Indoor Air Chemistry and Pollution:

A look at adverse health effects and environmental injustice

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Intro

Constituting indoor air chemistry are the complex transformations that occur both chemically and physically on compounds in indoor environments, encompassing reactions that occur with gaseous substances, particles, or on interior surfaces. It is imperative to understand indoor air chemistry as it can allow potentially toxic chemicals to form, which could negatively affect indoor air quality and harm humans' health with exposure. Additionally, since Americans spend an average of around 16 hours per day in a home, there is a large potential time window for exposure to chemicals circulating the indoor environment (National Academies of Sciences, Engineering, and Medicine, 2022). However, indoor air chemistry and its health effects can vary widely based on characteristics of the building and its location (e.g., in a heavily polluted area), which leads to the environmental injustices relating to indoor air quality.

This paper examines the sources of various indoor chemicals, beginning with the outdoor sources of indoor pollutants, leading into a discussion of the inequalities that arise as a result. Point sources in the indoor environment are then analyzed, along with the health effects of each pollutant.

Tropospheric Outdoor Sources of Health Impacts from Gas and OIl

In broader themes, environmental injustice that lies outside both the home and our communities, though estranged from the idea of indoor air quality, takes part and is important in a dialogue about air chemistry, quality and pollution.

Oil and gas; main elements in our electrical and heating system, powering our infrastructure and vehicle as well as transportation and commerce around the world, as we know, have harsh industrial negative externalities. The climate change effects of fossil fuels are mainly widely known, perhaps not widely believed. Going over them briefly, more intense storms and weather events, global warming, poor air quality and increased likelihood of irreversible damage, like the melting of the glaciers or the AMOC (Atlantic Meridian Ocean Conveyor) tipping. Taking the ice albedo effect calculated using (while ignoring the greenhouse effect and proving faint young earth theory)

$$T = \sqrt[4]{\frac{K_s \times (1-\alpha)}{4\sigma}},$$

T = Earth's temperature (in Kelvin),

K_s = Solar constant (~1361 W/m^2),

α = Earth's albedo

σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m^2K^4).

Original : $T = \sqrt[4]{\frac{1361\, W/m^2 \times (1-.30)}{4(5.67\times10^{-8} W/m^2K^4)}}$

5% Decrease in Albedo $T = \sqrt[4]{\frac{1361\, W/m^2 \times (1-.285)}{4(5.67\times10^{-8} W/m^2K^4)}}$

even small impacts have major consequences on temperature, for example, if the albedo where do decrease by 5% of what it is now, (.30) → (.285), the earth's temperature (again, ignoring greenhouse effect) would be 1.35 K warmer than at our current albedo (Francisco, n.d.). This all goes to show that small impacts can make large changes in climate, as a whole, and on a small scale as it is very well understood that a 1.5C warming is what environmental scientists agreed on trying to limit the earth's warming to and even a 5% change in one aspect would put us near that edge.

That being said; Oil and Gas and in turn electricity are things that the average American is concerned with , usually focused on the pricing of rather than the effects. This continues our discussion on socioeconomic issues regarding tropospheric air chemistry. Though solar panels, are eventually cheaper to collect and store energy from ($0.04 per kilowatt-hour (kWh), while fossil fuels can cost up to $0.22 per kWh.) the upfront cost is much more than an low income family would likely be able to afford; this would affect this example low income family directly but adds to the conversation of energy use and fossil fuels (Unpacking the True, 2023). The widespread effect of the national use of oil and gas which releases or reacts to create CH_4, CO_2, PM2.5, VOC's, NO_2, NO_x, O_3 among other chemicals. We are focusing on natural gas and oil to look at the adviser health risks, rather than coal and its CO_2 release and GWP (global warming potential)

