Greenhouse Gas Emissions in the Pharmaceutical Industry (2019–2025): A Descriptive and Inferential Statistical Analysis of Decoupling, Intensity Metrics, and Supply Chain Challenges – Part I

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Abstract

The pharmaceutical industry's contribution to global greenhouse gas (GHG) emissions presents a critical paradox: an inherently health-oriented sector whose operations generate substantial environmental burden. This study presents a comprehensive descriptive and inferential statistical analysis of GHG emissions data from 14 major pharmaceutical companies over 2019–2025, examining emissions trajectories, structural composition, intensity metrics, and drivers of energy intensity. Analysis reveals that Scope 3 emissions dominate carbon footprints, averaging 5.1 million $t.CO_2e$ – approximately 8.7 times greater than Scopes 1 and 2 (combined) mean value. While operational emissions (Scopes 1 and 2) declined substantially, with mean reductions of 41.3% and 61.4% in emissions intensity, respectively, Scope 3 emissions intensity showed only marginal improvement (mean: -17.7%, median: -22.1%). Upstream emissions, particularly purchased goods and services (Category 1), averaged 80.9% of Scope 3 footprints, highlighting supply chain decarbonisation as the primary challenge. While relative decoupling is evident across the sector, absolute decoupling remains elusive, with only 5 of 14 companies exhibiting true decoupling (decoupling ratio >3.0). Correlation analysis revealed moderate negative relationships between revenue and operational emissions intensity (Scope 1: $r = -0.42$, $p < 0.01$; Scope 2: $r = -0.38$, $p < 0.01$), but no significant correlation with Scope 3 intensity ($r = -0.12$, $p = 0.28$). The energy intensity of pharmaceutical manufacturing – driven by cleanroom HVAC systems consuming 50–75% of facility energy – emerges as a critical constraint on Scope 1 reduction. The findings suggest the pharmaceutical industry is progressing toward operational decarbonisation but faces fundamental structural challenges in addressing value chain emissions, with implied warming trajectories diverging between operational (1.5°C-aligned) and supply chain (2°C-aligned) performance. The results of the study carry implications for supplier engagement, process innovation, and collaborative industry action.

Keywords: *Pharmaceutical industry, GHG emissions, Scope 3 emissions, Emissions intensity, Energy intensity, Cleanroom energy consumption, Decoupling ratio, Supply chain decarbonization.*

INTRODUCTION

The health care sector occupies a paradoxical position in the global sustainability discourse. While its core mission is the preservation and improvement of human health, its operations contribute substantially to the very environmental crises that threaten public health worldwide. The health care sector contributes approximately 5% of global greenhouse gas (GHG) emissions, and the pharmaceutical industry's carbon footprint has been forecasted to triple by 2050 if left unchecked (Booth *et al.*, 2023; Deswal, 2025a; MGL, 2025). In 2019, the industry produced 55% more CO_2 per million dollars generated than the automotive industry, generating approximately 48.55 metric tons of CO_2 equivalent ($t.CO_2e$) per US$1 million in revenue (illuminem, 2025). By 2023, the sector's total emissions had reached an estimated 397 million $t.CO_2e$ (SLR, 2025).

Health Care Sector Classification

Major financial and industry authorities, such as the Global Industry Classification Standards (GICS) and the Sustainability Accounting Standards Board (SASB), identify

Table 1: Grouping or categorization of health care sector/industry.

Group / Sub-group	GICS & SASB Alignment	Core Business Activities
Pharmaceutical & Biotechnology - API Manufacturers - Formulation/Generic Manufacturers - Biotech / Innovator Pharma	**GICS:** Pharmaceuticals, Biotechnology & Life Sciences **SASB:** Biotechnology & Pharmaceuticals	Research, development, and production of pharmaceutical drugs, biotech products, and life sciences tools. - **API Manufacturers**: Chemical synthesis of active drug ingredients; extremely energy and waste-intensive. - **Formulation/Generic Manufacturers:** Processing APIs into finished dosage forms (tablets, capsules); generally lower intensity than API. - **Biotech / Innovator Pharma:** High R&D focus, often with less manufacturing impact but specific waste from labs.
Medical Equipment & Supplies	**GICS:** Health Care Equipment & Supplies **SASB:** Medical Equipment & Supplies	Design, manufacture, and distribution of devices (scalpels, pacemakers, diagnostic & imaging equipment).
Health Care Providers & Services	**GICS:** Health Care Providers & Services **SASB:** Health Care Delivery	Operation of hospitals, clinics, nursing homes, laboratories, and retail pharmacy chains.

"*Health Care*" as a primary industry or sector. Within this broader "*Health Care*" umbrella, three sectors/groups – *Pharmaceutical & Biotechnology*, *Medical Equipment & Supplies*, and *Health Care Providers & Services* – have been recognized based on similar business models and associated risks, including vastly different environmental profiles, as summarized in Table 1.

Environmental Sustainability Context

Sustainability has been a prime focus of every pharmaceutical company since the declaration of the 17 interconnected Sustainable Development Goals (SDGs) by the United Nations in 2016, with an aim to build a peaceful and prosperous planet for now and the future (Deswal and Deswal, 2025a). Pharmaceutical companies focus on all the SDGs for their contribution to environmental, social, and governance (ESG) aspects of sustainability (DDW, 2025b). Further, in response to global warming and its related impact on climate change, the pharmaceutical sector is committed to reducing its GHG emissions to limit global warming to 1.5°C (2.7 °F) compared to pre-industrial levels in accordance with the Paris Climate Agreement-2015 and the requirements of the Science Based Target Initiative (SBTi) standards (Deswal, 2025a and c).

On December 23, 2024, the World Health Organization (WHO, 2024) launched the "*Greener Pharmaceuticals' Regulatory Highway*" initiative, demanding that global regulatory bodies and stakeholders adopt sustainable practices that substantially reduce environmental impacts while ensuring the highest standards of safety and efficacy. Companies that commit to environmental sustainability will not only lead the way but also establish themselves as frontrunners in sustainability.

GHG Protocol Framework

The GHG Protocol's three-scope framework provides the foundational structure for understanding GHG emissions (Deswal, 2025b). Scope 1 encompasses direct emissions from sources owned or controlled by the company; Scope 2 covers indirect emissions from purchased energy; and Scope 3 includes all other indirect emissions across the value chain (Deswal and Deswal, 2025b). For pharmaceutical companies, Scope 3 emissions typically account for 61–80% of total footprint (SCW, 2025), with some estimates placing this figure as high as 80–90% (Deswal, 2025a). Purchased goods and services – particularly active pharmaceutical ingredients (APIs) and raw materials – constitute the largest single contributor to Scope 3 emissions, representing approximately 80% of pharma's Scope 3 footprint (PC, 2025).

Manufacturing Energy Intensity

The energy intensity of pharmaceutical manufacturing itself presents a fundamental challenge to decarbonisation. Cleanrooms and the heating, ventilation and air-conditioning (HVAC) systems that support them generate significant electricity demand, with HVAC systems for cleanrooms accounting for 36% to 67% of a facility's total energy use (PharmOut, 2025). More recent estimates suggest HVAC systems account for 50–75% of total energy consumption in pharmaceutical cleanrooms, and cleanrooms can consume up to 25 times more energy per square meter than standard commercial buildings (Capgemini, 2025). This inherent energy intensity helps explain why Scope 1 emissions—which include direct fuel combustion for heating and processes—have proven more difficult to abate than Scope 2 emissions, which can be addressed through renewable electricity procurement.

Industry Commitments

The pharmaceutical industry has demonstrated increasing commitment to emissions reduction. The 25 largest biotech and pharma companies reduced emissions intensity for Scopes 1 and 2 by approximately 10% since 2019 (MGL, 2025), while the European Federation of Pharmaceutical Industries and Associations (EFPIA) members reported average Scope 1 reductions of 16% and Scope 2 reductions of approximately 64% between 2019 and 2024 (EFPIA, 2026). However, Scope 3 targets remain less universal and exhibit greater variability in ambition (CPI, 2022). The My Green Lab 2025 report found that the implied temperature

increase for Scope 1 and 2 emissions is 1.04°C, aligning with a 1.5°C pathway; when Scope 3 emissions are included, the implied temperature rises to 1.9°C, highlighting the critical importance of value chain decarbonisation (MGL, 2025).

Objectives

This study aims to:

1. Quantify and characterise GHG emissions trajectories (Scopes 1, 2, and 3) across 14 major pharmaceutical companies from 2019–2025;
2. Analyse the structural composition of emissions, with particular focus on Scope 3 category breakdown;
3. Evaluate emissions intensity trends and decoupling patterns;
4. Examine the relationship between revenue growth and emissions performance;
5. Assess progress toward stated reduction targets; and
6. Identify key barriers to decarbonisation, including manufacturing energy intensity and supply chain complexity.

In practice, some of the companies having a primary focus on and core business activity aligned with the "*Pharmaceutical & Biotechnology*" group also deal in Medical Equipment & Supplies. Such companies have been considered as Pharmaceutical & Biotechnology companies, and termed as "*Pharmaceutical Companies*" in the present study for convenience.

