**Estimating Emissions from the Logistics Industry in the SoCal Inland Region**

The logistics sector is a significant economic driver in the SoCal Inland Region and is associated with considerable environmental impacts. One major impact is the emission of Greenhouse Gases (GHG). The analyses outlined below aim to assess GHG and other emissions from the logistics industry core components: building energy use and transportation. Additionally, we also provide an analysis of the potential for warehouse-sited solar to impact GHG emissions and consider the impacts of transportation electrification.

Warehouse Energy Use

A central component of the logistics industry are warehouses which can span more than 1,000,000 ft2. Due to their size, the buildings can have significant energy demands that are typically met with energy from the grid that is powered, to an extent, by fossil fuels. To improve our understanding of the GHG emissions associated with the logistics industry in the Inland SoCal Region we estimated GHG emissions associated with existing and planned warehouses across the region.

To estimate warehouse GHG emissions, we used energy benchmark data for warehouses in California sourced from the California Energy Commission which provides the GHG emission intensity for a sample of warehouses across California (<https://www.energy.ca.gov/media/8751>). We filtered this data to focus on warehouses located in San Bernardino and Riverside counties and calculated their average GHG emissions intensity (kgCO2e/ft²). We then used data from the Warehouse City project (<https://radicalresearch.shinyapps.io/WarehouseCITY/>) in combination with building footprint data (<https://hub.arcgis.com/datasets/esri::microsoft-building-footprints-features/about>) to estimate the building area of all warehouses across the SoCal Inland Region. Finally, we estimated the GHG emissions for each warehouse in the region by multiplying the average GHG emission intensity factor by the area of each warehouse.

|  | **Cumulative Warehouse Area (ft2)** | **Warehouse Energy Consumption (MW) per Year** | **Direct Warehouse Emissions (MTCO2e) per Year** | **All-Source Emissions (MTCO2e)** |
| --- | --- | --- | --- | --- |
| **Riverside** | 163,054,078 | 2,770,916 | 170,133 | 4,905,518 (2017) |
| **San Bernardino** | 306,914,564 | 5,215,660 | 320,239 | 15,974,244 (2016) |
| **Total** | 469,968,643 | 7,986,577 | 490,372 | 20,879,762 (2016-2017) |

*Table 1. Displays the estimates for warehouse area, energy use and emissions. For comparison, the table also includes estimates of all-source GHG emissions for Riverside and San Bernardino. However, it should be noted that the all-source estimates were performed in 2016 and 2017 and are not directly comparable.*

Using this approach, we estimate that there are approximately 470 million square feet of warehouses in the region (Table 1). This corresponds to an estimated warehouse energy use in the Inland SoCal Region of approximately 8 GWh annually which is associated with emissions of approximately 490,000 MTCO2e per year. Approximately 160,000 MTCO2e are associated with warehouses in Riverside County, and the other 310,000 MTCO2e are associated with warehouses in San Bernardino County. To put these results into context, in 2017 Riverside County emitted approximately 5,000,000 MTCO2e across all sources, and San Bernardino emitted approximately 16,000,000 MTCO2e across all sources in 2016. After adjusting for the age of the county GHG emission estimates, we estimate that warehouse energy usage is responsible for approximately 2-3% of all GHG emissions in the Inland SoCal Region.

While our analysis provides valuable insights into the GHG emissions from warehouse energy use in the Inland SoCal Region, it has several limitations. The GHG emission intensity values, based on a sample of warehouses, may not fully represent the diversity of operations and energy efficiency that characterize warehouses in the region. Additionally, the building footprint data may contain inaccuracies especially for warehouses built recently. Moreover, the analysis does not account for potential future changes in energy use or emission intensity due to, e.g., energy efficiency measures and increased renewable integration into the grid, which could significantly impact future emissions. Therefore, our estimates offer a useful high-level approximation but should be interpreted with these limitations in mind.

Warehouse Solar Potential

The substantial size of warehouses results in high energy usage but also presents a significant opportunity to generate energy through rooftop solar installations. Accordingly, we investigated the potential for solar installations on the extensive rooftops of regional warehouses. By evaluating the potential energy generation of these solar systems, we aim to identify effective pathways to mitigate the environmental impacts of the logistics industry.

