CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

BACHELOR THESIS

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF ENVIRONMENTAL SCIENCES
DEPARTMENT OF APPLIED ECOLOGY

Assessment of carbon footprint of the pharmaceutical industry in the EU

Bachelor Thesis

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

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BACHELOR THESIS ASSIGNMENT

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Environmental Data Science
Informatics

Thesis title

Assessment of carbon footprint of the pharmaceutical industry in the EU

Objectives of thesis

This study focuses on evaluating the carbon emissions of the pharmaceutical industry in the European Union. The aim of the study is to understand the carbon footprint of the pharmaceutical industry and its impact on the environment.(1)Quantify the carbon footprint of the pharmaceutical industry in the EU.
(2)Identify the main sources of greenhouse gas emissions in the pharmaceutical industry value chain.
(3)Evaluate the effectiveness of current carbon reduction efforts in the industry.
(4)Develop recommendations for reducing carbon emissions in the pharmaceutical industry.

Methodology

Collect data on the energy consumption and greenhouse gas emissions of pharmaceutical companies in the EU. Analysis of the carbon footprint of the industry value chain, including research and development, production, distribution, and disposal of pharmaceutical products. Identify the hotspots in the value chain where carbon emissions are most significant and where carbon reduction measures could be most effective. Assessment of the effectiveness of current carbon reduction efforts in the industry, including the use of renewable energy and energy-efficient technologies. Development of recommendations for reducing carbon emissions in the pharmaceutical industry, such as improving energy efficiency, using renewable energy sources, and reducing waste and packaging.

The proposed extent of the thesis

40

Keywords

Carbon footprint; EU; Greenhouse gas emissions; Pharmaceutical industry;

Recommended information sources

”Basics of the Carbon Cycle and the Greenhouse Effect”, https://gml.noaa.gov/outreach/carbon_toolkit/

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The Bachelor Thesis Supervisor

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Supervising department

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Electronic approval: 30. 1. 2024

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Head of department

Electronic approval: 6. 2. 2024

prof. RNDr. Michael Komárek, Ph.D.

Dean

Prague on 26. 03. 2024

Statement:

I hereby declare that I have independently elaborated the bachelor/final thesis with the topic of: 'Assessment of carbon footprint of the pharmaceutical industry in the EU' and that I have cited all the information sources that I used in the thesis as listed at the end of the thesis in the list of used information sources. I am aware that my bachelor/final thesis is subject to Act No. 121/2000 Coll., on copyright, on rights related to copyright and on amendments of certain acts, as amended by later regulations, particularly the provisions of Section 35(3) of the act on the use of the thesis. I am aware that by submitting the bachelor/final thesis I agree with its publication under Act No. 111/1998 Coll., on universities and on the change and amendments of certain acts, as amended, regardless of the result of its defense. With my own signature, I also declare that the electronic version is identical to the printed version and the data stated in the thesis has been processed in relation to the GDPR.

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Abstract:

The European Union's pharmaceutical industry is a major economic contributor, but its success comes with an environmental cost. This research investigates the carbon footprint of the top 10 EU pharmaceutical companies by revenue (2022) from 2015 to 2022. Data from company annual reports were collected and analyzed using R language and R Shiny tools for visualization.

The research reveals significant variability in carbon footprints, with Scope 1 (direct emissions) and Scope 2 (purchased energy) being the primary contributors. Companies like AstraZeneca, GSK, and Roche have shown promising reductions in Scope 1 emissions, potentially due to mitigation strategies. Similarly, GSK and Novartis exhibited a decrease in Scope 2 emissions, suggesting a shift towards cleaner energy sources.

Limited data for Scope 3 (indirect emissions across the value chain) hinders a comprehensive assessment, but high values reported by GSK and Novartis highlight its potential significance. A positive trend in energy consumption across most companies, with reductions by GSK and AstraZeneca, indicates progress towards sustainability. However, Novartis' upward trend in both energy consumption and Scope 1 emissions warrants further investigation.

These findings offer valuable insights for the EU pharmaceutical industry to prioritize emission reduction strategies, particularly focusing on cleaner energy sources and production processes. Further research is needed to gather comprehensive Scope 3 data to understand the industry's full environmental impact.

Key words: Carbon footprint; EU; Greenhouse gas emissions; Pharmaceutical industry.

Table of Contents

1. Introduction

Overview of the carbon footprint in the European Union, especially from the pharmaceutical sector.

The pharmaceutical industry holds a pivotal position in the European Union (EU) economy, making substantial contributions to its financial well-being. In the year 2020 alone, this sector generated impressive revenue and provided gainful employment for millions of individuals. On a global scale, the EU stands out as a key player in pharmaceutical research and development, dedicating a significant part of the world's total research and development (R&D) spending in 2020.

However, this success comes with a price. The pharmaceutical sector in the EU leaves a significant environmental impact. This impact is multifaceted, originating from diverse sources such as the manufacturing process, energy and resource consumption, and the transportation of products. Notably, the manufacturing process emerges as the primary contributor, accounting for more than a half of the total carbon footprint. Effectively addressing these factors is crucial for mitigating the environmental impact of the pharmaceutical industry in the EU and promoting sustainable practices.

To understand this impact better, it is important to understand the concept of a carbon footprint. A carbon footprint serves as a quantitative measure of the cumulative greenhouse gasses (GHGs) released into the atmosphere due to human activities, providing a tangible indicator of our ecological impact. To ascertain the carbon footprint of an individual, organization, or product, a meticulous tallying of emissions from all responsible activities is conducted. These activities encompass a wide array, including driving habits, residential energy usage, electricity consumption, and dietary choices.

Expressed typically in tons of CO2e (carbon dioxide equivalent), this metric employs CO2 as the predominant greenhouse gas due to its widespread prevalence and ease of measurement. Nevertheless, it is vital to acknowledge the significant contributions of other greenhouse gasses, such as methane and nitrous oxide, to the broader landscape of climate change.

By highlighting the environmental cost after discussing the economic benefits, the text creates a clearer cause-and-effect relationship. It then transitions smoothly to explain the concept of a carbon footprint, which is directly relevant to the environmental impact mentioned earlier.

2. Objectives

This study aimed to investigate various research inquiries to achieve a more comprehensive understanding of the carbon emissions generated by the pharmaceutical sector in the European Union and examine the factors that contribute to its fluctuations. The inquiries explored in the study were:

1. What was the carbon footprint of the pharmaceutical industry in the EU, and what were the contributing factors to its variability?
2. How did the carbon footprint of the EU pharmaceutical industry compare to other industries, and what strategies could be employed to diminish its environmental impact?
3. To what extent did EU pharmaceutical companies report and manage their carbon emissions, and what repercussions did this have on their overall carbon footprint?
4. How did various pharmaceutical manufacturing processes and supply chain practices influence the carbon footprint of the EU pharmaceutical industry?
5. What challenges and opportunities existed for reducing the carbon footprint of the EU pharmaceutical industry, and what policies and initiatives were in place to address this concern?

The significance of this research lay in its potential to heighten awareness regarding the carbon footprint of the pharmaceutical industry and to identify opportunities for emission reduction. Additionally, the findings aimed to contribute to the advancement of more sustainable pharmaceutical manufacturing processes and products.

3. Literature review

3.1 Introduction to Environmental Impact of Large-Scale Industries

3.1.1 Overview of the Global Environmental Impact of Industries

Urbanization, industrial advancement, demographic shifts, energy usage, and technological innovation have collectively played a pivotal role in reshaping the economic framework. Industrialization accelerates the pace of urbanization. Swift urban expansion and industrial growth pose challenges to achieving sustainable development goals. The adverse impacts of climate change stemming from carbon emissions are on the rise. With the escalation of CO_2 emissions, the manifestations of climate change are poised to become more serious, given the correlation between carbon emissions and increasing temperatures (Liton Chandra Voumik et al.,2022). The Industrial Revolution, starting in 1750, is seen as the onset of climate change. Compared to pre-industrial levels, CO_2 emissions were notably lower. However, greenhouse gas concentrations, particularly atmospheric CO_2, have risen significantly since then. (NOAA, 2023). Greenhouse gas levels have substantially increased compared to the onset of the industrial era. This is evidenced by atmospheric CO_2 concentrations, which peaked at 409.8 ppm (parts per million) in 2019, surpassing levels observed at any point in the past 800,000 years (Lindsey, 2020). Before the Industrial Revolution, the CO_2 concentration stood at 280 ppm. Throughout recent centuries, it has oscillated between 180 and 280 ppm. In the 1950s, there was an observed increase of approximately 0.7 ppm per year. Over the last decade, this rate has surged even further to 2.1 ppm per year (Butler J. H., 2013).

3.1.2 Transition to Sustainable Practices

Achieving net zero emissions demands substantial societal and industrial transformations. Governments and corporations are increasingly relying on technological innovations to meet these ambitious targets (Miller, 2020).

3.2. Understanding Carbon Footprints

3.2.1 Definition of Carbon Footprint

The term carbon footprint is frequently used to describe the comprehensive sum of CO_2 and other greenhouse gas (GHG) emissions attributed to either an individual or an organization (Carbon Trust, 2007).

3.2.2 Importance of Quantifying Carbon Emissions

Accurately measuring carbon emissions is the foundation for effective climate change mitigation strategies. Quantification allows for comparisons between industries and companies, pinpointing areas with the highest impact. This data empowers stakeholders to prioritize reduction efforts and track progress towards sustainability goals. Without quantifiable data, environmental impact remains elusive, hindering accountability and hindering the development of targeted solutions (IEA 50, 2023).

3.2.3 Application of Carbon Footprint Measurement in Industries

When evaluating an organization's environmental impact, it's crucial to account for a wide range of emission sources. This encompasses direct emissions from fuel usage and indirect impacts such as employee travel or emissions from suppliers. To provide a thorough understanding of the organization's footprint, it's essential to quantify as many emission sources as possible. Usually, the carbon intensity of a company refers to the relationship between its total greenhouse gas emissions, measured in metric tons of CO_2 equivalent and its overall revenues (Anquetin T., et al., 2022).

