturing.

$$NormTEI_i = \frac{TEI_i}{\frac{1}{N}\sum_{k \in I} TEI_k}$$

Where the numerator is Total Energy Intensity for establishment *i*, and the denominator is mean Total Energy Intensity in the 6-digit NAICS industry where establishment *i* belongs to.
The normalized energy/emission intensity measures have natural interpretation: their values reflect by how many times the energy/emissions per dollar of output for a particular establishment is bigger than the industry mean.

We plot the normalized energy/emission intensity densities both in levels and in logarithms (the only difference between them is x axis scaling).

One should keep in mind that the kernel density plots included in this report have been censored at the tails. This has been done for two reasons: (a) to prevent disclosure issues, since there are not many observations on the tails, and (b) to make the plots comparable across industries. In particular, the plot range has been restricted to [0,3] for level plots and to [-3,3] for logarithm plots[13]. The plots therefore provide information primarily about the establishments that are not too different from the other plants in their respective industry. The sample moments, on the other hand, are based on the entire research sample, that is, they include all survey observations except those that are very likely to be erroneous[14]. Because of these differences in construction, the findings based on visual comparison of the density plots might sometimes differ from the ones based on the tables of summary statistics.

NOTE ABOUT SAMPLE WEIGHTS

It should be noted that we did not use sample weights when we calculated the reported summary statistics and kernel densities. This section provides a (qualitative) discussion about the effects of sample weights on our results. In particular, we compare two sets of summary statistics – one set was calculated using the sample weights(adjusted for nonresponse) provided with the MECS micro data (weighted summary statistics), and the other set was calculated without those weights.

For the raw (non-normalized) energy intensity ratios, weighted means are smaller than unweighted ones by about 10% to 20%. This finding is broadly consistent with the results reported in the "Returns to Scale Analysis" section of this report: even though we could not reject constant returns to scale with respect to energy usage for most of the industries, the point estimates reported in that section suggest that large plants tend to be more energy intensive than smaller plants in the same industry (however, the difference is not statistically significant in most industries). At the same time, smaller plants have smaller probability to be selected for the survey, and they get assigned larger sample weights. Taken together, these two features of the data imply that the weighted means of the energy intensity ratios are slightly smaller than the unweighted.

[13] The range has been restricted uniformly across all industries in order to prevent possible information disclosure.
[14] When dealing with outliers, we have adopted rather cautious approach, dropping only extremely large and extremely small values.

Weighted distributions appear to be more skewed and have heavier tails (higher kurtosis) that the unweighted ones. However, the variance of the (non-normalized) energy intensity ratios almost does not change if we apply weights.

For the mean-normalized energy intensity ratios, means by industry are equal to 1 by construction. The weighted standard deviations are larger by about 20% on average, weighted distributions appear to be more skewed and have heavier tails (higher kurtosis) that the unweighted ones. However, those moments are often driven by observations on the tails. The appearance of the density graphs can be better described by robust measures of variation, such as interquartile range (q75-q25) and interdecile range (q90-q10). We found that these statistics look pretty similar regardless of weighting, which implies weights would ***not*** have much effect on the appearance of the density graphs.

One important issues is the use of the weight to stand for other establishments in the population that would be presumed to have the same characteristics. Smaller establishments tend to have higher sampling weights because they enter into the sample with lower probability. MECS weights are based on a derived energy measure of size from the Census of Manufacturers frame. So each establishment has a measure of size that is a proportion of the total measure of size of the industry. However, it is sample weight does not in itself represent an inverse of the proportion of the number of establishments in the sample. To do that, one would need to apply a population correction factor to the final weight.[15] This was not done for our weighted analyses.

To summarize, we found that the sample weights provided with the MECS data have moderate effect on the graphs and summary statistics in this report. One more consideration about weights: If we use the survey sample weights, we give more weight to smaller plants than we would do in the unweighted version. In other words, every plant existing in the industry get the same "voice". We are not sure this is the right thing to do if we are looking at the ratios (as opposed to totals), as energy intensity of large plants is probably more important for policy. Perhaps we should think about the pros and cons of presenting our results using weights proportional to plant size in the future.

COMPARISON WITH MECS TABULATIONS

The section provides a comparison between the energy intensity measures derived and analyzed in this report, and the energy intensity measures available in the MECS publications. We compare industry-level mean total energy intensities from our final sample with the energy consumption per dollar of value of shipments reported in Table 6.1 of the 2002 MECS data publication[16].

Even though both our analysis and publicly available MECS tabulations are based on the same MECS micro data set, our results and summary statistics cannot be directly comparable (in most cases) with the MECS tabulations, due to important differences in sample selection and data processing:

- **Imputations and missing values:** Since the MECS Methodology report does not provide the imputation details, it is hard to assess exactly how dropping the observations with

[15] Thanks to Bob Alder, EIA for pointing this out. For more information on this issue see (See http://www.eia.gov/emeu/mecs/mecs2002/methodology_02/meth_02.html#enept .)
[16] Available at http://www.eia.doe.gov/emeu/mecs/contents.html

missing data would affect the energy intensities (as compared with the similar statistics reported in the MECS tabulations).

- **Industry-wide ratios vs. mean of individual ratios**: The MECS tabulations report the ratio of total energy consumption in an industry to total value of shipments; in other words, within each industry, establishments are weighted by size. In contrast, for our analysis, we calculated energy intensity ratios (ratio of energy consumption per dollar of value of shipments) for each establishment and then calculated (unweighted) industry means. As a result, if there were no other differences in sample selection and data processing), in industries where large plants consume more energy per dollar of output, the energy intensity measures calculated in this report should be smaller than the ones found in MECS tabulations, and vice versa.17
- **Site vs. source energy:** The method total energy consumption is calculated for our analysis differs from the one used by the MECS. In particular, when converting physical units of different types of fuel and energy into comparable units (Btu, British thermal units), MECS uses the conversion ratios reflect the heat equivalents of the energy consumed. However, for the secondary energy sources such as electricity, the amount of energy received by energy consumers (site energy) is much smaller than the amount of energy in the raw fuel that was burnt to produce it (source energy), due to losses in the production, transmission, and delivery to the site. EPA has developed source-site ratios (for different energy forms) that reflect those losses18. . Among the other energy forms, electricity has the largest source-site ratio of 3.34, which means for each unit of energy in electricity delivered to consumer, 3.34 units of energy needs to be spent on its production, transmission, and delivery. As noted in the aforementioned Energy Star Methodology, accounting for these losses enables more complete assessment of energy efficiency19. Thus, our measures of total energy consumption reflect not only the energy consumed by establishments, but also losses in the production, transmission, and delivery to the site for the electricity consumed by that establishment. As a result, the energy intensity measures calculated in this report should be larger than the ones found in MECS tabulations (if there were no other differences in sample selection and data processing).

Given these multiple differences in data processing and methodology, the energy intensity measures derived and analyzed in this report can be either larger or smaller from the ones published in the MECS tabulations, depending on the industry. **Error! Reference source not found.** provides a comparison between these two variables for 21 manufacturing industries that are both analyzed in this report and have their energy consumption data publicly available at the

[17] In policy proposals, such as that in H.R. 2454, allocations have been weighted by size as in MECS- e.g., ratio of total GHG emissions in an industry to total value of shipments.

[18] EPA report "ENERGY STAR Performance Ratings Methodology for Incorporating Source Energy Use" that can be found at http://www.energystar.gov/ia/business/evaluate_performance/site_source.pdf

[19] For some industries that are co-located with electricity producers or generate own electricity (e.g. primary aluminum), it might make sense to exclude transmission and delivery (T&D) losses. However, this refinement is unlikely to change the results much, as T&D losses are about *20 times* smaller than conversion losses (source: EPA report "ENERGY STAR Performance Ratings Methodology for Incorporating Source Energy Use" referenced in the previous footnote. Also, see *Electricity Flow in the Annual Energy Review,* http://www.eia.doe.gov/emeu/aer/pdf/pages/sec8_3.pdf

NAICS 6-digit industry level. For nine[20] out of these 21 industries, our energy intensity measures turned out to be larger than those from MECS tabulations, and for the remaining 12 industries, the MECS numbers are larger. Those sectors for which this report has substantially higher intensity than in MECS include generally electric intensive sectors such as Newsprint Mills, Alkalies and Chlorine and Primary Aluminum. Lime is the exception to this pattern and bears further investigation. Sectors that have lower intensity tend to be those that have higher propensity to internally generated "by product" fuels; Pulp Mills, Paperboard Mills, and to a lesser extent Iron and Steel Mills, Other Basic Organic Chemicals, and Plastics Materials and Resins.

FINDINGS

The main focus of this analysis is on *variability* (rather than total or average) of the energy intensity and emission intensity within each industry. Tables 4-7 provide the four moments of the plant level distributions for the 27 industries for each of our four intensity measures.

[20] Those industries are Pulp Mills, Plastics Materials and Resins, Other Basic Organic Chemicals, Iron and Steel Mills, Paperboard Mills, Nitrogenous Fertilizers, Petrochemicals, Paper Mills (except Newsprint), and Wet Corn Milling

TABLE 3 COMPARISON OF ENERGY INTENSITIES

NAICS	Industry	Energy consumption to value of shipments, thousand BTU per dollar	
		This report	MECS tabulations
311221	Wet Corn Milling	25.8	26.2
322110	Pulp Mills	22.6	56.0
322121	Paper Mills, except Newsprint	22.0	22.5
322122	Newsprint Mills	52.0	29.1
322130	Paperboard Mills	32.3	42.1
325110	Petrochemicals	21.2	23.2
325181	Alkalies and Chlorine	120.3	63.2
325188	Other Basic Inorganic Chemicals	21.7	11.7
325192	Cyclic Crudes and Intermediates	12.8	12.6
325199	Other Basic Organic Chemicals	16.6	22.8
325211	Plastics Materials and Resins	9.3	14.5
325212	Synthetic Rubber	8.5	8.0
325222	Noncellulosic Organic Fibers	12.5	8.4
325311	Nitrogenous Fertilizers	49.3	58.7
327211	Flat Glass	28.8	22.5
327310	Cements	74.0	56.0
327410	Lime	168.8	101.9
327993	Mineral Wool	20.6	10.8
331111	Iron and Steel Mills	21.0	27.8
331312	Primary Aluminum	89.5	38.5
331511	Iron Foundries	14.1	7.7
	All manufacturing industries	N/A	4.2

Source: 2002 Manufacturing Energy Consumption Survey (MECS), Table 6.1 Ratios of Mfg. Fuel Consumption to Economic Characteristics (http://www.eia.gov/emeu/mecs/mecs2002/data02/pdf/table6.1_02.pdf) and the MECS and CM micro data.

TABLE 4 SUMMARY STATISTICS - TOTAL ENERGY INTENSITY

NAICS Code	Industry Name	Mean	Standard Deviation	Skewness	Kurtosis
311221	Wet Corn Milling	25.828	14.46	0.80	4.03
321219	Reconstituted Wood Product Manufacturing	22.154	16.20	1.76	8.28
322110	Pulp Mills	22.573	11.19	1.02	3.90
322121	Paper Mills, except Newsprint	22.027	15.24	2.51	13.54
322122	Newsprint Mills	52.049	22.25	-0.23	2.51
322130	Paperboard Mills	32.275	11.79	1.33	9.75
325110	Petrochemicals	21.222	20.60	1.22	3.33
325181	Alkalies and Chlorine	120.307	208.41	3.82	17.49
325188	Other Basic Inorganic Chemicals	21.711	32.20	4.28	26.90
325192	Cyclic Crudes and Intermediates	12.779	7.32	0.43	2.31
325199	Other Basic Organic Chemicals	16.557	19.79	2.28	8.53
325211	Plastics Materials and Resins	9.297	13.81	7.08	68.68
325212	Synthetic Rubber	8.515	8.43	1.04	2.78
325222	Noncellulosic Organic Fibers	12.520	8.64	1.36	4.59
325311	Nitrogenous Fertilizers	49.250	38.48	0.36	1.68
327211	Flat Glass	28.788	9.73	0.84	4.27
327212	Other Pressed and Blown Glass and Glassware Manufacturing	20.304	11.86	1.51	4.95
327310	Cements	73.991	30.76	0.27	5.01
327410	Lime	168.794	323.26	5.47	34.39
327992	Ground or Treated Mineral and Earth Manufacturing	23.542	23.54	1.07	2.97
327993	Mineral Wool	20.581	13.30	0.48	2.78
331111	Iron and Steel Mills	20.952	14.23	0.55	2.91
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	4.424	3.53	2.33	11.14
331312	Primary Aluminum	89.457	49.01	0.15	2.61
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	20.810	22.55	1.09	3.41
331511	Iron Foundries	14.110	6.58	1.08	6.63
335991	Carbon and Graphite Product Manufacturing	13.268	10.54	0.66	2.00

Note: total energy intensity is a ratio of energy consumption from all sources (including electricity) to total value of shipments. The unit of measurement is thousand BTU per dollar.

TABLE 5 SUMMARY STATISTICS - TOTAL FUEL INTENSITY

NAICS Code	Industry Name	Mean	Standard Deviation	Skewness	Kurtosis
311221	Wet Corn Milling	16.094	12.51	1.45	5.40
321219	Reconstituted Wood Product Manufacturing	8.706	11.09	2.37	9.93
322110	Pulp Mills	13.947	8.95	0.65	2.26
322121	Paper Mills, except Newsprint	13.116	10.61	1.53	6.27
322122	Newsprint Mills	14.253	13.63	1.24	3.87
322130	Paperboard Mills	20.931	9.78	1.75	12.29
325110	Petrochemicals	16.022	17.83	1.47	3.97
325181	Alkalies and Chlorine	77.062	211.99	4.00	18.38
325188	Other Basic Inorganic Chemicals	9.255	11.67	2.65	11.91
325192	Cyclic Crudes and Intermediates	8.731	6.62	0.76	2.16
325199	Other Basic Organic Chemicals	9.753	14.24	3.06	14.77
325211	Plastics Materials and Resins	4.397	9.20	4.88	31.19
325212	Synthetic Rubber	5.035	6.90	1.38	3.75
325222	Noncellulosic Organic Fibers	3.622	5.30	3.55	18.43
325311	Nitrogenous Fertilizers	36.188	34.19	0.49	1.77
327211	Flat Glass	20.865	9.20	0.72	5.16
327212	Other Pressed and Blown Glass and Glassware Manufacturing	11.609	10.14	2.34	9.58
327310	Cements	53.495	26.69	0.54	4.39
327410	Lime	157.350	323.51	5.48	34.46
327992	Ground or Treated Mineral and Earth Manufacturing	14.496	21.22	1.50	3.95
327993	Mineral Wool	11.000	10.05	0.84	2.85
331111	Iron and Steel Mills	7.600	8.55	2.49	9.12
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	1.304	1.48	1.58	5.46
331312	Primary Aluminum	4.618	6.08	2.95	11.48
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	6.785	13.15	3.01	11.79
331511	Iron Foundries	3.871	3.36	1.79	8.20
335991	Carbon and Graphite Product Manufacturing	5.415	5.73	1.31	3.77

Note: total fuel intensity is a ratio of energy consumption from all fuels (electricity consumption not included) to total value of shipments. The unit of measurement is thousand BTU per dollar.

TABLE 6 SUMMARY STATISTICS - TOTAL CO2 INTENSITY (DIRECT AND INDIRECT)

NAICS Code	Industry Name	Mean	Standard Deviation	Skewness	Kurtosis
311221	Wet Corn Milling	1683.20	1171.82	1.43	5.96
321219	Reconstituted Wood Product Manufacturing	1285.21	1065.49	2.15	9.73
322110	Pulp Mills	1452.43	737.16	0.73	2.35
322121	Paper Mills, except Newsprint	1447.42	1071.84	1.85	7.81
322122	Newsprint Mills	3054.61	1302.82	-0.15	2.70
322130	Paperboard Mills	2055.30	963.79	2.24	13.27
325110	Petrochemicals	1247.16	1407.98	1.96	6.69
325181	Alkalies and Chlorine	7940.62	16979.00	4.22	19.89
325188	Other Basic Inorganic Chemicals	1168.54	1720.08	4.25	26.68
325192	Cyclic Crudes and Intermediates	690.56	391.51	0.41	2.22
325199	Other Basic Organic Chemicals	925.22	1170.01	2.87	13.91
325211	Plastics Materials and Resins	504.22	739.76	6.92	66.42
325212	Synthetic Rubber	476.51	493.46	1.21	3.44
325222	Noncellulosic Organic Fibers	696.64	467.70	1.18	4.04
325311	Nitrogenous Fertilizers	2621.09	2047.92	0.36	1.68
327211	Flat Glass	1547.46	524.25	0.77	4.09
327212	Other Pressed and Blown Glass and Glassware Manufacturing	1084.74	632.49	1.49	4.89
327310	Cements	6151.83	2813.91	0.39	4.29
327410	Lime	15460.14	30229.63	5.37	33.50
327992	Ground or Treated Mineral and Earth Manufacturing	1510.19	1857.38	1.84	5.67
327993	Mineral Wool	1284.03	1071.19	1.51	5.22
331111	Iron and Steel Mills	1229.63	971.64	1.24	4.63
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	236.49	187.60	2.31	11.08
331312	Primary Aluminum	4833.64	2593.71	0.07	2.65
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	1293.80	1499.90	1.37	4.35
331511	Iron Foundries	820.81	404.38	1.56	10.76
335991	Carbon and Graphite Product Manufacturing	706.57	561.16	0.66	2.00

Note: total CO_2 intensity is a ratio of total CO_2 emissions (from all energy sources, including electricity) to total value of shipments. The unit of measurement is kilograms (kg) per thousand dollars (or metric tons per million dollars).

TABLE 7 SUMMARY STATISTICS - DIRECT CO2 EMISSION INTENSITY (FUELS)

NAICS Code	Industry Name	Mean	Standard Deviation	Skewness	Kurtosis
311221	Wet Corn Milling	1165.48	1108.86	1.84	6.95
321219	Reconstituted Wood Product Manufacturing	570.00	823.58	2.67	11.12
322110	Pulp Mills	993.65	729.15	0.79	2.52
322121	Paper Mills, except Newsprint	973.45	893.52	1.47	4.89
322122	Newsprint Mills	1044.37	984.99	1.00	3.04
322130	Paperboard Mills	1451.92	893.61	2.34	13.83
325110	Petrochemicals	970.60	1258.68	2.18	7.48
325181	Alkalies and Chlorine	5640.56	17240.00	4.28	20.17
325188	Other Basic Inorganic Chemicals	506.07	635.26	2.57	11.07
325192	Cyclic Crudes and Intermediates	475.27	348.63	0.71	2.15
325199	Other Basic Organic Chemicals	563.31	907.20	4.30	29.35
325211	Plastics Materials and Resins	243.59	495.58	4.69	29.42
325212	Synthetic Rubber	291.45	416.76	1.60	4.79
325222	Noncellulosic Organic Fibers	223.42	312.06	2.70	12.04
325311	Nitrogenous Fertilizers	1926.35	1819.57	0.49	1.77
327211	Flat Glass	1126.08	495.54	0.64	4.87
327212	Other Pressed and Blown Glass and Glassware Manufacturing	622.26	541.63	2.31	9.42
327310	Cements	5061.71	2620.20	0.55	3.92
327410	Lime	14851.45	30244.50	5.38	33.53
327992	Ground or Treated Mineral and Earth Manufacturing	1029.03	1791.70	2.17	6.75
327993	Mineral Wool	774.47	929.94	1.92	6.42
331111	Iron and Steel Mills	519.50	801.29	3.10	12.05
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	70.55	78.70	1.55	5.38
331312	Primary Aluminum	321.38	643.66	3.87	16.87
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	547.90	1190.28	3.05	11.86
331511	Iron Foundries	276.24	300.98	2.13	9.79
335991	Carbon and Graphite Product Manufacturing	288.92	305.22	1.31	3.77

Note: direct CO_2 emission intensity is a ratio of direct CO_2 emissions (from all fuels, excluding purchased electricity) to total value of shipments. The unit of measurement is kilograms (kg) per thousand dollars (or metric tons per million dollars).

