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IDENTIFICATION DECARBONIZATION CHALLENGES IN THE PHARMACEUTICAL INDUSTRY THROUGH OPERATIONAL EMISSION ASSESSMENT:- CASE OF AURANGABAD INDUSTRIAL SECTOR

A Multi-Scale Assessment of Operational Carbon Emissions and Industrial Decarbonization Pathways

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Abstract: Abstract: The pharmaceutical industry is among the most power-consuming industrial industries because of the usage of controlled environments, high-throughput production industries, and high-regulation criteria.. The study assesses the operational carbon emissions in pharmaceutical sectors in the city of Aurangabad in India, and particularly, determining the major decarbonization challenges. The research uses the Greenhouse Gas (GHG) Protocol framework to categorize emissions as Scope 1, Scope 2 and Scope 3 and examines the site, building, and process level of emissions. The case studies of large, medium, and small-scale industries are chosen as three industrial clusters, Waluj, Shendra, and Chikalthana MIDC. The results indicate that the Scope 2 emissions are predominant because of consumption of electricity due to HVAC systems and cleanroom activities whereas the Scope 1 emissions are caused by use of fossil fuel-based utilities. The HVAC systems, granulation processes, and utilities are considered to be the significant contributors determined by the hotspot analysis. The benchmarking outcomes indicate that the small-scale industries are the highest emitters, as a result of ineffective infrastructure, whereas large-scale industries are comparatively better but still rely on grid electricity.

Index Terms **-** Decarbonization; Pharmaceutical Industry; Operational Carbon; HVAC Systems; Benchmarking; Emission Hotspots.

I. INTRODUCTION

The high growth of the industrial sector has played a critical role in the growth of worldwide carbon emissions with dire environmental and climatic impacts. The pharmaceutical industry, among other industrial industries is very energy-consuming because it requires regulated manufacturing conditions, ongoing production, and high standards of quality. Such operational needs require a lot of energy, particularly of the HVAC systems, cleanroom conditions, and specialized equipment, and the sector contributes greatly to greenhouse gas emissions. Decarbonization of the pharmaceutical sector is a tricky task as it involves striking a balance between the sustainability agenda and regulatory adherence and efficiency. Compared with other industries, pharmaceutical manufacturing processes cannot be easily altered because of strict guidelines associated with the quality and safety of the products. That is why it is essential to know the origin and the distribution of the carbon emissions to come up with effective strategies. The study targets Aurangabad, a big pharmaceutical hub in India and seeks to estimate the emission of carbon in operations at different levels of industry. The analysis of emissions on a site, building, and process level detects the important challenges and opportunities of decarbonization

II.Methodology

The research follows the systematic and integrated approach in the measurement of operational carbon emissions in pharmaceutical industries. This study starts with an extensive background research that looks into the trends of emission in the world and how the pharmaceutical industry contributes to greenhouse gases emissions. This is followed by the definition of the scope of the study through the setting of system boundaries at three levels, i.e., industry (site), building, and process.

Primary and secondary sources are used in collecting the data. Primary data involve the analysis of industrial layout, process flow charts and system settings whereas secondary data is acquired by the use of industry reports, emission factor databases and literature. The data obtained is then utilized to subdivide the system into major systems like HVAC systems, process equipment, and utility systems.The energy mapping is performed in order to determine the energy consumption pattern in various processes. The level of electricity use and fuel consumption are measured and transformed to carbon emission levels based on standard emission factors. The emissions calculated are included in the GHG Protocol framework as Scope 1, Scope 2, and Scope 3 emissions.