To ensure an accurate assessment of the carbon footprint, it's important to adopt a structured approach and systematically categorize all potential emission sources. Typically, emissions are classified based on the degree of control the organization exercises over them. There are three main types of emissions:

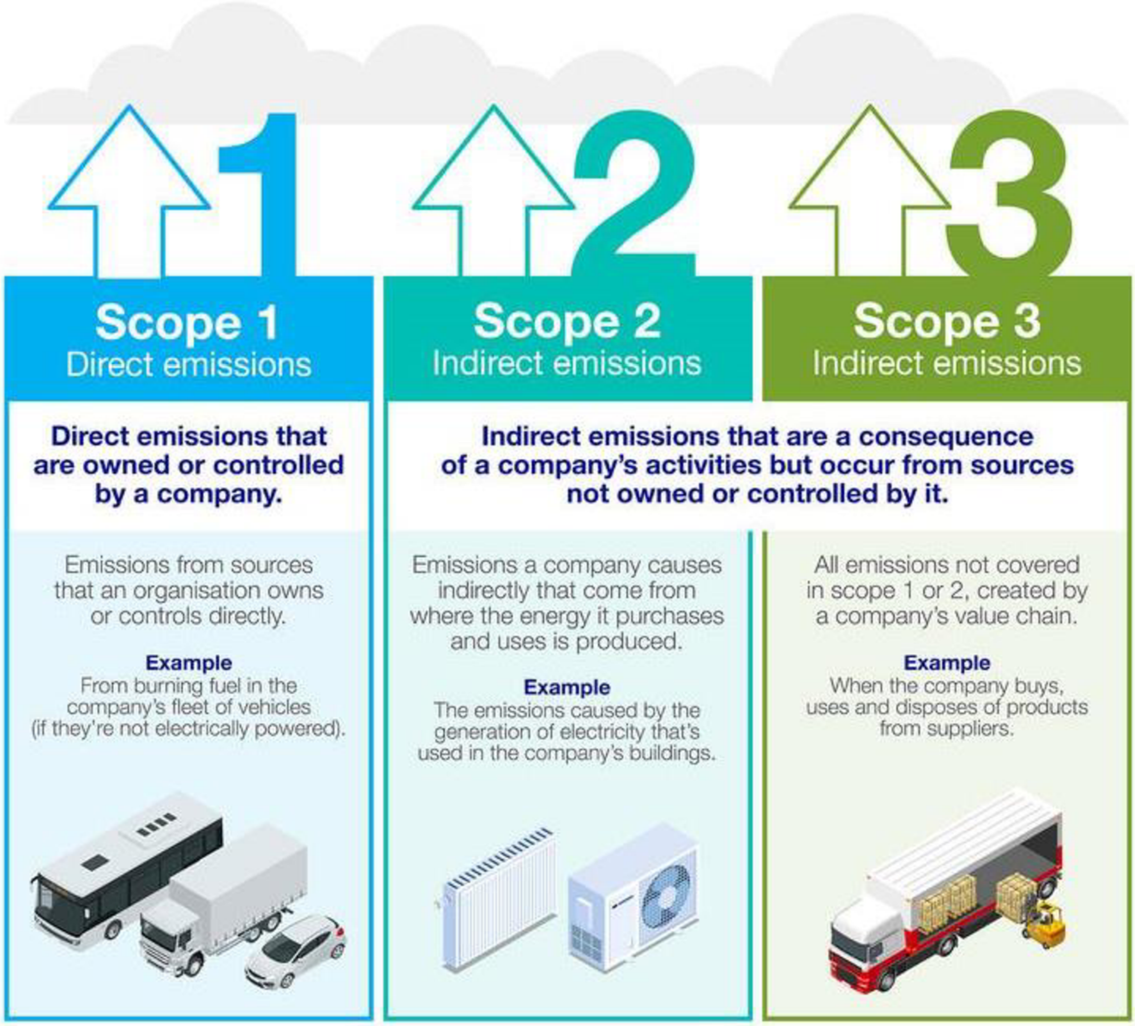


Figure 1: Overview of the Scopes of emissions from companies.
Source: National Grid, 2023

1. Direct emissions, also termed as Scope 1 emissions, originate from activities directly controlled by the organization itself. This commonly includes the combustion of fuels like gas for heating, resulting in the release of CO2, along with other gasses like methane and nitrous oxide from specific processes such as chemical production or fertilizer usage.
2. Scope 2 emissions arise from the electricity consumption of an organization. While the organization does not directly oversee how electricity is generated, its purchasing decisions indirectly impact CO2 emissions because a majority of electricity is sourced from fossil fuels.

3. Indirect emissions, known as Scope 3 emissions, stem from the products and services utilized by an organization. Each purchase of an item or service carries its own emissions. The usage of these products and services affects the overall carbon footprint. For instance, the manufacturing of a product involves emissions from the extraction of raw materials and transportation. Furthermore, emissions from the use and disposal of products can be traced back to the organization.

The warming observed globally can be attributed to CO2-induced radiative forcing, but this factor alone explains only around half of the total measured increase in temperature (Choi S. H. and Manousiouthakis V. I., 2022).

3.3 Carbon Footprint in the Pharmaceutical Industry

3.3.1 Previous Studies on Environmental Impact in Pharmaceuticals

The healthcare industry has a crucial role in adjusting to climate change, yet it also contributes significantly to greenhouse gas emissions. In high-income countries, the carbon footprints of health-care systems have been estimated to be 3–10% of the total national GHG emissions (Rui Wu PhD., 2019).

3.3.2 Identified Sources of Carbon Emissions in the Pharmaceutical Sector

In the realm of carbon emissions within the pharmaceutical sector, several key sources have been identified, shedding light on significant contributors to the industry's carbon footprint. One such source lies in manufacturing processes, where energy consumption for production facilities, equipment operation, and waste management plays a pivotal role. According to a study conducted by the International Energy Agency (IEA) in 2022, the pharmaceutical sector is accountable for approximately 2% of global industrial energy consumption, underlining the magnitude of its impact (IEA, 2022).

In 2018, the electricity usage (including both purchased and self-generated) within the pharmaceutical manufacturing sector amounted to around 12.3 billion kWh. This number has been steadily rising, increasing by approximately 5% annually, reaching 13.0 billion kWh in 2019 and further to 13.6 billion kWh in 2020 (Chen Y., et al., 2023).

Furthermore, the complex and geographically dispersed nature of the pharmaceutical supply chain presents a substantial challenge in mitigating carbon emissions. This is primarily due to the extensive transportation involved, encompassing the movement of raw materials, intermediate products, finished goods, and ultimately, waste disposal. A 2021 report by Accenture estimated that the pharmaceutical supply chain contributes a significant 20-30% of the industry's total carbon footprint. This emphasizes the crucial role of optimizing logistics and transportation networks, exploring alternative modes like electric vehicles or rail, and fostering collaboration throughout the supply chain to minimize unnecessary movement and its associated emissions. (Accenture, 2021)

While quantifying the precise impact remains a challenge, R&D activities within the pharmaceutical industry likely contribute to carbon emissions through various sources. These include energy-intensive laboratory operations, resource-demanding equipment use, and, in some cases, animal testing. To address this, the 2020 World Wildlife Fund (WWF) report calls for increased transparency and the adoption of sustainable practices within R&D processes. This could involve such practices as optimizing laboratory energy use in the form of implementing energy-efficient equipment, adopting green building practices, and utilizing renewable energy sources. One more practice might be reducing reliance on single-use plastics, and exploring reusable or biodegradable alternatives for labware and consumables. (WWF, 2020)

3.3.3 Case Studies on Carbon Footprint Reduction Strategies

As the first example, AstraZeneca has embarked on a comprehensive sustainability journey with its "Ambition Zero" program, aiming to attain carbon neutrality throughout its entire value chain by 2030. This ambitious endeavor encompasses a range of strategic initiatives aimed at minimizing environmental impact. Among these initiatives are the adoption of renewable energy sources, the implementation of energy-efficient manufacturing processes, and the integration of sustainable packaging solutions. Through these concerted efforts, AstraZeneca has reported notable progress, with a commendable 26% reduction in absolute greenhouse gas emissions observed from 2015 to 2021 (AstraZeneca, 2022).

The second example is Novo Nordisk's Circular Economy Approach, which has embraced a circular economy approach, prioritizing waste reduction and the optimization of resource utilization across the entire product lifecycle. Central to this approach is the implementation of closed-loop systems, which facilitate the recycling and reuse of materials, particularly in manufacturing processes involving solvents and water. By minimizing reliance on virgin materials and maximizing resource efficiency, Novo Nordisk has made significant strides in reducing its environmental footprint. Notably, the company achieved an impressive 20% reduction in CO2 emissions per insulin production unit from 2010 to 2020, underscoring the efficacy of its circular economy initiatives in driving sustainable outcomes (Novo Nordisk, 2024)

3.4 Factors Influencing Carbon Footprint Variability

3.4.1 Types of Pharmaceuticals and Their Impact

Biologics vs. Small Molecules: Biologics, often derived from living organisms, generally have a larger carbon footprint compared to small molecule drugs due to complex manufacturing processes involving cell cultures, fermentation, and purification steps. Studies suggest biologics can contribute 2-20 times more emissions compared to small molecules per kilogram of active pharmaceutical ingredient (API) (Koukoutsis G., et al., 2013).

Potency and Dosage: Highly potent drugs requiring smaller doses typically have a lower carbon footprint per unit efficacy compared to less potent drugs requiring larger doses. This is because the environmental impact associated with manufacturing, transportation, and disposal is spread across a smaller amount of the active ingredient (Neele Puhlmann, et al., 2024).

API Complexity: The complexity of the API synthesis process directly affects the energy consumption and associated emissions. Drugs requiring multi-step synthesis with hazardous chemicals or high energy demands will have a larger carbon footprint compared to those with simpler synthesis processes (Schüller T., 2023).

3.4.2 Influence of Manufacturing Processes on Carbon Emissions

Energy Source: The type of energy used to power manufacturing facilities significantly impacts their carbon footprint. Facilities relying on fossil fuels like coal or natural gas will have a higher carbon footprint compared to those utilizing renewable energy sources like solar, wind, or geothermal (Jimenez D., 2022).

Resource Efficiency: Inefficient manufacturing processes that lead to waste generation, high energy consumption, or excessive water usage contribute to a larger carbon footprint. Implementing practices like lean manufacturing, optimizing energy usage, and minimizing waste can significantly reduce emissions (Ekins P., HugheN., 2016).

Supply Chain Management: The ecological footprint stemming from every stage of the supply chain, starting from the acquisition of raw materials to the distribution of final products, plays a pivotal role in the environmental impact. Employing sustainable sourcing strategies, streamlining logistical processes, and fostering partnerships with suppliers to integrate eco-friendly practices are effective measures for curbing emissions throughout the value chain (Faster Capital, 2023).

3.5 Comparative Analysis with Other Industries

3.5.1 How the EU Pharmaceutical Industry Compares to Other Sectors

Studies suggest the EU pharmaceutical industry's direct and indirect greenhouse gas (GHG) emissions (Scope 1 & 2) contribute around 0.1% of global emissions (Belkhir L., 2018).

This appears modest compared to industries like automotive (46.4 million tons of CO2 in 2015) (Belkhir L., 2019). However, a crucial distinction lies in emission intensity, which measures emissions per unit of revenue.

Research indicates the EU pharmaceutical industry's emission intensity is a staggering 55% higher than the automotive sector (Chris Lo, 2021). This means for every euro earned, the pharmaceutical industry produces significantly more carbon emissions. This higher intensity stems from several factors:

- Energy-intensive Manufacturing: Pharmaceutical production relies heavily on specialized facilities with high energy demands for temperature control, sterilization, and specialized equipment (Deloitte, 2015).
- Complex Supply Chains: The global nature of pharmaceutical production, with raw materials sourced from various locations, leads to increased transportation emissions (Scope 3) (Antonio G. Oliveira, 2023).
- Waste Management: The disposal of hazardous chemicals and drug waste poses environmental challenges (Kanagamani K., et al., 2020).

While carbon emissions are a major concern, the pharmaceutical industry's environmental impact extends further. Here are a few more aspects to consider:

- Water Usage: Large volumes of water are used throughout pharmaceutical manufacturing, raising concerns about water scarcity in some regions (OECD, 2019).
- Pollution from Wastewater: Manufacturing processes can generate wastewater containing pollutants that require careful treatment before release.