Even though our analysis is restricted to a set of energy-intensive trade-exposed manufacturing industries, both the mean energy intensity and emission intensity vary greatly across industries in our sample. For example, mean energy use per dollar of output in Lime Manufacturing (NAICS 327410) is almost forty times larger[21] than in Iron and Steel Pipe and Tube Manufacturing from Purchased Steel (NAICS 331210). It is for this reason that the graphs are normalized to the mean of intensity, allowing us to focus on the relative range of performance when comparing across industries. Figures 1-4 plot the distributions for each of four intensity measures, normalized to the mean intensity. In other words, the individual plant level intensity is divided by the corresponding industry mean from Tables 4-7. The distribution of these normalized intensities is shown via the kernel density plots in Figures 1-4 (the appendix contains larger versions of these plots grouped by industry rather than intensity measure). A kernel density is a nonparametric representation of an empirical distribution and can be thought of as a form of smoothed histogram.

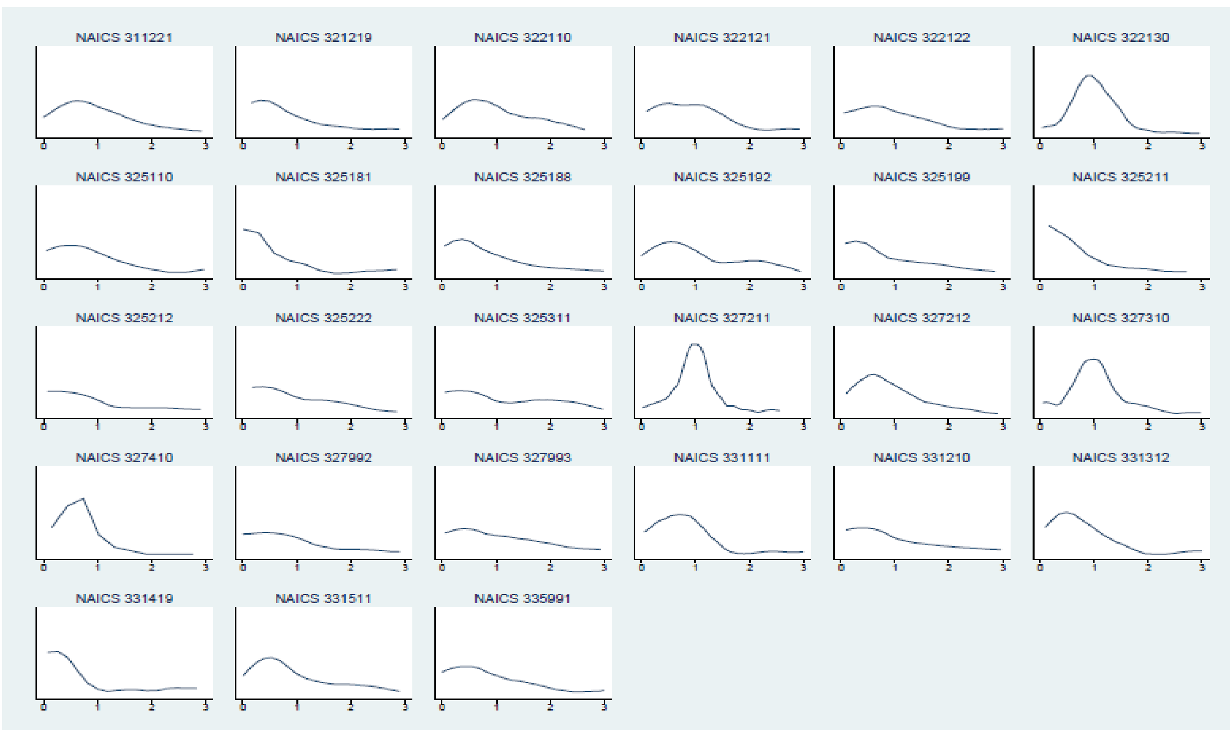

FIGURE 1 DIRECT FUEL INTENSITY - LEVELS NORMALIZED TO THE INDUSTRY MEAN

[21] These findings can differ from the comparisons based on the (publicly available) industry total energy use and total output numbers, for two reasons: first, we treated the outliers very conservatively; second, we did not weight plants in the sample by size.

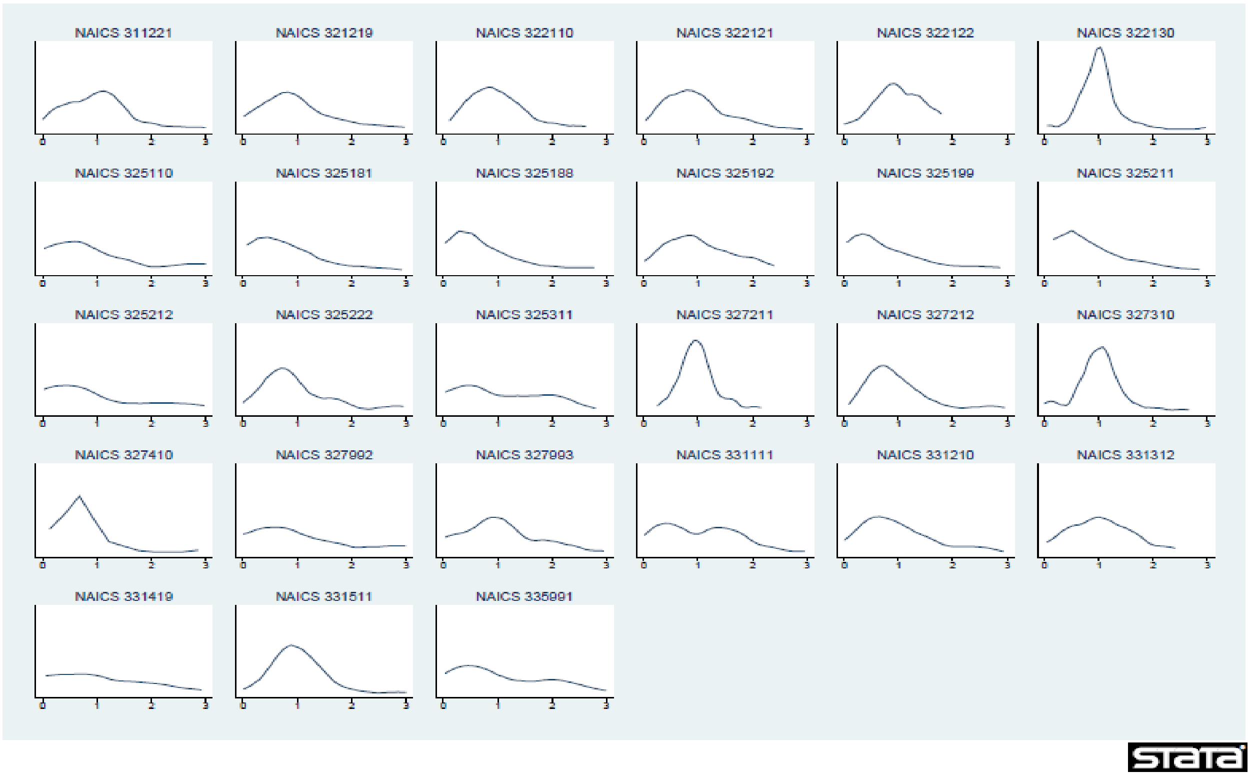

FIGURE 2 TOTAL ENERGY INTENSITY - LEVELS NORMALIZED TO INDUSTRY MEANS

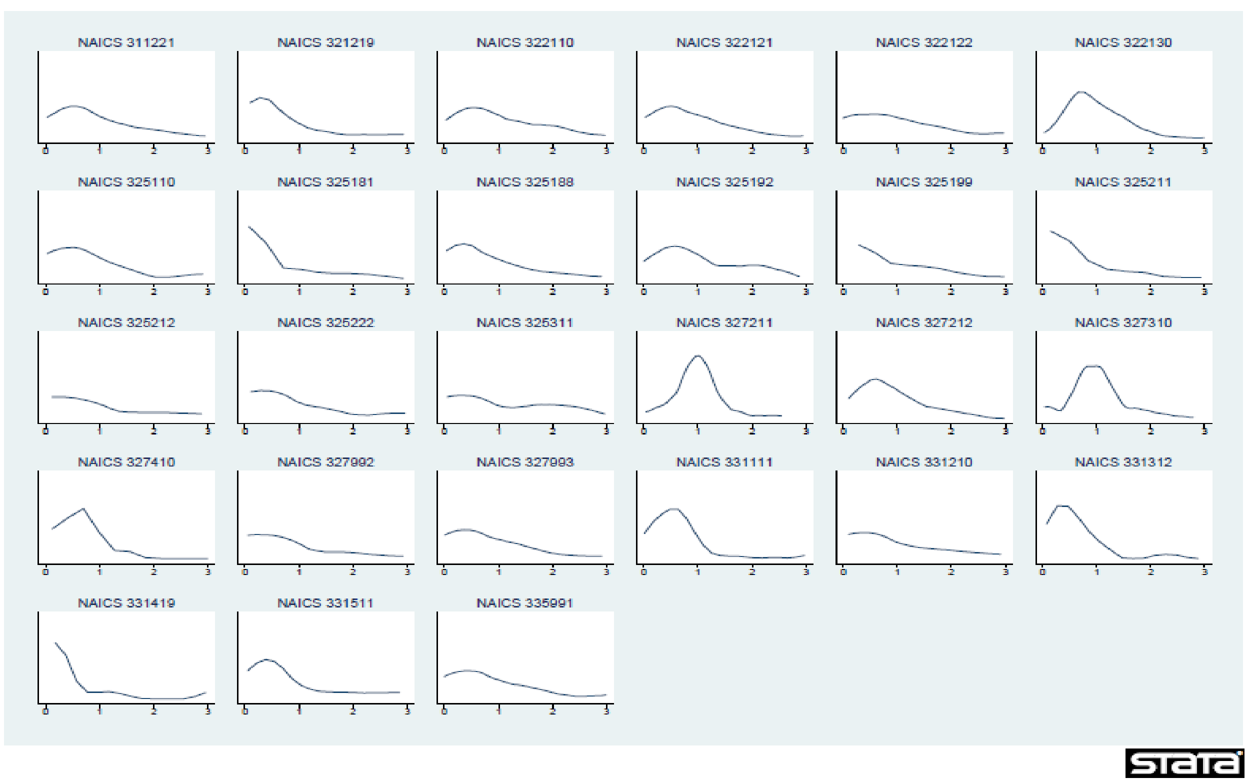

FIGURE 3 DIRECT CO2 EMISSIONS INTENSITY - LEVELS NORMALIZED TO THE INDUSTRY MEAN

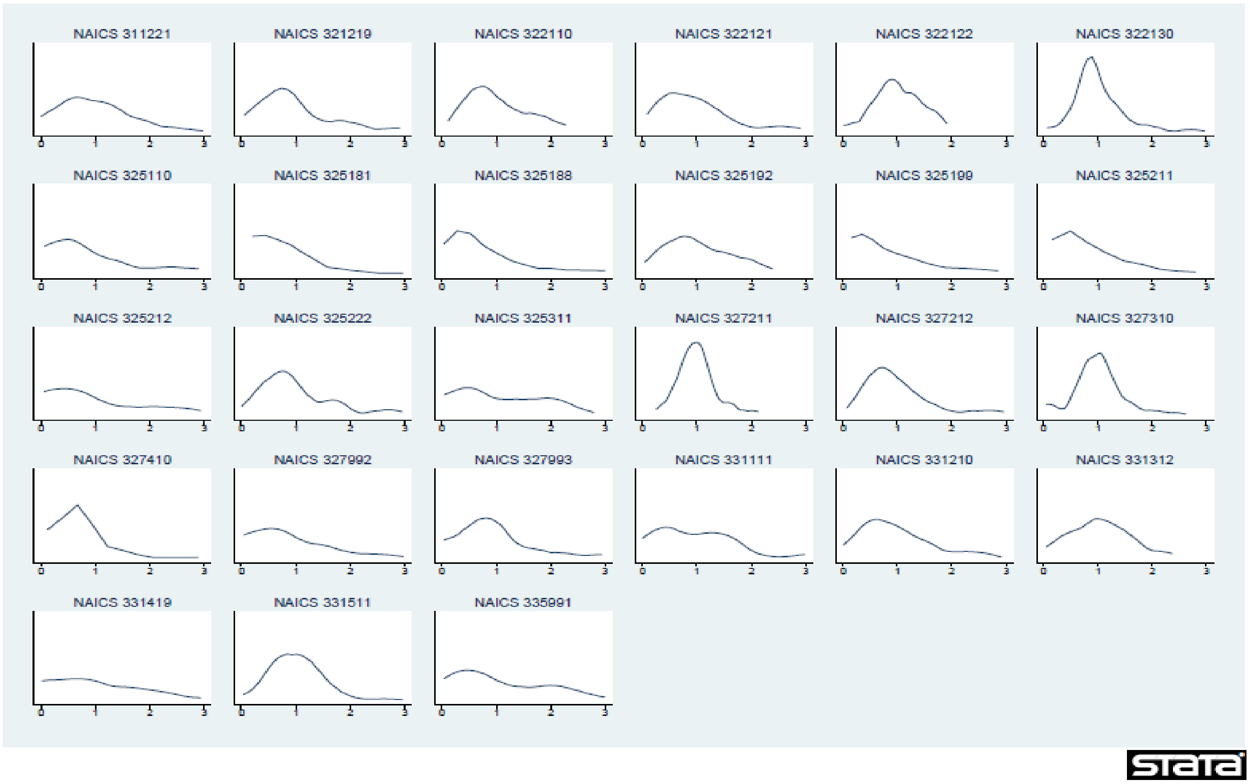

FIGURE 4 TOTAL DIRECT AND INDIRECT EMISSIONS INTENSITY - LEVELS NORMALIZED TO THE MEAN

Within-industry energy intensities tend to have unimodal distribution, that is, the distribution that has only one distinct mode. However, for some industries, the density plots have several "humps", but those humps are usually small compared to the mode. Few exceptions: Iron and Steel Mills (NAICS 331111) and Carbon and Graphite Product Manufacturing (NAICS 335991) appear to have two distinct peaks for total energy intensity and total CO2 release, but not for fuel energy intensity and fuel CO2 release, which suggests that the second mode comes from plant specific differences in electricity consumption. In the case of Iron and Steel Mills there is a subset of plants using a primarily electric based process using scrap steel. These differences reflected in distribution in other industries may also arise from specific electric based processes or specific products that are more electric (less fuel) intensive.

Visual examination of the density plots suggests that the distributions of four measures of energy/emission intensity for the same industry look quite similar. Furthermore, the shape of distribution of the (mean-normalized) energy intensity is nearly identical to the one of the emission intensity when they both reflect the same set of energy sources (all energy sources or all fuels). These findings suggest that the variation in the energy intensity is a more important determinant of the emission intensity distribution within an industry than differences in energy-related CO2 emissions per MBtu across various fuel types.

As can be seen from the kernel density plots in levels, the distributions of energy intensity and emission intensity measures are skewed to the right, that is, the mass of the distribution is concentrated on the left of the figure. Sample skewness statistics confirm this observation, as almost all of them are positive (positive skewness statistics indicate long right tails, negative – long left tails, and distributions with zero skewness are symmetric around the mean). The only exception is Newsprint Mills industry (NAICS 322122): for this industry, the distributions of the energy intensity and emission intensity from all energy sources are slightly skewed to the left[22], but the distributions of the same measures based on direct fuels use are still skewed to the right. The right skewness apparently stems from the fact that the measures of interest can only take non-negative values; moreover, by construction, all values below the mean are clustered between 0 and 1, while values higher than mean can take fairly large values. Hence, these distributions cannot have long left (negative) tails, but can have long right tails. As can be seen from the table of summary statistics, the Lime Manufacturing industry (NAICS 327410) appears to have the most skewed distribution of the energy intensity and emission intensity measures: the bulk of the observations are smaller than the mean, and there are few observations that are significantly larger than the mean.

It is useful to rank or group the plants according to similar distribution characteristics. Tables 6-7 present the sample statistics for all four of our intensity measures, sorted by the total energy intensity. Table 6 presents the standard deviation normalized by the mean. This makes it possible to compare across industries. Skewness and kurtosis do not require this normalization to be comparable.

Kurtosis is a measure of the "peakedness" of a distribution, or conversely, the heaviness of the tails of a distribution. A normal distribution has a kurtosis of 3. "Flat" or heavy tailed distributions will have kurtosis greater than 3 and light tailed distributions will have kurtosis less than 3. When we look at table 8, we see that more of the distributions are "flat" or heavy tailed. A few have a "peak" similar to a normal distribution, e.g. Mineral Wool, Synthetic Rubber, Iron and Steel Mills, Ground or Treated Mineral and Earth Manufacturing, and Petrochemicals.

[22] The corresponding density plot drops at around 2, suggesting that very few (if any) plants have energy/carbon intensity bigger than twice the mean.

TABLE 8 COEFFICIENT OF VARIATION (STANDARD DEVIATION DEVIDED BY THE MEAN) - SORTED BY COEFFICIENT OF VARIATION OF THE TOTAL ENERGY INTENSITY

NAICS Code	Industry Name	Total	Fuel MBTU	Total CO_2	Fuel CO_2
327410	Lime	0.522	0.486	0.511	0.491
325181	Alkalies and Chlorine	0.577	0.364	0.468	0.327
325211	Plastics Materials and Resins	0.673	0.478	0.682	0.492
325188	Other Basic Inorganic Chemicals	0.674	0.793	0.679	0.797
325199	Other Basic Organic Chemicals	0.837	0.685	0.791	0.621
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	0.923	0.516	0.863	0.460
327992	Ground or Treated Mineral and Earth Manufacturing	1.000	0.683	0.813	0.574
325212	Synthetic Rubber	1.010	0.730	0.966	0.699
325110	Petrochemicals	1.030	0.899	0.886	0.771
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	1.255	0.882	1.261	0.896
335991	Carbon and Graphite Product Manufacturing	1.258	0.945	1.259	0.947
325311	Nitrogenous Fertilizers	1.280	1.058	1.280	1.059
321219	Reconstituted Wood Product Manufacturing	1.367	0.785	1.206	0.692
322121	Paper Mills, except Newsprint	1.445	1.236	1.350	1.089
325222	Noncellulosic Organic Fibers	1.449	0.683	1.490	0.716
331111	Iron and Steel Mills	1.473	0.889	1.266	0.648
327993	Mineral Wool	1.547	1.095	1.199	0.833
327212	Other Pressed and Blown Glass and Glassware Manufacturing	1.712	1.145	1.715	1.149
325192	Cyclic Crudes and Intermediates	1.745	1.318	1.764	1.363
311221	Wet Corn Milling	1.786	1.287	1.436	1.051
331312	Primary Aluminum	1.825	0.760	1.864	0.499
322110	Pulp Mills	2.018	1.558	1.970	1.363
331511	Iron Foundries	2.144	1.151	2.030	0.918
322122	Newsprint Mills	2.339	1.046	2.345	1.060
327310	Cements	2.406	2.004	2.186	1.932
322130	Paperboard Mills	2.738	2.141	2.133	1.625
327211	Flat Glass	2.957	2.269	2.952	2.272

TABLE 9 SKEWNESS - SORTED BY THE SKEWNESS OF TOTAL ENERGY INTENSITY

NAICS Code	Industry Name	Total	Fuel	Total CO_2	Fuel CO_2
322122	Newsprint Mills	-0.227	1.241	-0.152	0.997
331312	Primary Aluminum	0.154	2.953	0.073	3.868
327310	Cements	0.270	0.537	0.391	0.550
325311	Nitrogenous Fertilizers	0.358	0.488	0.359	0.489
325192	Cyclic Crudes and Intermediates	0.432	0.759	0.408	0.712
327993	Mineral Wool	0.477	0.837	1.509	1.917
331111	Iron and Steel Mills	0.552	2.489	1.240	3.100
335991	Carbon and Graphite Product Manufacturing	0.658	1.310	0.659	1.313
311221	Wet Corn Milling	0.799	1.452	1.429	1.844
327211	Flat Glass	0.844	0.724	0.774	0.636
322110	Pulp Mills	1.016	0.651	0.726	0.789
325212	Synthetic Rubber	1.038	1.377	1.208	1.600
327992	Ground or Treated Mineral and Earth Manufacturing	1.071	1.499	1.845	2.175
331511	Iron Foundries	1.083	1.788	1.557	2.126
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	1.086	3.005	1.369	3.054
325110	Petrochemicals	1.222	1.467	1.956	2.185
322130	Paperboard Mills	1.333	1.752	2.235	2.340
325222	Noncellulosic Organic Fibers	1.358	3.555	1.176	2.699
327212	Other Pressed and Blown Glass and Glassware Manufacturing	1.505	2.341	1.488	2.311
321219	Reconstituted Wood Product Manufacturing	1.759	2.371	2.145	2.675
325199	Other Basic Organic Chemicals	2.282	3.058	2.870	4.296
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	2.328	1.578	2.313	1.546
322121	Paper Mills, except Newsprint	2.513	1.534	1.854	1.474
325181	Alkalies and Chlorine	3.823	4.004	4.223	4.280
325188	Other Basic Inorganic Chemicals	4.280	2.652	4.246	2.566
327410	Lime	5.472	5.485	5.373	5.379
325211	Plastics Materials and Resins	7.082	4.875	6.917	4.686