Natural Gas, the gas that heats your home, or runs a stove is made of mostly Hydrocarbons , 97% of which are Methane (Composition of Natural, 2023), and oil or petroleum is made up of organic compounds, heteroatom compounds (S,N,O), hydrocarbons (C, H), metals and organic (Ni, V, Fe) and inorganic (Na+, Ca++, Cl-) (Ese, n.d.). There can be over 350 hydrocarbons and 200 sulfur compounds found within crude oil, though the hydrocarbons make a majority of the mass of crude oil, the non- hydrocarbons have an important role in catalysis petroleum processing (Aitani, 2004). In any specific sample of crude oil there can be a high concentration of compounds that are hard to identify or trace. Crude oil is refined into many different uses , gasline, kerosene (jet fuel) diesel and other petroleum products like asphalt, or petroleum jelly and lubricants like vaseline(Quick, 2002). Crude Oil is a complex topic and would require a much more complicated dive into its chemical makeup.

What we can do however is dive into three main factors when it comes to health and air quality: these are PM2.5, Ozone and NO_2 within the troposphere and how it acts there, and how it acts on people, then how those people act on the economy and health systems (Buonocore et al., 2023). We will see, where oil and gas mining and refining disproportionately affects people, and that chemistry, especially air chemistry in the troposphere does not exist in a vacuum.

PM 2.5

PM 2.5 is Particulate Matter under the size of 2.5µm that has significant human health harm effects as it can breach into the lung and alveoli. PM 2.5 has many sources as it is a size based requirement , rather than a chemical one. However as this is focused on anthropogenic oil and gas, the sources in particular we are looking at are Diesel, petrol and coal combustion which emit PM2.5 made of Elemental carbon (EC), Sulfates (SO4), Oil burning which produces PM2.5 made of Vanadium (V), Nickel (Ni), Manganese (Mn), Iron (Fe) and Organic carbon (OC) and particulate matter also contains VOC's (Thangavel et al., 2022). Particulate Matter is composed of primary and secondary components, Primary PM is from direct particle emissions, and secondary which accounts for a percentage of PM2.5, is formed from atmospheric photochemical oxidation of gases such as SO_2, NO_x and NH_3 which reactions lead to SO^{-2}_4 from SO_2 (Thangavel et al., 2022),

$$SO_2 + OH\cdot \rightarrow HSO_3\cdot$$

$$HSO_3\cdot + O_2 \rightarrow SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

NO_3 from NO_x

$$NO_2 + O_3 \rightarrow NO_3 + O_2$$

and the gas to particle equilibrium between NH_3 and NH_4

$$NH_3(g) + H^+(aq) \leftrightarrow NH_4^+(aq)$$

(The equilibrium between NH_3 and NH_4^+ depends on pH of the environment temperature and the relative humidity (RH))

As PM2.5's structure and make up is not as easily traced as O_3 or NO_2, its residence times are not easily uniform or calculated the same. Estimates put the lower tropospheric (where the majority of PM2.5 is found) residence time of PM2.5 at a few days to weeks before being removed by wet or dry deposition (EPA, 2023). PM2.5 Does not break down, or get catalyzed to likes of other compounds, it has a more physical removal process.

OZONE

Ozone in the troposphere remains for hours to weeks. Ozone is a secondary pollutant in the troposphere. It results from sunlight reacting with NO_x and VOCs and CH_4 emitted largely by human activities (Tropospheric Ozone, n.d.).

$HO_2 + NO \rightarrow OH + NO_2$

$CH_3O_2 + NO \rightarrow CH_3O + NO_2$

$RO_2 + NO \rightarrow RO + NO_2$

Followed by photolysis

$NO_2 + hv \rightarrow NO + O$

$O + O_2 + M \rightarrow O_3 + M$

NO_2 and NO_x

NOx has a lifetime of only a few hours in the lower troposphere, and a one to two weeks in the upper troposphere. NO_2 comes anthropogenically from fossil fuel combustion, biomass burning, soils, lightning as NO but goes through rapid cycling(Jaeglé's, n.d.).