MATERIALS AND METHODS

Selection of Pharmaceutical Companies

Initially, the top twenty pharmaceutical companies based on revenues (net sales) were shortlisted. Thereafter, the greenhouse gases (GHG) emissions and revenue data were compiled and structured as per the requirement. The companies whose data availability was limited and/or inadequate (particularly Scope 3 emissions) were not considered, including AbbVie, Amgen, Gilead Sc, Boehringer Ingelheim, and Bayer (Pharma Division).

Finally, fourteen major pharmaceutical companies were considered – tabulated in Table 2 along with their revenues (net sales) during the financial years from 2019 to 2025, and other details.

Data Source and Scope

The dataset comprises revenue information (Table 2), GHG emissions and the latest GHG emissions reduction targets for the 14 pharmaceutical companies. The major data sources include secondary data from company websites, including Sustainability / Corporate Social Responsibility (CSR) / Environmental Social Governance (ESG) Reports, Annual Reports, Financial Disclosures, Integrated Reports, policy documents/position statements, data summary reports, infographics and other disclosures such as information obtained directly from company websites, etc., in the public domain and cover the period 2019–2025. The GHG emissions and revenue/sales data of the companies are on an annual basis for respective financial years starting on January 1 and ending on December 31. The notable exception is Takeda, where the financial year begins on April 1 and ends on March 31 of the following year. The dataset includes:

- Scope 1 emissions (Direct GHG emissions from owned or controlled sources), in $t.CO_2e$: 93 data points.
- Scope 2 emissions (Indirect GHG emissions from purchased energy), in $t.CO_2e$: 93 data points.
- Scope 3 emissions (Value chain GHG emissions), in $t.CO_2e$: 84 data points.
- Scopes 1 and 2 combined, in $t.CO_2e$: 93 observations.
- Total GHG emissions (Sum of Scopes 1, 2, and 3), in $t.CO_2e$: 84 data points.

Table 2: Annual revenues / net sales of the pharmaceutical companies during the period 2019 to 2024.

S. No.	Name of the Pharmaceutical Company	Abbreviations Used	Country	Revenues / Net Sales in a Financial Year[#] (in billion USD)						
				2019	2020	2021	2022	2023	2024	2025
1	Johnson & Johnson	J&J	USA	82.06	82.58	78.74	79.99	85.16	88.82	94.19
2	Roche	Roche	Switzerland	66.38	63.36	68.70	66.26	65.32	66.82	67.95
3	Merck Sharp & Dohme	MSD	USA	39.12	41.52	48.70	59.28	60.12	64.17	65.01
4	Pfizer	Pfizer	USA	40.91	41.65	81.29	100.33	59.55	63.63	62.58
5	AstraZeneca	AstraZen	UK	24.35	26.62	37.42	44.35	45.81	54.07	58.74
6	Novartis	Novartis	Switzerland	47.45	48.66	51.63	50.55	45.44	50.32	54.53
7	Bristol Myers Squibb	BMS	USA	26.15	42.52	46.39	46.16	45.01	48.30	48.19
8	Sanofi	Sanofi	France	42.15	42.60	46.23	47.39	50.16	46.07	48.92
9	Eli Lilly	Eli Lilly	USA	22.32	24.54	28.32	28.54	34.12	45.04	65.18
10	GlaxoSmithKline	GSK	UK	43.21	44.06	46.91	36.34	37.72	40.13	43.00
11	Novo Nordisk	Novo Nord	Denmark	19.45	20.24	22.38	25.00	33.70	40.30	42.89
12	Takeda[*]	Takeda	Japan	30.20	29.94	32.43	30.30	28.18	30.24	29.72
13	Merck KGaA	Merck KGaA	Germany	18.09	19.99	23.23	23.34	22.67	22.89	22.83
14	Teva	Teva	Israel	16.89	16.66	15.88	14.93	15.85	16.54	17.30

[#]Financial Year: January 1 to December 31. [*]Financial Year: April 1 to March 31 of the following year.

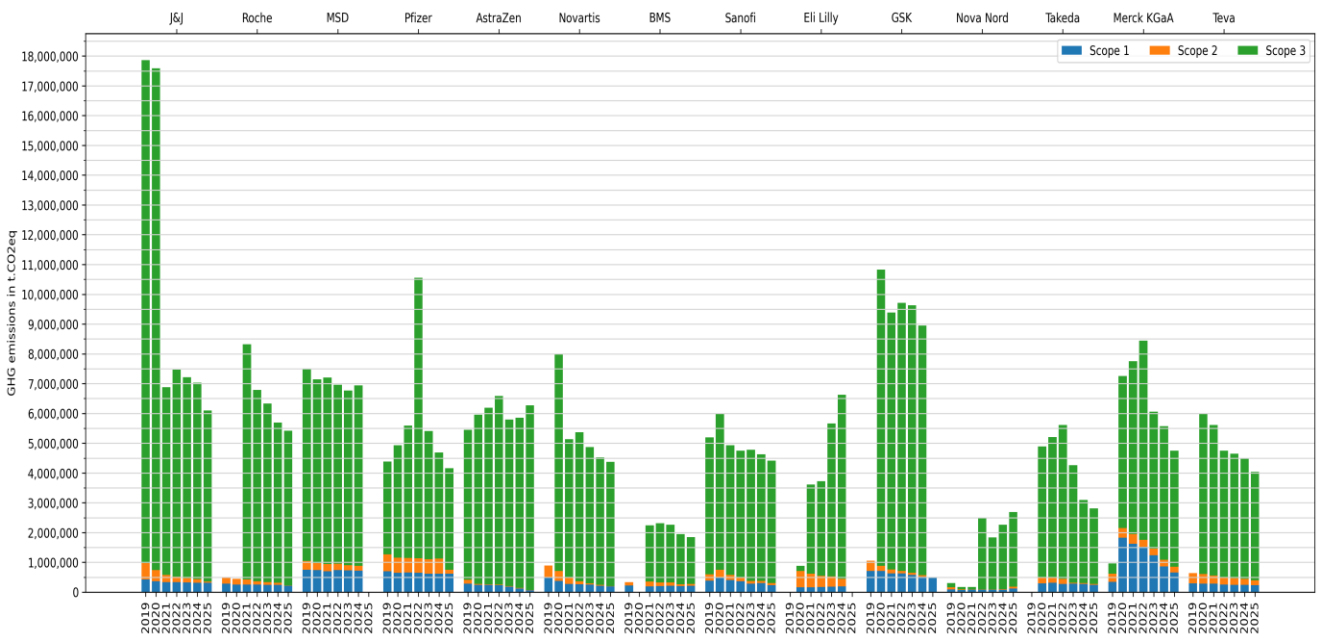

Fig. 1: Annual scope-wise GHG emissions of the 14 pharmaceutical companies during the period 2019-2025.

Note: Stacked bars represent total emissions per year, with Scope 1 (direct emissions), Scope 2 (energy-related indirect emissions), and Scope 3 (value chain emissions) shown as components.

- Category-wise Scope 3 GHG emissions, in $t.CO_2e$: Disaggregated into Upstream (Categories 1–8) and downstream (Categories 9–15) components/emissions.
- Revenue (net sales) data, in annual sales in billion USD.
- Emissions intensity, in $t.CO_2e/million\ USD\ revenue$
- Target data: Latest base years, reduction targets, and net-zero commitments.

Although the companies report Scope 2 emissions, both location-based emissions and market-based emissions. However, in the present study, market-based Scope 2 emissions have been used and analyzed because market-based emissions more accurately reflect a company's commitment to reduce emissions through renewable energy procurement.

In most cases, the company's environmental sustainability data is regularly revised, modified, evolved and updated due to structural changes, changes in calculation methodologies, improvements in the accuracy of emission factors/activity, and other factors. Because of this, every effort has been made to consider the latest reported data in the public domain, wherever possible

Analytical Framework

The analysis employs both descriptive and inferential statistical methods. Descriptive statistics characterize central tendencies, dispersion, and distributional properties of emissions and intensity metrics. Inferential techniques include trend analysis, correlation analysis between emissions intensity and revenue, and comparative assessment of target achievement.

Emissions intensity (EI) is calculated as (Deswal, 2025a):

$$EI = Emissions\ (t.CO_2e)/Revenue\ (million\ USD)$$

This ratio metric enables normalisation across companies of varying sizes and facilitates meaningful comparison of operational efficiency.

Decoupling ratio (DR) is computed as:

$$DR = \%\ Reduction\ in\ Intensity/\%\ Increase\ in\ Revenue$$

Decoupling ratio is not a standalone measure of environmental performance, and must be evaluated alongside absolute GHG emissions trends (the ultimate climate metric), revenue growth context (high growth can overwhelm efficiency gains), and data anomalies (revenue decrease or intensity increases distort the ratio)

All statistical analyses were conducted using standard software packages, with significance levels set at $\alpha = 0.05$ for the statistical tests being performed. Missing data were handled through listwise deletion for relevant analyses.