TABLE 10 KURTOSIS (SORTED BY THE KURTOSIS OF TOTAL ENERGY INTENSITY)

NAICS Code	Industry Name	Total	Fuel	Total CO_2	Fuel CO_2
325311	Nitrogenous Fertilizers	1.683	1.768	1.685	1.767
335991	Carbon and Graphite Product Manufacturing	2.004	3.765	2.005	3.772
325192	Cyclic Crudes and Intermediates	2.307	2.163	2.217	2.153
322122	Newsprint Mills	2.508	3.869	2.695	3.043
331312	Primary Aluminum	2.613	11.477	2.650	16.873
327993	Mineral Wool	2.782	2.853	5.216	6.419
325212	Synthetic Rubber	2.783	3.747	3.441	4.795
331111	Iron and Steel Mills	2.907	9.118	4.632	12.045
327992	Ground or Treated Mineral and Earth Manufacturing	2.968	3.955	5.670	6.751
325110	Petrochemicals	3.333	3.971	6.690	7.476
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	3.407	11.787	4.354	11.863
322110	Pulp Mills	3.904	2.262	2.353	2.517
311221	Wet Corn Milling	4.034	5.402	5.959	6.954
327211	Flat Glass	4.272	5.164	4.090	4.871
325222	Noncellulosic Organic Fibers	4.586	18.430	4.042	12.042
327212	Other Pressed and Blown Glass and Glassware Manufacturing	4.946	9.575	4.892	9.417
327310	Cements	5.008	4.386	4.293	3.923
331511	Iron Foundries	6.633	8.196	10.763	9.787
321219	Reconstituted Wood Product Manufacturing	8.283	9.935	9.727	11.118
325199	Other Basic Organic Chemicals	8.534	14.768	13.911	29.351
322130	Paperboard Mills	9.751	12.294	13.271	13.829
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	11.138	5.459	11.075	5.376
322121	Paper Mills, except Newsprint	13.538	6.267	7.808	4.894
325181	Alkalies and Chlorine	17.489	18.377	19.890	20.170
325188	Other Basic Inorganic Chemicals	26.904	11.914	26.681	11.067
327410	Lime	34.395	34.460	33.500	33.532
325211	Plastics Materials and Resins	68.678	31.190	66.420	29.420

The distributions of the energy intensity and emission intensity measures appear much more symmetric in the logarithmic scale (see figures 5-8); moreover, most of the distribution graphs are bell-shaped similar to normal distribution[23]. About half of the log distributions have long left tails, which implies that some observations are smaller than the mean by 10 or more times (equivalently, there are plants that use more than 10 times less energy per unit of output that the industry average). However, it is possible that these observations result simply from reporting errors, if some plants fail to report their energy consumption in full. This may be more likely with industries that use waste fuels, e.g. Cement, or have large use of internally generate biomass, e.g. Paperboard Mills.

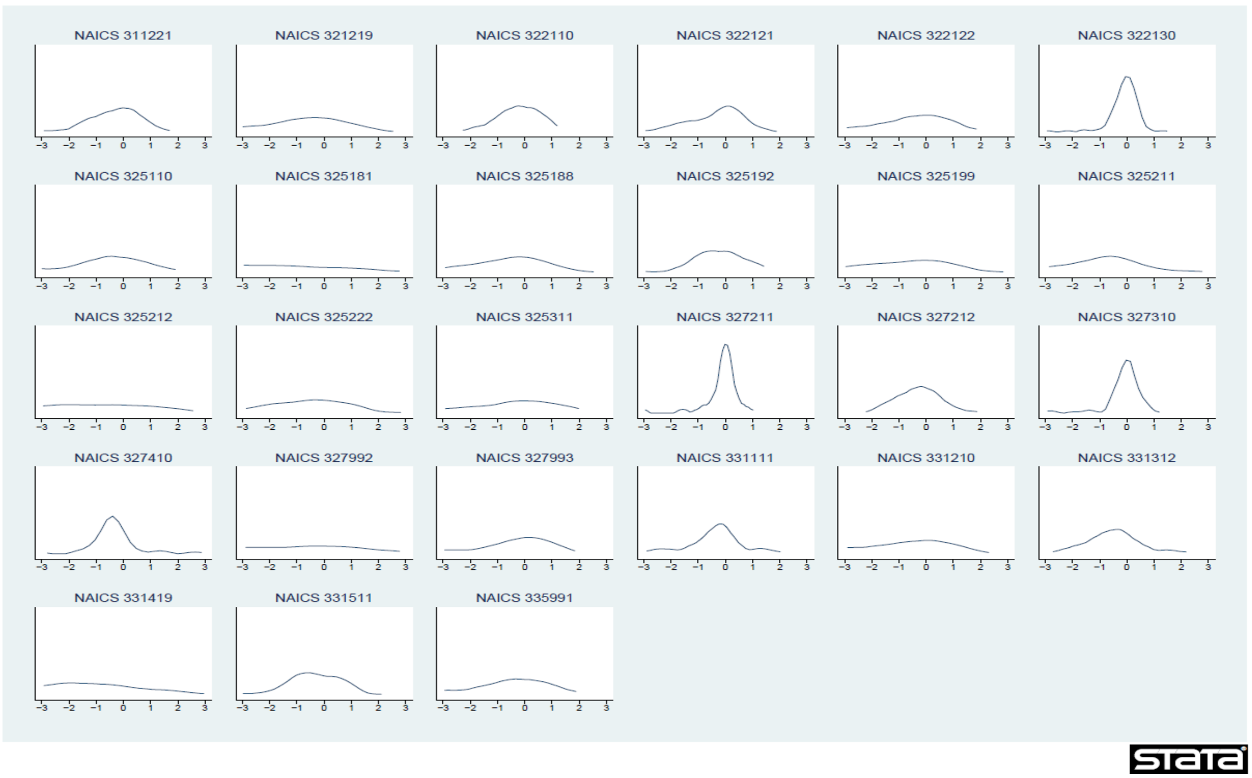

FIGURE 5 KERNEL DENSITY PLOTS - FUEL INTENSITY, LOG SCALE

[23] This suggests that normal distribution might be suitable for a model describing logarithm of energy/emission intensity; thus, lognormal distribution could work well for modeling energy/emission intensities in levels.

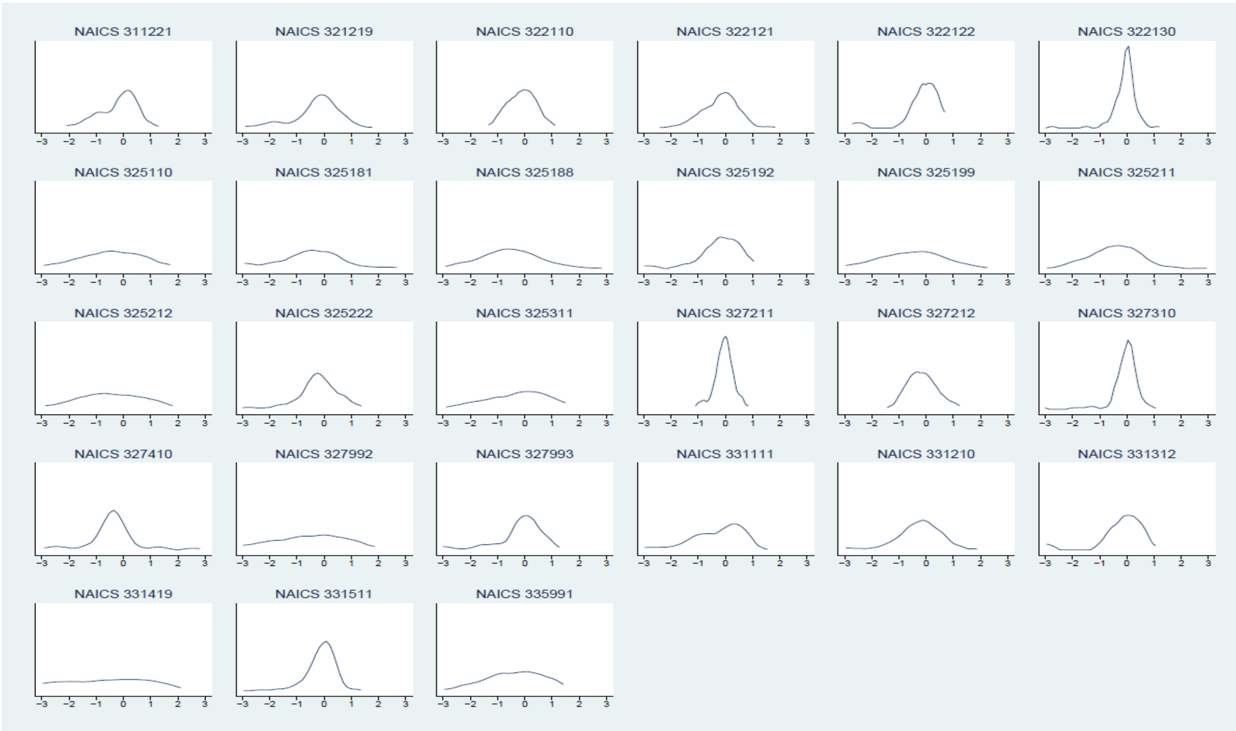

FIGURE 6 KERNEL DENSITY PLOTS - TOTAL ENERGY INTENSITY, LOG SCALE

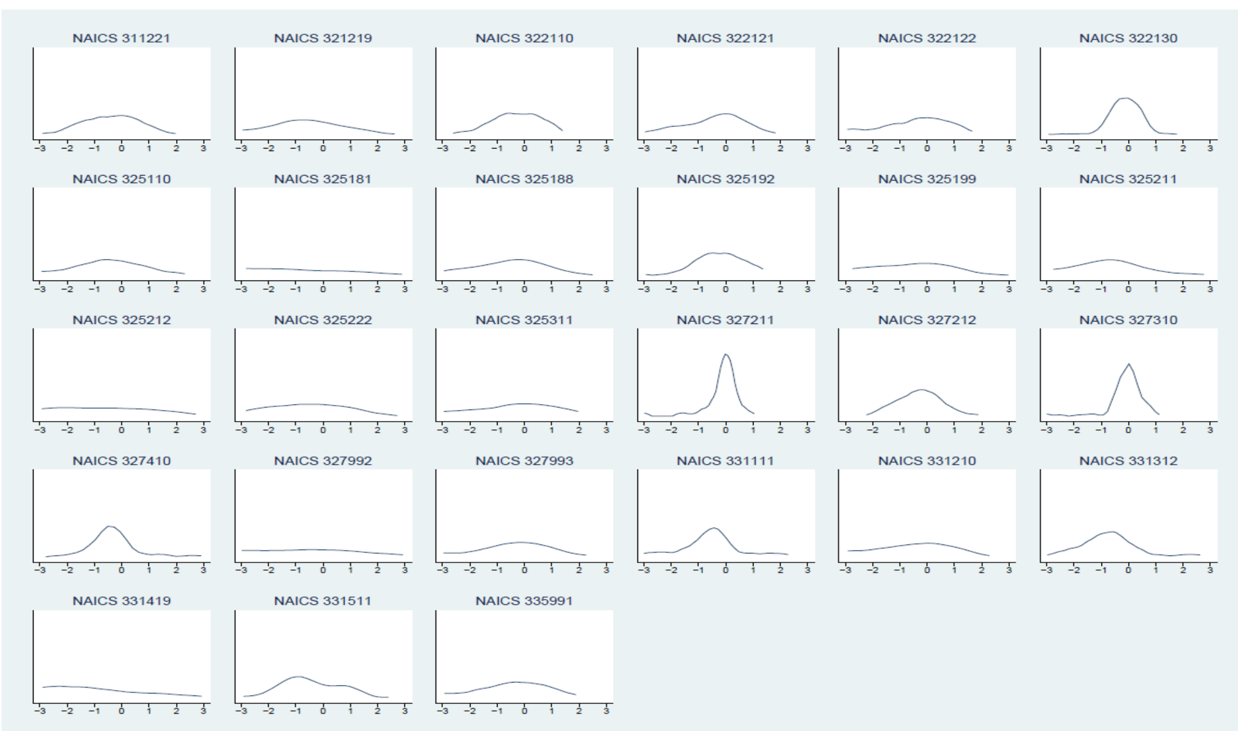

FIGURE 7 KERNEL DENSITY PLOTS - COMBUSTION EMISSIONS INTENSITY (FUELS), LOG SCALE

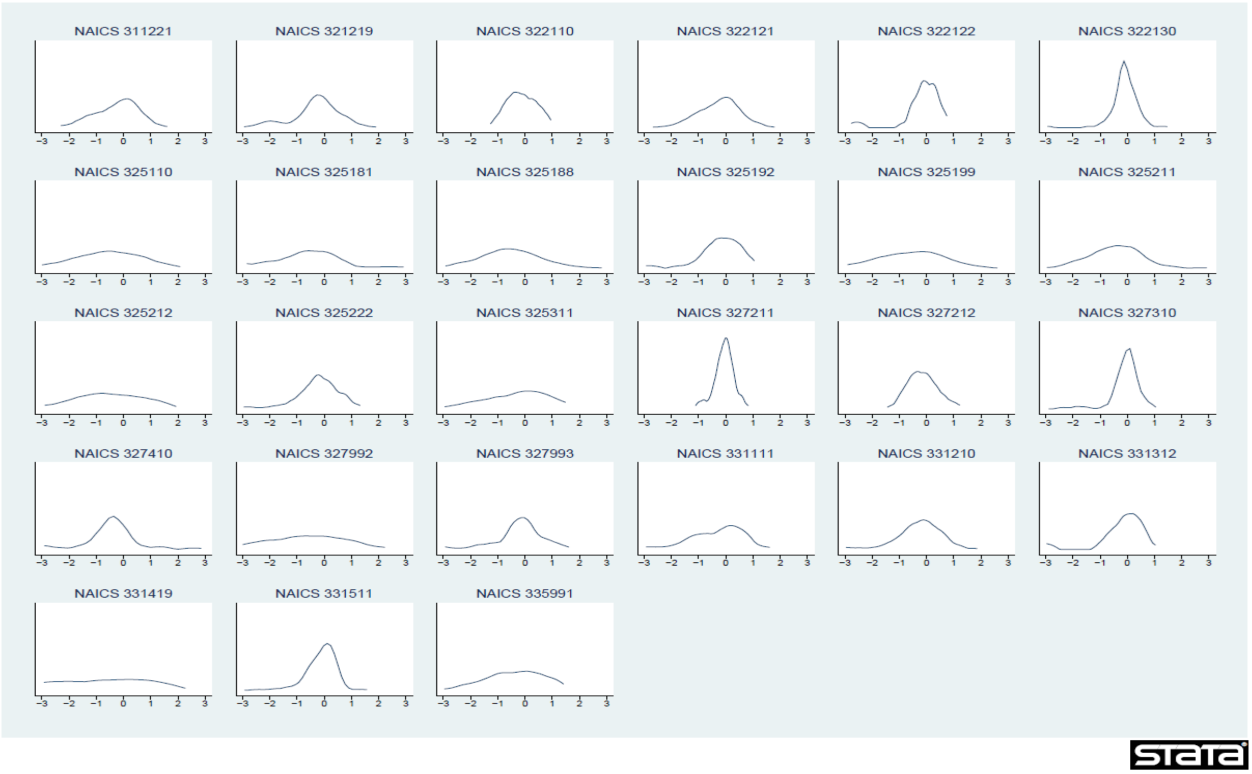

FIGURE 8 KERNEL DENSITY PLOTS - TOTAL CO2 EMISSIONS (DIRECT AND INDIRECT), LOG SCALE

RETURNS TO SCALE ANALYSIS

In this section we report results regarding returns to scale with respect to industries' energy consumption. If there is a pattern of systematic higher or lower energy use that is not proportional to the level of plant activity then intensity ratios can be misleading. For example, if large plants have engineering advantages such that they can be more efficient then an increase in plant size would result in a less than proportional increase in energy. On the other hand large plants may specialize in more (or less) energy intensive product, with a similar resulting bias in intensity. Specifically, we show results from simple univariate regressions for each industry, and document that for most industries, the returns to scale is not significantly different from one. As a result, in most industries there are constant returns to scale with respect to energy usage. This finding suggests that the distribution of energy intensities may be an appropriate measure for the distribution of industries' energy efficiency.

For the returns to scale analysis we use a simple univariate regression with the following specification:

$$\log(y) = \alpha + \beta \log(x) + \varepsilon$$

where :

x – takes the value of total value of shipment, or total value added in a 6 digit industry.

y – takes the value of energy consumption expressed in MBTU.

To test for constant returns to scale we use a standard t-statistic. Specifically, to test for constant returns to scale in a univariate regression we compute: $t = \frac{b-1}{std\,(b)}$, where now b is an estimate of β. If the sample size is large enough, the distribution of t is close enough to the normal distribution. With smaller sample sizes one has to use the t-statistic.

First we report the regression results both with and without the sample weights provided with the MECS data, using total value of shipment as the dependent variable. Table 9 below reports the results from regressing the variable energy consumption on total value of shipment (tvs) for each 6 digit level NAICS industry. That is, x = tvs; and y = total energy usage.

From these results, one can potentially conclude that the weighted data probably is exacerbating measurement errors, especially given the relatively small sample sizes. To see this, one can compare the weighted and unweighted coefficient estimates for example in industries: 327310 (Cements), 327993 (Mineral Wool), 331111 (Iron and Steel Mills), 331210 (Iron and Steel Pipe and Tube Manufacturing from Purchased Steel), or 331419 (Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)). The probable small sample sizes, potential measurement errors compounded with the sample weights give rise to implausible large returns to scale. As a result it is probably more instructive to look at the results from the unweighted regressions.

Even from the unweighted regressions, the coefficients are still very large. One potential explanation for these large coefficients may potentially come from vertical integration in some industries. For example some firms that are vertically integrated may produce energy for their own consumption. This however may bias the resulting coefficients.

To address this issue, we now run the same regression, this time however with the dependent variable being total value added. That is, y = log(va), where value added equals total value of shipments less cost of materials. Just as before, we report results from both the weighted and unweighted regressions (see table 10).

Just as before, because of potential measurement errors and small sample sizes, let us consider the unweighted regression results. First, notice that the coefficients in general are lower when the dependent variable is total value added, which suggests that some industries may be vertically integrated. Second, there are still however some industries with returns to scale significantly higher than 1, see: 311221 (Wet Corn Milling), 327310 (Cements), and 331111 (Iron and Steel Mills).

For most sectors the returns to scale are not to be statistically significantly different from one. This suggests that the distribution of energy intensities may be an appropriate measure. There are a few exceptions to this. NAICS with a one * reject CRS for both TVS and VA; NAICS with a two * can't reject that CRS = 1 with TVS, but reject with VA; NAICS with a three * reject CRS = 1 with TVS , but not with VA .

For the case of rejecting CRS for both TVS and VA there is one industry, Pulp Mills, where larger plants tend to have lower energy intensity, i.e. there is a scale advantage to size with respect to energy. For the other four Wet Corn Milling, Cements, Iron and Steel Mills, Iron Foundries the result suggests the opposite, that large plant are relatively more energy intensive. The coefficient is very large in some cases. In these cases it may be that there is a subsector of the industry, dominated by small facilities that perform low energy intensive final finishing. The large coefficient in cement is particularly surprising, but this industry may have plants that perform finish grinding or bagging only. The upstream component of cement, clinker production, is the most energy intensive stage of production. Additional analysis of all of these sectors is warranted.

For the case where we reject CRS = 1 with TVS , but not with VA, this pattern of results suggest that large establishments are more verticaly integrated, since the inclusion of materials reduces the scale effect. This makes sense for many of these sectors, e.g. Plastics Materials and Resins, Synthetic Rubber, Noncellulosic Organic Fibers, etc.