3.5.2 Strategies Employed by Other Industries to Reduce Environmental Impact

Several industries are implementing strategies to lessen their environmental impact, which can be valuable lessons for the pharmaceutical sector:

Renewable energy adoption: Shifting towards renewable energy sources like solar, wind, and geothermal power can significantly reduce reliance on fossil fuels and associated emissions (Jimenez D., 2022).
Circular economy principles: Implementing circular economy principles like resource efficiency, product life cycle extension, and waste reduction can minimize environmental impact (Ellen MacArthur Foundation, 2023).
Sustainable supply chain management: Collaborating with suppliers to adopt sustainable practices throughout the supply chain can significantly reduce the overall footprint (Verónica H. Villena and Dennis A. Gioia, 2020).

3.5.3 Lessons Learned and Applicability to the Pharmaceutical Sector

By analyzing successful strategies from other industries, the pharmaceutical sector can identify and implement relevant solutions:

Invest in energy efficiency: Upgrading facilities and processes to optimize energy consumption can significantly reduce emissions.
Promote local sourcing: Reducing reliance on long-distance transportation by sourcing materials and manufacturing closer to final destinations can lower the carbon footprint.
Implement eco-design principles: Designing products with recyclability and end-of-life considerations in mind can minimize waste and resource consumption.
Collaboration and knowledge sharing: Partnering with other stakeholders, including academia, policymakers, and NGOs, can foster innovation and accelerate progress towards sustainability.

3.6 Reporting and Management of Carbon Emissions

3.6.1 Current Practices of EU Pharmaceutical Companies in Reporting Emissions

The European Union (EU) has instituted a range of regulations and programs aimed at fostering transparency and responsibility in the reporting of carbon footprints by corporations, notably within the pharmaceutical sector. Below is an outline of current practices:
Compulsory Reporting:

- EU Emissions Trading System (EU ETS): This framework is applicable to facilities surpassing specified emission thresholds, encompassing certain pharmaceutical manufacturing facilities. Entities falling under the purview of the ETS are obligated to submit their yearly validated emissions data (EU ETS, 2021).

- Corporate Sustainability Reporting Directive (CSRD): Set to be enforced from December 2023, the CSRD mandates sizable corporations, including numerous pharmaceutical entities, to disclose details regarding their sustainability endeavors, encompassing greenhouse gas emissions. This requirement aims to offer a more thorough insight into emissions within the industry (EU Commission, 2021).

Voluntary Programs:

- Global Reporting Initiative (GRI): Numerous pharmaceutical corporations adhere to the GRI Standards for sustainability reporting, incorporating guidelines on disclosing greenhouse gas emissions (GRI, 2023).
- Carbon Disclosure Project (CDP): This platform enables companies to divulge their environmental metrics, including emissions, to investors and stakeholders. Many pharmaceutical entities actively engage with the CDP (CDP, 2017).

3.7 Challenges and Opportunities

3.7.1 Challenges Faced by Pharmaceutical Industry in Reducing Carbon Footprint

The UN COP 26 conference suggested that action must be taken now to limit global temperatures to 1.5 °C or below by the end of this century (Dwivedi et al., 2022). Some indications propose that renewable energy could serve as a solution for enhancing energy security and addressing environmental degradation within BRICS nations. Consequently, prioritizing the development of alternative energy sources, promoting green urbanization, and adopting environmentally-friendly urban development practices should be a part of all governments' energy and environmental plans worldwide (Liton Chandra Voumik et al., 2022)

3.7.2 Policies and Initiatives in Place to Address Carbon Emissions

General EU Climate Strategies:

- European Climate Law (ECL)

At the core of the issue lies a critical aim: establishing a legally binding goal to attain net-zero greenhouse gas emissions across all EU member states by 2050. This ambitious target carries significant implications for various sectors, particularly the pharmaceutical industry. The implementation of a mandatory regulatory framework signifies a significant change, compelling pharmaceutical firms to actively participate in reducing carbon emissions. This involves a thorough restructuring of operational procedures, including stricter regulations governing manufacturing, energy use, and waste management.

Key to these advancements is the European Climate Law (ECL), which outlines a mandatory path toward achieving climate neutrality. Under this legal directive, the pharmaceutical sector is at a juncture, requiring rapid adjustments in operations and a shift in resource allocation toward sustainable endeavors. Adhering to the ECL not only emphasizes the urgent need to decrease emissions but also offers an opportunity for industry stakeholders to showcase their dedication to environmental stewardship.

This legislative drive is poised to stimulate emission reduction initiatives within the pharmaceutical industry, potentially yielding extensive advantages. By fostering a fair environment where companies are encouraged to prioritize environmental sustainability, the ECL promotes a more equitable business landscape. Furthermore, by aligning industry practices with broader climate goals, this regulatory framework has the potential to drive collective efforts toward a greener, more sustainable future (ECL, 2023).

- 2050 Long-Term Strategy

In the 2050 Long-Term Strategy, a pivotal objective is delineated: charting a course for the EU to attain climate neutrality by 2050, encompassing precise decarbonization benchmarks tailored to various sectors.

With respect to the Pharmaceutical Sector, this strategy furnishes a panoramic vision for the industry's pivotal role in transitioning towards a low-carbon economy. Such foresight can furnish a compass for companies, aiding them in formulating their own sustainability targets and harmonizing with forthcoming regulations.

At its core, the LTS functions as a strategic roadmap for the pharmaceutical sector's voyage towards decarbonization, furnishing lucidity and guidance for enduring investments and pioneering innovations. This proactive, forward-thinking stance impels companies to ardently embrace sustainable methodologies, positioning them at the vanguard of regulatory compliance and ecological stewardship (European Commission, 2023).

- Fit for 55 Package:

The Fit for 55 Package represents an extensive initiative with a fundamental objective: introducing a variety of innovative policies and modifications to existing ones, all aimed at achieving a significant 55% reduction in EU greenhouse gas emissions by 2030, as compared to the levels recorded in 1990.

In the context of the Pharmaceutical Sector, the implications of this package are substantial. The specified measures, such as the revamped Emissions Trading System (ETS) and the implementation of the Carbon Border Adjustment Mechanism (CBAM), harbor the potential to directly influence both the carbon footprint and production expenses within the pharmaceutical realm.

At the heart of this discussion lie several notable considerations: the FF55 package introduces a broad spectrum of policy measures designed to address carbon emissions specifically within the pharmaceutical sphere. The restructured ETS may lead to increased compliance expenditures, while the CBAM holds the potential to encourage the adoption of production methods characterized by lower carbon output. These endeavors are positioned to stimulate transformative changes and hasten the sector's progression towards the adoption of sustainable frameworks (European Commission, 2023).

Pharmaceutical Industry-Specific Initiatives:

- Pharmaceutical Supply Chain Initiative (PSCI):

The Pharmaceutical Supply Chain Initiative (PSCI) stands as a pivotal voluntary endeavor geared towards bolstering the sustainability of pharmaceutical supply networks. Its overarching ambition encompasses the implementation of measures directed at bolstering energy efficiency and curbing greenhouse gas emissions.

At its core, the initiative aims to revolutionize the landscape of pharmaceutical supply chains, spotlighting the imperative of sustainability, particularly in terms of energy efficiency and greenhouse gas reduction efforts. This endeavor carries profound implications for the sector, underlining the necessity for active engagement and transparent reporting mechanisms to gauge progress towards predefined targets.

Central to its ethos is the cultivation of collaborative synergies among industry stakeholders, fostering an environment conducive to the exchange of insights and best practices. Though the adoption of sustainable practices may initially pose operational cost escalations due to requisite investments, the long-term benefits are poised to outweigh these initial challenges.

Crafted under the stewardship of prominent pharmaceutical entities and healthcare organizations, the PSCI delineates its focus across five pivotal domains: energy conservation, climate change mitigation, water stewardship, waste management, and responsible sourcing practices. Integral to its framework are the plethora of resources and tools provided to facilitate seamless implementation, underscoring its commitment to effecting tangible change within the industry landscape (PSCI, 2024).

- Medicines for Europe (MFE):

Medicines for Europe (MFE), serving as a pivotal trade association advocating for the interests of generic and biosimilar medicine manufacturers throughout Europe, has embarked on a transformative path encapsulated within its "Sustainability Charter." This forward-looking initiative highlights a strong dedication to decreasing carbon emissions, demonstrating a resolute commitment to advancing sustainability within the sector.

At its core, MFE aims to rally the generic and biosimilar medicines sector in Europe towards achieving sustainability excellence. The introduction of the "Sustainability Charter" marks a significant moment, urging members to embrace its principles and specified commitments. Through this framework, MFE aims to catalyze a shift in industry mindset, potentially encouraging smaller enterprises to prioritize sustainability concerns.

However, the path toward sustainability is not without its challenges. MFE's efforts may face obstacles in enforcing compliance and monitoring adherence to the outlined standards. Nonetheless, the combined endeavors outlined in the "Sustainability Charter" symbolize a collective determination to overcome such barriers and progress towards a more environmentally friendly and sustainable future.

At the heart of MFE's mission lies a collaborative spirit, underscored by the exchange of knowledge and a dedication to continual improvement. The "Sustainability Charter" sets forth ambitious goals that encompass reducing greenhouse gas emissions, managing waste effectively, and adopting responsible sourcing practices. By fostering an atmosphere conducive to collaboration and ongoing enhancement, MFE aims to cultivate a culture of sustainability excellence that permeates every aspect of the industry landscape (MFE, 2024).

- European Federation of Pharmaceutical Industries and Associations (EFPIA):

The European trade association representing research-based pharmaceutical companies has introduced its comprehensive "Roadmap to 2030," outlining the steadfast commitments of its members towards sustainability initiatives, with a particular focus on addressing concerns related to climate change. This initiative highlights the collective efforts of major pharmaceutical entities and aims to guide the broader industry towards more sustainable practices.

Key to this initiative is the commitment of research-based pharmaceutical companies operating within Europe to various aspects of sustainability, including climate change mitigation, water stewardship, and the promotion of a circular economy.

While acknowledging the challenges associated with implementation across diverse member organizations, the roadmap also presents collaborative opportunities and mechanisms for sharing information, fostering a culture of shared responsibility and progress.

Beyond rhetoric, the roadmap provides practical resources and tools tailored to support member entities in achieving sustainability targets. Through fostering innovation and collaboration, it aims to enhance the capabilities of participating companies and facilitate industry-wide transformation (EFPIA, 2024).

4. Methodology

4.1 Definition of Scope and Selection of Companies

The foundation of this study lies in defining its scope, a crucial step in ensuring the relevance and significance of the research. The focus was narrowed down to the top 10 pharmaceutical companies in the European Union by revenue in 2022 (Global Data, 2023). Focusing on the top companies by revenue ensures capturing a significant portion of the EU's pharmaceutical industry activity and their associated environmental impact. Additionally, these companies are more likely to have readily available data on their emissions and energy consumption due to their size and public reporting requirements, aiming to create a representative sample of the industry for a thorough analysis of energy consumption and greenhouse gas emissions.