$NO + O_3 \rightarrow NO_2 + O_2$

$NO_2 + hv\ (+O_2) \rightarrow NO + O^3$

Daytime sink formation: ›

$NO^2 + OH + M \rightarrow HNO^3 + M$

at night:

$NO_2 + O_3 \rightarrow NO_3 + O_2$

$NO_3 + NO2 + M \rightarrow N_2O_5 + M$

$N_2O_5 + aerosol (+H_2O) \rightarrow 2 HNO_3$

As you can see, reactors and reactants have roles within each other's equations, some requiring sunlight and some with certain relationships.

Proximity, Health and Injustice

Now that we have understood where these main actors come from, and where they go, we can now dive into health effects. While it's understood these reactions take place outside, it's notable that any result or mid-stage may end up indoors at any time, homes and buildings are not airtight. The chemistry outside the home is just as important as inside, when it comes to living life.

In 2016, emissions and eventual air pollution though other reactions as seen above, caused 410 000 asthma exacerbations, 2200 new cases of childhood asthma and 7500 excess deaths in the US (Figure 1, Figure 2)(Buonocore et al., 2023). In Figure three you can see overlap with where there were point and non point production sources, emissions largely originate from oil and gas producing regions in Texas, Oklahoma, Wyoming, Colorado, North Dakota, Pennsylvania, West Virginia and southern California. Mortality cases per million people are largely centered around O&G producing areas—Texas (TX), Louisiana (LA), Oklahoma (OK), western Pennsylvania (PA), West Virginia (WV), and North Dakota (ND), and a few counties in Colorado (CO), Wyoming (WY), and New Mexico (NM) (Buonocore et al., 2023). However, many urban populations and cities experience downwind effects, noting that many of these air pollutants have lifespans enough to travel from point sources to major cites. Many of these point sources experience stronger effects and quantities, and these point sources are more rural industrial towns with lower income populations (Disparities in the Impact, 2023) Low socioeconomic status consistently increases the risk of premature death from fine particle pollution. In contrast, health impacts of air pollution emissions from oil and gas in 2016 totaled at $77 billion (Buonocore et al., 2023). A disparity of costs seen.

Indoor Air Quality, Chemistry and Socioeconomic Status

Aside from the already mentioned and heavily effective outdoor tropospheric chemistry, indoor air chemistry has many more obvious point sources, and usually come from an individual using an appliance, tool, product etc. These have more complicated chemical compass, and can be from a variety of sources (Fuel-burning combustion appliances, Tobacco products, Deteriorated asbestos-containing insulation (EPA, 2024b), Candles, Products for household cleaning and maintenance, Central heating and cooling systems and humidification devices) We are attempting to look at items and sources that could more disproportionate effect lower income populations as opposed to a higher income household that might have regularly updated appliances, more expensive 'natural' products, maintained heating and cooling systems, and better air filtration systems, as well as likely living further from the sources of outdoor pollutants as aforementioned.

CO

Carbon Monoxide is likely the most known indoor pollutant. CO is an odorless, colorless gas that is a product of combustion of organic matter, when there is insufficient oxygen supply. Sources of CO in the home, or in a building are Gas Stoves, Tobacco smoke, Automobile Exhaust, Generators and gasoline powered equipment, space heater and worn or poorly adjusted combustion devices like boilers or furnaces (EPA, 2024c) CO in homes is present no matter a gas stove or appliance, at levels of .05 to 5 ppm, but in homes with gas stoves can be up to 30 ppm, which already nears the threshold to exhibit symptoms of CO poisoning.

Indoor CO does not have a significant amount of harmful reactions in the home, mostly creating products of O_2, CO_2, or NO_2 some of which are not great for air quality, but would reduce the levels of CO. Very rarely, but in some specific industrial environments, or indoor environments with Ni and 4CO nickel carbonyl can be formed which is extremely toxic (Johns, 2023).

$$Ni(s) + 4\,CO(g) \rightarrow Ni(CO)4(g)$$

CO has one of the most significant inequality, affecting those in low income and marginalized communities more than people in less marginalized communities. In Wisconsin there was an alignment of people of color, poverty and CO ED visit rates (García, 2023). Due to expensive home equipment like furnaces and stoves being costly to replace or fix in homes, or being maintained by apartment buildings, CO in homes is harder to manage.