To assess the solar potential of warehouse roofs in the region, we utilized data from the Warehouse City Project and the building footprint data (see above). We assumed that the area of the warehouse footprint was equivalent to the rooftop area and that no rooftop solar installations currently exist on any of the warehouses. We then used two approaches to estimate the percentage of collective roof area suitable for PV systems. For the lower-end estimate, we based our calculations on an NREL report indicating that, in general, approximately 60% of rooftop areas are suitable for PV installation (https://www.nrel.gov/docs/fy14osti/60593.pdf). For the upper-end estimate, we employed the US Department of Housing and Urban Development’s methodology for calculating building rooftop area (https://files.hudexchange.info/resources/documents/Appendix-F-Rooftop-Calculation-Tool.pdf). Although this method required the width and length of the building, which were not available, we assumed the rooftop area to be square and applied a six-foot setback due to fire code requirements. Together, this approach allowed us to estimate the maximum potential rooftop area suitable for PV systems on warehouses across the region.

Once we had the suitable rooftop area estimates we converted the rooftop areas into PV system size in kW using a standard formula provided by NREL (https://pvwatts.nrel.gov/pvwatts.php). Next, we used the NREL PVWatts tool (https://pvwatts.nrel.gov) to estimate the total annual energy generation which takes into account the local climate and standard system specifications on energy generation. Finally, we utilized the EPA’s equivalency calculator which accounts for regional grid characteristics (https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator) to estimate the avoided GHG emissions associated with the PV generation.

|  | **Suitable Rooftop Area (millions of ft2)** | **Potential PV System Capacity (GW)** | **Potential PV Energy Generation (GW)** | **Avoided GHG Emissions (millions of MTCO2e)** |
| --- | --- | --- | --- | --- |
| **Riverside** | 98 – 152 | 2.0 – 3.0 | 3,332 – 5,171 | 0.8 - 1.2 |
| **San Bernardino** | 184-288 | 3.7 - 5.8 | 6,271 – 9,816 | 1.5 – 2.3 |
| **Total** | 282-440 | 5.6 – 8.8 | 9,604 – 14,988 | 2.3 – 3.5 |

*Table 2. This table displays estimates of the suitable area for rooftop solar on warehouses in the Inland SoCal region. It also shows the corresponding potential PV system capacity, energy generation of these systems and the potential GHG reductions.*

This approach resulted in estimates of approximately 100-150 million ft² and 180-290 million ft² of total rooftop area suitable for PV systems in Riverside and San Bernardino counties, respectively (Table 2). These values correspond to potential annual PV energy generation of 9,000 - 15,000 GWh per year. If we assume that all the energy generated by rooftop solar installations replaces energy that would have been consumed from the grid, this would correspond to a reduction of 2.3 - 3.5 million metric tons of CO2e per year, significantly surpassing the 490,000 MTCO2e per year we estimated for warehouse energy use in the region (Table 1). This suggests that installing rooftop solar on 14-21% of the warehouses could potentially offset the GHG emission associated with warehouse energy use in the Inland SoCal Region.

This analysis of rooftop solar potential for warehouses in the region has several limitations that need to be considered. Firstly, warehouse size was used to determine roof size without accounting for the structural integrity of roofs, which is crucial for supporting solar panels. The variability in rooftop orientation, shading, and obstructions were not considered, which could impact the efficiency and feasibility of solar installations. We also assumed that there are no existing solar PV systems on the warehouses. Moreover, connecting significant amounts of solar to the grid would likely require substantial upgrades to existing infrastructure, which could limit the potential solar integration capacity. Finally, we did not account for the timing of energy use, which would likely not correspond exactly with PV energy generation, thus limiting the ability of solar to offset energy use and decrease emissions.

Transportation Emissions Associated with the Logistics Industry

Medium- and Heavy-Duty Vehicles (MHDVs) are integral to the warehouse and logistics industry, utilizing various vehicle types for transport. MHDVs are a significant source of GHG and particulate matter emissions. To estimate emissions from MHDVs in Riverside and San Bernardino counties, we utilized the approach detailed in the Warehouse CITY tool developed by Radical Research LLC. Specifically, the Warehouse CITY tool assumes that there are 0.67 MHDV trips per 1,000 square feet of warehouse space. The average MHDV trip is assumed to be 38 miles based on data provided to Radical Research from Streetlight. The emission values are derived from the 2022 EMFAC fleet-average estimates for the SCAQMD.

|  | **MHDV Trips per Year (millions)** | **MHDV Miles (millions) per Year** | **CO2 Emissions (millions of MT)** | **Nox Emissions (MT)** | **Diesel PM2.5 Emissions (MT)** |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Riverside** | 40 | 1,516 | 1.7 | 2,819 | 25 | |
| **San Bernardino** | 75 | 2,854 | 3.2 | 5,307 | 47 | |
| **Total** | 115 | 4,370 | 4.8 | 8,127 | 72 | |