TABLE 11 RETURNS TO SCALE ESTIMATES - TOTAL VALUE OF SHIPMENTS AND TOTAL ENERGY

NAICS code	Industry	Coefficient β weighted regression	Standard Error	Coefficient β (unweighted regression)	Standard Error
311221*	Wet Corn Milling	1.239	0.051	1.238	0.050
321219	Reconstituted Wood Product Manufacturing	0.943	0.106	0.980	0.138
322110*	Pulp Mills	0.981	0.081	0.981	0.081
322121	Paper Mills, except Newsprint	0.940	0.040	0.902	0.048
322122	Newsprint Mills	1.506	0.212	1.506	0.212
322130	Paperboard Mills	1.440	0.097	1.024	0.040
325110	Petrochemicals	1.011	0.090	0.984	0.089
325181	Alkalies and Chlorine	1.314	0.272	1.347	0.267
325188**	Other Basic Inorganic Chemicals	1.040	0.074	0.894	0.085
325192	Cyclic Crudes and Intermediates	1.116	0.089	1.116	0.089
325199***	Other Basic Organic Chemicals	1.302	0.063	1.217	0.068
325211***	Plastics Materials and Resins	1.256	0.035	1.181	0.043
325212***	Synthetic Rubber	1.142	0.061	1.231	0.083
325222	Noncellulosic Organic Fibers	1.048	0.091	1.003	0.085
325311***	Nitrogenous Fertilizers	1.353	0.121	1.353	0.121
327211***	Flat Glass	1.129	0.055	1.129	0.055
327212	Other Pressed and Blown Glass and Glassware Manufacturing	1.111	0.029	1.031	0.055
327310*	Cements	2.182	0.047	1.738	0.093
327410	Lime	1.187	0.201	1.187	0.201
327992	Ground or Treated Mineral and Earth Manufacturing	0.924	0.278	1.415	0.231
327993***	Mineral Wool	1.505	0.093	1.300	0.104
331111*	Iron and Steel Mills	1.423	0.037	1.288	0.051
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	1.602	0.050	1.057	0.111
331312***	Primary Aluminum	1.195	0.087	1.297	0.139
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	1.864	0.596	1.092	0.525
331511*	Iron Foundries	1.160	0.051	1.125	0.040
335991***	Carbon and Graphite Product Manufacturing	1.518	0.121	1.320	0.154

TABLE 12 RETURNS TO SCALE ESTIMATES -TOTAL VALUE ADDED AND TOTAL ENERGY

NAICS code	Industry	Coefficient β (weighted regression)	Standard Error	Coefficient β (unweighted regression)	Standard Error
311221*	Wet Corn Milling	1.199	0.068	1.199	0.068
321219	Reconstituted Wood Product Manufacturing	1.136	0.110	0.838	0.126
322110*	Pulp Mills	0.852	0.102	0.852	0.102
322121	Paper Mills, except Newsprint	0.852	0.044	0.798	0.050
322122	Newsprint Mills	1.086	0.192	1.086	0.192
322130	Paperboard Mills	1.452	0.070	0.980	0.040
325110	Petrochemicals	1.059	0.100	1.027	0.097
325181	Alkalies and Chlorine	1.177	0.258	1.203	0.254
325188**	Other Basic Inorganic Chemicals	0.995	0.078	0.777	0.087
325192	Cyclic Crudes and Intermediates	0.997	0.120	0.997	0.120
325199***	Other Basic Organic Chemicals	1.267	0.081	1.097	0.088
325211***	Plastics Materials and Resins	1.339	0.057	1.071	0.063
325212***	Synthetic Rubber	1.140	0.071	1.197	0.099
325222	Noncellulosic Organic Fibers	0.949	0.104	0.908	0.095
325311***	Nitrogenous Fertilizers	1.286	0.170	1.286	0.170
327211***	Flat Glass	1.137	0.072	1.137	0.072
327212	Other Pressed and Blown Glass and Glassware Manufacturing	1.121	0.033	1.027	0.067
327310*	Cements	1.983	0.061	1.304	0.083
327410	Lime	1.056	0.198	1.056	0.198
327992	Ground or Treated Mineral and Earth Manufacturing	0.836	0.295	1.281	0.281
327993***	Mineral Wool	1.184	0.069	1.109	0.088
331111*	Iron and Steel Mills	1.517	0.048	1.196	0.066
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	1.866	0.077	0.979	0.127
331312***	Primary Aluminum	1.102	0.111	1.090	0.175
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	1.728	0.294	1.301	0.306
331511*	Iron Foundries	1.187	0.051	1.111	0.043
335991***	Carbon and Graphite Product Manufacturing	1.544	0.207	0.985	0.212

Note: NAICS with a one * reject CRS for both TVS and VA; NAICS with a two ** can't reject that CRS = 1 with TVS, but reject with VA; NAICS with a three *** reject CRS = 1 with TVS, but not with VA .

CONCLUSION

The identification of the 44 energy intensive, trade exposed 6-digit NAICS industries has been based on published total energy costs and value of shipments. This report shows that a wide pattern of distribution of energy intensity, defined as either fuel use (MBTU) to total value of shipments or total energy use (Fuels and electricity) to total value of shipments, within the 27 of these sectors with sufficiently robust data for analysis. CO_2 emission intensity distributions follow patterns seen in the associated energy measures. There are almost no industries where the distributions of intensities follow a “well behaved” normal bell curve, with the possible exception of total energy and CO2 intensity of newsprint mills and Primary Aluminum; to a lesser extent Cyclic Crudes and Intermediates and Cements. For others, the differences in the distributions may be due to vertical integration, as in paper and paperboard mills, or various chemical sectors. In others the difference may be due to reporting issues of alternative fuels, processes that are uniquely electric intensive, or the existence of specialized sub-sectors of the 6-digit NAICS.

This report is not intended to settle the issue of why these distributions differ, but to provide a quantification of these distributions that relies on a standard set of government-collected, plant-level data. This report can then be the basis of further examination of why these distributions differ across industries and whether these differences “matter” when it comes to climate policy in relationship to energy intensive, trade exposed manufacturing.

APPENDIX

Kernel density plots for mean-normalized energy intensities and emission intensities, by industry:

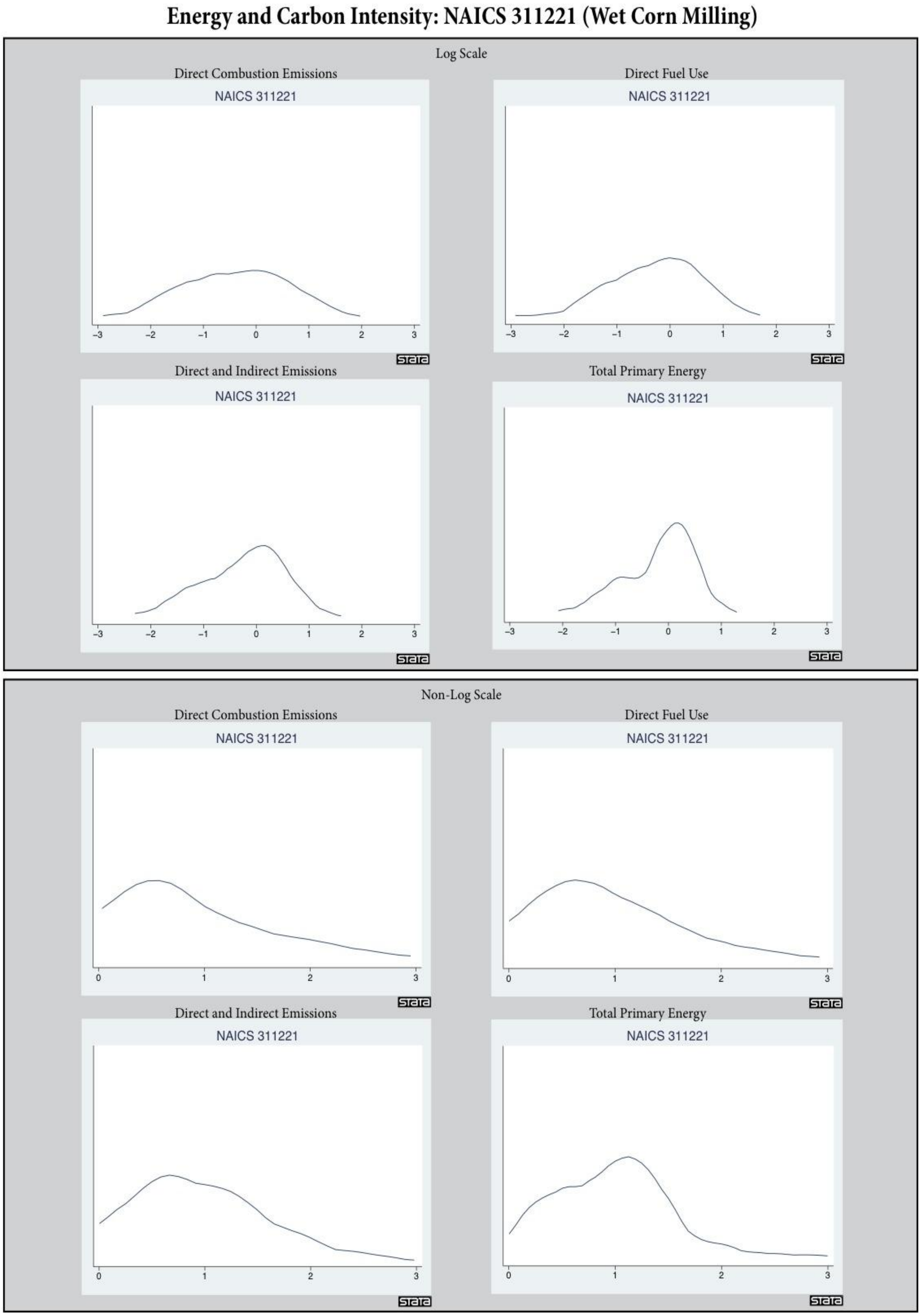

FIGURE 9: NAICS 311221 (WET CORN MILLING)

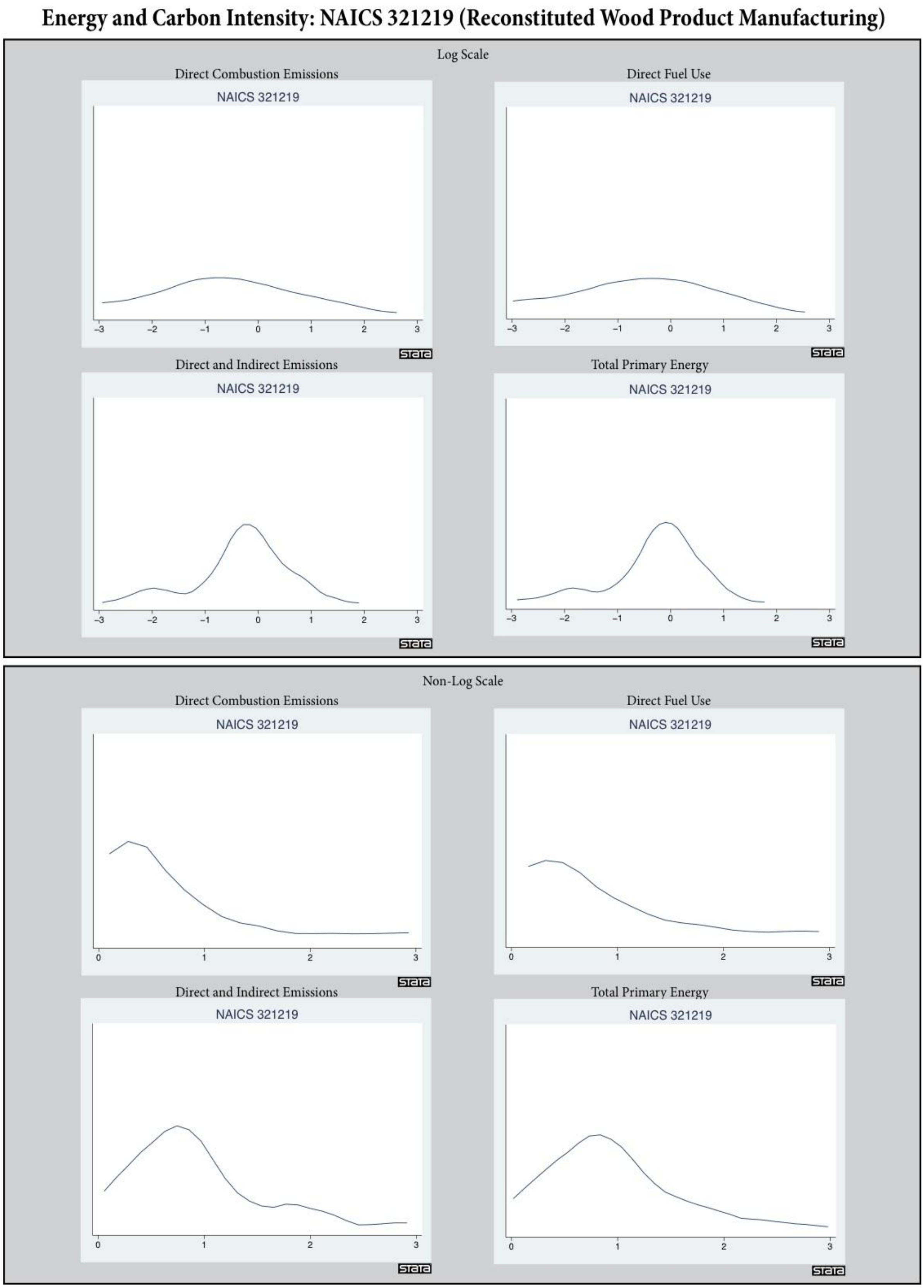

FIGURE 10: NAICS 321219 (RECONSTITUTED WOOD PRODUCT MANUFACTURING)

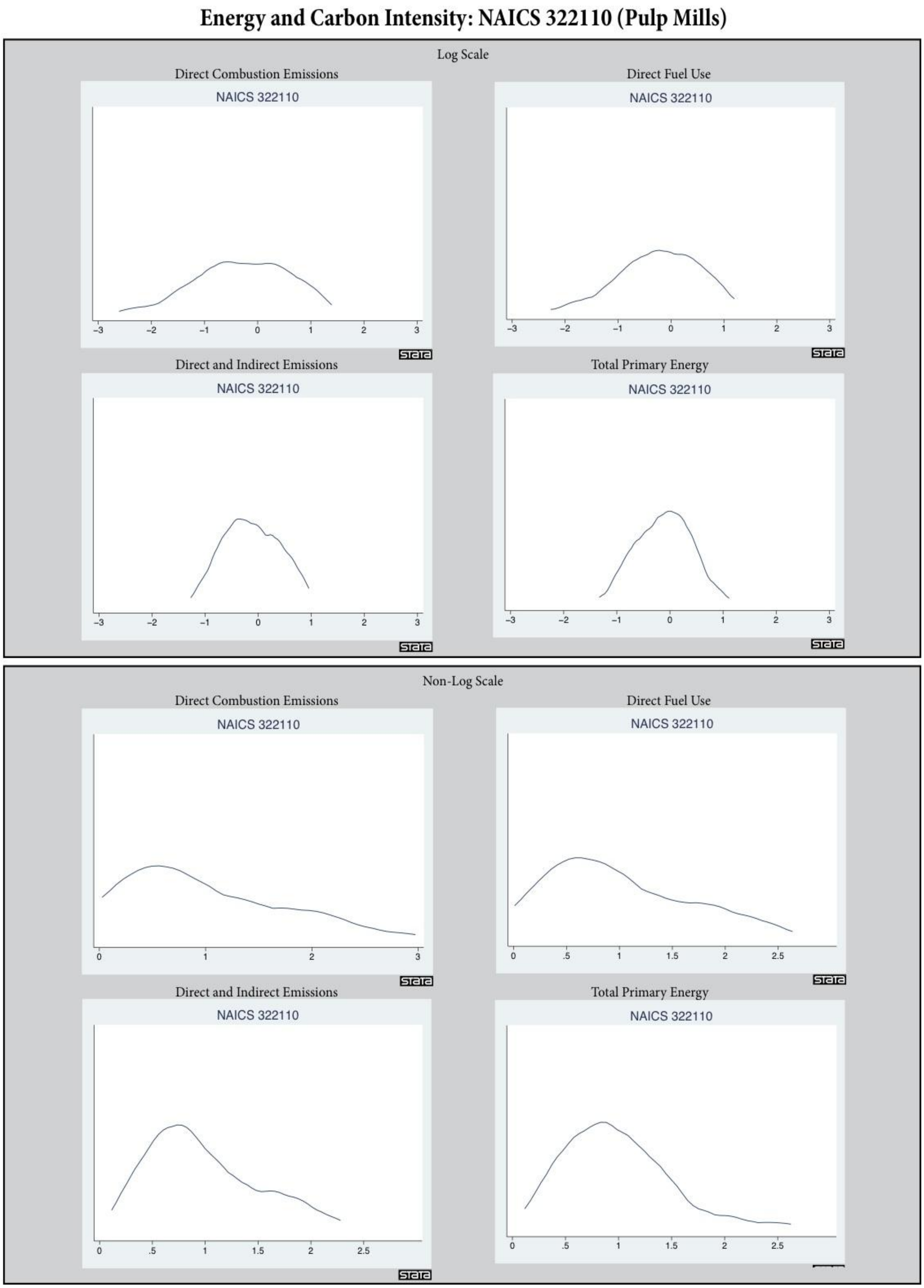

FIGURE 11: NAICS 322110 (PULP MILLS)

Energy and Carbon Intensity: NAICS 322121 (Paper Mills, except Newsprint)

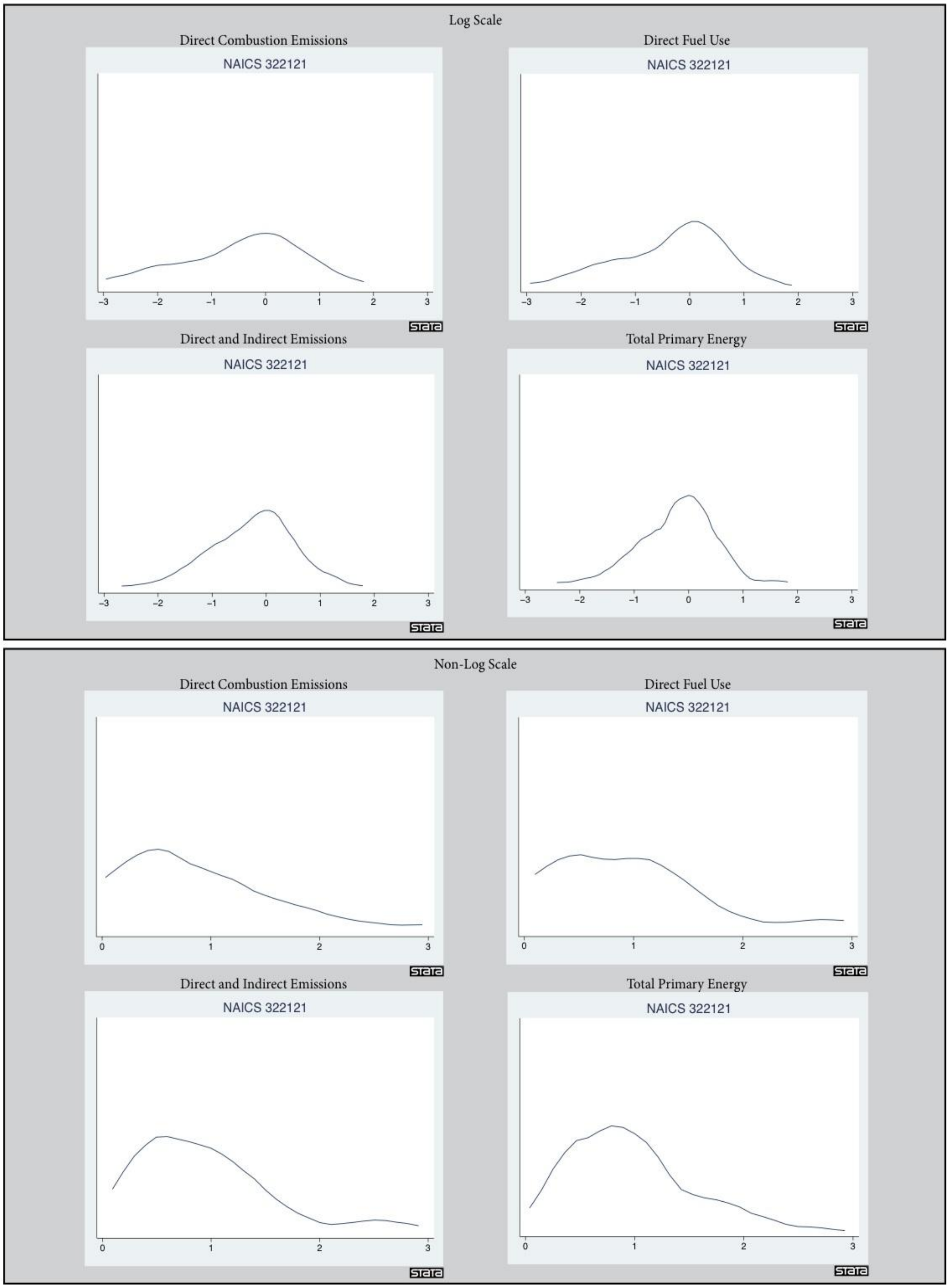

FIGURE 12: NAICS 322121 (PAPER MILLS, EXCEPT NEWSPRINT)