The health effects of a CO exposure generally stem from its ability to impede oxygen circulation throughout the body, and its impact on the body depends on the amount that is inhaled. CO can cause poor coordination, extreme fatigue, headaches, confusion, vomiting, vertigo, and it can worsen cardiovascular conditions (Southard et al., n.d.). A chronic exposure to a low concentration of CO can increase the impact of disease in the individual. On the other end, extremely high levels (CO poisoning) are fatal; those who are at highest risk of death from high levels of CO include the elderly, infants, pregnant women, and those with preexisting cardiopulmonary diseases (Southard et al., n.d.).

To help mitigate accidental CO poisoning, more states could enforce having detectors in residential buildings, fire departments could have more outreach on safety, prevention and detection and free CO detectors.

PM.2.5

PM2.5 Has a variety of sources in the home cooking and combustion activities, certain hobbies, wood burning and candles. PM 2.5 has a significant source from the outside, and can be biological by origin. Though the sources of PM2.5 are less unequal, looking at fresh air and candles we can learn some interesting science, and more inequities in attempting to have clean air. In communities where power outages are more common, outside of the surface level scented candles, candles might be needed for light or heat. To reduce the amount of PM2.5 circulating in a home, one can install exhaust fans, have professionals ensure all appliances are running smoothly, run air filters, and make sure filters are changed regularly in HVAC Systems. All of which cost money. Opening windows, while effective when burning wood or candles, still allowed for an inflow of PM 2.5 from the outside, which would likely be higher in concentration in areas that are more industrial and lower socioeconomic statuses.

In terms of its health effects, PM2.5 is capable of reaching deep lung tissues and corroding the walls of alveoli (the structures responsible for gas exchange), subsequently harming pulmonary function. As a result of the small size of these particles, they are able to travel into the lungs with inhaled air and diffuse through the systemic blood circulation, inflicting damage on other body regions. Resulting conditions can include asthma, respiratory inflammation, cardiopulmonary problems, increased risk of cancers, cardiovascular disease, tuberculosis, cataracts, and low birth weight (Xing et al., 2016; Cincinelli & Martellini, 2017). Additionally, studies have reported that a 10 $\mu g/m^3$ increase in air concentration of PM2.5 is associated with a 2.07 percent increase in occurrence of respiratory diseases, an eight percent increase in related hospitalizations, a four percent increase in general mortality, a six percent increase in cardiopulmonary disease death rates, an eight percent increase in lung cancer prevalence, and a 15 to 27 percent increase in its mortality (Xing et al., 2016).

NO_2

NO_2 interior sources are the same as many compounds listed above , appliances with combustion elements, tobacco. NO_2 levels indoors with a gas stove lead to increased concentration of NO_2 in the home varying from undetectable to 49.55 μm/m^3. ONe can take the same steps to reduce NO_2 in the home as they could with CO_2 (Jarvis et al., 2010).

NO_2 is known to be an irritant to mucous membranes of the eyes, nose, and throat (Southard et al., n.d.). Exposure to low levels of the substance can exacerbate asthma and COPD symptoms, making bronchial smooth muscle more reactive to stimuli prompting airway constriction in those with asthma and further impairing pulmonary processes in individuals with COPD (National Academies of Sciences, Engineering, and Medicine, 2022). At sustained higher level exposures, effects can include shortness of breath and chronic bronchitis (Southard et al., n.d.).

VOCs

Volatile organic compounds are different from most of the previous pollutants mentioned in this paper. VOCs are what an average consumer might think of as chemicals, found in aerosol spray, pain and paint strippers, air fresheners, adhesives and pesticides. VOCs are almost always found indoors at a higher level than outdoors. Indoors has an avenger 2 to 5 times more VOC concentration than outdoors with certain activities up to 1000 more than background outdoor levels. Notable VOCs are formaldehyde (CH_2O), methylene chloride (CH_2Cl) from spray paints and paint strippers , Benzene (C_6H_6) from paints and smoking, perchloroethylene (C_2Cl4) from dry cleaning. These four can all be reasonably found in a home, being found in high concentrations when care is not taken with certain chemicals, they also all happen to increase chances of giving you cancer (EPA, 2024b).