The chosen companies for this study, based on the online resource Global Data (Global Data, 2023):

1.Novo Nordisk AS

2. Novartis AG

3. F. Hoffmann-La Roche Ltd

4. AstraZeneca Plc

5. Sanofi

6. GSK plc

7. Bayer AG

8. Novozymes

9. Lonza Group

10. Genmab.

The period for which the data will be analyzed was determined to be 8 years, from 2015 to 2022, and was justified by the availability of annual reports of companies. This criterion ensured that the study captured insights from key players, offering a comprehensive understanding of industry trends.

4.2 Data Collection

To collect information about emissions of selected companies, there were 2 stages:

- collect data from annual reports from company's web sites (links to the reports are stored in the bibliography section)
- code development to represent the data

The first stage included searching for company annual reports, sorting by year and storing them locally in csv files.

The subsequent phase involved the development of code, using the R programming language [Appendix 1], to collect relevant data and systematically archive it into individual CSV documents. This strategy was consciously chosen to not only expedite the data collection process but also to eliminate potential errors that might arise.

4.3 Data Storage and Organization

The collected data were systematically stored in CSV files, ensuring accessibility and ease of management. This structured organization of data facilitated subsequent analysis, enabling the establishment of correlations between various variables. As a result, there are 10 separated csv files, one file for each company from the scope, containing the whole available information about emissions for the selected time range [Appendix 2].

4.4 Data Analysis and Visualization

Following the collection and organization of data, attention was directed towards the analysis and presentation of patterns and trends in greenhouse gas emissions and energy consumption from the chosen pharmaceutical companies. In this context, the implementation of an R Shiny app [Appendix 3] offers an expedited means to select emission types and visualize data, thereby accelerating the identification of key insights within the complex landscape of greenhouse gas emissions and energy consumption in the pharmaceutical sector.

4.4.1 Development of the R Shiny Application

The process began with the creation of an R Shiny application, with the aim of facilitating user navigation through charts. The application allows users to dynamically select specific companies and emission types, streamlining the exploration process.

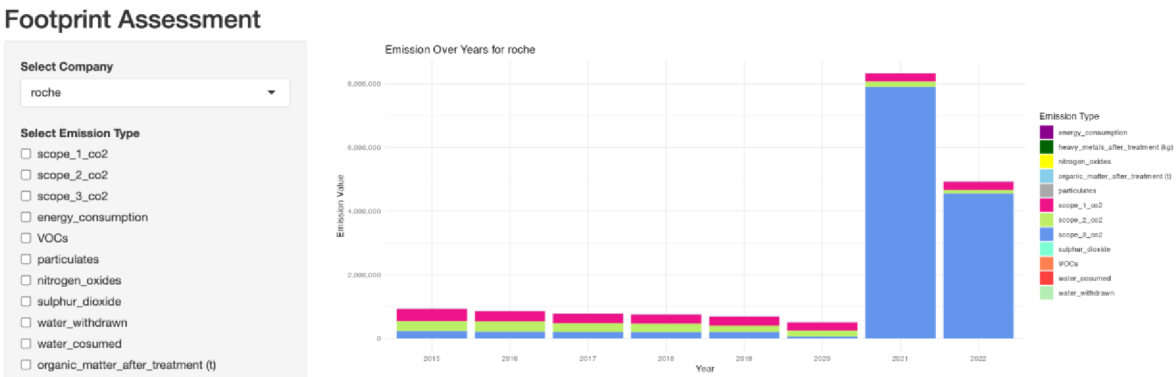
By utilizing R Shiny, a responsive and intuitive interface was established, enabling users to interact effortlessly with the data.

4.4.2 Implementation of ggplot2 graphs

For the visual representation of data, the ggplot2 library within the R Shiny application was employed. This library provides a variety of customizable and visually clear charts, aligning with the objective of presenting information in a straightforward manner.

4.4.3 User-Driven Exploration

The essence of the analysis lies in user interaction. Through the R Shiny application, users can choose companies and emission types, prompting the generation of dynamic graphs. This interactive feature empowers users to discover insights tailored to their specific interests and questions. Instead of passively observing static data, users actively explore, gaining a deeper understanding of the nuances within the pharmaceutical industry's energy consumption and greenhouse gas emissions.



type_emission	2015	2016	2017	2018	2019	2020	2021	2022
scope_1_co2	379457.00	319538.00	291850.00	284890.00	282184.00	251943.00	254060.00	249961.00
scope_2_co2	317183.00	320860.00	270123.00	263973.00	195766.00	189003.00	168735.00	114519.00
scope_3_co2	224243.00	209660.00	203814.00	195530.00	201522.00	56937.00	7898074.00	4550518.00
energy_consumption	10297.00	9824.00	9219.00	9185.00	8983.00	8420.00	8306.00	8396.00
VOCs	116.00	124.00	101.00	85.00	85.00	73.00	86.00	80.00
particulates	26.00	21.00	20.00	20.00	13.00	16.00	18.00	16.00
nitrogen_oxides	228.00	219.00	232.00	201.00	133.00	113.00	118.00	113.00
sulphur_dioxide	11.00	6.00	7.00	5.00	4.00	3.00	4.00	2.00
water_withdrawn	18.90	18.20	15.90	16.60	15.90	14.90	15.40	14.90
water_cosumed	3.50	3.10	3.00	3.40	3.10	2.80	2.70	2.90
organic_matter_after_treatment (t)	190.00	149.00	144.00	185.00	127.00	76.00	76.00	80.00
heavy_metals_after_treatment (kg)	160.00	164.00	129.00	149.00	228.00	174.00	131.00	137.00

Figure 2: Overview of the R Shiny application. Source: Author

5. Results

5.1 Carbon Footprint of the EU Pharmaceutical Industry

The analysis investigates the variability of carbon footprints within ten EU pharmaceutical companies. By conducting a granular analysis of each emission category, considering the limitations of the available data, the research identifies shared trends and quantifies the relative significance of various emission sources. This facilitates the pinpointing of key contributors to the overall environmental impact and the subsequent identification of potential areas for improvement. While the absence of data from a wider industry sample restricts the formation of a comprehensive picture of the EU pharmaceutical sector's carbon footprint, the insights gleaned from this focused analysis provide valuable information to guide further research and inform the development of sustainable practices within the pharmaceutical industry.

1. Scope 1 Emissions:

Direct emissions from owned or controlled sources, such as fuel combustion in boilers and industrial processes, represent a substantial contributor to the carbon footprint of the analyzed companies. Companies like AstraZeneca (379,457 - 245,117 t CO2eq in 2015-2022), GSK (888 - 626 t CO2eq in 2016-2022), and Roche (379,457 - 249,961 t CO2eq in 2015-2022) exhibit significant levels of scope 1 emissions. Analyzing trends within each company reveals potential improvements. For instance, AstraZeneca shows a consistent decrease in scope 1 emissions over the period, suggesting successful implementation of mitigation strategies:

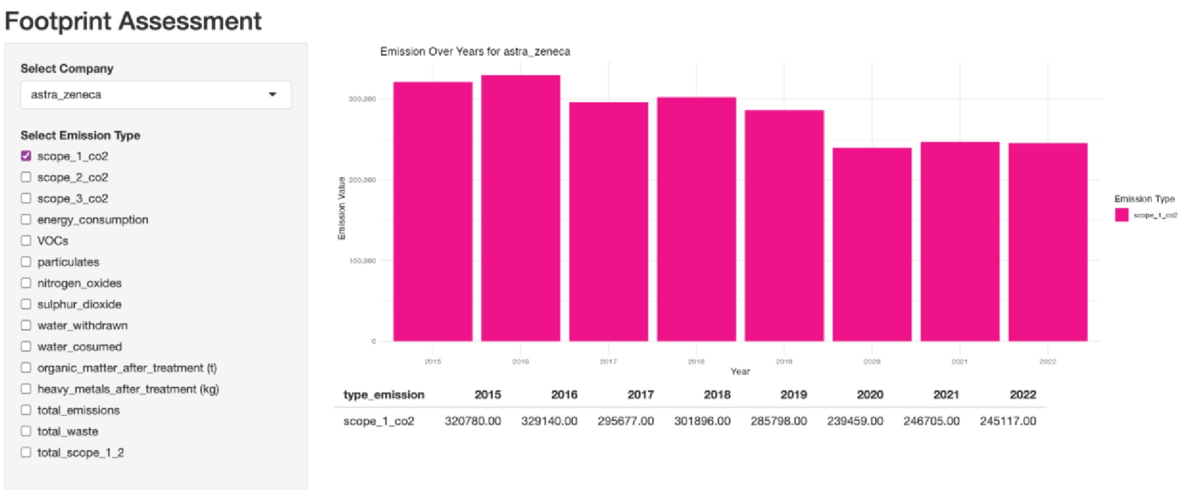


Figure 3: Scope 1 emission for AstraZeneca company. Source: Author

Roche company exhibits a downward trend in Scope 1 CO2 emissions, with a decrease from 379,457 tonnes in 2015 to 249,961 tonnes in 2022. This suggests potential improvements in efficiency within their production processes.

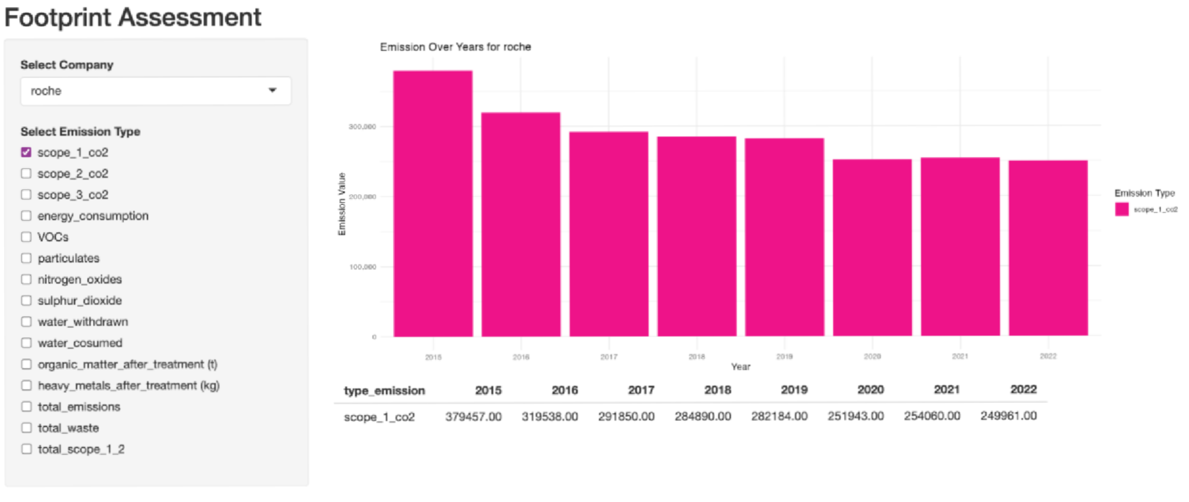


Figure 4: Scope 1 emission for Roche company. Source: Author

Similarly, GSK shows a downward trend in Scope 1 CO2 emissions, decreasing from 888 tonnes in 2016 to 626 tonnes in 2022. This could be attributed to their investments in renewable energy sources.