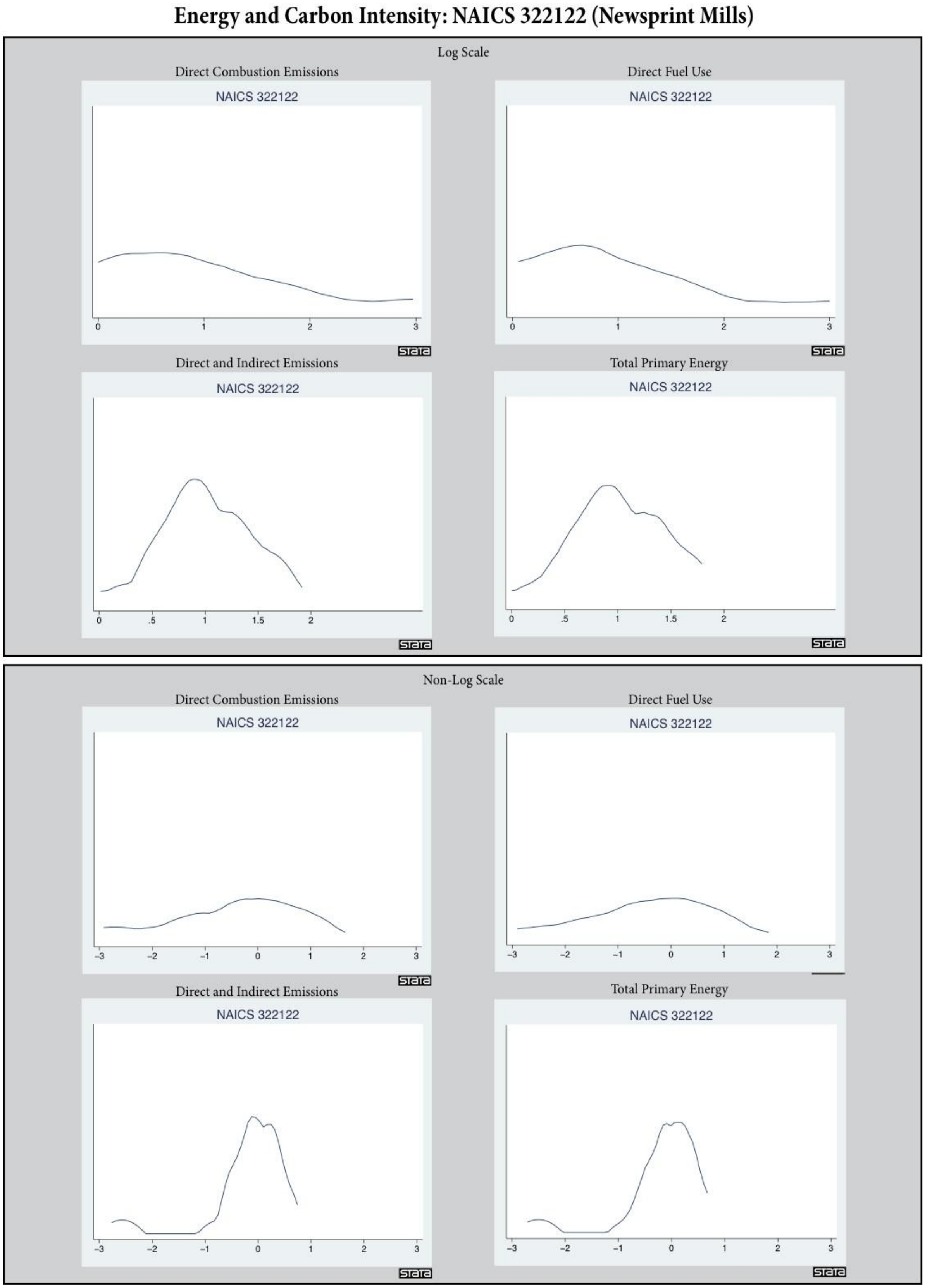

FIGURE 13: NAICS 322122 (NEWSPRINT MILLS)

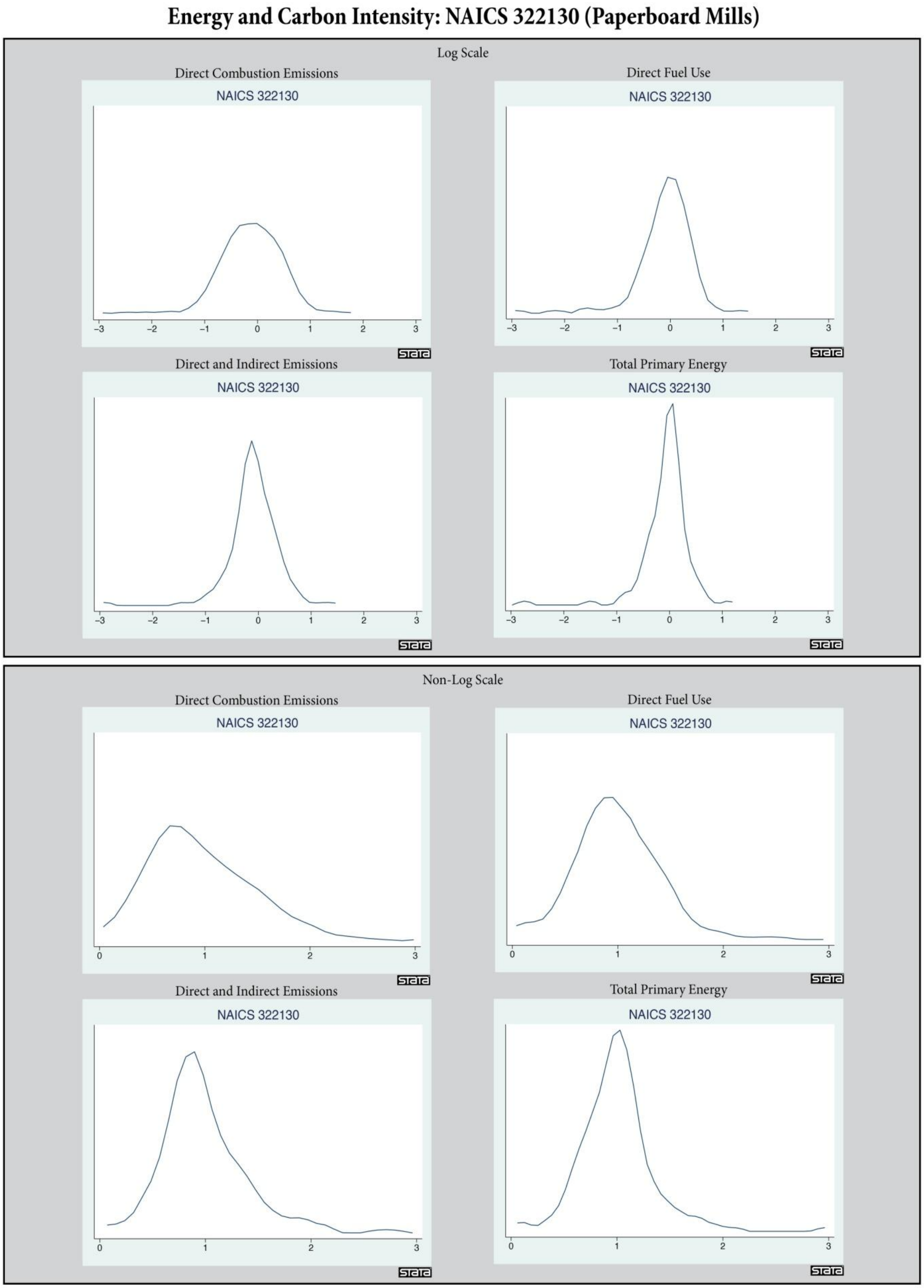

FIGURE 14: NAICS 322130 (PAPERBOARD MILLS)

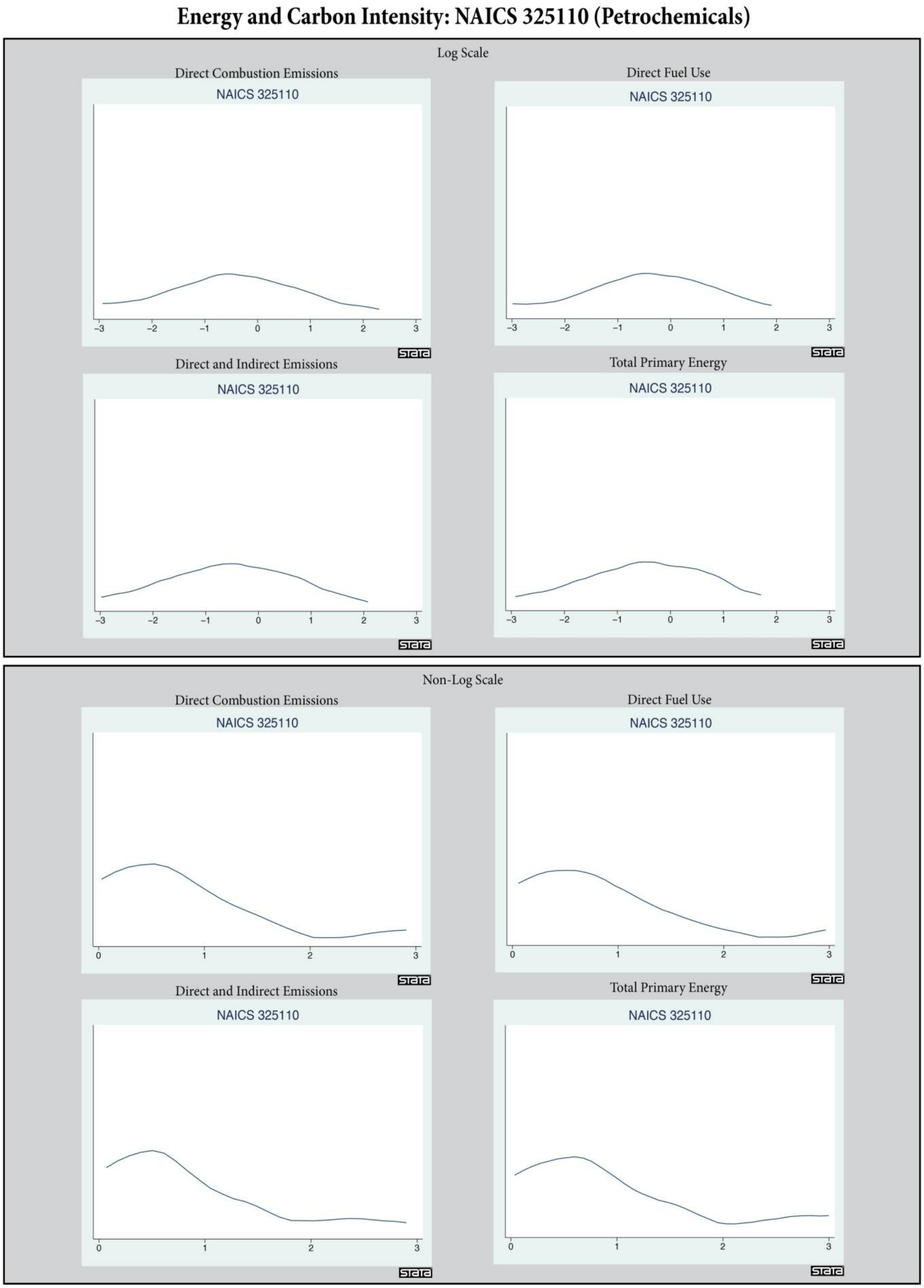

FIGURE 15: NAICS 325110 (PETROCHEMICALS)

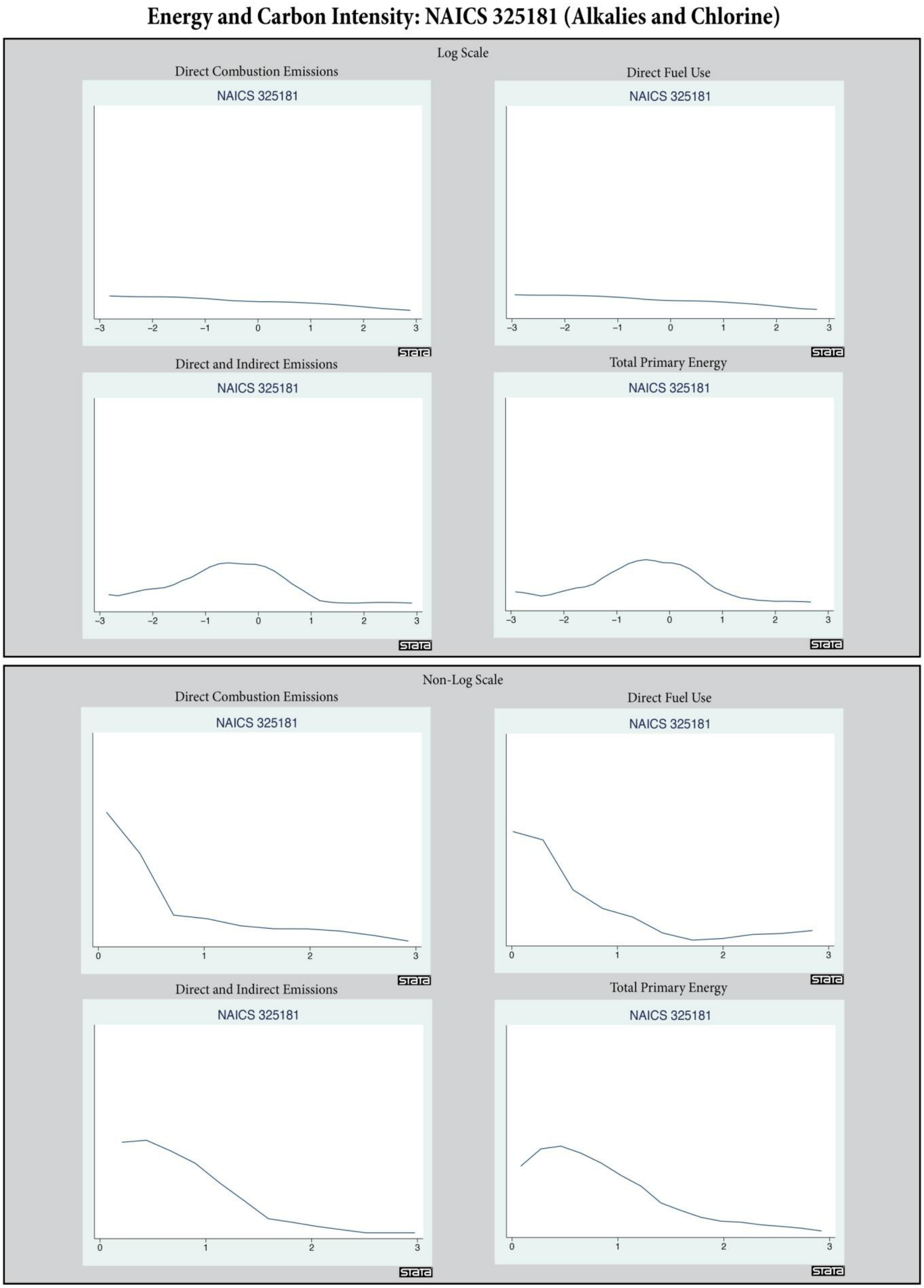

FIGURE 16: NAICS 325181 (ALKALIES AND CHLORINE)

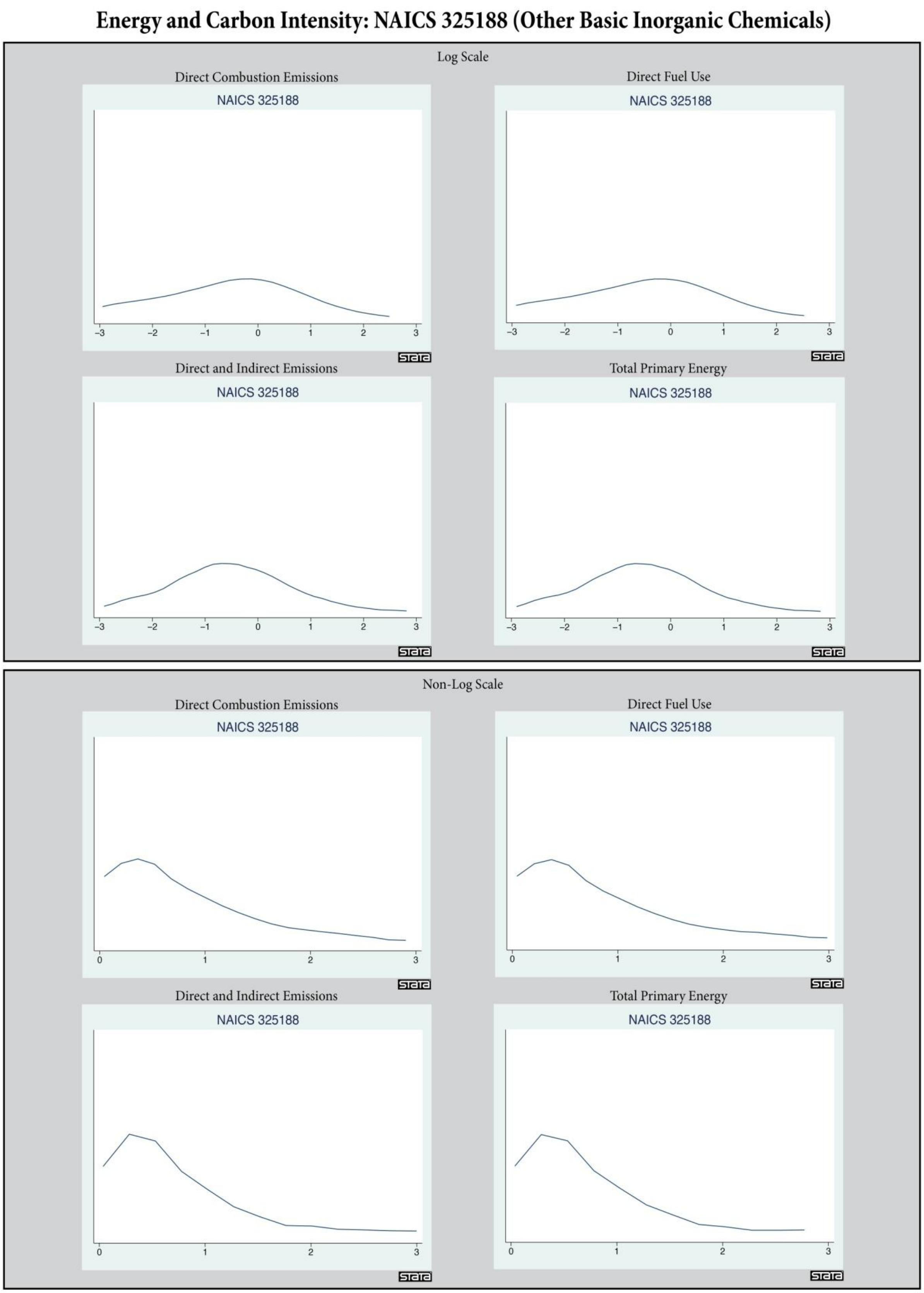

FIGURE 17: NAICS 325188 (OTHER BASIC INORGANIC CHEMICALS)