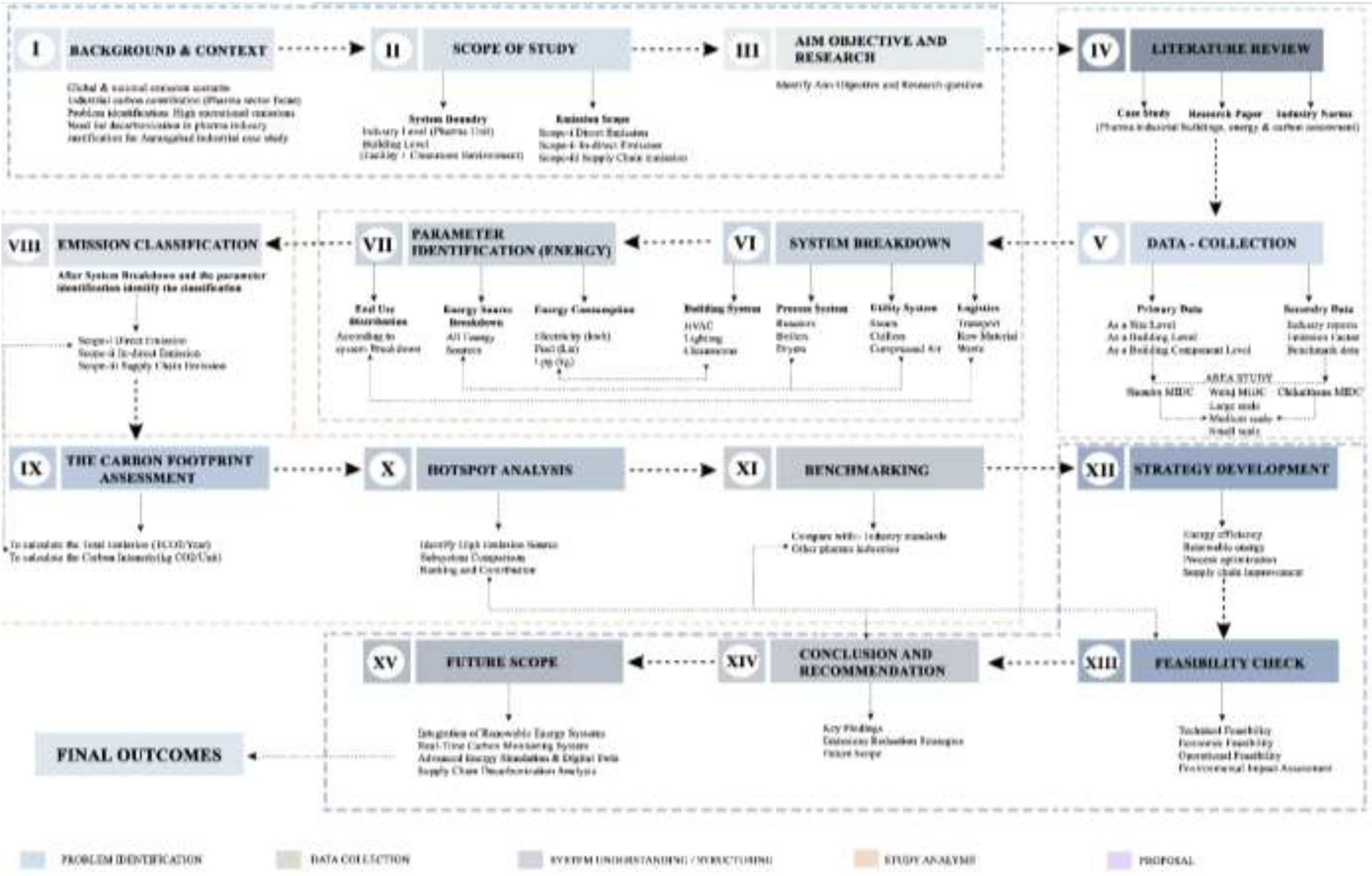
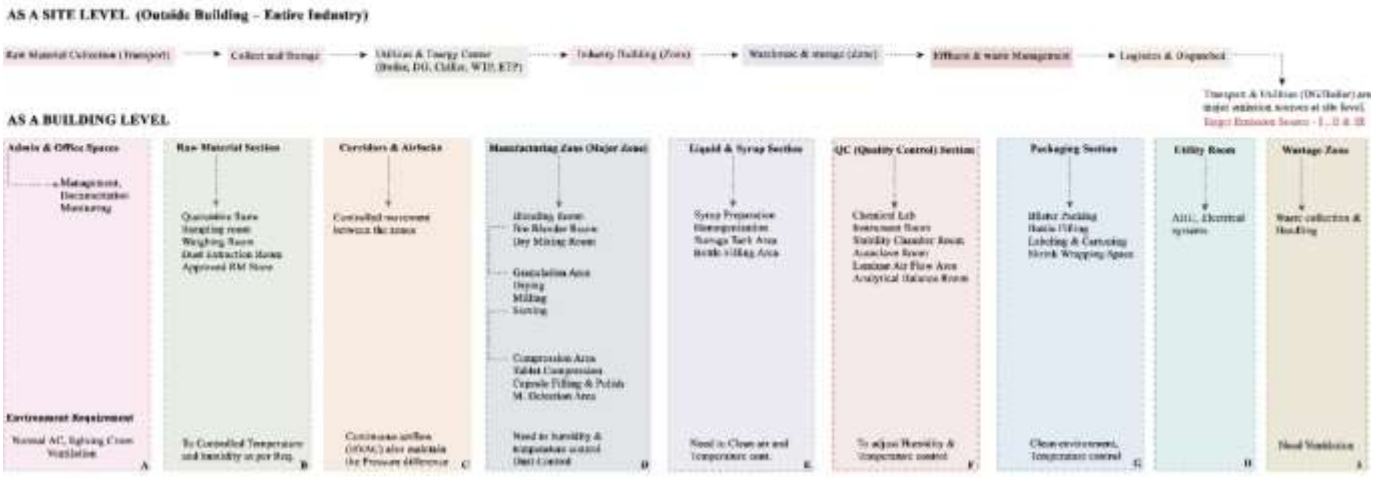