*Table 3. This table displays estimates on the number of trips, miles driven and emission associated with MHDVs and the logistics industry.*

Adopting this approach, we estimate that there are approximately 115 million MHDV trips per year associated with the logistics industry in the region (Table 3). This corresponds to an estimate of over 4 billion miles driven in the region by the MHDVs and emissions of approximately 5 million MTCO2e per year. After adjusting for the age of the county GHG emission estimates, we estimate that MHDVs associated with the logistics industry are responsible for approximately 20-25% of all GHG emissions in the Inland SoCal Region. In addition to GHG emissions, MHDVs are also associated with other harmful emissions. Indeed, we estimated that these vehicles emit approximately 70 MT of diesel particulate matter and 8,000 MT of NOx per year across the region.

The emissions associated with the logistics industry can be mitigated through the transition to zero-emission vehicles. The California Air Resources Board (CARB) has outlined comprehensive strategies for the electrification of medium and heavy-duty vehicles(https://ww2.arb.ca.gov/resources/documents/zero-emission-road-medium-and-heavy-duty-strategies). Indeed, California has developed regulations to facilitate the transition to zero emission MHDVs. Specifically, requirements for drayage fleets mandate that beginning in 2024, all new drayage trucks must be zero-emission vehicles (ZEVs) and by 2035 drayage services can only be performed by ZEVs. From the 2036 model year onwards, all regulated Class 2b-8 vehicles produced or delivered for sale in California must be ZEVs. This will require significant charging infrastructure to support the increased demand for electric vehicle charging, ensuring that the fleet of zero-emission MHDVs can operate efficiently and reliably throughout the regions. The electrification of transportation will have a significant impact on GHG and other harmful emissions across the region.

There are several major caveats to this analysis. First, the analysis is based on a number of critical assumptions such as the number of truck trips per warehouse based on the size of the warehouses. These assumptions were based on limited amounts of data and may not be representative of smaller warehouses. Additionally, the current emission estimates do not account for vehicle idling, which can significantly contribute to total emissions near warehouses and likely results in underestimating the actual emissions. Moreover, we do not know the variability of MHDVs in terms of their efficiency, and it is likely that some already incorporate hybrid and other more efficient technologies. Furthermore, variations in warehouse operational practices, such as the frequency of loading and unloading activities and the types of goods transported, can also influence the emission estimates. Future analyses should consider these factors to provide a more accurate assessment of MHDV-related emissions in the region.

Discussion

Overall, our estimates provide a high-level approximation of the environmental impacts associated with the logistics industry in the Inland SoCal Region. These estimates should be interpreted with caution, considering the limitations and assumptions inherent in the analysis. Future work should aim to refine these estimates by incorporating more detailed data on warehouse operations and vehicle characteristics. By addressing these factors, we can develop a more comprehensive understanding of the pathways to mitigate the environmental impacts of the logistics industry in this region. However, our approach did allow us to draw several conclusions:

* Emissions associated with MHDVs and the logistics industry likely result in nearly a quarter of all GHG emissions for the region and they are a significant source of other harmful emissions such as diesel PM2.5;
* Energy consumption by warehouses across the region is associated with significantly less GHG emissions than from MHDVs, but is still a significant source of GHG emissions for the region;
* Warehouse rooftops likely present a significant opportunity for solar energy generation and could offset GHG emissions from warehouse energy use (not including MHDVs) during the daylight hours.

Warehouses in the SoCal Inland Region consume a considerable amount of energy from the grid, contributing an estimated 2-3% of the region’s total GHG emissions. However, the flat rooftop areas that characterize these warehouses present a significant opportunity for solar installation, which could completely offset daytime energy use (Table 1 and 2). The addition of energy storage systems could further supply emission-free energy when solar panels are not generating power. Further, while we did not investigate energy efficiency measures due to a lack of warehouse-specific data, it is likely that such measures would be a cost-effective way to reduce energy consumption and emissions.

Although the direct energy use by warehouses is a significant contributor to GHG emissions across the region, it is relatively minor compared to the transportation emissions associated with the logistics industry. We estimated that MHDVs associated with the logistics industry contribute 20-25% of all GHG emissions across the region and also emit large quantities of other harmful pollutants (Table 3). This problem will be mitigated as transportation is electrified. However, this will be a relatively slow process which will likely take several decades before emissions reach sustainable levels. The region can facilitate the transition to electric MHDVs by ensuring adequate charging infrastructure is in place and by providing businesses and fleet owners with information about new clean transportation technologies and existing programs that support the purchase of electric trucks and chargers.