RESULTS

Overview of GHG Emission Data

The analysis encompasses greenhouse gas (GHG) emissions data from 14 major pharmaceutical companies spanning the period 2019-2025, with observations distributed across Scope 1 (n=93), Scope 2 (n=93), and Scope 3 (n=86), as presented in the stacked bar chart Fig. 1. The categorization of emissions follows the established frameworks of the Greenhouse Gas Protocol (WRI and WBCSD, 2011), which delineates direct operational emissions (Scope 1), energy-related indirect emissions (Scope 2), and value-chain indirect emissions (Scope 3). The comprehensive dataset enables a robust examination of emission patterns, trends, and interrelationships across different emission scopes and categories, providing empirical grounding for the sector's

Table 3: Descriptive statistics of GHG Emissions (metric tons CO_2 equivalent, $t.CO_2e$).

Metric	Scope 1	Scope 2	Scope 3	Scope 1&2 (Combined)	Total (Sum of Scopes 1, 2 &3)
Observations (n)	93	93	84	93	84
Mean	4,02,885	1,86,526	51,03,497	5,89,414	56,88,500
Median	2,86,704	1,68,735	48,55,000	4,83,923	55,06,499
Standard Deviation (SD)	3,18,387	1,49,371	27,39,304	3,99,686	28,94,185
Coefficient of Variation (CV)	0.79	0.80	0.54	0.68	0.51
Minimum	62,587	7,000	80,000	73,903	1,70,000
Maximum	18,27,123	5,70,388	1,68,92,158	21,51,821	1,78,60,988
Interquartile Range (IQR)	3,62,689	1,91,571	23,07,580	4,38,896	24,86,453

decarbonization ambitions as outlined by industry roadmaps (EFPIA, 2023).

Across all companies, Scope 3 emissions dominate the total carbon footprint, contributing substantially more than Scope 1 and Scope 2 emissions. Most companies exhibit a general decline in total GHG emissions over the study period, primarily driven by reductions in Scope 3 emissions, although the magnitude of reduction varies among companies. Companies such as Johnson & Johnson, GSK, Merck KGaA, and Roche report comparatively higher overall emissions, while Scope 1 and Scope 2 emissions remain relatively small and stable in comparison. Overall, the graph (Fig. 1) indicates that reducing value chain (Scope 3) emissions is the key driver for achieving meaningful decarbonization in the pharmaceutical sector.

Descriptive Statistics of GHG Emissions

Table 3 presents summary statistics for GHG emissions across all three scopes and the study period. Several patterns emerge from these descriptive statistics.

Scope 1 Emissions

The pharmaceutical companies demonstrate considerable heterogeneity in direct emissions, ranging from a minimum of 62,587 $t.CO_2e$ (AstraZeneca, 2025) to a maximum of 1,827,123 $t.CO_2e$ (Merck KGaA, 2020), with a mean of 402,885 $t.CO_2e$, and a median of 286,704 $t.CO_2e$, (SD = 318,387). This suggests that a small number of companies with extensive manufacturing operations disproportionately contribute to direct emissions within the sector, a pattern previously observed in cross-industry sustainability reporting analyses (Deloitte, 2023). Over the study period, 11 of the 14 companies demonstrated declining Scope 1 emissions trends, with Merck KGaA showing the most dramatic reduction from 1,827,123 (2020) to 657,835 $t.CO_2e$ (2025), representing a 65.8% decrease.

Scope 2 Emissions

Indirect emissions from purchased energy show a more compressed distribution (mean = 186,526; median = 168,735; SD = 149,371). The lower variability relative to Scope 1 suggests more consistent energy procurement patterns across the industry. Notably, J&J's Scope 2 emissions exhibited a dramatic decline from 542,756 $t.CO_2e$ in 2019 to 42,811 $t.CO_2e$ in 2025, reflecting aggressive renewable energy procurement strategies and corporate power purchase agreements. Over the study period, all 14 companies demonstrated declining Scope 2 emissions trends.

Scope 3 Emissions

Scope 3 emissions dominate the carbon footprint, with a mean value (5.10 million $t.CO_2e$) approximately 12.7 times greater than the Scope 1 mean, 27.4 times greater than the Scope 2 mean and 8.7 times greater than the Scopes 1 and 2 (combined) mean. This finding aligns with industry-wide observations that Scope 3 emissions are roughly five times greater than Scope 1 and 2 combined (MGL, 2025). The standard deviation of 2.74 million $t.CO_2e$ reflects substantial inter-company variability in supply chain complexity and reporting comprehensiveness. This dominance of Scope 3 is consistent with sector-wide analyses indicating that over 80% of the pharmaceutical industry's carbon footprint resides within the upstream and downstream value chains (McKinsey, 2022). The coefficient of variation is lowest for Scope 3 (0.54), suggesting greater relative consistency in Scope 3 emissions despite higher absolute values. This may reflect the fact that Scope 3 emissions are largely driven by purchased goods and services – a universal feature of pharmaceutical manufacturing—whereas Scope 1 and 2 emissions vary more widely depending on manufacturing footprint and energy procurement strategies (Deswal, 2025d, e, f, g, h, I and j). The interquartile range for Scope 3 (2.31 million $t.CO_2e$) is particularly notable, indicating substantial spread in value chain emissions across companies, with the largest emitters (J&J, GSK, Roche, MSD, Merck KGaA) exceeding the smallest emitters (Novo Nordisk, BMS, Takeda) by an order of magnitude.

The high standard deviation across all scopes reflects substantial heterogeneity in company size, operational scale, and reporting practices. Companies with comprehensive reporting and large manufacturing footprints, such as J&J and Pfizer, contribute the highest absolute emissions, while smaller or more focused companies like Novo Nordisk and BMS report lower figures.

Temporal Trends in GHG Emissions (2019–2025)

Scope 1 Trends

Scope 1 emissions declined by 28.0% in mean terms and 36.0% in median terms from 2019 to 2025 Table 4. Eleven of 14 companies achieved absolute reductions, with the most dramatic reductions observed at AstraZeneca (-78.1%),

Table 4: Temporal trends in GHG emissions during the period from 2019/2020 to 2025.

Scope	Mean 2019/2020#* ($t.CO_2e$)	Mean 2025 ($t.CO_2e$)	% Change (Mean)	Median 2019/2020#* ($t.CO_2e$)	Median 2025 ($t.CO_2e$)	% Change (Median)	Companies with Reduction	Companies with Increase
Scope 1#	4,13,928	2,97,941	-28.0%	3,63,000	2,32,166	-36.0%	11 of 14	3 of 14
Scope 2#	2,94,250	66,926	-77.3%	2,90,450	52,905	-81.8%	14 of 14	0 of 14
Scope 1&2#	7,08,178	3,64,867	-48.5%	6,31,781	2,89,755	-54.1%	13 of 14	1 of 14
Scope 3*	63,51,462	39,08,415	-38.5%	53,77,473	38,95,507	-27.6%	11 of 14	3 of 14
Total*	71,56,249	42,62,270	-40.4%	59,87,319	43,77,100	-26.9%	11 of 14	3 of 14

#2019-2025 period; *2020-2025 period due to limited data for Scope 3.

Novartis (-60.3%), and GSK (-32.7%). However, three companies – Merck KGaA (+92.9%, though this reflects reporting changes), Eli Lilly (+20.8%), and Novo Nordisk (+39.5%) – showed increases in Scope 1 emissions. The Merck KGaA increase is particularly noteworthy and may reflect expanded manufacturing capacity or methodological changes in reporting.

The Scope 1 decline aligns with sectoral ambitions to meet the Intergovernmental Panel on Climate Change (IPCC, 2022) mitigation pathways. Notably, this observed reduction substantially exceeds the 4.2% annual decline rate required to align with the Paris Agreement's 1.5°C scenario as defined by the Science Based Targets initiative (SBTi, 2023), indicating that pharmaceutical companies are making demonstrable progress in operational decarbonization.

Scope 2 Trends

Scope 2 emissions showed the most substantial improvement, declining by 77.3% in mean terms and 81.8% in median terms Table 4. All the 14 companies achieved absolute reductions, with AstraZeneca (-91.6%), Novartis (-96.3%), and GSK (-98.0%) achieving near-complete decarbonisation of purchased electricity. The dramatic Scope 2 reductions are attributable to the pharmaceutical industry's aggressive transition to renewable electricity procurement and on-site renewable generation, with companies such as AstraZeneca, Novartis, GSK, and J&J committing to 100% renewable electricity targets.