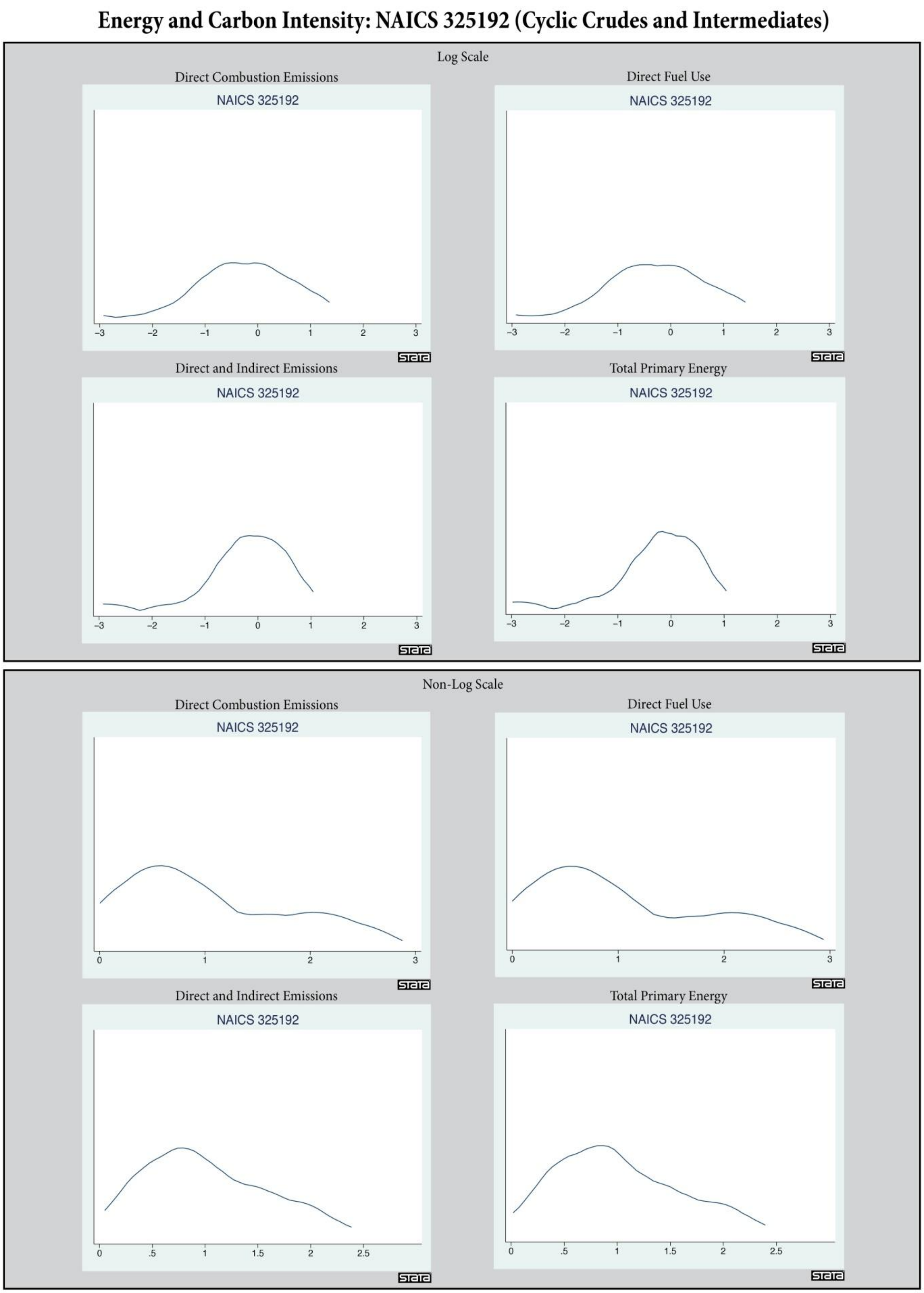

FIGURE 18: NAICS 325192 (CYCLIC CRUDES AND INTERMEDIATES)

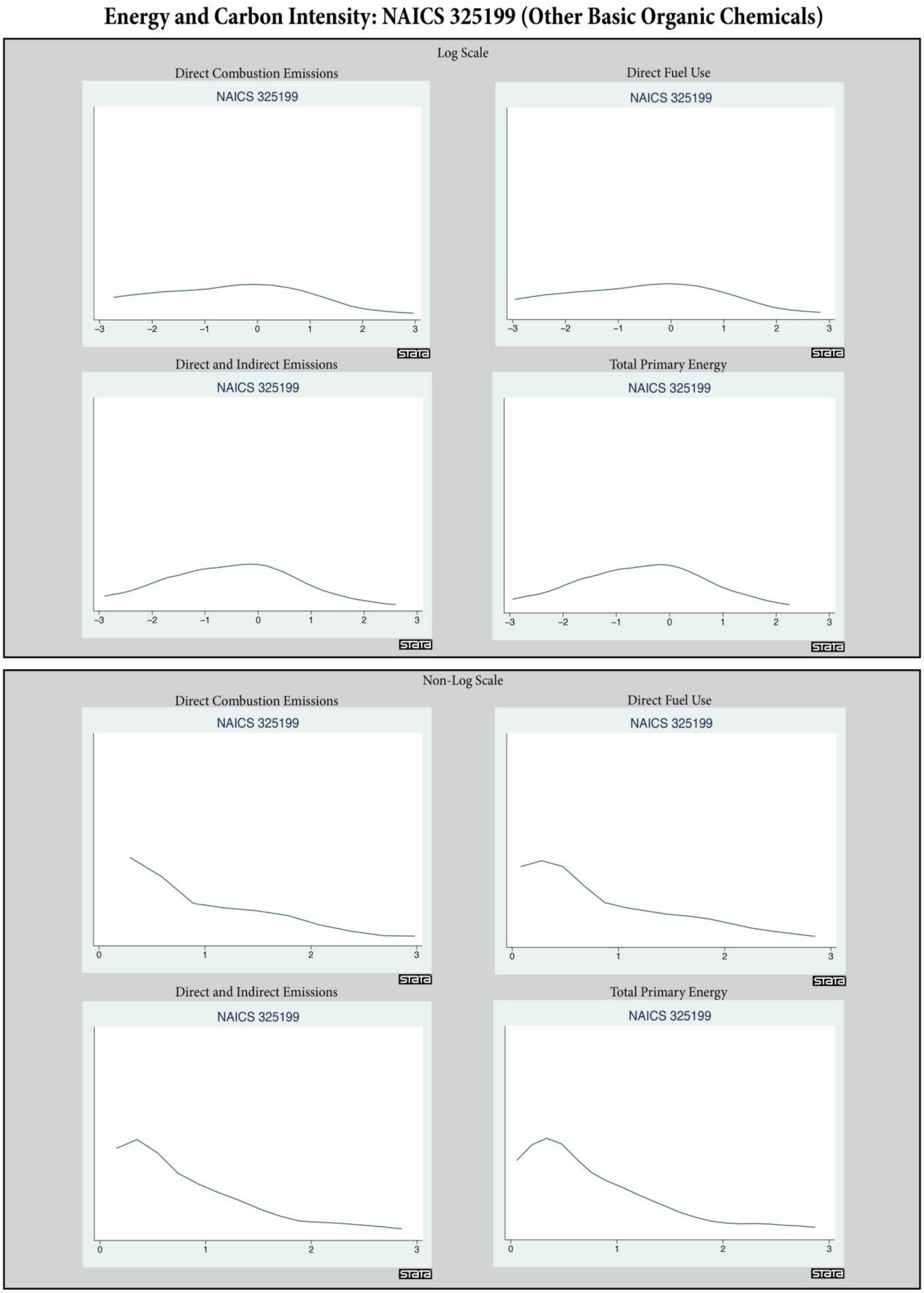

FIGURE 19: NAICS 325199 (OTHER BASIC ORGANIC CHEMICALS)

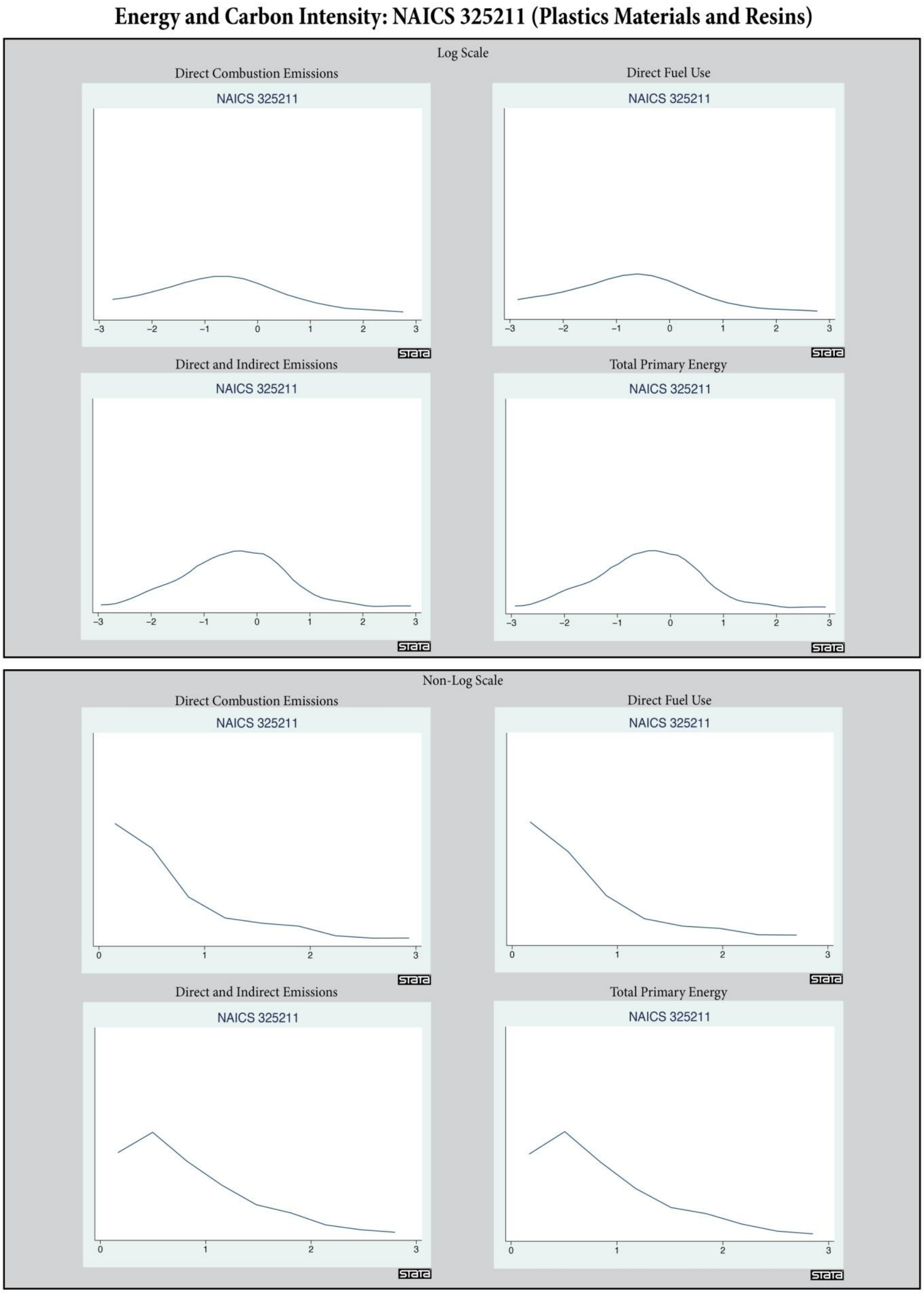

FIGURE 20: NAICS 325211 (PLASTIC MATERIALS AND RESINS)

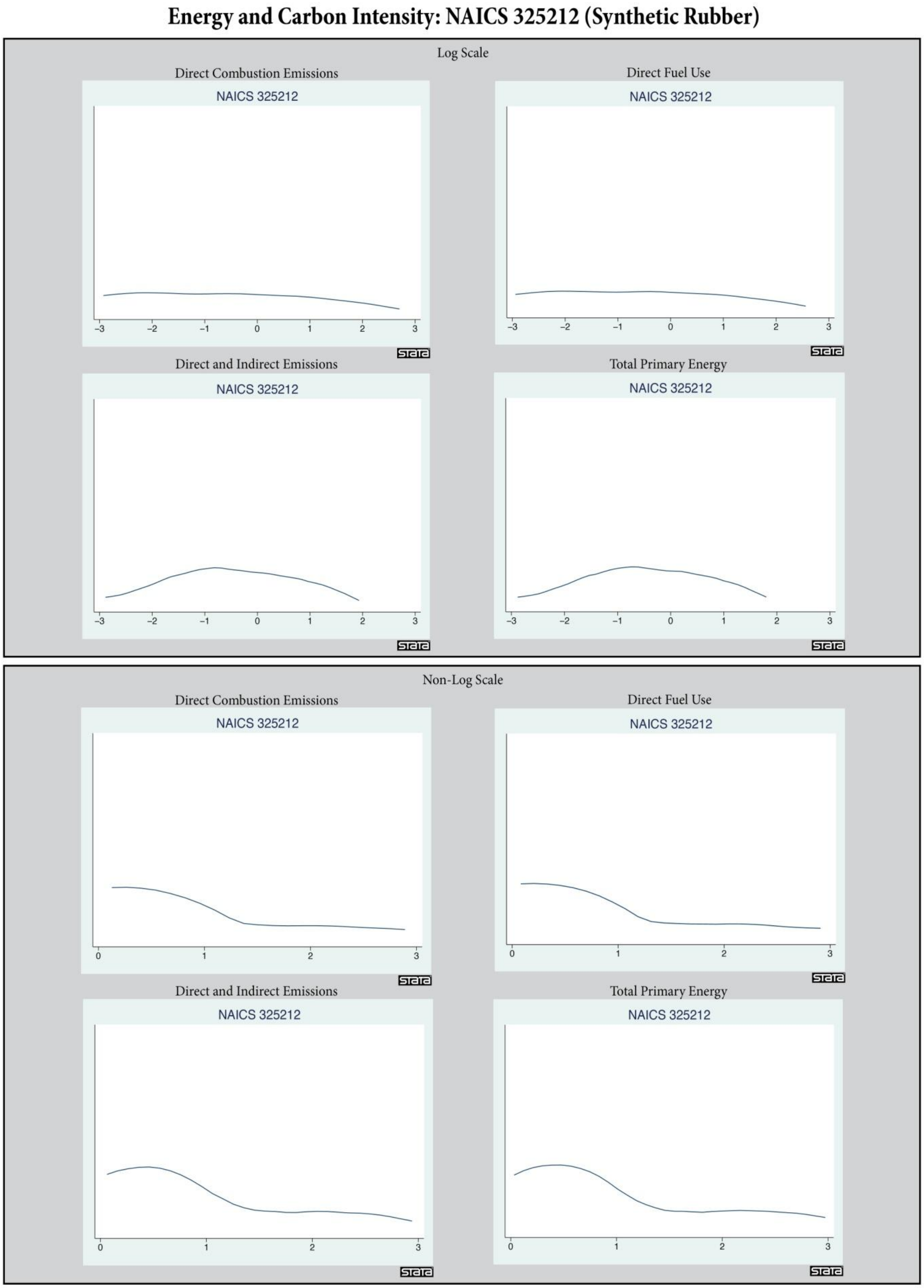

FIGURE 21: NAICS 325212 (SYNTHETIC RUBBER)

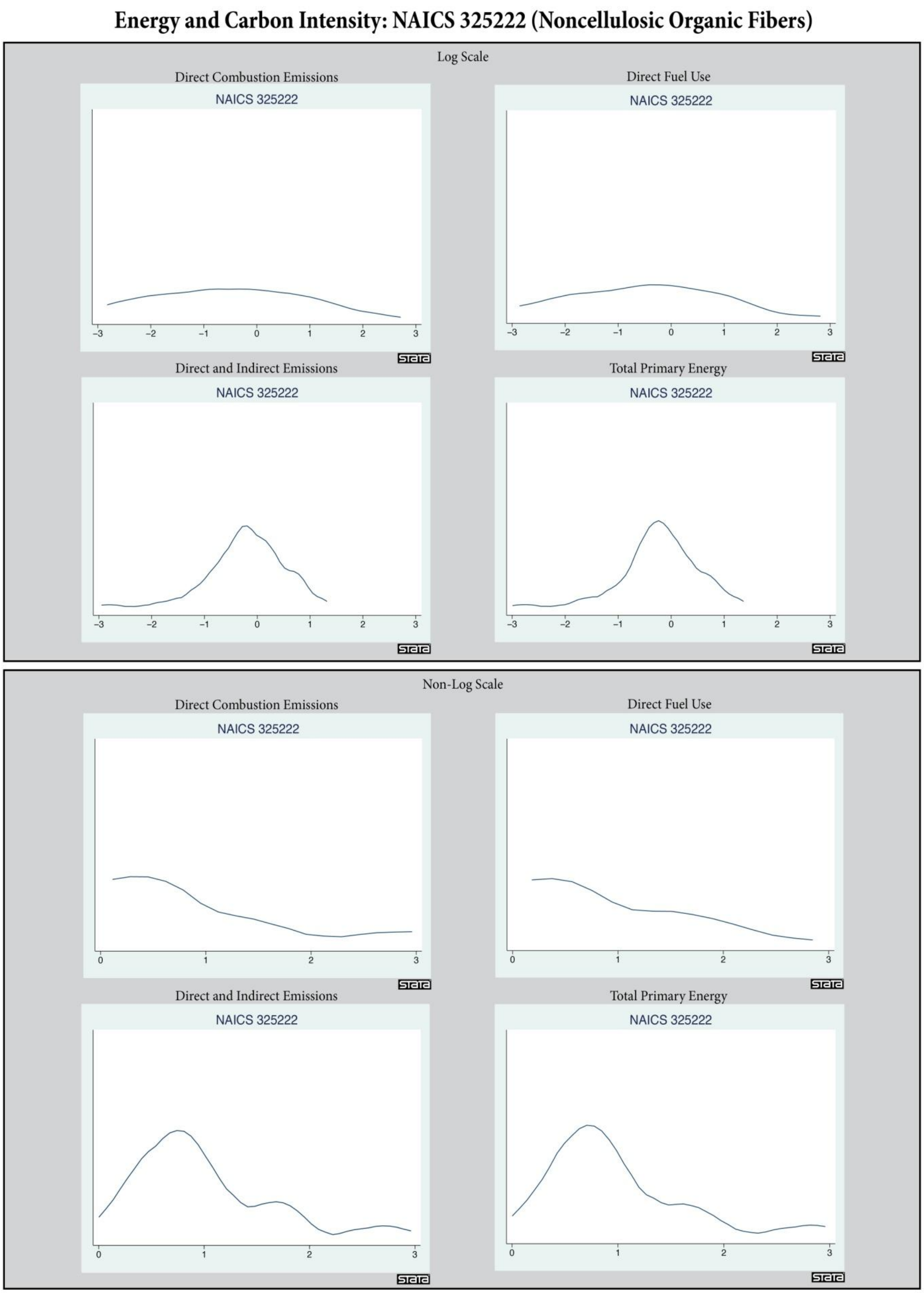

FIGURE 22: NAICS 325222 (NONCELLULOSIC ORGANIC FIBERS)

FIGURE 23: NAICS 325311 (NITROGENOUS FERTILIZER)