Figure 2.1: Methodology (Prepared by Author)

II. Pharmaceutical Industry Operational Flow

To understand operational carbon emissions in the pharmaceutical industry, the system is analyzed at three hierarchical levels: Site Level, Building Level, and Process Level. This multi-scale approach enables identification of emission sources and energy demand patterns across the entire industrial system.

- AS A SITE LEVEL (INDUSTRY SCALE) At the site level, emissions are associated with the overall industrial infrastructure, utilities, and logistics systems
- AS A BUILDING LEVEL (FACILITY SCALE) At the building level, emissions are dominated by environmental control systems required for pharmaceutical manufacturing
- AS A PROCESS LEVEL (PRODUCTION SCALE) At the process level, emissions are generated from specific manufacturing operations and equipment usage



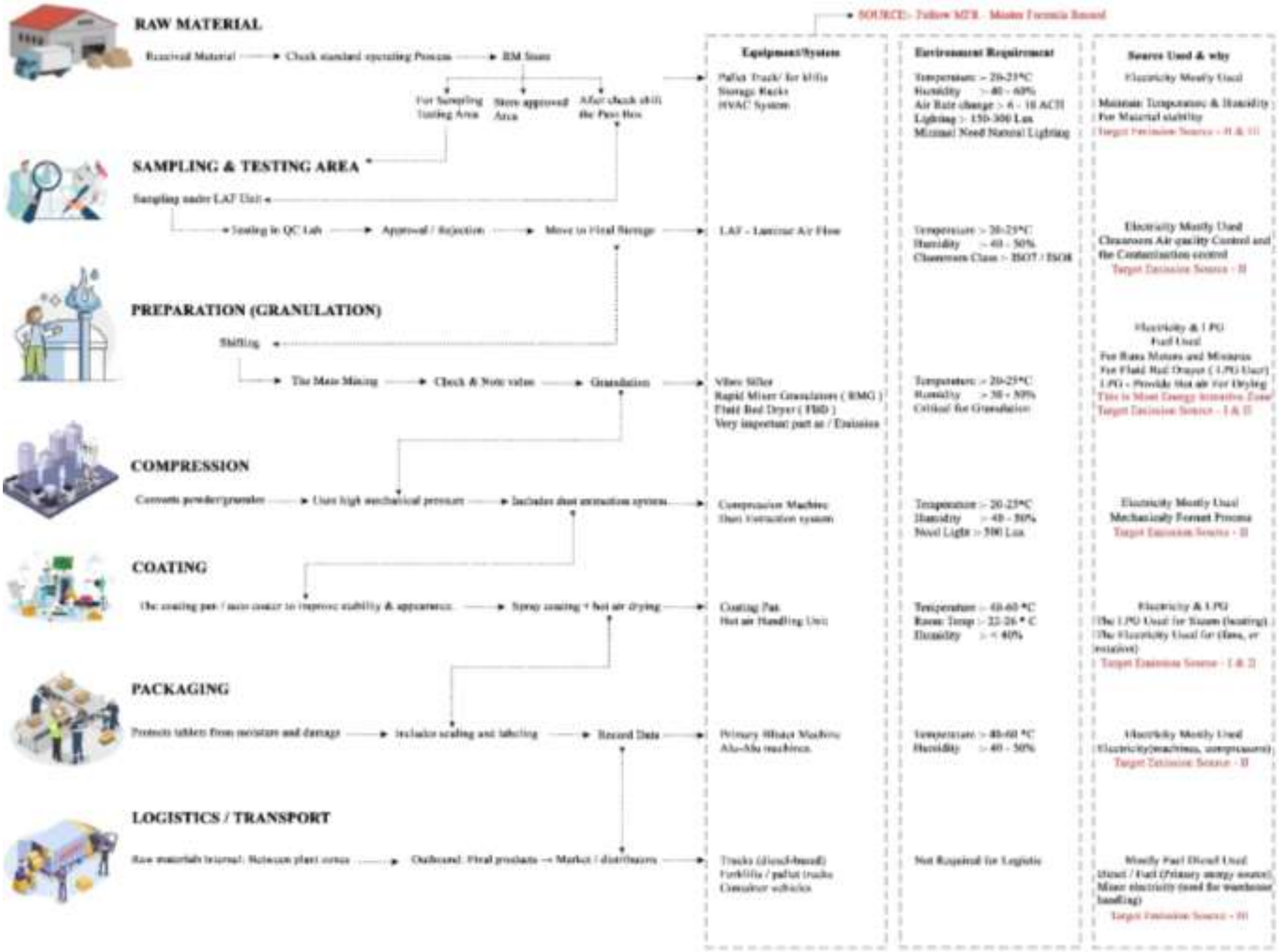


Figure 3.2: As a Process Level Pharma Industry Process Source:- Prepared by Author

Linking Flow with Emission Distribution

Level	Major Source	Emission Scope