Scope 3 Trends

Unlike Scopes 1 and 2, Scope 3 emissions exhibited markedly heterogeneous patterns characterized by an initial increase (2019-2022) followed by a decline from 2022 onward. This pattern likely reflects improved reporting completeness in earlier years rather than actual emission increases, as companies expanded their supply chain reporting boundaries. While mean emissions declined by 38.5%, median emissions declined by 27.6.3% during the period 2020-2025 Table 4. Eleven companies achieved absolute reductions, and three companies showed increases. The most substantial reductions were achieved by J&J (-66.0%) and Novartis (-42.6%). However, Eli Lilly (+106.7%

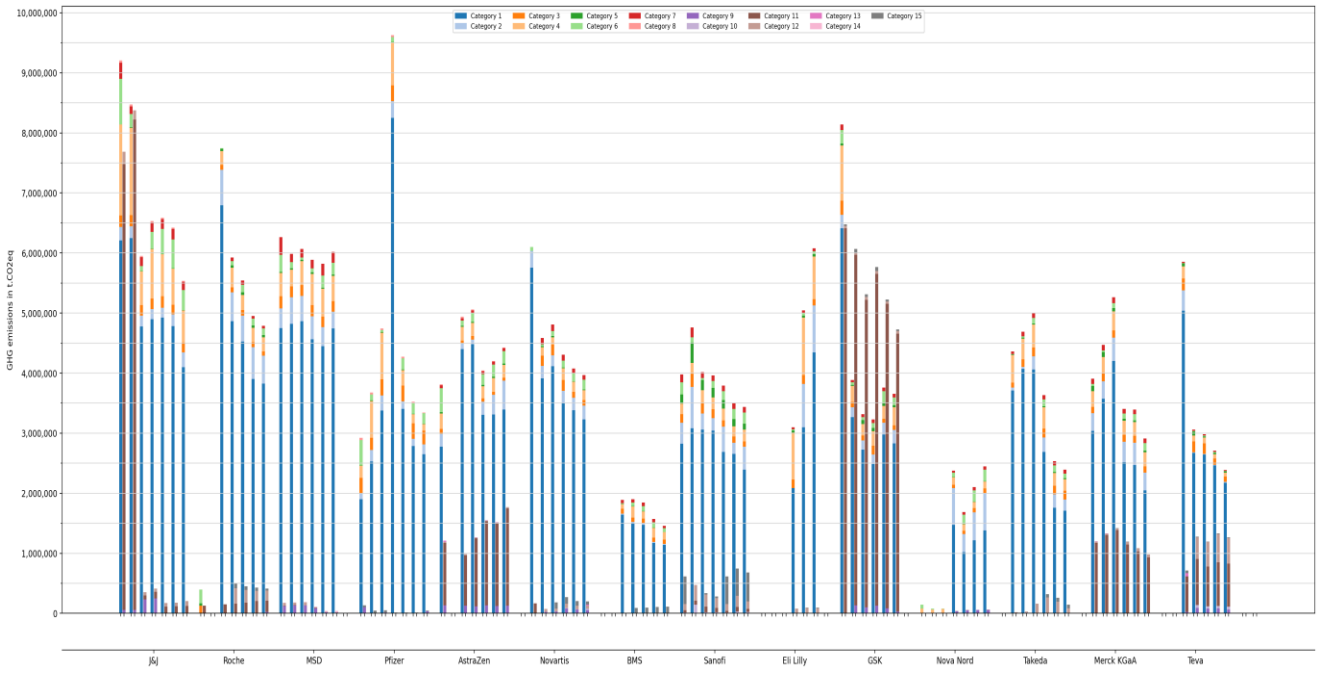

Fig. 2: Category-wise upstream and downstream emissions of the 14 pharmaceutical companies during the period 2019-2025.

Note: For each year, upstream emissions (Categories 1–8) are shown as one stacked bar adjacent to a stacked bar representing downstream emissions (Categories 9–15), enabling comparison of both the magnitude and composition of Scope 3 emissions over time.

during 2021-2024), AstraZeneca (+23.3%) and Pfizer (+9.4%) showed increases.

The persistence of Scope 3 as the dominant emission source – comprising 85-95% of total emissions for most companies—underscores the critical importance of supply chain decarbonization as a strategic priority for the industry (McKinsey, 2022; EFPIA, 2023).

Total Emissions Trends

Total emissions (Scopes 1–3) showed overall decline, with a mean reduction of 40.4% and a median reduction of 26.9%. As with Scope 3, 11 of 14 companies achieved absolute total emissions reductions, while 3 showed increases. The divergence in total emissions trajectories reflects the interplay between Scope 3 growth (driven by business expansion and reporting changes) and Scopes 1 and 2 reductions.

Scope 3 Composition Analysis

The graph, Fig. 2, compares upstream and downstream Scope 3 GHG emissions of 14 pharmaceutical companies over the period 2019–2025, with emissions disaggregated by all Scope 3 categories. Overall, upstream emissions constitute the larger share of total Scope 3 emissions for most companies and years, primarily driven by purchased goods and services and other supply-chain-related activities, whereas downstream emissions are dominated by the use of sold products where applicable. The graph also highlights substantial inter-company variability and year-to-year changes in Scope 3 emissions, reflecting differences in operational scale, product portfolio, and emission management practices across the pharmaceutical sector.

Across companies with available data, upstream emissions averaged 80.9% of total Scope 3 emissions, with purchased goods and services (Category 1) consistently representing the largest single category (62.9%). For J&J, Category 1 accounted for approximately 4.1–6.2 million $t.CO_2e$ annually, representing up to 75.8% of total Scope 3 emissions. Similarly, for Pfizer, Category 1 constituted up to 88.2% of Scope 3 emissions across the study period. For MSD, Category 1 consistently exceeded 73% of Scope 3 emissions, reaching 78.3% in 2024.

GSK represents a notable exception to the upstream-dominant pattern. GSK's downstream emissions (Category 11: transportation and distribution) are exceptionally high—5.5 million $t.CO_2e$ in 2022, representing 61.4% of total Scope 3 emissions. This likely reflects GSK's extensive global supply chain and distribution network, which may be more carbon-intensive than competitors' networks. Alternatively, it may reflect differences in boundary definitions or emission factor choices.

The upstream concentration has critical implications for decarbonisation strategy. As noted in the literature, approximately 80% of pharma's Scope 3 emissions originate from purchased goods and services (PC, 2025), making procurement and supplier engagement the primary levers for Scope 3 reduction. The data confirm that downstream emissions—including transportation, distribution, and product use—represent a comparatively modest share of total Scope 3 footprints for most companies, with GSK being the primary exception.

Category 1 emissions trends are heterogeneous. J&J achieved a 34.0% reduction in Category 1 emissions, reflecting successful supplier engagement. GSK achieved a remarkable 55.9% reduction, though this is partly attributable to changes in reporting methodology. However, Pfizer experienced a 39.3% increase in Category 1 emissions, reflecting business growth outpacing supply chain decarbonisation. AstraZeneca's Category 1 emissions increased by 22.4%, consistent with its overall Scope 3 growth.

Emissions Intensity Analysis

Emissions intensity (EI)—emissions per unit of revenue—provides a more nuanced picture of decarbonisation progress that accounts for business growth and enables comparison across companies of different sizes. Fig. 3 (a and b) depicts the emission intensities of 14 pharmaceutical companies, and Table 5 presents summary statistics for emissions intensity across all three scopes and the study period.

Scope 2 Emissions Intensity

It showed the most substantial improvement, declining by 74.2% in mean terms and 84.1% in median terms. This dramatic reduction is attributable to the pharmaceutical industry's aggressive transition to renewable electricity procurement. Companies such as AstraZeneca (96.5% reduction), Novartis (96.8% reduction), and GSK (98% reduction) achieved near-complete decarbonisation of purchased electricity intensity. The Scope 2 intensity reduction substantially outperforms Scope 1 (-33.8%), Scope 3 (-46.1%), and total intensity (-48.1%), suggesting that purchased electricity decarbonisation has been the low-hanging fruit in the industry's emissions reduction strategy. This finding is consistent with industry observations that switching to renewable electricity contracts is a relatively straightforward and cost-effective means of reducing operational carbon footprint (SCW, 2025).

Scope 1 Emissions Intensity

It exhibited the least improvement, with a mean reduction of 33.8%. The median reduction was 58.2%. The gap between mean and median reductions suggests that the distribution of Scope 1 intensity improvements is skewed, with a few companies achieving exceptional reductions while others lag. The increase in standard deviation from 5.73 (2019) to 7.61 (2025) indicates growing divergence in Scope 1 performance—some companies are rapidly decarbonising manufacturing operations, while others are making slower progress. The pharmaceutical manufacturing process's inherent energy intensity, particularly cleanroom HVAC systems consuming 50–75% of facility energy (Capgemini, 2025), explains why Scope 1 intensity has proven more difficult to abate than Scope 2.