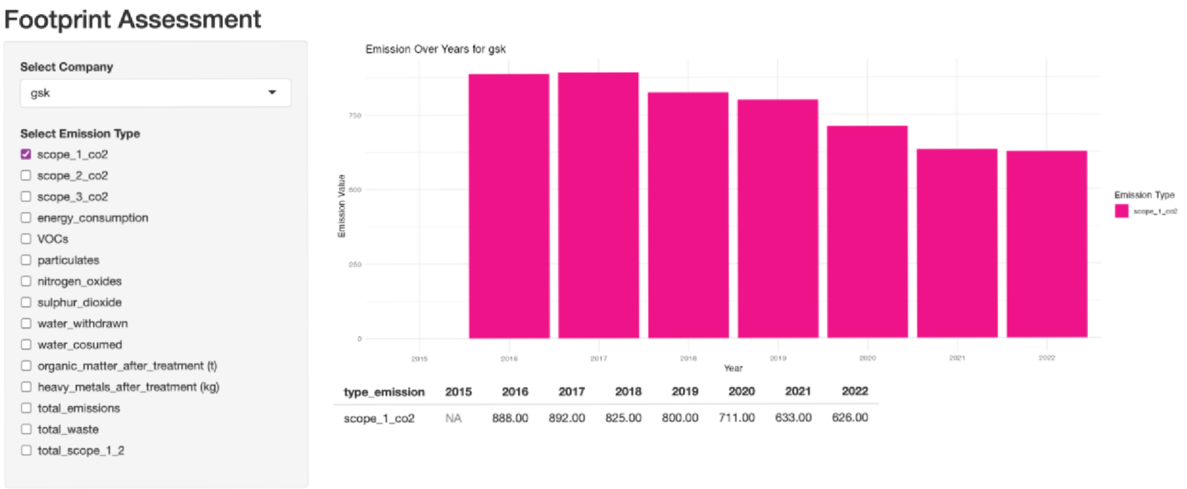


Figure 5: Scope 1 emission for GSK company. Source: Author

Meanwhile, Novartis shows an upward trend in Scope 1 CO_2 emissions, increasing from 333 tonnes in 2015 to 343.1 tonnes in 2022:

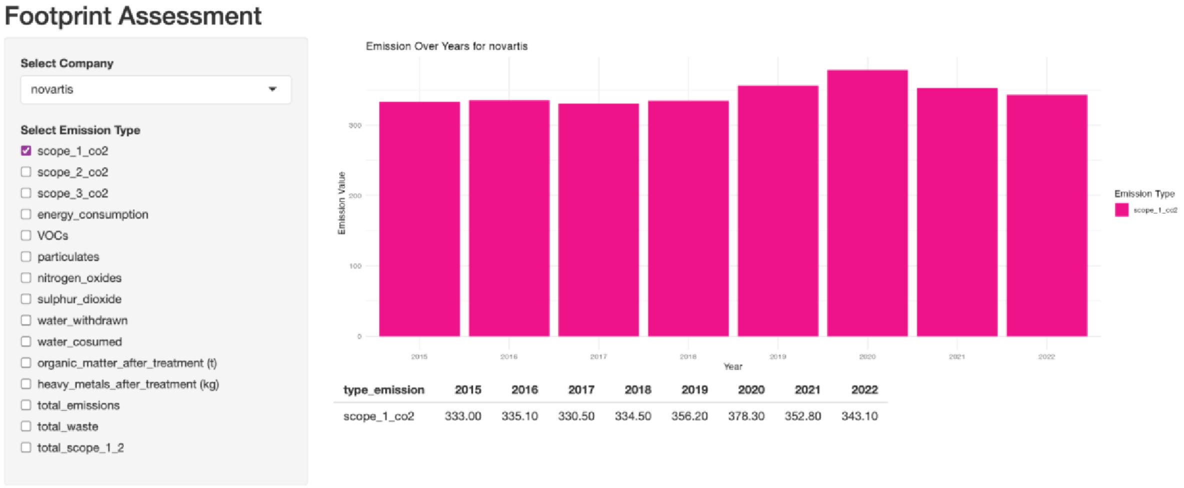


Figure 6: Scope 1 emission for Novartis company. Source: Author

2. Scope 2 Emissions:

Indirect emissions associated with purchased electricity, heat, or cooling contribute significantly to the carbon footprint of several companies. Roche (317,183 - 114,519 t CO2eq in 2015-2022), Lonza Group (250 - 198 t CO2eq in 2015-2022), and Novartis (504.5 - 147.5 t CO2eq in 2015-2022) demonstrate substantial scope 2 emissions. Interestingly, Novartis shows a significant decrease in scope 2 emissions over time, potentially indicating a shift towards cleaner energy sources. Investigating the specific electricity mixes used by these companies and exploring opportunities for on-site renewable energy generation or procurement of cleaner electricity sources could be crucial for further emission reduction.

GSK shows a significant downward trend for Scope 2 emissions from 2016 to 2022:

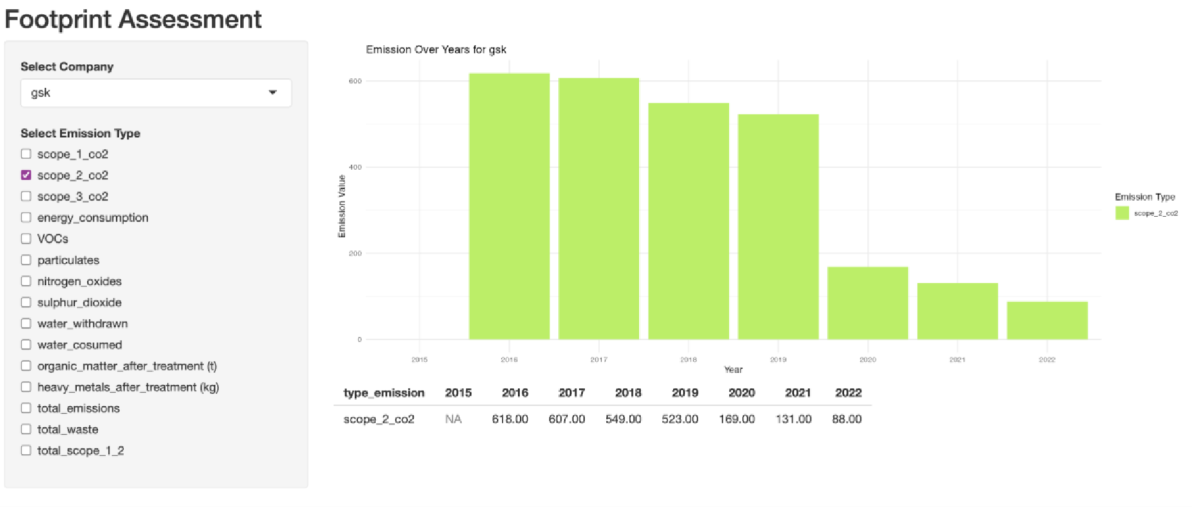


Figure 7: Scope 2 emission for GSK company. Source: Author

Roche showcase the same positive trend towards cleaner energy sources:

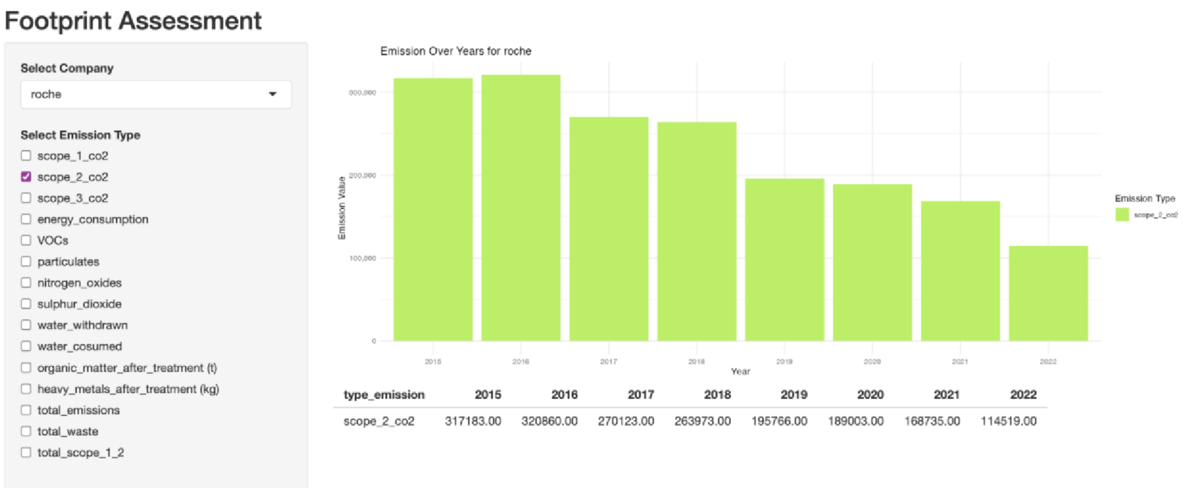


Figure 8: Scope 2 emission for Roche company. Source: Author

3. Scope 3 Emissions:

While data for scope 3 emissions, encompassing indirect emissions throughout the value chain, is limited for most companies, GSK (17,896 - 9235 t CO_2eq in 2016-2022) and Novartis (190.3 - 99.20 t CO_2eq in 2015-2022) report high values, suggesting this could be a contributor, nevertheless they show a significant downward trend in Scope 3 emissions for the selected period of time. Limited data hinders a comprehensive assessment, but it highlights the importance of considering the entire value chain when evaluating the carbon footprint of pharmaceutical companies. Further research and data collection efforts focusing on scope 3 emissions across the industry are crucial for a more complete understanding of its impact:

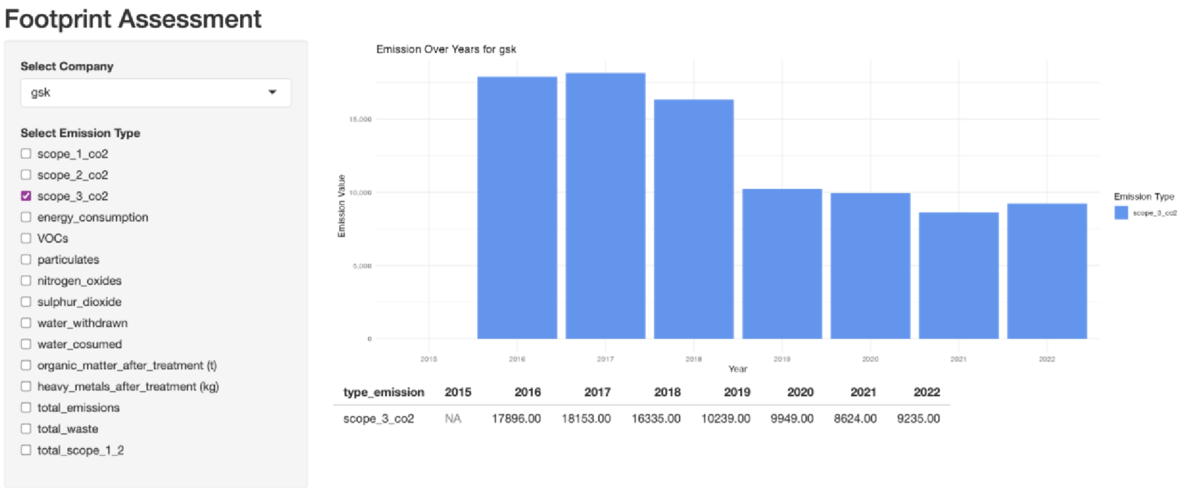


Figure 9: Scope 3 emission for GSK company. Source: Author

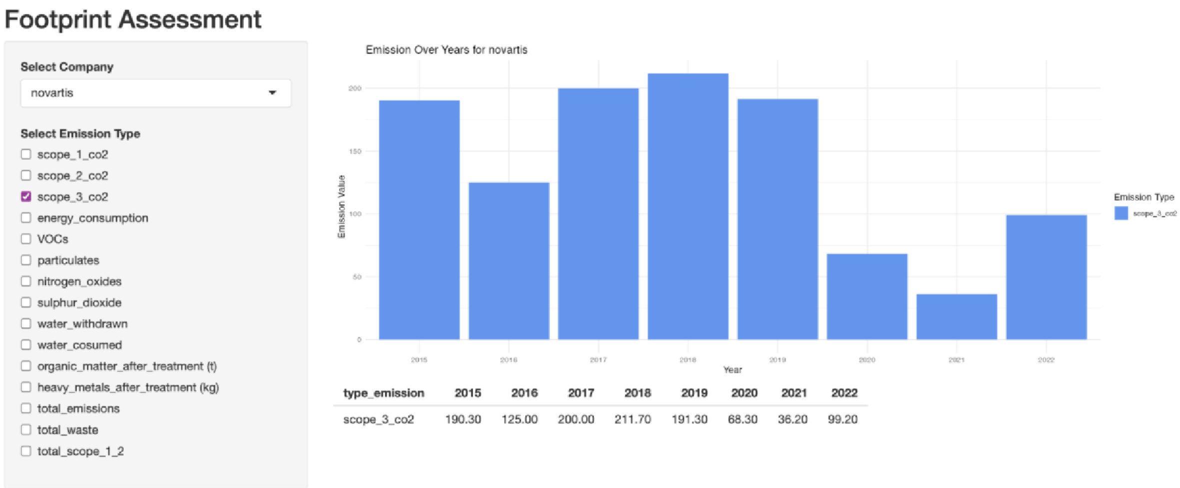


Figure 10: Scope 3 emission for Novartis company. Source: Author

4. Energy Consumption:

The data suggests a strong correlation between energy consumption and overall emissions. Companies with high energy consumption, such as GSK (16,390.8 - 9,932.4 MWh in 2016-2022) and Novo Nordisk (2,778 - 3,677 MWh in 2015-2020), likely have significant emission footprints.

Overall, a positive trend emerges in energy consumption data, with most companies demonstrating a decrease over the years:

The GSK company exhibits a significant reduction in energy consumption, dropping from 16,391 in 2015 to 9,932 in 2022. This suggests successful implementation of energy-saving measures within their operations.

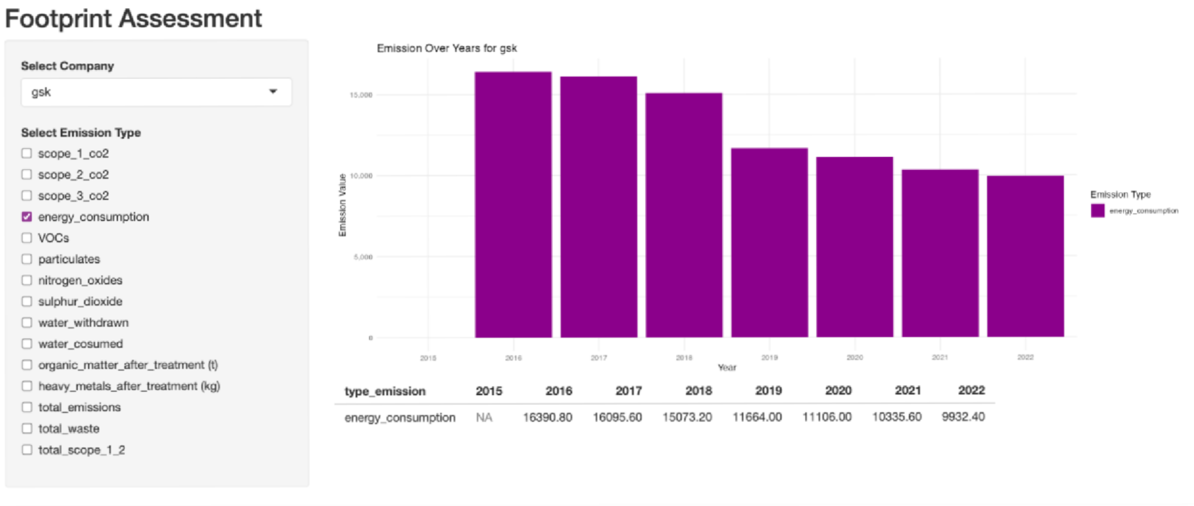


Figure 11: Energy consumption for GSK company. Source: Author

AstraZeneca also shows a downward trend in energy consumption:

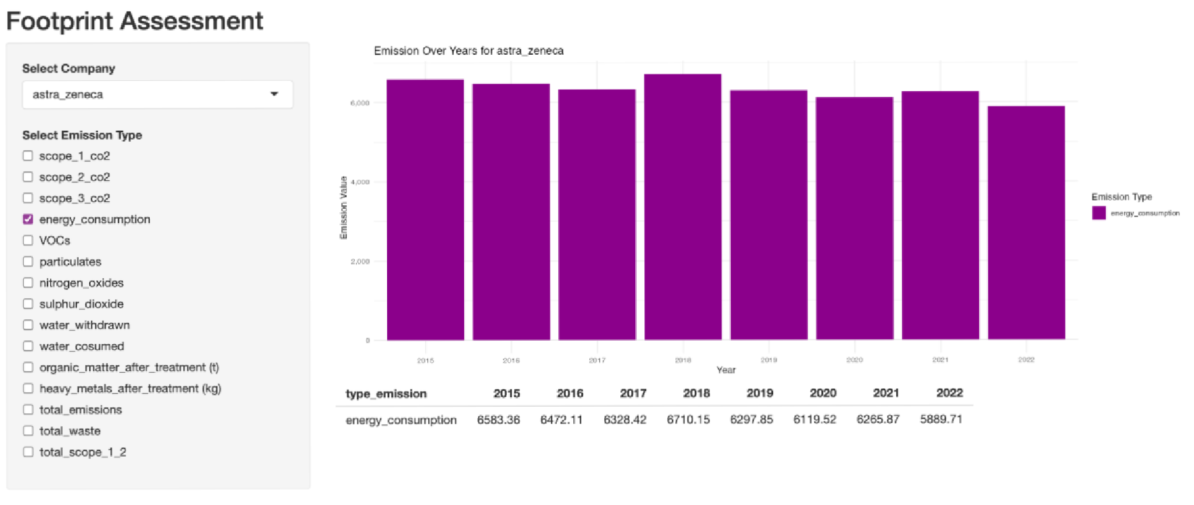


Figure 12: Energy consumption for AstraZeneca company. Source: Author

Otherwise, Novartis shows an upward trend in energy consumption, increasing from 13,440 toe in 2015 to 96,000 toe in 2022:

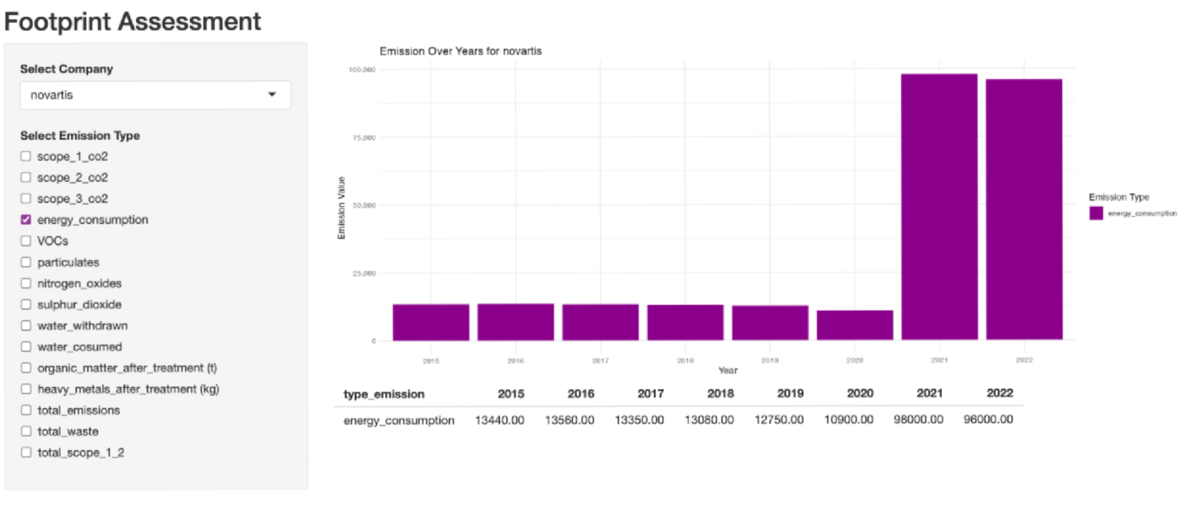


Figure 13: Energy consumption for Novartis company. Source: Author

The same way Novo Nordisk showcases the significant upward trend in energy consumption for selected period of time:

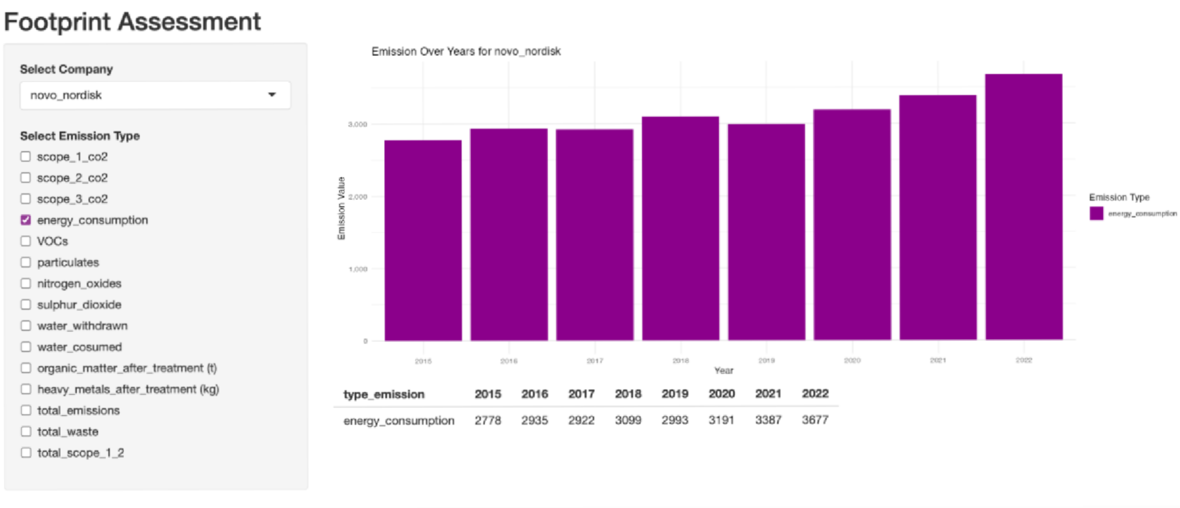


Figure 14: Energy consumption for Novo Nordisk company. Source: Author

6. Discussion

The analysis of these ten companies revealed a nuanced and concerning picture of the EU pharmaceutical industry's environmental footprint. While all companies reported on Scope 1 (direct emissions from owned facilities) and Scope 2 (indirect emissions from purchased electricity), significant variations were observed. For instance, companies like GSK exhibited fluctuations in Scope 3 emissions (indirect emissions across the value chain), with figures ranging from 17,896 t CO_2eq to 9,235 t CO_2eq. This highlights the critical need for a more comprehensive approach, as Scope 3 emissions are often the largest contributor for pharmaceutical companies. Encompassing aspects like raw material production, product transportation, and end-of-life disposal, Scope 3 can be several times higher than a company's direct emissions.