Site Level	DG & Transport	Scope 1 & 3
Building	HVAC & Lighting	Scope 2
Process	Equipment & Drying	Scope 1 & 2

Table 4.1: Linking Flow

III. Case Study: Aurangabad Pharmaceutical Industry

The research takes a systematic and integrated approach to evaluate operational carbon emissions in pharmaceutical industries. The Aurangabad is a large pharmaceutical center of Maharashtra, comprising three main industrial clusters of various levels of activity. Waluj MIDC is large scale industries with fully developed infrastructure, Shendra MIDC is medium scale industries with average development and Chikalthana MIDC is small scale industries with old infrastructure and inefficiencies.

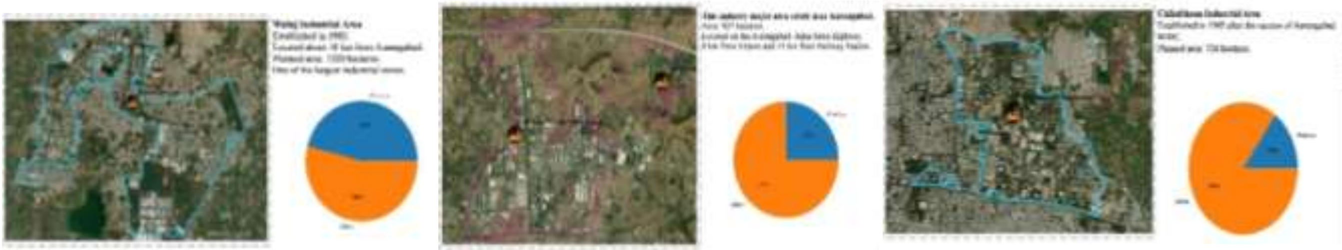


Figure 5.1:Location of industry (Waluj Chikalthana & Shendra MIDC) with Pharmaceutical or other industry Ratio in (%)

Source:- Prepared by Author

V.1.0 Case A: Large-Scale Pharmaceutical Industry

Large Scale Industry Location:- Waluj Maharashtra

Level	Monthly Energy (kWh)	Total kWh
Building Level	32079	308319
Process Level	276240	