Formaldehyde is one indoor air pollutant that is often found in greater concentrations indoors compared to the outdoor environment, as it is commonly found in newer homes as it is used in the production of furniture, carpets, drapes, particleboard, and paneling (Southard et al., n.d.). In addition to being a known carcinogen, exposure to formaldehyde can be accompanied by coughing, rashes, headaches, dizziness, and eye, nose, or throat inflammation. Exposure to VOCs in general is often accompanied by the aforementioned symptoms, in addition to kidney, liver, or central nervous system damage (*Volatile Organic*, 2024).

Common Indoor Occurrences

Candles

The US Candle market alone is worth 2 billion dollars; aside from aromatherapeutic and decorative, giving a 'cozy feeling' , candles are also used in power blackouts for light and for heat. Candles are a source of PM2.5. And suggested by the EPA to leave a window open while burning, as with the mitigation of any indoor air pollutant. Candles can emit VOCs specifically Benzene, and formaldehyde in large quantities when lit (Ahn et al., 2015),. Candles , while 'sooting' can also release soot, a PM, that is chemically similar to Diesel soot, diesel, a product of crude oil. Some candles have cored wicks, which have metals intertwined with the wick, releasing trace amounts of metal into the air. Before 2003, lead was allowed to be in candles(Scented Candles, n.d.) . Candles cost seem to outweigh the benefit, Opening a window when lighting is the least one should do. Tossing out the candle altogether, if you can, seems better.

Tobacco & Smoking

Cigarettes contain over 4,000 compounds, at least 40 of which are considered cancer casing. Cigarette smoke, however, doesn't just affect the smoker, but the air quality of the place they live, and people who live near them (EPA, 2023) . Environmental Tobacco Smoke (ETS), or secondhand smoke, causes over 3,000 lung cancer related deaths and between 150,000 to 300,000 respiratory infections in children (Schmeltz et al., 1975).. CO level in rooms where Cigarettes are smoked increase, depending on the ‘box’ volume and ventilation rates in and out, but a considerable amount compared to outdoor usage, along with other NO_x exhalations. There is a correlation between socioeconomic states and cigarette usage, though no specific account for in-home usage.

<u>How to Mitigate and Improve indoor and outdoor Air Quality</u>

Outdoor

Unfortunately, outdoor air quality is a slow moving train. To make changes in energy and transportation sectors, Is a large task that the government cannot currently handle, and Texas, whose point sources were looked at can't handle without changes, especially as new heat and cold waves hit texas at unprecedented highs. Air Quality will disproportionately affect lower people in lower socioeconomic standings, who live closer to point sources or who live down wind. The adverse effects of Oil and Gas production will continue to be deadly and costly. The recommendation to begin tackling this issue is 1) making it know, how environment injustice is a part of all chemistry, and engineer discoveries and machinery that creates emissions, 2) The best way to begin to mitigate is to switch to non-combustible energy resources on a grand scale, solar, wind, geothermal, hydro-elecric or nuclear power, and start to move away from fossil fuels and biofuels (why though remain more net neutral regarding carbon, still contribute to PM2.5,).

Indoor

Indoor air quality and air chemistry, though still extremely affected by the outdoor chemistry and climate at the moment, are easier to mitigate and control on an individual basis. The knowledge of threats of CO, VOC,s and other chemicals is already enough to be able to take action without spending money or making any structural changes to the energy grid. Opening a window when cooking is gas, especially if a stove may be faulty or old can reduce the level of many chemicals; in winter months, not using a stove as heat by opening it, but running with it shut, so as to not release as much gas. If heating systems are down, and candles or wood fires, generators or space heaters are used, make sure to keep areas well ventilated, or a window slightly cracked to speed up the diffusion of chemicals out of the house. With more financial resources, buying air filters, or making your own with a box fan and a hepa filter, making sure all combustion and gas equipment in your house is being maintained regularly. If cars are owned, make sure they are shut off in the garage, or not idling. Actively choosing not to smoke inside, or if necessary, finding a spot with a window or ventilation, the same goes for substances with known VOC's. Throwing away every candle. There are many ways an individual can lower the risk of air pollution within their own home, no matter their chemistry knowledge or socioeconomic status.