Focusing on energy consumption directly impacts Scope 1 and 2 emissions. Companies like AstraZeneca's success in lowering energy use by nearly 700 MWh (from 6583.36 MWh in 2015 to 5889.71 MWh in 2022) demonstrates the potential of energy efficiency measures. However, tackling Scope 3 emissions, which can be up to 4.3 times higher for public companies according to My Green Lab (2022), requires a broader strategy that extends beyond a company's direct operations. Collaboration with suppliers to adopt sustainable practices and optimizing logistics to minimize transportation emissions are crucial steps towards a more holistic approach.

However, the effectiveness of these initiatives relies heavily on consistent reporting and robust management practices.

<u>Emission Reporting</u>

According to recent analyses of the top 100 pharmaceutical companies worldwide, it was found that only half disclosed more than two years of Scope 1 emissions data, and one third provided more than two years of Scope 3 data. This suggests inconsistent and limited reporting practices within the industry. Additionally, a study conducted by PSCI in 2023 identified a lack of standardized reporting protocols among many companies, hampering comparability of emission data and progress assessment. This underscores the necessity for mandatory and standardized carbon emission reporting within the EU pharmaceutical sector.

Emission Management

Although some companies are implementing proactive measures, a comprehensive report by ISPOR in 2023 indicates a widespread need for broader adoption of emission reduction strategies. These strategies may encompass:

- Investment in renewable energy sources and energy-efficient upgrades for manufacturing facilities.
- Optimization of supply chains to minimize transportation emissions and exploration of circular economy principles to reduce waste.
- Participation in carbon offsetting initiatives to mitigate unavoidable emissions.

Effects of Reporting and Management Practices

There remains a research gap concerning the measurable impact of reporting and management practices on the overall carbon footprint of the EU pharmaceutical industry. While certain companies report reductions in emissions, further research is necessary to establish a causal relationship and evaluate the collective impact across the sector. This research could involve longitudinal studies analyzing changes in reported emissions alongside company sustainability reports and data from emission trading schemes.

As highlighted, limited reporting and inconsistent management strategies hinder our ability to assess the true impact of current initiatives. This emphasizes the need for standardized reporting protocols and the widespread adoption of comprehensive emission reduction strategies.

The analysis of environmental data from ten EU pharmaceutical companies revealed a concerning diversity in their environmental footprint. While all companies reported Scope 1 and Scope 2 emissions, significant variations were observed. Notably, GSK and Novartis exhibited high and fluctuating Scope 3 emissions (17,896 - 9235 t CO_2eq and 190.3 - 99.20 t CO_2eq respectively), highlighting the critical need for comprehensive emission assessment across the entire value chain. This aligns with Sharma et al. (2022) who emphasized the importance of such assessments.

The analysis suggests that pharmaceutical manufacturing, with its intricate processes and specialized equipment, likely has a higher environmental impact compared to healthcare services. This aligns with the established notion that energy-intensive industries tend to leave larger environmental footprints (UNEP, 2021).

Companies like AstraZeneca have demonstrated significant success in reducing energy consumption (from 6583.36 MWh in 2015 to 5889.71 MWh in 2022). This achievement suggests that implementing energy efficiency measures can yield substantial environmental benefits.

Furthermore, companies like Roche have reported reductions in key air pollutants. VOC emissions have decreased from 116 kg/year to 80 kg/year, particulate matter has fallen from 26 kg/year to 16 kg/year, and nitrogen oxide emissions have dropped from 233 kg/year to 113 kg/year. These declines point to the effectiveness of emission control strategies in mitigating the industry's impact on air quality.

Companies like Sanofi have made progress in water conservation efforts. Their water usage has decreased from 12671.32 kWh in 2015 to 12122.29 kWh in 2022. This trend highlights the potential for water use optimization within the pharmaceutical sector.

The pharmaceutical sector is actively taking measures to diminish its carbon footprint, but there's more to be accomplished. These initiatives hold promise for substantial reductions in greenhouse gas emissions and environmental protection.

As underscored, limited reporting and inconsistent management approaches impede the capacity to evaluate the genuine impact of current endeavors. This highlights the necessity for standardized reporting protocols and widespread adoption of comprehensive emission mitigation strategies, as delineated in the preceding section. Pioneering companies such as Roche set a precedent in transparent reporting by furnishing detailed data on air and water pollutants alongside greenhouse gas emissions. Similarly, Sanofi serves as a model for innovative waste management methods, showcasing substantial potential for emissions reduction through responsible waste disposal practices. By integrating these approaches with rigorous reporting and management protocols, the EU pharmaceutical industry can markedly diminish its environmental footprint and foster a sustainable trajectory.

Key Strategies for Sustainability:

- Transition to renewable energy sources: Several companies are transitioning to solar, wind, and geothermal power, demonstrating the importance of this strategy.
- Optimize supply chains: Batch processes and transportation emissions were identified as key areas for reduction. Companies like Lonza (reduction in

energy consumption) exemplify the potential for streamlining logistics and exploring alternative manufacturing methods.

- Minimize packaging in cold chain shipping: Efforts are underway to decrease packaging and explore reusable options. Companies like Pfizer and AstraZeneca are leading the way in this area.
- Transitioning to reusable and recyclable packaging in cold chain shipping: The industry is shifting towards more sustainable packaging solutions.
- Bringing back parts of the manufacturing process: Some companies are reintegrating segments of their manufacturing domestically to mitigate transportation emissions, as exemplified by Merck.

These are just a few examples, and there's significant room for improvement. Through persistent investment in innovative technologies and sustainable practices, the pharmaceutical industry has the potential to significantly diminish greenhouse gas emissions and safeguard the environment for future generations.

Recommendations.

Building on the insights gained from the data analysis and evaluation of current efforts, this section proposes a set of recommendations to guide the pharmaceutical industry towards a more sustainable future. These recommendations address the identified hotspots within the value chain and aim to significantly reduce the industry's carbon footprint.

Optimize Packaging:

- Adopt sustainable materials: Encourage the use of recycled, recyclable, and biodegradable materials in packaging, minimizing the environmental impact of single-use plastics.
- Implement refillable and reusable packaging solutions: Explore the feasibility of refillable containers and reusable shipping materials, potentially through collaborations with logistics and packaging companies.
- Minimize packaging size and weight: Analyze packaging needs and optimize design to minimize material usage without compromising product integrity.

Enhance Transportation Efficiency:

- Invest in fuel-efficient vehicles: Transition towards electric or hybrid vehicles for deliveries, particularly for local and regional transportation.

- Consolidate shipments and optimize routes: Utilize logistics management software and collaborate with suppliers and distributors to optimize shipping routes and minimize empty vehicle journeys.
- Explore alternative transportation modes: Evaluate the feasibility of rail or sea freight for longer distances, considering factors like cost, efficiency, and emissions impact.

Transitioning to Renewable Energy:

- Embrace on-site renewable energy solutions: Emplacement of solar panels, wind turbines, or geothermal systems can effectively power manufacturing facilities, diminishing reliance on non-renewable resources. Pfizer serves as a notable exemplar of this approach.
- Engage renewable energy providers: Forge enduring partnerships with renewable energy suppliers through extended contracts, guaranteeing a steadfast and sustainable source of clean energy. GlaxoSmithKline's pledge to achieve 100% renewable energy utilization by 2025 serves as a compelling instance.

Implement Efficient Manufacturing Processes:

- Adopt continuous manufacturing: Implement continuous manufacturing processes whenever feasible. This approach offers significant environmental benefits compared to traditional batch methods, leading to reduced energy consumption, water usage, and waste generation. Companies like Novartis and GSK are actively exploring this approach.
- Explore fermentation-based manufacturing: Investigate the potential of fermentation-based production methods as a more sustainable alternative to traditional chemical synthesis.

Minimize Waste and Enhance Recycling:

- Develop and implement sustainable waste management strategies: Invest in recycling and upcycling initiatives to reduce waste generation and divert materials from landfills.
- Collaborate with waste management companies: Partner with specialized firms to ensure proper handling and disposal of hazardous waste, minimizing environmental impact.

- Minimize cold chain packaging waste: Explore methods to reduce packaging size and weight in cold chain shipping, while maintaining product integrity. Consider examples like Sonoco's recyclable packaging options.

Rethink Supply Chain Strategies:

- Evaluate the environmental impact of sourcing locations: Assess the carbon footprint associated with globalized supply chains and explore possibilities for reshoring critical manufacturing steps to reduce transportation emissions. Companies like Merck are already taking steps in this direction.
- Promote collaboration within the industry: Encourage collaboration among pharmaceutical companies, suppliers, and logistics providers to share best practices and jointly develop sustainable solutions across the value chain.
- Through the adoption of these holistic suggestions, the pharmaceutical sector can markedly diminish its carbon emissions and play a pivotal role in fostering a sustainable tomorrow. Such endeavors necessitate ongoing investments in pioneering technologies, the embrace of sustainable methodologies, and collective cooperation within the industry.

Challenges and Opportunities for Reduction

Challenges:

Technological Limitations: Embracing cleaner technologies, especially within established infrastructure, poses a significant challenge. For instance, Sanofi’s existing facilities for solar power integration can be complex and expensive (Sanofi, 2022). Collaboration with research institutions like Germany's Fraunhofer Institute for Chemical Technology (ICT) could equip Sanofi with cost-effective solutions for integrating renewables (Fraunhofer, 2024).

Regulatory Hurdles: The complex and varied waste disposal regulations across the EU hinder Novo Nordisk's goal of implementing a uniform, sustainable waste management system (NovoNordisk, 2024). Streamlined EU-wide regulations, as advocated by the EFPIA, could create a more supportive environment for pharmaceutical companies to implement sustainable practices (EFPIA, 2024).

Consumer Behavior: Research conducted by the University College London School of Pharmacy revealed a lack of awareness among consumers regarding the environmental implications of various pharmaceutical products, medicines, and supplements (Russo M. Di., et al., 2023). Initiatives such as public awareness campaigns spearheaded by organizations like the European Biopharmaceutical Association (EBEA) have the potential to enlighten buyers about sustainable alternatives and empower them to make informed decisions not only regarding their choices but also regarding the appropriate utilization of medicines (EBEA, 2016).