Table 5.1: Energy Consumption Data as per Primary Data Collection

Step-I Electricity Bill Calculation

Given: Tariff =Rs.16 / kWh (as per Govt Norms)

Monthly Bill = 308,319 X 16

Rs. 4933104 (5.1)

(50 lakh) as per Interview

Step-II Scope 1 Emission (Diesel)

Diesel Used (1050 L/month)

1050×2.68= (Factor Considered IPCC Norms)

$=2814$ kg CO_2

$= 2.81$ TCO_2/Month (5.2)

Coal Emission

6000 X 2.42= 14,520 kg CO_2

2.81+14.52 = 17.33 TCO_2/month (5.3)

Step-III Scope2 Emission (Main - Electricity)

CO_2 = 308,319 X 0.82

= 252,821 kg CO_2/Month (5.4)

To Calculate the Annual Emission **:-** 252.82 X 12 = 3033.84 TCO_2/ year

Step-IV Scope-3 Emission (Transport , Supply chain)

Distance Considered:

Pune To Waluj :- 230 km

Mumbai To Waluj :- 330 km

To Considered The Average Value = 280 km

Considered as per Surway (This is Average Consideration)

20 truck trips /Month & Load = 10 ton/Truck

20 X 10 X 280 = 56,000

CO2= 56,000 X 0.10 =5600 kg CO_2

= 5.6 TCO_2/Month (5.5)

Scope	Source	Emission (TCO_2/Month)
Scope-I	Diesel	2.81
Scope-II	Electricity	252.82
Scope-III	Transport	5.60
Total		**261.23**

Table 5.2: Total Emission Calculation (CASE-A)

V.1.1 Case B: Medium-Scale Pharmaceutical Industry

Step-I Electricity Bill Calculation

Given: Tariff =Rs.13 / kWh (as per Govt Norms)

Monthly Bill = 207692 X 13

Rs. 2700074 (5.1.1)

(27 lakh) as per Interview

Step-II Scope 1 Emission (Diesel)

Diesel Used (1200 L/month)

1200 X 2.68= (Factor Considered IPCC Norms)

=3216 kg CO_2

= 3.21 TCO_2/Month (5.1.2)

Coal Emission

4000 X 2.42= 9680 kg CO_2

3.21+9.68 = 12.89 TCO_2/month (5.1.3)

Step-III Scope2 Emission (Main - Electricity)

CO_2 = 207698 X 0.82

= 170.312 kg CO_2/Month (5.1.4)

Step-IV Scope-3 Emission (Transport , Supply chain)

Distance Considered:

Pune To Chikalthana :- 223 km

Mumbai To Chikalthana :- 340 km

Hyderabad to chikalthana :- 550 km

To Considered The Average Value = 370 km

Considered as per Surway (This is Average Consideration)

20 truck trips /Month & Load = 10 ton/Truck

20 X 10 X 370 = 74000

CO2= 74000 X 0.10 =7400 kg CO_2

= 7.40 TCO_2/Month (5.1.5)

Scope	Source	Emission (TCO_2/Month)
Scope-I	Diesel/Coal	9.68
Scope-II	Electricity	170.32
Scope-III	Transport	7.40
Total		**187.40**

Table 5.1.1: Total Emission Calculation (CASE-B)

V.2.0 Case C: Small-Scale Pharmaceutical Industry

Step-I Electricity Bill Calculation

Given: Tariff =Rs.13 / kWh (as per Govt Norms)

Monthly Bill = 61540 X 13

Rs. 800020 (5.2.1)

(8-9 lakh) as per Interview

Step-II Scope 1 Emission (Diesel)
Diesel Used (500 L/month)

$$500 \times 2.68 = \text{(Factor Considered IPCC Norms)}$$
$$= 1340 \text{ kg } CO_2$$
$$= 1.34 \text{ } TCO_2\text{/Month} \quad (5.2.2)$$

LPG Emission

$$300 \times 3 = 900 \text{ kg } CO_2$$
$$1.34 + 0.90 = 2.24 \text{ } TCO_2\text{/month} \quad (5.2.3)$$

Step-III Scope2 Emission (Main - Electricity)

$$CO_2 = 61540 \times 0.82$$
$$= 50.45 \text{ kg } CO_2\text{/Month} \quad (5.2.4)$$