Scope 3 Emissions Intensity

It declined by 46.1% in mean terms and 48.8% in median terms from 202 to 2025. All companies, except Eli Lilly and Novo Nordisk, achieved reductions in Scope 3 emission

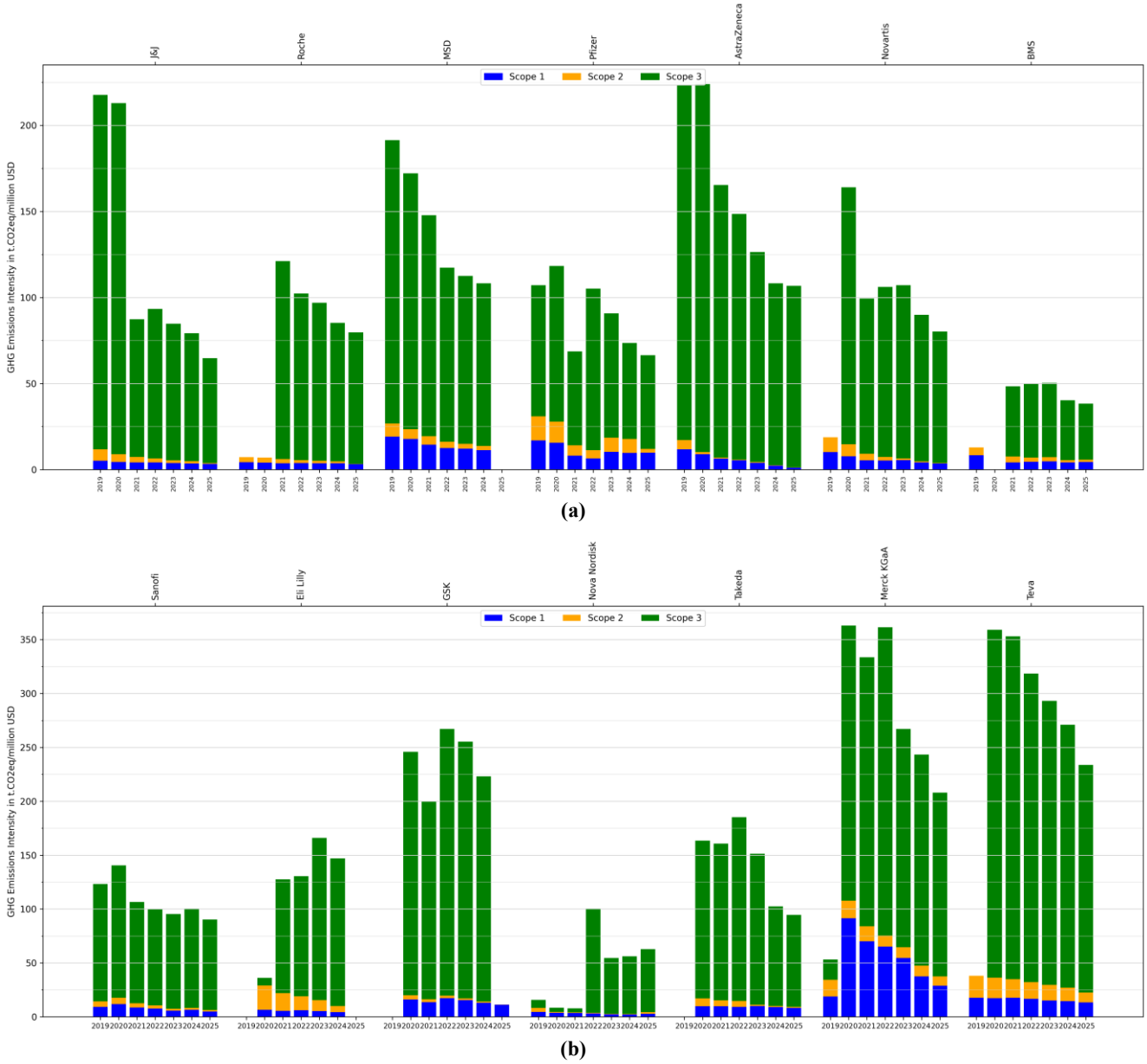

Fig. 3: Annual scope-wise emission intensities (EIs) of the 14 pharmaceutical companies during the period 2019-2025.

Table 5: Emissions intensity summary statistics ($t.CO_2e/million\ USD\ revenue$).

Metric	Scope 1 Intensity	Scope 2 Intensity	Scope 3 Intensity	Total Intensity
Mean (2019)	10.95	7.03	122.08	139.24
Mean (2025)	6.43	2.71	100.46	109.15
% Change (Mean)	-41.3%	-61.40%	-17.70%	-21.60%
Median (2019)	9.13	5.15	98.13	111.79
Median (2025)	4.36	1.43	76.48	80.27
% Change (Median)	-52.2%	-72.20%	-22.10%	-28.2%
Min-Max Range (2019)	4.34-19.09	2.95-22.45	7.46-206.39	15.73-223.63
Min-Max Range (2025)	1.07-28.81	0.13-9.36	32.56-211.12	38.26-233.70
Standard Deviation (2019)	5.05	4.90	73.24	75.14
Standard Deviation (2025)	8.49	2.81	61.48	65.54

intensities. Some companies with large Scope 3 footprints achieved substantial reductions (e.g., J&J: -70.1%; AstraZeneca: -50.6%; Novartis: -48.8%; Pfizer: -39.8%; MSD: -36.5%). Eli Lilly showed significant intensity increases (+29.9% during the 2021-2024 period), possibly due to business growth outpacing supply chain decarbonisation. Novo Nordisk's emissions intensity increased by +1378.9% (during the 2020-2025 period) and

Table 6: Company-specific emissions intensity performance and decoupling ratio analysis.

Company	Period	Change in Total GHG Emissions Intensity (%)	Revenue Growth (%)	Decoupling Ratio (*DR*)	Absolute Total GHG Emissions Change (%)	Interpretation
J&J	2019-25	-70.2%	+14.8%	4.74	-65.8%	Strong decoupling
Roche	2021-24	-34.2%	-1.1%	31.70: N/A	-34.9%	Revenue declining, but effective decarbonization
MSD	2019-24	-43.5%	+64.0%	0.68	-7.3%	Weak decoupling
Pfizer	2019-25	-38.0%	+53.0%	0.72	-5.1%	Weak decoupling
AstraZeneca[#]	2019-25	-52.3%	+141.2%	0.37: N/A	+15.2%	GHG emissions increasing
Novartis	2020-25	-51.1%	+12.1%	4.22	-45.2%	Strong decoupling
BMS	2021-25	-20.9%	+3.9%	5.36	-17.8%	Strong decoupling
Sanofi	2019-25	-26.7%	+16.1%	1.65	-15.0%	Moderate decoupling
Eli Lilly[#]	2021-24	+15.4%	+59.1%	-0.26: N/A	+83.5%	Negative (failed) decoupling
GSK*	2020-24	-9.3%	-8.9%	1.04: N/A	-17.4%	Revenue declining, but effective decarbonization
Novo Nordisk[#]	2019-25	+298.7%	+120.5%	-2.48: N/A	+779.1%	Negative (failed) decoupling
Takeda*	2020-25	-42.1%	-0.7%	60.14: N/A	-42.5%	Revenue declining, but effective decarbonization
Merck KGaA	2020-25	-42.7%	+14.2%	3.01	-34.5%	Strong decoupling
Teva	2020-25	-34.9%	+3.8%	9.18	-32.4%	Very strong decoupling

Note: *For revenue-declining companies (GSK and Takeda), the decoupling ratio is not interpretable due to a negative denominator; in these cases, absolute reductions in energy consumption are the more relevant metric.

[#]For increasing absolute GHG emissions companies (AstraZeneca, Eli Lilly and Novo Nordisk), the decoupling ratio is to be interpreted in light of increasing absolute emissions.

requires careful interpretation in view of expansion of its Scope 3 reporting boundaries, making the apparent increase partly attributable to improved reporting completeness rather than actual emissions growth.

The standard deviation of Scope 3 intensity declined from 86.2 to 53.1%, suggesting some convergence in performance. This recalcitrance of Scope 3 intensity reflects the inherent complexity of supply chain decarbonisation, which requires engagement with numerous suppliers across diverse geographies and regulatory contexts (PC, 2025).

Total GHG Emissions Intensity

It declined by 48.2% in mean terms and 53.4% in median terms from 2020 to 2025. This aggregate improvement places the sample ahead of the industry-wide finding that the 25 largest biotech and pharma companies reduced Scope 3 intensity by roughly 5% (MGL, 2025), though the difference may reflect sample composition and the study period. The decline in total intensity was driven primarily by Scope 2 reductions, with Scope 3's improvement influencing and reflecting the overall progress.

Company-Specific Intensity Trends

Fig. 3 and Table 6 illustrate the substantial variation in emissions intensity performance across the 14 companies.

J&J achieved the most substantial total emissions intensity reduction (-70.2%), far exceeding the sample average. This performance reflects comprehensive decarbonisation across all scopes (-65.8% reductions in total GHG emissions), including a 66.0% reduction in absolute Scope 3 emissions – the most substantial Scope 3 reduction in the sample. J&J's success is attributable to aggressive renewable energy procurement, supply chain engagement programmes, and manufacturing efficiency improvements.

Roche also achieved strong total emissions intensity reductions (-34.2%), despite its negative revenue growth (-1.1%) during the period 2021-2025, suggesting the company's aggressive decarbonisation efforts.

MSD and Pfizer achieved strong emissions intensity reductions (-43.5% and -38.0%) largely based on their substantial revenue growth (+64.0% and +53.0%), despite reductions of 7.3% and 5.1%, respectively, in total GHG emissions. However, the latest emissions intensity of MSD (108.19 $t.CO_2e/million\ USD\ revenue$) in 2024 is much higher than that of Pfizer (66.44 $t.CO_2e/million\ USD\ revenue$) in 2025.

AstraZeneca achieved the strongest absolute Scopes 1 and 2 reduction (-82.4%) and intensity reduction for operational emissions, but absolute Scope 3 emissions increased by 23.3% (absolute total emissions increased by 15.2%), tempering total emissions intensity improvement (-52.3%). The company's rapid revenue growth (+141.2%) created a substantial decoupling challenge, with Scope 3 emissions growing despite intensity improvements.