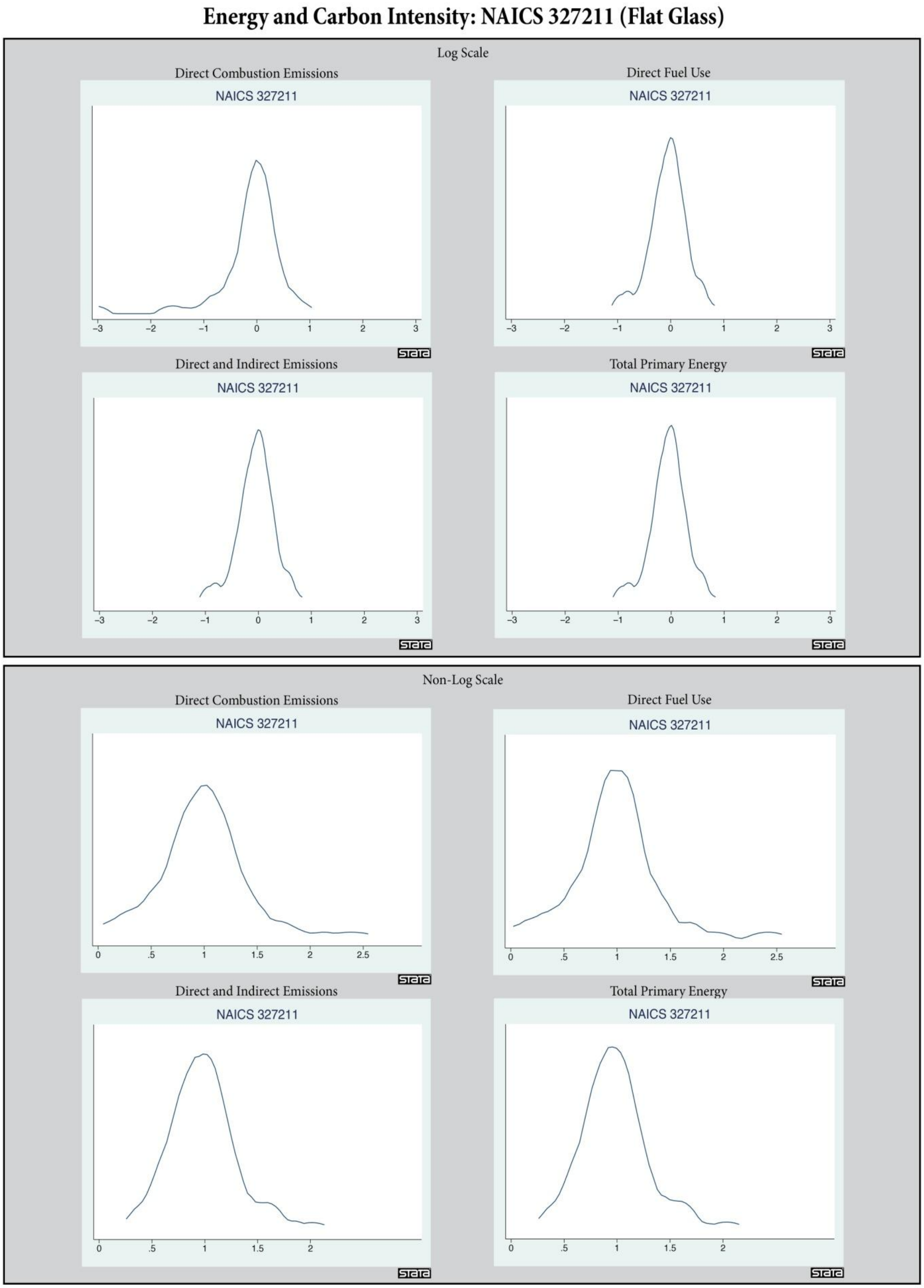

FIGURE 24: NAICS 327211 (FLAT GLASS)

Energy and Carbon Intensity: NAICS 327212 (Other Pressed and Blown Glass and Glassware Manufacturing)

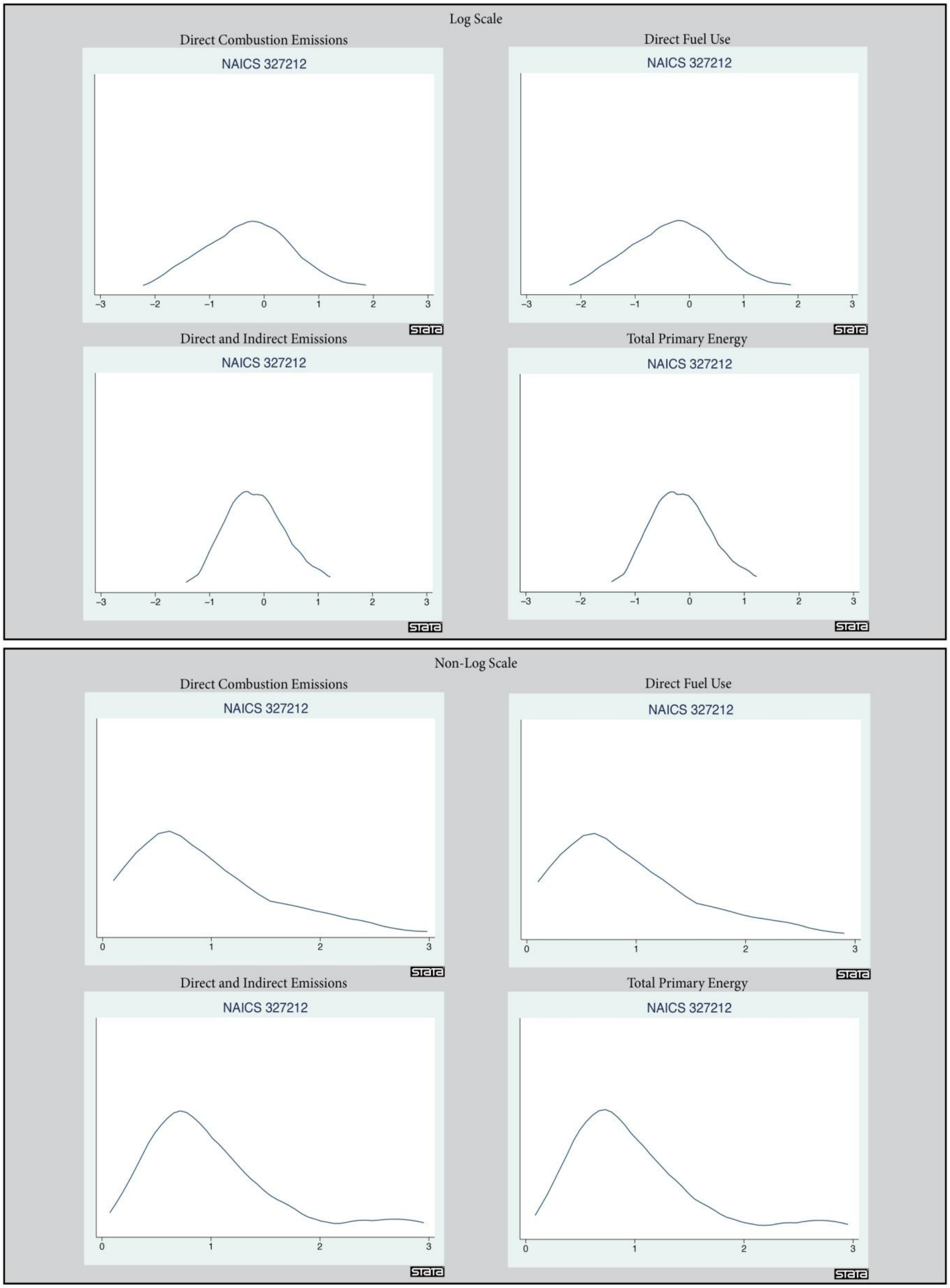

FIGURE 25: NAICS 327212 (OTHER PRESSED AND BLOWN GLASS AND GLASSWARE MANUFACTURING)

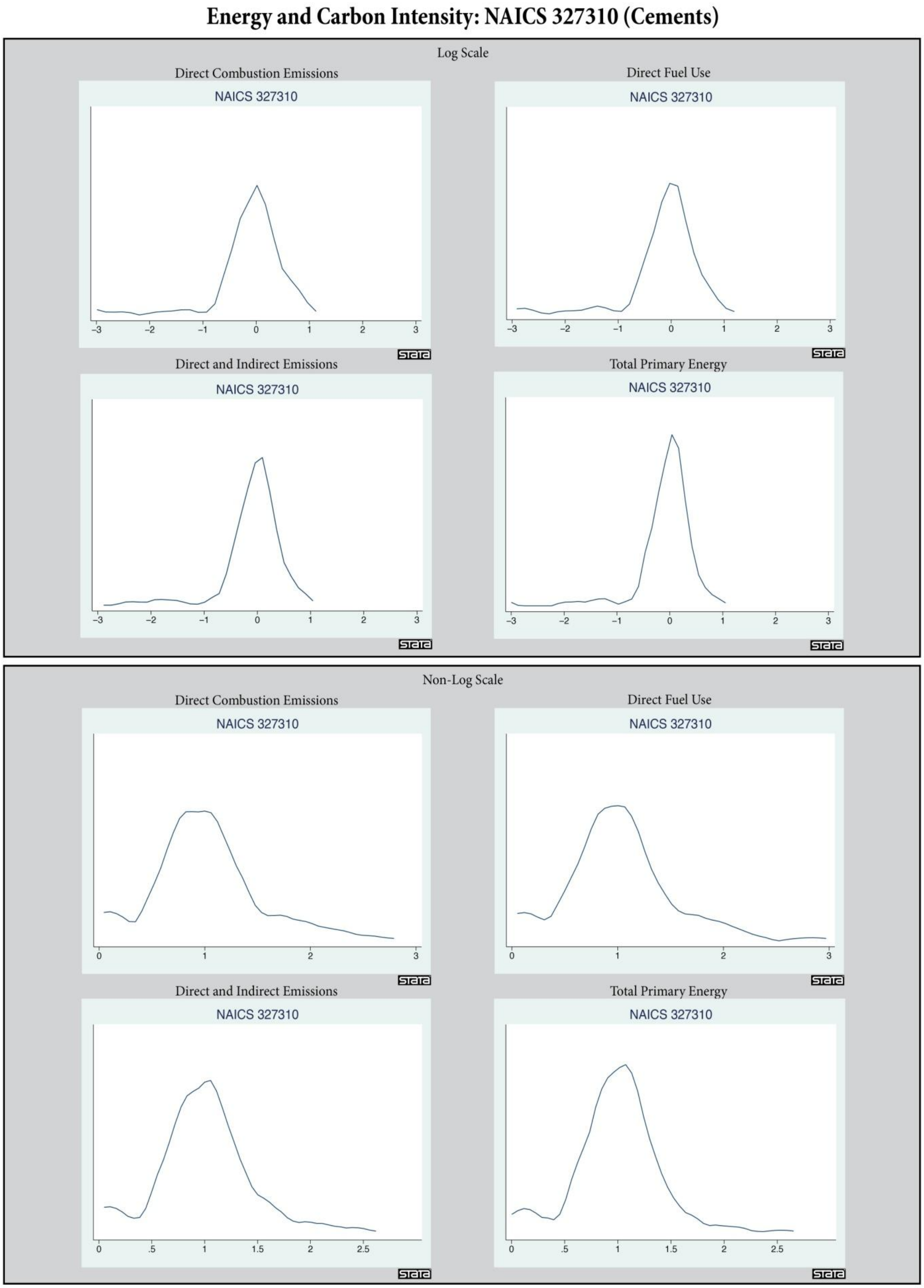

FIGURE 26: NAICS 327310 (CEMENTS)

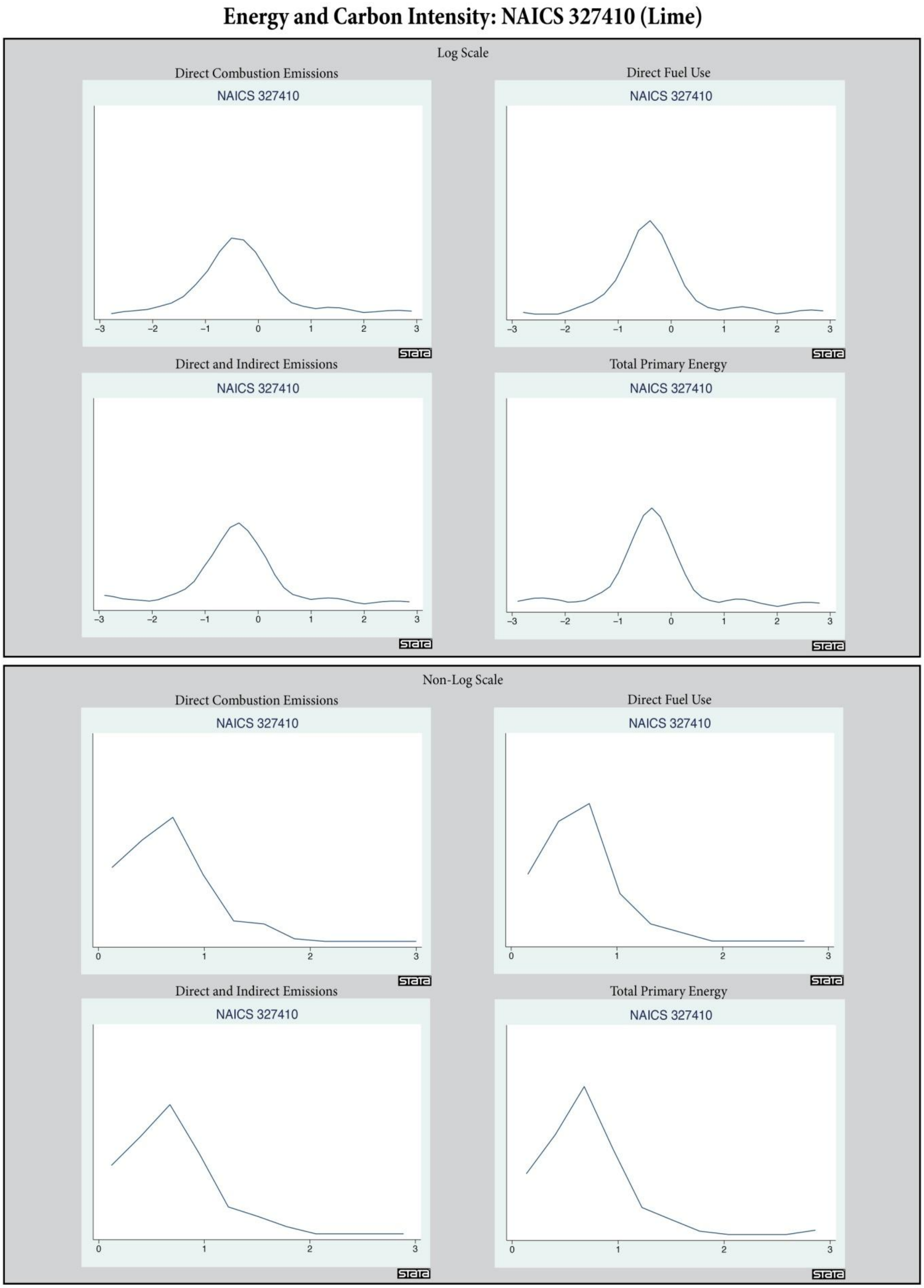

FIGURE 27: NAICS 327410 (LIME)

FIGURE 28: NAICS 327992 (GROUNDED OR TREATED MINERAL AND EARTH MANUFACTURING)

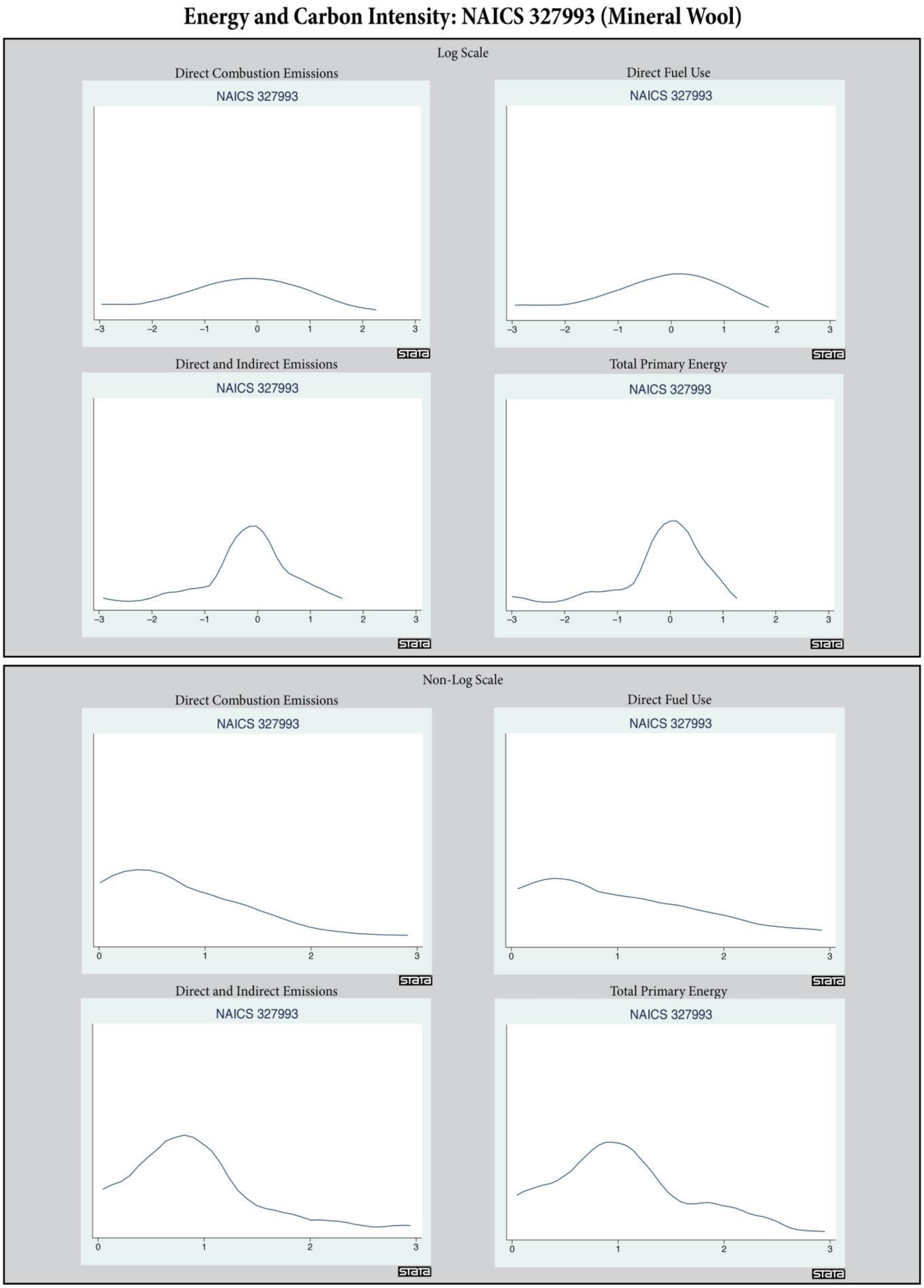

FIGURE 29: NAICS 327993 (MINERAL WOOL)

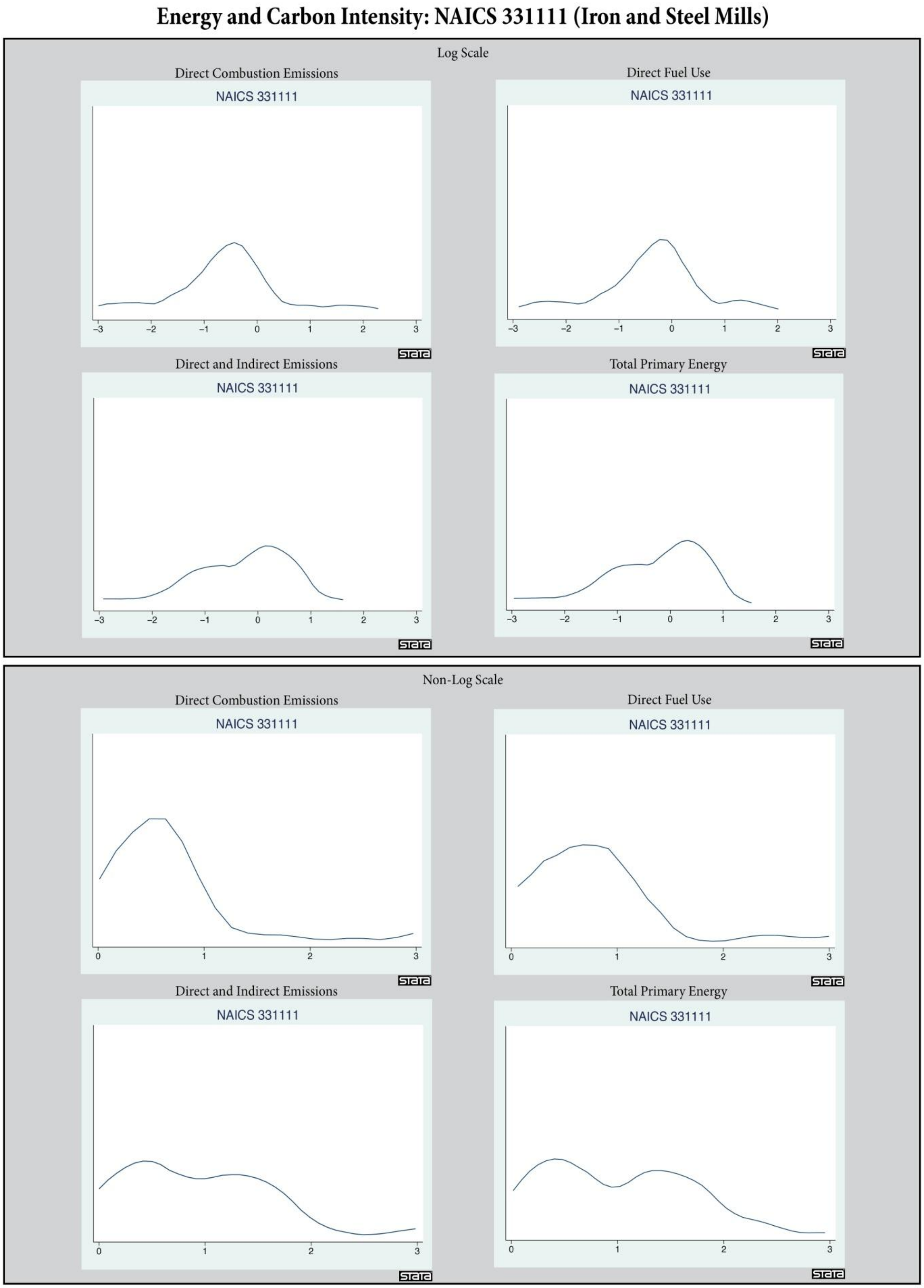

FIGURE 30: NAICS 331111 (IRON AND STEEL MILLS)