Step-IV Scope-3 Emission (Transport , Supply chain)
Distance Considered:
Pune To Shendra :- 230 km
To Considered The Average Value = 230 km
Considered as per Surway (This is Average Consideration)
20 truck trips /Month & Load = 10 ton/Truck

$$20 \times 10 \times 230 = 13800$$
$$CO2 = 13800 \times 0.10 = 1380 \text{ kg } CO_2$$
$$= 1.38 \text{ } TCO_2\text{/Month} \quad (5.2.5)$$

Scope	**Source**	**Emission (TCO_2/Month)**
Scope-I	Diesel/Coal	1.34
Scope-II	Electricity	50.45
Scope-III	Transport	1.38
Total		**53.17**

Table 5.2.1: Total Emission Calculation (CASE-C)

VI. Comparative Analysis

Industry Scale	**Scope 1**	**Scope 2**	**Scope 3**	**Total (TCO_2/month)**
Large	17.33	252.82	5.60	261.23
Medium	9.68	170.32	7.40	187.40
Small	2.24	50.45	1.38	53.17

Table 6.1.0: Emission Comparison Across Scales

The comparative analysis reveals that large-scale industries emit the most carbon (261.23 tCO 2/month) then medium and small-scale industries. Nevertheless, in any case, the Scope 2 emissions (consumption of electricity) prevail, which means that pharmaceutical industries are extremely reliant on electrical systems, including HVAC and cleanrooms. The emission of Scope 1 and Scope 3 is relatively insignificant, and this emphasizes that the main focus of emission control should be energy efficiency and the optimization of electricity sources. The computed intensity of carbon emission of the pharmaceutical plant is about 0.82 TCO 2 per 1000 kWh, which is at the top of the average industrial emission range in India. The efficient industrial operations, according to benchmarks based on the Central Electricity Authority (CEA) and Bureau of Energy Efficiency (BEE), would ideally have a level of emissions being lower than 0.8 TCO 2 per 1000 kWh.

VII. Hotspot Analysis

This table determines the main emission generating systems at various levels of industries. It indicates that the main hotspots are HVAC systems and granulation/drying processes, which have the greatest consumption of energy. Other types of emissions, such as boilers and process equipment, are also high contributors to emissions particularly in large-scale industries.

Process/System	Large Scale	Medium Scale	Small Scale
HVAC Systems	Very High	Very High	High
Granulation/Drying	High	High	Moderate
Compression	Medium	Medium	Low
Coating	High	High	Moderate
Utilities (Boilers)	High	Medium	Low

Table 7.1.0: Emission Hotspot Across Scales

VIII. Benchmark Analysis

The benchmarking analysis shows that carbon intensity of all industry scales is about 0.82 tCO 2/MWh, which is at the highest end of the permissible industrial range (0.6-0.8). This implies that the industries are in a high emission zone, and there is the need to enhance energy efficiency and integration of renewable energy.

Industry Scale	Carbon Intensity (TCO_2/MWh)	Performance
Large	0.82	High
Medium	0.82	High
Small	0.82	High

Table 8.1.0: Emission Intensity Benchmarking

IX. Benchmark Gap Analysis

It is a table that has determined the key emission-emitting systems at various industry levels. It demonstrates that HVAC systems and granulation/drying operations represent the main hotspots, and they constitute the greatest energy usage. Other contributors of much emission are utilities such as boilers and process equipment particularly in large-scale industries.

Parameter	Current Status	Benchmark	Gap Level
HVAC Efficiency	Low	High Efficiency	High
Renewable Energy	Limited	50–80%	High
Fuel Dependency	Fossil-based	Clean Energy	High
Process Optimization	Moderate	Advanced	Medium

Table 9.1.0: Emission Intensity Benchmarking

X. Observation

The comparison of pharmaceutical industries in Waluj, Shendra and Chikalthana MIDC indicates that Scope 2 emissions prevail in all sizes with over 85-95 percent of the total emissions. This can be mainly attributed to constant power use needed in HVAC systems, cleanroom processes and process equipment. We find that carbon intensity is constant (0.82 tCO 2 /MWh), and thus it is seen that large, medium, and small-scale industries do not depend on scale efficiency as they are systemically dependent on grid electricity. Also, the process-level activities like granulation and drying are key sources of energy demands, and transportation (Scope 3) plays a relatively minor role. Small scale industries are more inefficient and large scale industries have more total emissions but with relatively better operational control.