Novartis achieved the third most substantial total emissions intensity reduction (-51.1%) after J&J (-70.2%) and AstraZeneca (-52.3%). The performance reflects comprehensive decarbonisation across all scopes (-45.2% reductions in total GHG emissions), including a 42.6% reduction in absolute Scope 3 emissions – one of the most substantial Scope 3 reductions in the sample. Novartis' success is attributable to aggressive renewable energy procurement, supply chain engagement programmes, and manufacturing efficiency improvements.

BMS and Sanofi achieved moderate emissions intensity reductions (-20.9% and 26.7%, respectively). However, Sanofi's emissions intensity reductions were largely based on

its revenue growth of +16.1% compared to +3.9% for BMS. Further, the emissions intensity of Sanofi (90.32 $t.CO_2e/million\ USD\ revenue$) is much higher than that of BMS (38.26 $t.CO_2e/million\ USD\ revenue$) in 2025.

GSK achieved marginal emissions intensity reductions (-9.3%) due to its negative revenue growth (-8.9%) during the period 2020-2025 despite 17.4% reductions in the total absolute emissions.

Takeda achieved strong total emissions intensity reductions (-42.1%), despite its negative revenue growth (-0.7%) during the period 2020-2025, suggesting the company's aggressive decarbonisation efforts.

Eli Lilly and Novo Nordisk showed intensity increases (+15.4% and +298.7%, respectively), driven primarily by extraordinary revenue growth (+59.1% and +120.5%) that outpaced supply chain decarbonisation efforts. Novo Nordisk's intensity increase is partly attributable to expanded Scope 3 reporting boundaries, illustrating the importance of methodological consistency in performance assessment.

Merck KGaA and Teva achieved strong intensity reductions (-42.7% and -34.9%, respectively), but these companies started from the highest emissions intensity baselines in the sample (363.02 and 359.05 $t.CO_2e/million\ USD\ revenue$, respectively). Despite reductions, they remain the most emissions-intensive companies in the sample, suggesting structural challenges in their manufacturing operations.

Decoupling Ratio Analysis

The decoupling ratio (DR) illustrates the challenge of achieving absolute emissions reductions in growing businesses.

Strong Decoupling Performance

Companies with decoupling ratios > 3.0 demonstrate exceptional ability to reduce emissions intensity while growing revenue. These include Teva (9.18), BMS (5.36), J&J (4.74), Novartis (4.22), and Merck KGaA (3.01), as shown in Table 6. Teva, BMS, J&J, Novartis and Merck KGaA achieved strong decoupling, indicating that GHG emissions efficiency improvements substantially outpaced revenue growth. J&J stands out with the largest intensity reduction (-70.2%) and strong absolute emissions reduction (-65.8%), achieving true operational decarbonization with effective decoupling.

Moderate Decoupling Performance

Companies with DR between 1.0-3.0 show meaningful but less aggressive decoupling. Sanofi's DR of 1.65 indicates genuine emissions cutting – emissions efficiency more than revenue growth, but the emissions reduction is not substantially outpacing their economic growth.

Weak Decoupling Performance

Companies with DR < 1.0 show a slower reduction in absolute emissions intensity than in revenue growth, meaning improvements in emissions efficiency lag behind business expansion. These include Pfizer (0.72) and MSD (0.68).

Special Cases Requiring Careful Interpretation

Table 7: Correlation between emissions intensity and revenue.

Emissions Intensity	Correlation Coefficient (r)	p-value	n	Interpretation
Scope 1	-0.42	<0.01	93	Moderate negative correlation
Scope 2	-0.38	<0.01	93	Moderate negative correlation
Scope 3	-0.12	0.28	84	Weak, non-significant
Total Intensity	-0.29	0.01	84	Weak-to-moderate negative correlation

- *Revenue-declining companies*: The decoupling ratio formula is not applicable when revenue declines (denominator is negative). For such companies – Roche, GSK and Takeda, DR should be interpreted with caution as absolute emissions reductions are the more relevant metric. The exceptionally high DRs of Takeda (60.14) and Roche (31.70) and moderate DR of GSK (1.04) are technically anomalous due to revenue declines (Takeda: -0.7%; Roche: -1.1%; GSK: -8.9%). So, these companies cannot claim 'strong absolute decoupling' in the macroeconomic sense; however, the substantial reduction in absolute GHG emissions (Takeda: -42.5%; Roche: -34.9%; GSK: -17.4%) demonstrates a genuine, commendable and effective achievement in decarbonization.
- *Explosive growth overwhelms efficiency*: AstraZeneca's DR of 0.37, suggesting weak decoupling, presents a concerning case – despite a -52.3% emissions intensity reduction, absolute emissions actually increased by +15.2% due to massive revenue growth (+141.2%). This highlights the limitation of emissions intensity metrics: efficiency gains were overwhelmed by business expansion.
- *Negative decoupling:* Novo Nordisk and Eli Lilly are the two companies that exhibited negative decoupling, where emissions intensity increased – meaning emissions grew faster than revenue. Both absolute emissions and intensity moved in the wrong direction, representing failed decoupling. The decoupling ratios of 2.48 (Novo Nordisk) and 0.26 (Eli Lilly) are misleading (data anomaly) but confirm poor performance.

Correlation Between Emissions Intensity and Revenue

Pearson correlation analysis was conducted to examine the relationship between emissions intensity and revenue, with results presented in Table 7.

Correlation analysis revealed a moderate negative correlation between revenue and emissions intensity for Scope 1 ($r = -0.42$, $p < 0.01$) and Scope 2 ($r = -0.38$, $p < 0.01$), suggesting that larger companies tend to operate with lower operational emissions intensity. This may reflect economies of scale, greater access to capital for efficiency investments, more robust sustainability infrastructure, and greater bargaining power in renewable electricity procurement. The coefficient

Table 8: Latest base year for GHG emissions reduction targets and comparison – Stated vs. Achieved reductions (2025).

Company	Latest Base Year		Target (% reduction w.r.t. Base Year)			Achieved Reductions (%)		Target Status	
	Scope 1 & 2	Scope 3	Scope 1 & 2	Scope 3	Net Zero	Scope 1 & 2	Scope 3	Scope 1 & 2	Scope 3
J&J	2021	2016	44% by 2030	20% by 2030	2045	-37.6	-31.0	On track	Ahead of schedule
Roche[1]	2022	2019	70% by 2029	18% by 2025	2045	-39.1	-34.2	On track	Ahead of schedule
MSD[2]	2019	2019	46% by 2030	30% by 2030	2045	-15.6	-6.0	Progressing	Progressing
Pfizer	2019	2019	46% by 2030	90 % by 2040	2040	-40.9	-66.0	On track	On track
AstraZeneca	2015	2019	98% by 2026	50% by 2030	2045	-88.1	23.3[#]	On track	Off track[#]
Novartis	2022	2022	90% by 2030	42% by 2030	2040	-44.0	-16.5	On track	On track
BMS	2022	2022	54.6% by 2033	54.6% by 2033	2050	-14.6	-21.1	Progressing	Progressing
Sanofi	2019	2019	55% by 2030	30% by 2030	2045	-49.3	-10.4	On track	Progressing
Eli Lilly[3]	2020	2020	100% by 2030			-36.6	106.7^	Progressing	Off track^
GSK[2]	2020	2020	80% by 2030	80% by 2030	2045	-44.7	-15.7	Progressing	Progressing
Novo Nordisk	2024	2024	100% by 2030	33% by 2030	2045	81.2^	16.1^	Off track^	Off track^
Takeda	2016	2022	65% by 2030	25% by 2030	2040	-60.3	-50.9	On track	Ahead of schedule
Merck KGaA	2020	2020	50% by 2030		2040	-60.3	-23.7^	Ahead of schedule	-
Teva	2019	2020	46.2% by 2030	25% by 2030	2045	-39.1	-32.1	On track	Ahead of schedule

[1]Scope 3 reductions w.r.t. 2021. [2]Scope 3 reductions in 2024. [3]Scope 1&2 and Scope 3 reductions in 2024 w.r.t. 2021.

[#]AstraZeneca's Scope 3 achievement shows emissions increase due to business growth.

^Eli Lilly, Novo Nordisk, and Merck KGaA achieved reductions in intensity but not absolute emissions.

of determination (r^2 = 0.18 for Scope 1; 0.14 for Scope 2) indicates that revenue explains approximately 14–18% of the variation in operational emissions intensity, suggesting that other factors—including manufacturing processes, energy efficiency, and decarbonisation strategy—play substantial roles.

However, the correlation between revenue and Scope 3 intensity was weak and non-significant (r = -0.12, p = 0.28), indicating that supply chain emissions do not exhibit the same scale efficiencies as operational emissions. This finding has important implications: it suggests that while larger pharmaceutical companies can leverage their scale to reduce operational footprint, supply chain decarbonisation presents a uniformly challenging problem regardless of company size. This finding is consistent with the observation that Scope 3 emissions are primarily driven by purchased goods and services – a universal feature of pharmaceutical manufacturing—rather than company-specific operational efficiencies.

The correlation between revenue and total intensity was weak-to-moderate and statistically significant (r = -0.29, p = 0.01), reflecting the combined influence of operational and supply chain emissions. Larger companies tend to have lower total emissions intensity, but the effect is less pronounced than for operational emissions alone.