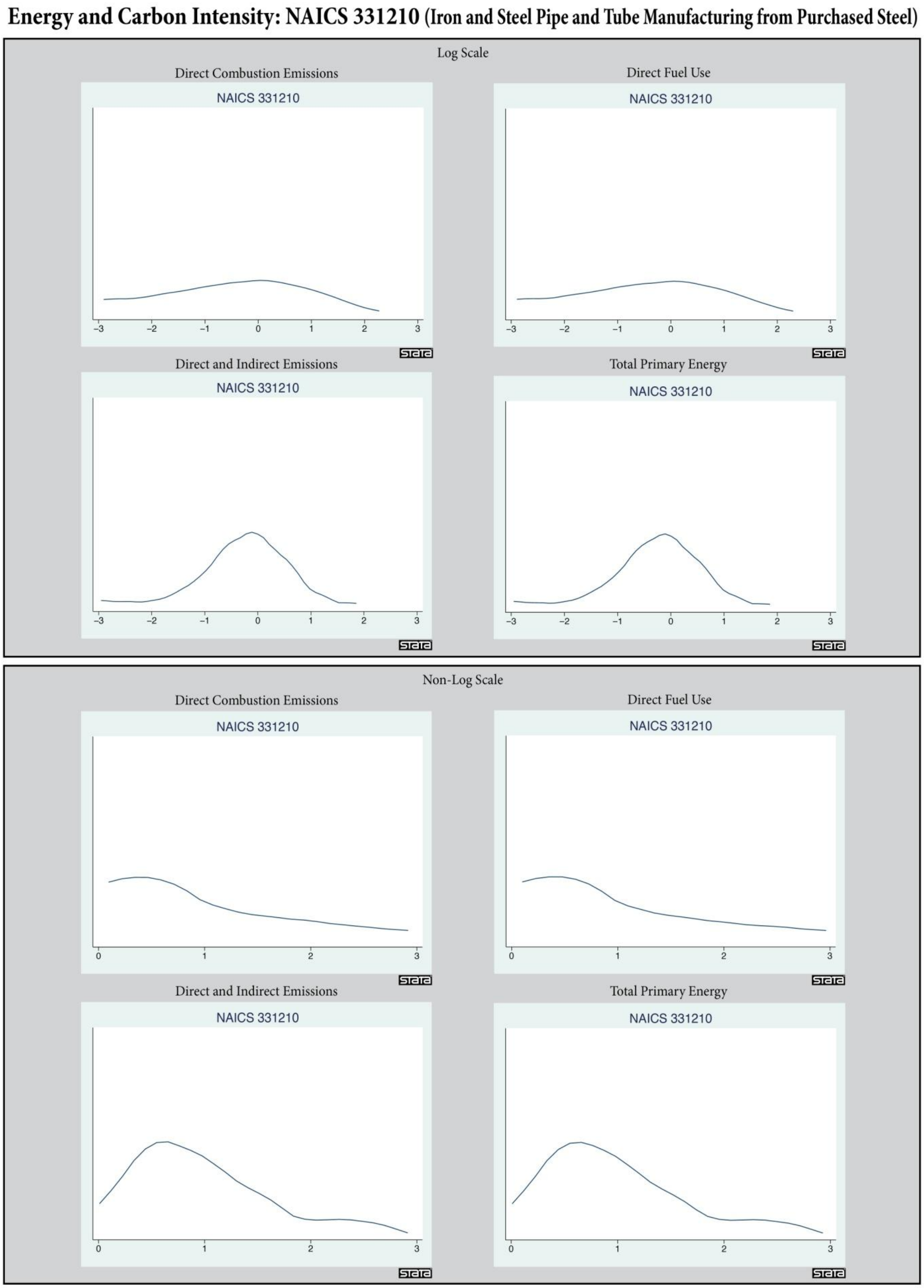

FIGURE 31: NAICS 331210 (IRON AND STEEL PIPE AND TUBE MANUFACTURING FROM PURCHASED STEEL)

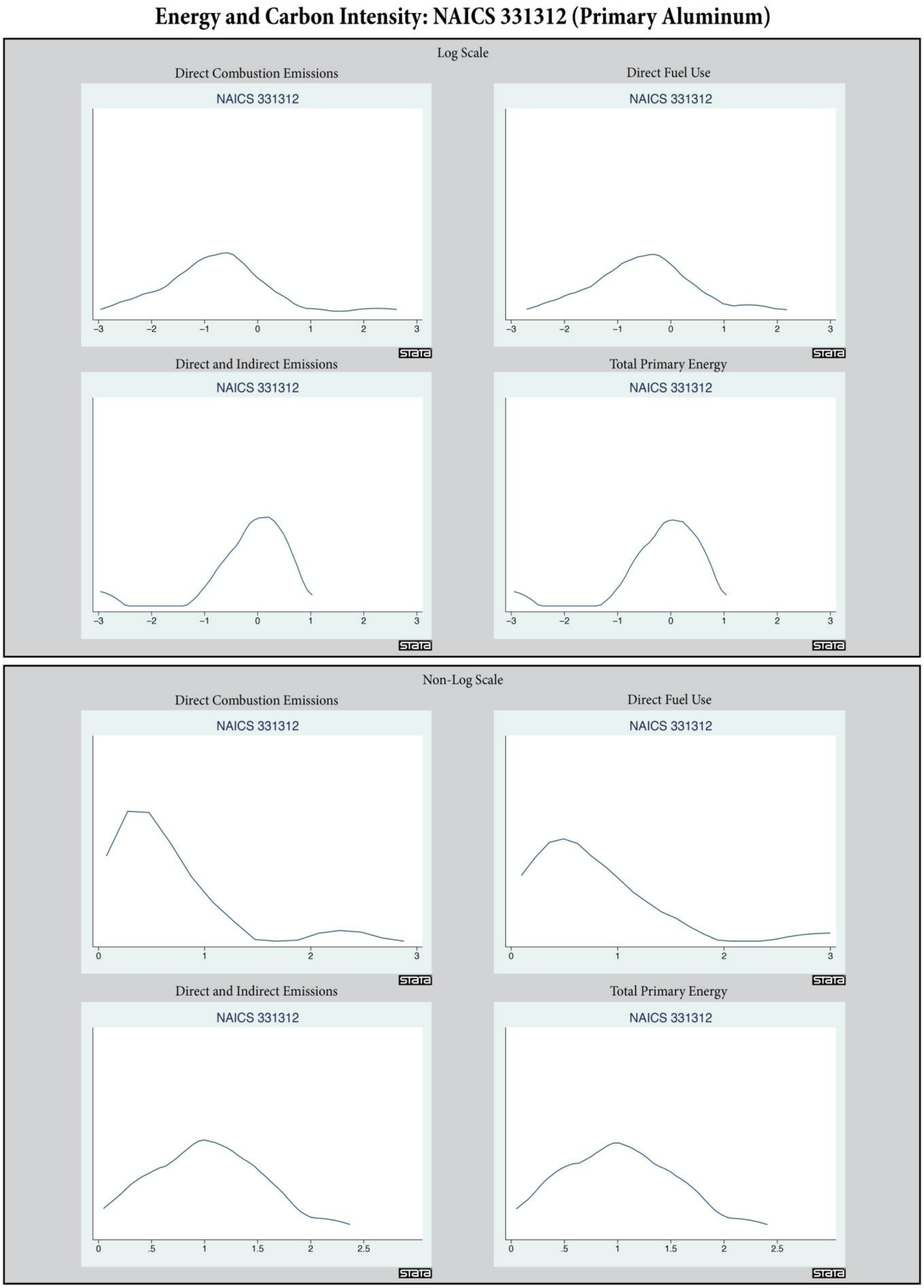

FIGURE 32: NAICS 331312 (PRIMARY ALUMINUM)

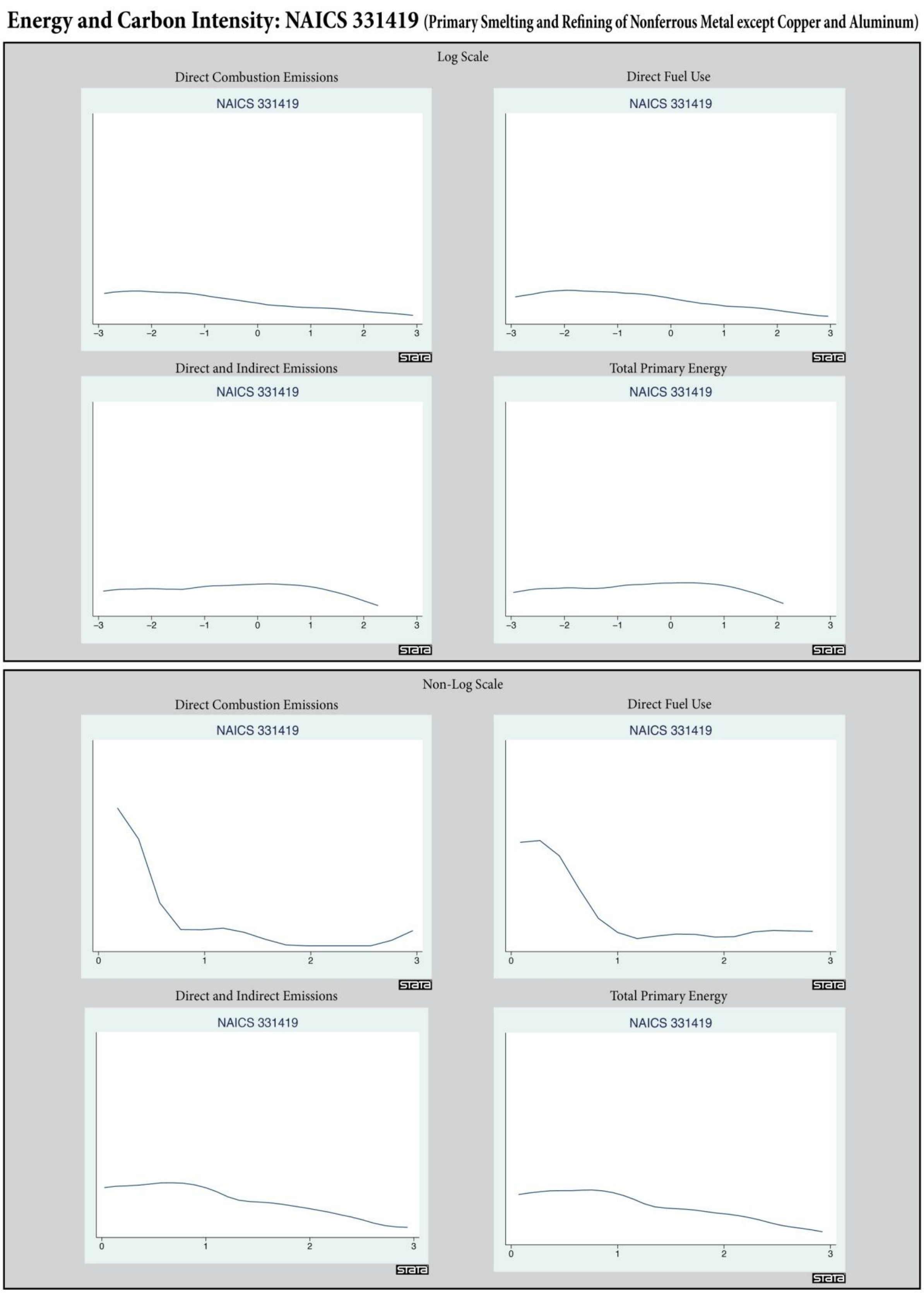

FIGURE 33: NAICS 331419 (PRIMARY SMELTING AND REFINING OF NONFERROUS METAL EXCEPT COPPER AND ALUMINUM)

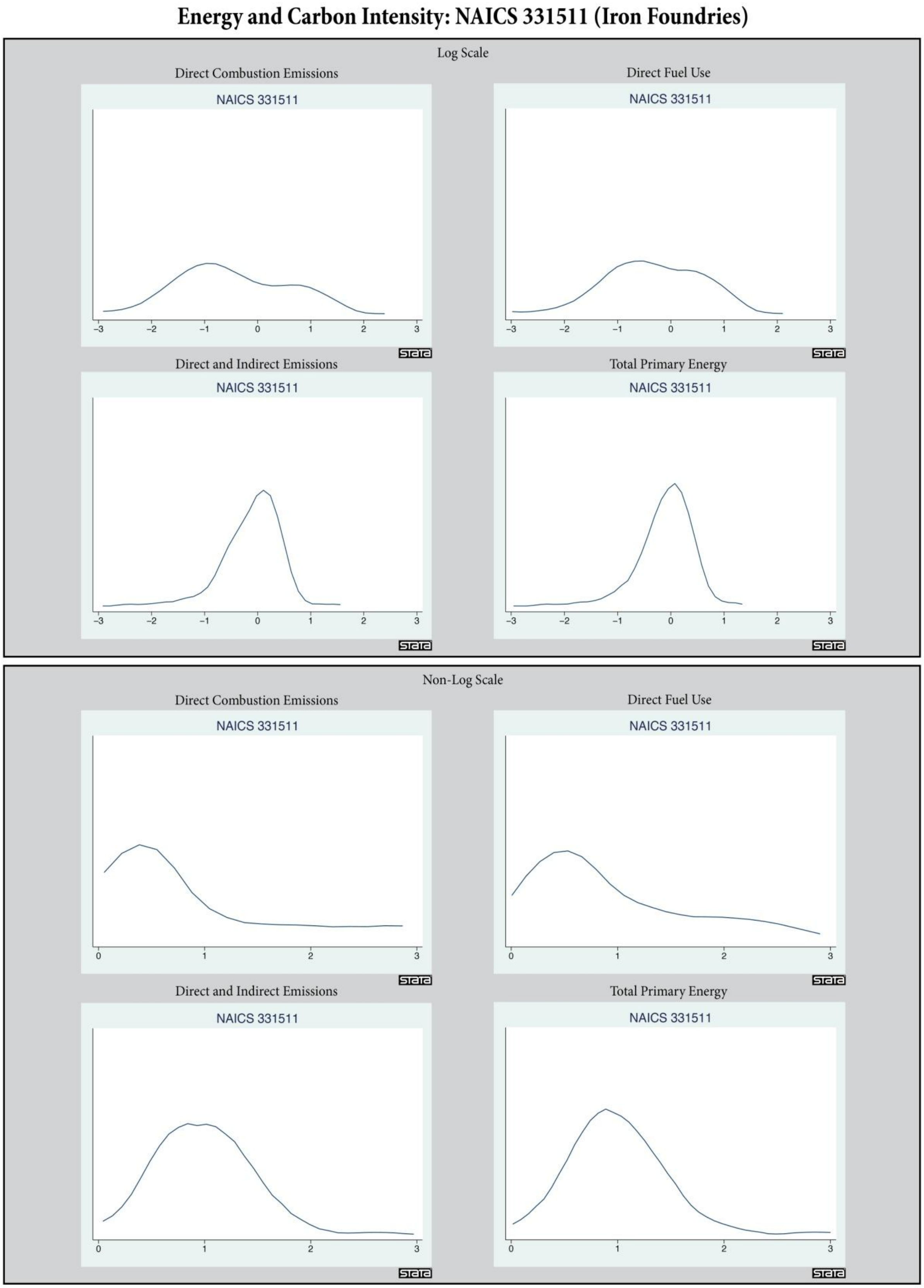

FIGURE 34: NAICS 331511 (IRON FOUNDRIES)

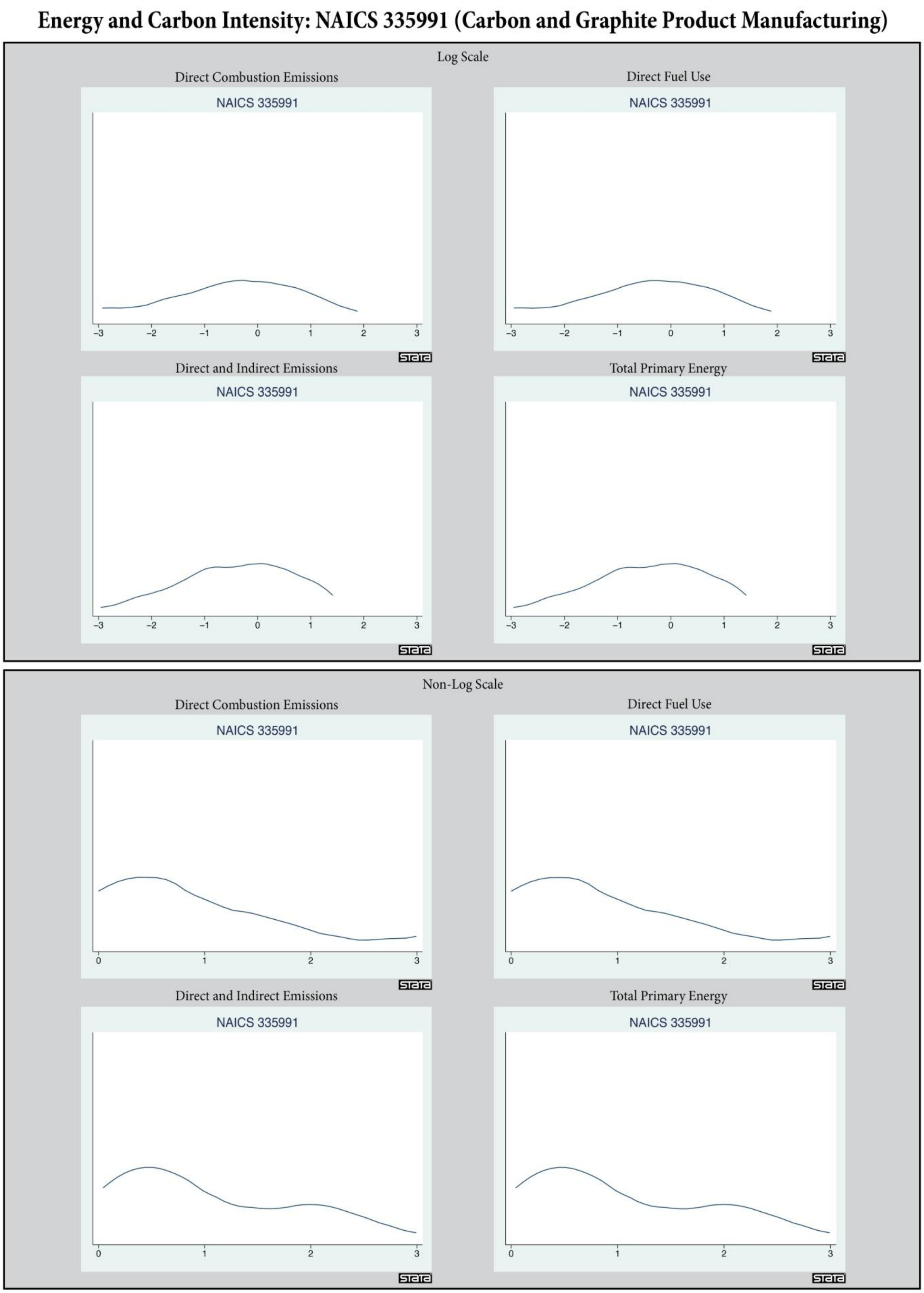

FIGURE 35: NAICS 335991 (CARBON AND GRAPHITE PRODUCT MANUFACTURING)