XI. Problem Identification

The study identifies several critical challenges that hinder effective decarbonization in the pharmaceutical industry:

- High dependency on electricity-based HVAC systems
- Continuous operation of cleanrooms leading to non-stop energy demand
- Use of fossil fuels (diesel, LPG, coal) in utilities
- Limited adoption of renewable energy sources
- Energy-intensive processes like granulation, drying, and coating
- Inefficient infrastructure in small-scale industries
- Lack of integrated energy management systems

XII. Discussion

The results of this study demonstrate that operational carbon emissions in the pharmaceutical industry are predominantly driven by electricity consumption, particularly at the building level. HVAC systems and cleanroom operations account for the largest share of energy use, making Scope 2 emissions the most significant contributor across all industry scales. This indicates that the sector's carbon profile is largely influenced by environmental control requirements rather than direct fuel consumption alone.

Furthermore, process-level analysis reveals that energy-intensive operations such as granulation, drying, and coating contribute substantially to overall emissions. While large-scale industries exhibit higher total emissions, small-scale industries tend to show relatively higher inefficiencies due to outdated infrastructure and limited technological optimization. This highlights the need for scale-sensitive strategies in addressing emission reduction.

The consistent carbon intensity observed across all case studies suggests a systemic dependence on grid-based electricity, emphasizing the importance of transitioning towards cleaner energy sources. Given the operational and regulatory constraints of pharmaceutical manufacturing, decarbonization requires a structured and integrated approach.

Therefore, to address these challenges effectively, a Decarbonization Framework is proposed, focusing on multi-level interventions at site, building, and process scales to achieve sustainable emission reduction.

XIII. Conclusion

The study concludes that the pharmaceutical industry is a highly energy-intensive sector where operational carbon emissions are predominantly driven by electricity consumption. Across all three industrial scales—large, medium, and small—it is evident that Scope 2 emissions, mainly from HVAC systems and cleanroom operations, contribute the highest share of total emissions. This highlights the critical role of building-level systems in influencing overall carbon performance.

Despite variations in industry size, the carbon intensity remains nearly constant at approximately 0.82 TCO_2/MWh, indicating a strong dependence on grid-based electricity rather than operational efficiency alone. Process-level activities such as granulation, drying, and coating further increase energy demand, while Scope 1 emissions from fossil fuel usage and Scope 3 emissions from transportation contribute comparatively less.

The findings emphasize that decarbonization in the pharmaceutical sector is complex due to regulatory requirements and continuous operational needs. However, significant emission reduction can be achieved by improving HVAC efficiency, adopting renewable energy sources, reducing fossil fuel dependency, and optimizing energy-intensive processes. A combined approach integrating building systems, process efficiency, and clean energy transition is essential for achieving long-term sustainability and progressing towards a net-zero emission pathway.

References

[1] Central Electricity Authority (CEA). (2023). CO_2 Baseline Database for the Indian Power Sector. https://cea.nic.in

[2] Bureau of Energy Efficiency (BEE). (2022). Energy Efficiency in Industrial Sector. https://beeindia.gov.in

[3] IPCC. (2021). Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp

[4] Carbon Footprint in Pharmaceutical Industry https://t-esco.in/f/carbon-footprint-in-the-pharmaceutical-industry

[5] Pharmaceutical Industry Carbon Footprint – Literature Review (ISPOR 2023) https://www.ispor.org/docs/default-source/intl2023/ispor23dehipawalaposter-pdf.pdf

[6] Sustainability in Pharmaceutical Manufacturing (IJPS Journal) https://www.ijpsjournal.com/article/Sustainability%2B%2BGreen%2BQA%2Bin%2BPharmaceutical%2BManufacturing%2BIntegrating%2BEnvironmental%2BResponsibility%2Binto%2BPharmaceutical%2BQuality%2BSystems

[7] Scope 3 Emission Calculation Guidance (PSCI) https://pscinitiative.org/downloadResourceFile?resource=779