Conclusion

We all die! Well, eventually (well yes!). The chemistry between tropospheric air pollutants from oil and gas sources and their health impacts sets the stage for the environmental injustices relating to indoor air quality. Fossil fuel combustion releases harmful chemicals like

PM2.5, O_3, NO_2, and NO_x, which not only impact tropospheric air quality but also infiltrate into indoor environments, disproportionately affecting communities that are geographically close to sources of these pollutants. Particularly affecting lower-income populations, this spread of pollution from industrial areas into residential spaces exacerbates health inequities.

Eliminating these environmental disparities of indoor air quality is no easy feat and cannot simply be addressed by using renewable energy sources and adopting smarter practices at home to avoid releasing potential toxins into the indoor air of one's home. For instance, those who are oftentimes most affected by chemicals from fossil fuel emissions entering their home may not be able to afford a cleaner energy source. Ultimately, though, it is imperative to understand the interconnectedness of outdoor and indoor air quality in order to develop solutions that can promote the least possible health risk of the indoor air quality in all homes.

Figure 1

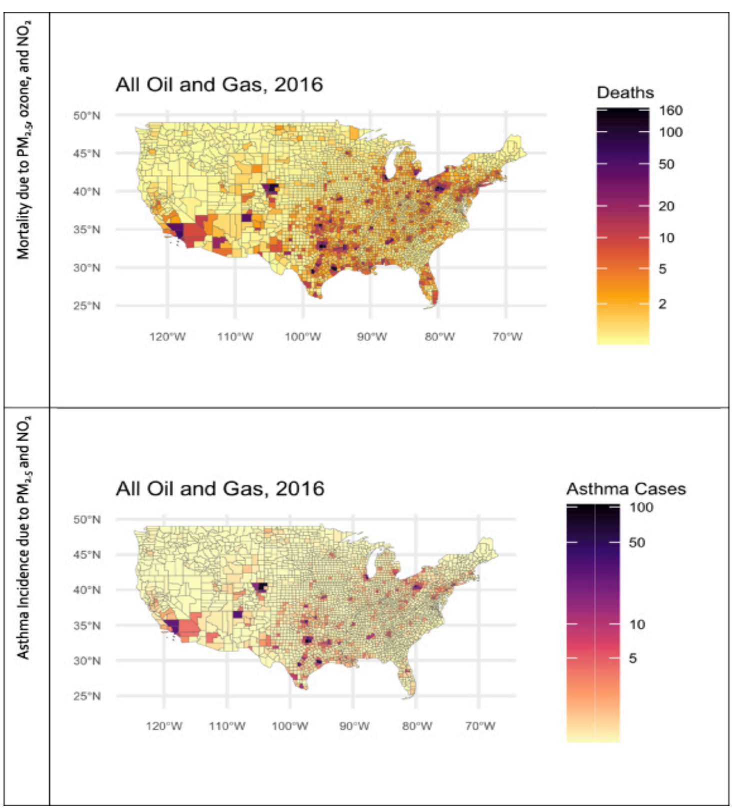


Figure 2

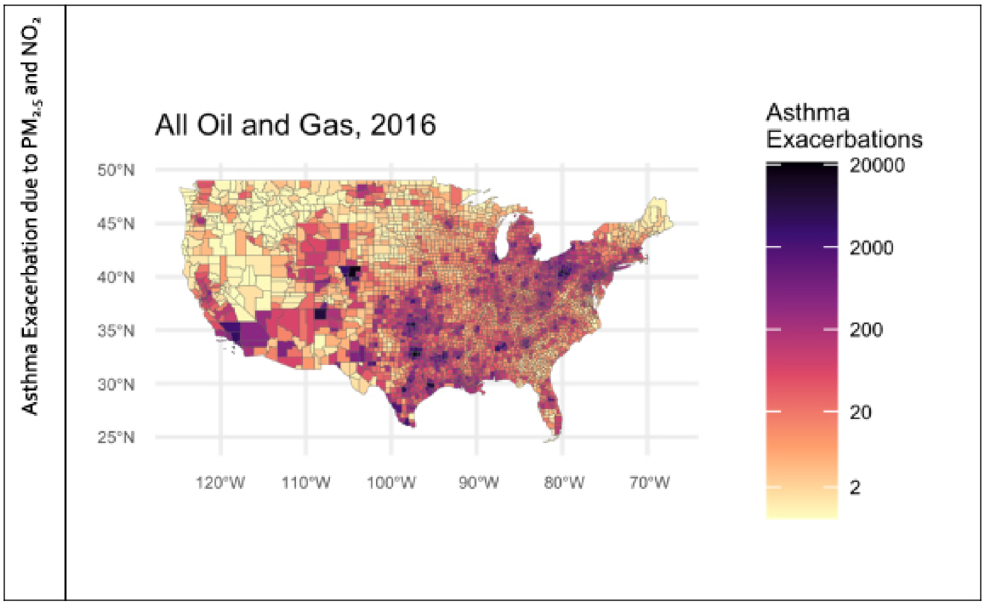
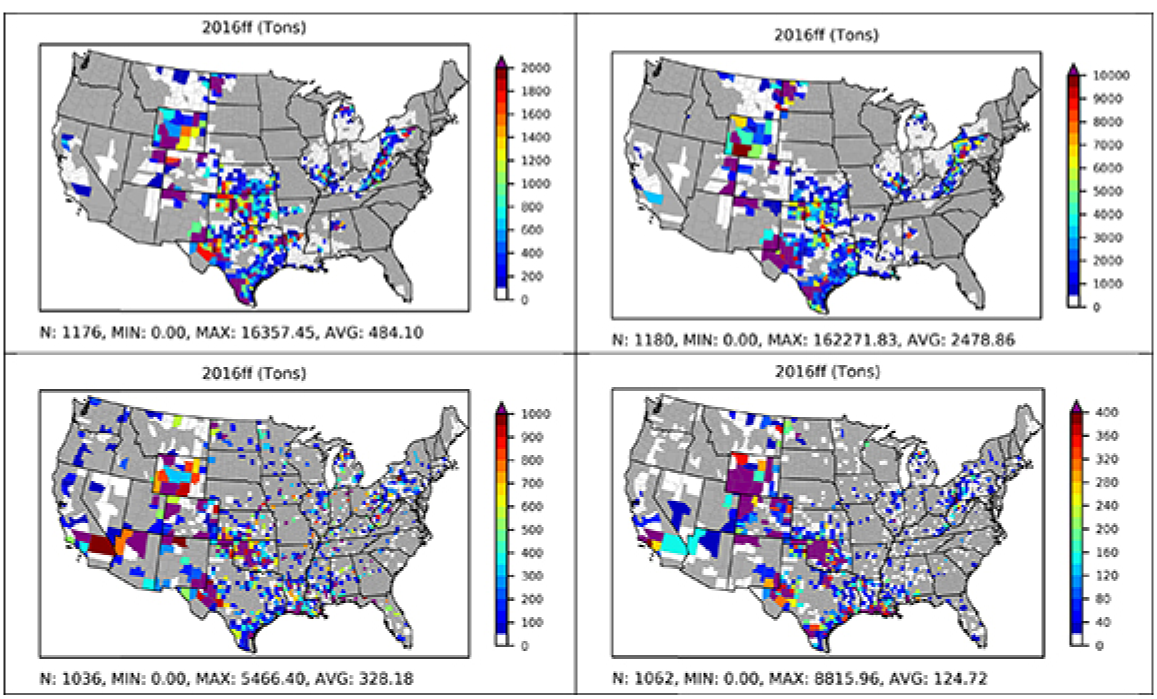


Figure 3



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