Target Setting and Achievement

All 14 companies have established Scope 1 and 2 reduction targets, with over two-thirds aiming for near-term reductions by 2030. Scope 3 targets are less universal and exhibit greater variability in ambition. Net-zero target years range from 2040 (Pfizer, Novartis, Takeda, and Merck KGaA) to 2050 (BMS), with 2045 being the most common commitment year. Table 8 presents the latest base year for GHG emissions reduction targets and net-zero targets set by the companies, along with a comparison of stated vs. achieved reductions by 2025. Achieved reductions are calculated as percentage reduction from respective base years (2025 data vs. base year).

Scopes 1 and 2 Target Achievement

The data suggest that most companies are on track to meet their Scope 1 and 2 targets. J&J has achieved a 37.6% reduction against a 44% target (2025 vs. 2030 target year), indicating good progress. Roche's 39.1% reduction against a 70% target (2029 target year) suggests good progress, though the target year is only four years away. MSD has achieved a 15.6% reduction against a 46% target by 2030, though the target year is only five years away. Pfizer is on track at a 40.9% reduction against 46% by 2030. AstraZeneca is on track at an 88.1% reduction against 98% by 2026. Novartis is on track at a 44.0% reduction against 90% by 2030, though the target year is only five years away. BMS has achieved a 14.6 % reduction against a 54.6% target by 2033. Sanofi is on track at a 49.3% reduction against 55% by 2030, indicating good progress. Eli Lilly has achieved a 36.6% reduction by 2024 against an ambitious target of 100% by 2030, though the target year is only six years away. GSK achieved a 44.7% reduction against an 80% target by 2030, though the target year is only five years away. Takeda has achieved a 60.3% reduction against a 65% target by 2030, exhibiting strong progress.

Merck KGaA has achieved its interim target of a 50% reduction by 2030 from its base year 2020, ahead of schedule, with a 60.3% reduction by 2025.

Teva has achieved a 39.1% reduction against a 46.2% target by 2030, demonstrating strong progress.

However, Novo Nordisk's Scopes 1 and 2 increased by 81.2% in 2025 from its base year 2024 against its ambitious target of 100% by 2030, indicating it is off track.

Scope 3 Target Achievement

Scope 3 target achievement is more variable. J&J has significantly exceeded its 20% reduction target, achieving a 31.0% reduction. Roche has exceeded its 18% target, achieving a 34.2% reduction. Takeda has significantly exceeded its 25% target, achieving a 50.9% reduction. Teva has exceeded its 25% target, achieving a 32.1% reduction.

Further, many companies are on track and progressing to achieve their Scope 3 reduction targets. Pfizer has achieved a 66.0% reduction and is on track towards its 90% target by 2040. Novartis has achieved a 16.5% reduction and is on track towards its 42% target by 2030. MSD has achieved a 6.0% reduction against a 30% target by 2030, though the target year is only five years away. BMS has achieved a 21.1% reduction against a 54.6% target by 2033, and is progressing towards the set target. Sanofi has achieved a 10.4% reduction against a 30% target by 2030, though the target year is only five years away. GSK has achieved a 15.7% reduction against an 80% target by 2030, and has prioritised decarbonization as the target year is only five years away.

However, some companies are off track. AstraZeneca shows a 23.3% increase in Scope 3 emissions against a 50% reduction target, reflecting the challenge of decoupling supply chain emissions from rapid business growth. Eli Lilly shows a 106.7% increase in Scope 3 emissions (though from a low 2020 base year), reflecting extraordinary business growth. Novo Nordisk shows a 16.1% increase in Scope 3 emissions, though this is largely attributable to the recent base year (2024) and expanded reporting boundaries.

Merck KGaA has no specified Scope 3 target, reflecting the still-emerging nature of Scope 3 target setting.

Implications for Net-Zero Pathways

Net-zero refers to the status of reducing GHG emissions throughout the value chain by at least 90% and counterbalancing the remaining (leftover) emissions through permanent removal and storage of carbon from the atmosphere (Deswal, 2025k). The divergence between Scopes 1&2 and Scope 3 performance has critical implications for net-zero achievement. Companies like J&J, Roche, Takeda and Teva are on track for all targets, suggesting their net-zero commitments are credible. However, companies like AstraZeneca, Eli Lilly and Novo Nordisk face significant challenges in aligning Scope 3 (in particular) with net-zero pathways.

As the My Green Lab report (MGL, 2025) found, the implied temperature increase for Scope 1 and 2 emissions is 1.04°C, aligning with a 1.5°C pathway; when Scope 3 emissions are included, the implied temperature rises to 1.9°C. This analysis of the 14 companies corroborates this finding: operational emissions show meaningful progress, but value chain emissions remain the binding constraint on the sector's climate alignment.

DISCUSSION

The Emission Intensity Challenge in Pharmaceutical Manufacturing

The relatively modest improvement in Scope 1 intensity (-41.3%) compared to Scope 2 (-61.4%) and the growing divergence in Scope 1 performance (standard deviation increasing from 5.05 to 8.49) warrants particular attention, as it points to the fundamental energy intensity of pharmaceutical manufacturing itself. Pharmaceutical production is inherently energy-intensive, driven by the stringent environmental controls required for aseptic manufacturing. Cleanrooms and the HVAC systems that support them generate significant electricity demand, with HVAC cleanroom systems accounting for 36% to 67% of a facility's total energy use (PharmOut, 2025). More recent estimates suggest HVAC systems account for 50–75% of total energy consumption in pharmaceutical cleanrooms, and cleanrooms can consume up to 25 times more energy per square meter than standard commercial buildings (Capgemini, 2025).

This energy intensity helps explain why Scope 1 emissions – which include direct fuel combustion for heating and processes – have proven more difficult to abate than Scope 2 emissions. While companies can reduce Scope 2 emissions through renewable electricity procurement (a relatively straightforward contractual change), Scope 1 reductions require fundamental process changes: replacing natural gas with biomethane for high-heat manufacturing, improving thermal efficiency, and transitioning fleets to electric vehicles. These measures entail capital investment, technological innovation, and operational restructuring that take time to implement.

The pharmaceutical sector's emissions intensity relative to revenue – 48.55 $t.CO_2e/million\ USD\ revenue$ – places it 55% higher than the automotive industry (illuminem, 2025). This comparison is striking given that pharmaceutical products are typically high-value, low-volume compared to automotive manufacturing. The explanation lies in the energy-intensive nature of drug production: the combination of strict temperature and humidity controls, high air change rates (20–60 air changes per hour in cleanrooms), and the energy demands of purification and formulation processes collectively create a substantial energy footprint per unit of economic output.

The Scope 3 Challenge: Supply Chain Complexity

The data confirm that Scope 3 emissions represent the dominant and most intractable component of pharmaceutical carbon footprints. The recalcitrance of Scope 3 intensity (median change: -22.1%, mean: -17.7%) reflects several structural challenges:

Supplier Heterogeneity

Pharmaceutical supply chains span thousands of suppliers across dozens of countries, each with different regulatory frameworks, energy grids, and decarbonisation capabilities. Engaging this diverse supplier base in meaningful emissions reduction requires substantial resources and coordination. As the Supply Chain Wizard (SCW, 2025) report notes, approximately 80% of pharma's Scope 3 emissions originate from purchased goods and services, making supplier engagement the primary lever for Scope 3 reduction.

API Manufacturing Concentration

A significant portion of API manufacturing occurs in countries with fossil fuel-based electricity grids, meaning that even when pharmaceutical companies reduce their own operational emissions, the upstream carbon intensity of their purchased goods may remain high. This creates a structural challenge that individual companies cannot fully address through their own actions.

Data Quality and Methodological Inconsistency

Scope 3 reporting exhibits considerable variability in completeness and methodology. Companies use different emission factors, boundary definitions, and estimation techniques, making direct comparison and progress tracking challenging. This methodological inconsistency likely contributes to the observed heterogeneity in Scope 3 trajectories and complicates target setting and verification.

Growth-Emissions Tension

Several companies in the sample experienced substantial revenue growth during the study period (AstraZeneca: +141%, Eli Lilly: +59%, Pfizer: +53%). For these companies, absolute Scope 3 emissions increased despite intensity improvements, reflecting the challenge of decoupling business growth from value chain emissions. This is evident in the decoupling ratios: companies with low decoupling ratios (Pfizer: 0.72; MSD: 0.68; AstraZeneca: 0.37) achieved intensity reductions but revenue growth substantially exceeded intensity improvements, leading to absolute emissions increases.

Downstream Emissions

While most companies have upstream-dominant Scope 3 profiles, GSK stands out with 56.4% downstream emissions. This heterogeneity suggests that different business models and supply chain structures create different decarbonisation challenges. For GSK, transportation and distribution (Category 11) is the dominant emissions category, requiring different mitigation strategies than purchased goods and services.

Decoupling: Progress and Persistent Challenges

The concept of decoupling – separating economic growth from environmental impact – is central to assessing genuine sustainability progress. The data reveal partial but incomplete decoupling in the pharmaceutical sector.

Relative Decoupling

Relative decoupling (reduced emissions intensity) is evident across most companies and scopes. Total emissions intensity declined by 21.6% in mean terms, indicating that the sector is becoming more efficient in generating revenue per unit of emissions. This relative decoupling is particularly pronounced for Scope 2 emissions, reflecting the successful transition to renewable electricity. All but two companies (Eli Lilly, Novo Nordisk) achieved relative decoupling for total emissions, suggesting broad progress in emissions efficiency.

Absolute Decoupling

Absolute decoupling (reduced absolute emissions despite growth) is more variable. While 13 of 14 companies reduced absolute Scope 1 and 2 emissions between 2019 and 2025; whereas, 11 of 14 achieved absolute Scope 3 reductions. Companies with the highest revenue growth – AstraZeneca (141.2%), Novo Nordisk (120.5%) and Eli Lilly (59.1%) – were those with increased Scope 3 emissions (and in turn increased total emissions), suggesting that business expansion currently outpaces supply chain decarbonisation efforts.

The decoupling ratio provides a more nuanced measure. Companies with high ratios (Teva: 9.18; BMS: 5.36; J&J: 4.74; Novartis: 4.22; Merck KGaA: 3.01) achieved substantial intensity reductions relative to their revenue changes, indicating effective decoupling. Further, Takeda, Roche and GSK demonstrated a genuine and effective achievement in decarbonization by exhibiting total emissions reduction by 42.5%, 34.9% and 17.4%, respectively. Companies with moderate decoupling ratios (Sanofi: 1.65) show meaningful but less aggressive decoupling. Low ratios (Pfizer: 0.72; MSD: 0.68) achieved only modest intensity improvements relative to revenue growth, suggesting that economic growth is only weakly decoupled from emissions.

This pattern aligns with the broader industry observation that operational emissions are roughly aligned with a 1.5-degree Celsius pathway, while supply chain emissions keep the sector's total climate impact closer to 2 degrees Celsius. The My Green Lab 2025 report (MGL, 2025) found that the implied temperature increase for Scope 1 and 2 emissions is 1.04°C, aligning with a 1.5°C pathway; when Scope 3 emissions are included, the implied temperature rises to 1.9°C. Our analysis corroborates this finding: operational emissions show meaningful progress, but value chain emissions remain the binding constraint on the sector's climate alignment.

Implications for Policy and Practice

The findings carry several implications for pharmaceutical companies, investors, and policymakers:

Prioritise Supplier Engagement

Given that purchased goods and services constitute the largest Scope 3 category, companies must intensify supplier engagement programmes. Initiatives like "*Energize*," which supports suppliers in adopting 100% renewable electricity, represent promising models that should be scaled. J&J's 34.0% reduction in Category 1 emissions demonstrates the potential of effective supplier engagement.

Accelerate Process Innovation

The modest Scope 1 intensity improvements highlight the need for technological innovation in manufacturing processes. This includes developing lower-carbon alternatives for high-heat processes, improving HVAC efficiency through advanced control systems, adopting energy-efficient equipment, and exploring biomethane alternatives for natural gas.

Standardise Scope 3 Reporting

The variability in Scope 3 reporting methodologies hampers progress tracking and target setting. Greater standardization – potentially through industry-wide frameworks like the GHG Protocol's Scope 3 guidance—would enable more meaningful comparison and accountability. The divergent Scope 3 trajectories observed may reflect methodological differences as much as actual emissions performance.

Align Targets with Growth Trajectories

Companies experiencing rapid growth should set Scope 3 targets that account for business expansion, potentially using intensity-based targets rather than absolute targets to maintain ambition while accommodating growth. The challenges faced by AstraZeneca and Eli Lilly in achieving absolute Scope 3 reductions despite rapid growth illustrate this tension.

Address Structural Challenges

The energy intensity of pharmaceutical manufacturing presents structural challenges that individual companies cannot fully address. Industry-wide initiatives to develop lower-carbon manufacturing processes, share best practices, and invest in shared infrastructure (e.g., renewable energy for API manufacturing hubs) are essential.

Leverage Collaborative Initiatives

Given the systemic nature of supply chain emissions, individual company action is insufficient. Collaborative industry initiatives, multi-stakeholder partnerships, and sector-wide decarbonisation roadmaps are essential for addressing the shared challenges of supplier engagement and methodological standardisation. The pharmaceutical sector's collective action through initiatives like the Sustainable Markets Initiative Health Systems Task Force represents a promising model.

Methodological Reflections

Several methodological considerations shape and limit the interpretation of these findings.

- Scope 3 reporting exhibits significant variability in completeness and methodology across companies, with 14.29% of potential Scope 3 observations missing (84 of 98). This variability affects the comparability of aggregate statistics.
- Base years for reduction targets vary considerably (ranging from 2015 to 2024), complicating direct comparisons of progress. This temporal difference should be taken into account when comparing progress.
- The dataset represents a subset of the industry – primarily large, publicly traded multinational corporations – and may not be representative of smaller or private pharmaceutical companies which may have less robust sustainability infrastructure.
- Differences in Scope 3 boundary definitions – which categories are included, which emission factors are used – may significantly affect reported emissions and complicate cross-company comparisons. The striking difference between GSK and other companies in downstream emissions share (56.4% vs. average 16.6%) may reflect methodological choices as much as actual supply chain characteristics.
- Additionally, slight discrepancies in data may arise from unit conversions.

Future research should address these limitations by incorporating a broader sample of companies, distinguishing between reported and projected data, and examining the relationship between emissions performance and financial metrics such as profitability and R&D investment. Additionally, life cycle assessment studies that quantify the emissions associated with specific pharmaceutical products would complement the corporate-level analysis presented here. Longitudinal studies tracking Scope 3 reporting methodology changes would help distinguish actual performance improvements from methodological artifacts.

CONCLUSION

This analysis of GHG emissions data from 14 major pharmaceutical companies over 2019–2025 reveals a sector in transition, characterised by meaningful progress in operational decarbonisation but persistent challenges in value chain emissions reduction.

Operational emissions (Scopes 1 and 2) are declining meaningfully, with Scope 2 intensity improving by 61.4% - a testament to the pharmaceutical industry's successful transition to renewable electricity. Scope 1 intensity declined by 41.3%, reflecting progress in manufacturing efficiency, though the pace of improvement is slower than for Scope 2, constrained by the inherent energy intensity of pharmaceutical manufacturing.

However, Scope 3 emissions – which constitute the vast majority of the sector's carbon footprint (mean: 5.10 million $t.CO_2e$, 8.7 times Scopes 1 and 2 combined) – remain stubbornly resistant to reduction. While 11 of 14 companies achieved absolute Scope 3 reductions, mean intensity improved by only 17.7%, and companies with the highest revenue growth experienced Scope 3 increases despite intensity improvements. The upstream concentration of Scope 3 emissions (average 80.9%), particularly purchased goods and services (Category 1, 62.9% of Scope 3), highlights supply chain decarbonisation as the primary challenge.

The energy intensity of pharmaceutical manufacturing itself emerges as a critical constraint on decarbonisation progress. The stringent environmental controls required for drug production, particularly the energy demands of cleanroom

HVAC systems consuming 50–75% of facility energy, create a substantial and irreducible baseline of energy consumption. While renewable electricity procurement can address Scope 2 emissions, Scope 1 reductions require more fundamental process innovation – a longer and more capital-intensive transition.

The decoupling analysis reveals that J&J, Novartis, BMS, Teva, and Merck KGaA emerge as genuine leaders, exhibiting strong absolute emissions intensity reductions with meaningful revenue growth – demonstrating true decoupling. Conversely, Pfizer and MSD represent growth-heavy decouplers, achieving efficiency improvements with increased absolute emissions but not enough to offset expansion.

The partial decoupling observed – relative decoupling is evident across the sector (mean total intensity reduction: -21.6%), but absolute decoupling remains elusive, with 6 of 14 companies exhibiting effective and/or meaningful decoupling – suggests that the pharmaceutical industry is making progress but is not yet on a trajectory consistent with limiting global warming to 1.5°C. As the My Green Lab (MGL, 2025) report concluded, operational emissions align with a 1.5°C pathway, but once supply chains are included, the sector's climate impact remains closer to 2°C.

Achieving deeper decarbonisation will require intensified supplier engagement, accelerated process innovation, standardised reporting frameworks, and collaborative industry action. The pharmaceutical industry's core mission is the protection of human health; aligning its operations with this mission requires not only the development of lifesaving medicines but also the reduction of the environmental burden associated with their production. The sector's progress on operational emissions demonstrates that meaningful decarbonisation is possible; the challenge now is to extend that progress to the value chain, transforming the entire pharmaceutical ecosystem toward sustainability.

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Disclaimer

The study is purely for academic purposes and, in light of the methodological complexities detailed in Part III (Deswal and Deswal, 2026), does not aim to directly compare emissions or reductions between companies. Direct numerical comparisons are inherently problematic due to heterogeneous accounting, varying Scope 3 boundaries, and differing emission factors. Instead, the analysis focuses on proportional metrics, intensity ratios, and contextual trends. It is crucial to interpret GHG emissions as vital tools for internal improvement rather than instruments for external comparison. The findings should be viewed within each company's operational realities and reporting practices.

Data Availability Statement

Data used in this study can be found in public pharmaceutical company reports. Further, the data presented in this study can be made available by the first author on request.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

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