Opportunities:

Progress in Sustainable Technologies: British-Swedish multinational AstraZeneca is piloting a program in collaboration with Siemens to utilize artificial intelligence (AI) for optimizing energy consumption in their manufacturing plants, potentially leading to significant emission reductions (AstraZeneca, 2023)

Circular Economy Approach: Swiss pharmaceutical company Novartis has partnered with recycling specialists Veolia to develop a closed-loop system for recovering and reusing valuable materials from used glass vials, minimizing waste (Novartis, 2023).

Collaboration: The Innovative Medicines Initiative (IMI), a public-private partnership funded by the EU, brings together pharmaceutical companies, research institutions, and patient groups to develop new, sustainable solutions for drug discovery and manufacturing processes, fostering innovation through collaboration (IMI, 2023).

Policy and Initiatives:

The European Union's pharmaceutical strategy, aligned with the Green Deal, outlines specific initiatives to promote sustainability in the sector. These include:

Financial incentives: Grants and tax breaks for companies developing and adopting eco-friendly technologies for production, packaging, and waste management.

Regulatory framework: Revision of existing regulations to encourage resource efficiency and lifecycle assessment throughout the medicine lifecycle.

Promoting eco-design: Mandating the use of biodegradable and recyclable materials in packaging and encouraging product redesign to minimize waste.

Knowledge-sharing platforms: Establishing platforms for collaboration and knowledge exchange between pharmaceutical companies, research institutions, and environmental groups to accelerate the development and implementation of sustainable practices.

These initiatives aim to address specific challenges in the pharmaceutical sector, such as:

- High energy and water consumption during manufacturing.
- Large volumes of hazardous waste generated from production processes.
- Environmental impact of pharmaceutical residues in wastewater and soil.

While these initiatives offer a promising start, their long-term effectiveness requires monitoring and evaluation to gauge their impact on emissions reduction and identify areas for improvement. Additionally, further research is needed to explore additional policy instruments tailored to address the unique challenges and opportunities of the pharmaceutical industry in its transition towards a more sustainable future.

Future research efforts might focus on several key areas:

Broadening the Sample Size: Incorporating data from a more diverse representation of the EU pharmaceutical industry, encompassing a wider spectrum of company sizes and specializations, would yield a more comprehensive understanding of the sector's environmental impact.

Advocating Scope 3 Reporting: Implementing standardized reporting of scope 3 emissions throughout the industry would facilitate a thorough assessment of the pharmaceutical sector's environmental footprint. Achieving this would necessitate collaborative efforts among industry leaders, policymakers, and regulators to establish transparent reporting protocols.

Investigating Escalating Emissions: Further exploration is warranted to elucidate the factors contributing to the escalating scope 1 emissions and energy consumption observed in Novartis and Novo Nordisk. This may entail scrutinizing company reports, conducting interviews with industry stakeholders, or employing life cycle assessment methodologies to identify specific areas necessitating improvement.

Comparative Life Cycle Assessment (LCA): Undertaking a comparative LCA across the entire value chain would serve as a valuable analytical tool. Such an assessment would evaluate the environmental ramifications of the pharmaceutical industry in contrast to other sectors like healthcare and chemicals. This comprehensive analysis would encompass all stages of a product's life cycle, from resource extraction and manufacturing to product utilization and disposal. By juxtaposing the environmental burdens across various industries, policymakers and businesses can prioritize mitigation strategies effectively.

7. Conclusion

This study investigated the carbon footprint of the European Union's pharmaceutical industry, especially from the 10 largest pharmaceutical companies in the EU (based on the revenue), revealing a diverse landscape with varying footprints across companies. Energy consumption and specific stages within the value chain, particularly Scope 3 emissions (indirect emissions throughout the lifecycle), emerged as key contributors. However, limited data on Scope 3 emissions hinders a comprehensive picture, highlighting the need for improved reporting practices.

While some companies, like AstraZeneca, Roche, GSK demonstrate proactive efforts by reporting emissions and implementing reduction strategies, inconsistencies and a lack of standardization across the sector remain. Technological limitations, regulatory hurdles, economic considerations, and consumer behavior pose additional challenges.

However, advancements in sustainable technologies, embracing circular economy principles, and fostering collaboration among stakeholders present significant opportunities. The EU's pharmaceutical strategy, with its focus on financial incentives, regulatory frameworks, and knowledge-sharing platforms, offers a promising path forward. Continuously monitoring and evaluating these initiatives, alongside exploring additional policy instruments, will be crucial for ensuring their long-term effectiveness.

The industry itself can significantly reduce its environmental impact by adopting robust emission reporting protocols and implementing comprehensive emission reduction strategies. Pioneering companies within the sector provide valuable models for success, including transitioning to renewable energy, optimizing supply chains, minimizing packaging waste, and implementing efficient manufacturing processes.

By persistently investing in innovative technologies, widespread adoption of sustainable practices, and fostering industry-wide collaboration, the EU pharmaceutical industry can significantly reduce its greenhouse gas emissions and environmental footprint. These collective efforts are essential for safeguarding the environment for future generations and ensuring the long-term sustainability of the pharmaceutical sector itself.

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Appendices

Appendix 1: preprocess the files with data. Implemented in R language

```r
library(shiny)
library(ggplot2)
library(dplyr)
library(reshape2)

setwd("/Users/janekom/Desktop/uni/THESIS/emissions_data")

file_path <- "/Users/janekom/Desktop/uni/THESIS/emissions_data"

# Create a function to read the files from the directory and then change the col names
update_and_read_data <- function(file_path) {
  data <- read.csv(file_path)
  new_colnames <- c("type_emission", "2015", "2016", "2017",
                    "2018", "2019", "2020", "2021", "2022")
  colnames(data) <- new_colnames
  return(data)
}

# Create a function to apply the "update_and_read_data" function to all files
companies <- c("roche", "astra_zeneca", "bayer",
               "genmab", "gsk", "lonza_group",
               "novartis", "novo_nordisk", "novozymes",
               "sanofi")

data_list <- list()

# Loop through the companies
for (company in companies) {
  file_path <- paste0(company, "_emissions.csv")
  variable_name <- paste0(company, "_data")
  assign(variable_name, update_and_read_data(file_path))
  data_list[[variable_name]] <- get(variable_name)
}
```

Appendix 2: Tables with emissions data.

A.Novo Nordisk AS:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
scope_1_co2	379457	319538	291850	284890	282184	251943	254060	249961
scope_2_co2	317183	320860	270123	263973	195766	189003	168735	114519
scope_3_co2	224243	209660	203814	195530	201522	56937	7898074	4550518
energy_consumption	10297	9824	9219	9185	8983	8420	8306	8396
VOCs	116	124	101	85	85	73	86	80
particulates	26	21	20	20	13	16	18	16
nitrogen_oxides	228	219	232	201	133	113	118	113
sulphur_dioxide	11	6	7	5	4	3	4	2
water_withdrawn	18.9	18.2	15.9	16.6	15.9	14.9	15.4	14.9
water_cosumed	3.5	3.1	3	3.4	3.1	2.8	2.7	2.9
organic_matter_after_treatment (t)	190	149	144	185	127	76	76	80
heavy_metals_after_treatment (kg)	160	164	129	149	228	174	131	137

B. Novartis AG:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
scope_1_co2	333.0	335.1	330.5	334.5	356.2	378.3	352.8	343.1
scope_2_co2	504.5	508.7	463.4	452.4	412.5	335.5	292.7	147.5
scope_3_co2	190.3	125.0	200.0	211.7	191.3	68.3	36.2	99.2
energy_consumption	13440	13560	13350	13080	12750	10900	98000	96000
VOCs	66.40	43.59	75.58	78.98	26.59	443.0	304.7	333.7
particulates	61.64	54.55	58.42	58.26	12.91	11.4	7.7	6.2
nitrogen_oxides	233.81	230.67	231.14	236.59	236.32	212.0	190.6	176.7
sulphur_dioxide	19.50	15.04	15.40	13.62	4.56	4.3	3.1	3.0
water_withdrawn	75.4	75.4	72.3	69.2	66.7	54.7	47.6	50.6
water_cosumed								
organic_matter_after_treatment (t)								
heavy_metals_after_treatment (kg)								

C. F. Hoffmann-La Roche Ltd:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
scope_1_co2	379457	319538	291850	284890	282184	251943	254060	249961
scope_2_co2	317183	320860	270123	263973	195766	189003	168735	114519
scope_3_co2	224243	209660	203814	195530	201522	56937	7898074	4550518
energy_consumption	10297	9824	9219	9185	8983	8420	8306	8396
VOCs	116	124	101	85	85	73	86	80
particulates	26	21	20	20	13	16	18	16
nitrogen_oxides	228	219	232	201	133	113	118	113
sulphur_dioxide	11	6	7	5	4	3	4	2
water_withdrawn	18.9	18.2	15.9	16.6	15.9	14.9	15.4	14.9
water_cosumed	3.5	3.1	3	3.4	3.1	2.8	2.7	2.9
organic_matter_after_treatment (t)	190	149	144	185	127	76	76	80
heavy_metals_after_treatment (kg)	160	164	129	149	228	174	131	137

D. AstraZeneca Plc:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
scope_1_co2	320780	329140	295677	301896	285798	239459	246705	245117
scope_2_co2	336689	219574	170851	144863	133971	213617	228138	260945
scope_3_co2	6310359	7661092	5855309	6273907	7234606	6388133	6017727	5689936
energy_consumption	6583.36	6472.11	6328.422	6710.15	6297.85	6119.5248	6265.8684	5889.71
VOCs			3454	3511	3883			
particulates								
nitrogen_oxides								
sulphur_dioxide								
water_withdrawn								
water_cosumed			3.89	4	3.55			
organic_matter_after_treatment (t)								
heavy_metals_after_treatment (kg)								

E. Sanofi:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
scope_1_co2					380543		360074	338380
scope_2_co2					300321		173766	150429
scope_3_co2					4798263		4353877	4470633
energy_consumption					12671.316		12541.3164	12122.2944
VOCs								
particulates								
nitrogen_oxides								
sulphur_dioxide								
water_withdrawn								
water_cosumed								
organic_matter_after_treatment (t)								
heavy_metals_after_treatment (kg)								

F. GSK plc:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
scope_1_co2		888	892	825	800	711	633	626
scope_2_co2		618	607	549	523	169	131	88
scope_3_co2		17896	18153	16335	10239	9949	8624	9235
energy_consumption		16390.8	16095.6	15073.2	11664	11106	10335.6	9932.4
VOCs								
particulates								
nitrogen_oxides								
sulphur_dioxide								
water_withdrawn		11.4	11.6	10.1	8.0	8.6	5.9	5.9
water_cosumed		14.42	14.67	12.77	10.2	9.7	7.9	7.5
organic_matter_after_treatment (t)								
heavy_metals_after_treatment (kg)								
total_waste		136.6	135.7	124.2	117.0	63.0	63.1	57.2

G. Bayer AG:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
total_emissions	4.62	4.64	3.63	5.45	12.58	11.80	11.08	11.93
scope_1_co2	4.41	4.30	2.50	3.90	2.13	2	1.93	1.91
scope_2_co2	5.30	5.57	3.63	5.45	3.71	1.75	1.56	1.56
scope_3_co2	9.71	9.87	10.03	9.65	9.96	9.20	8.94	8.6
energy_consumption	24677	26243	25832	28900	39200	35900	34800	35500
VOCs	1.61	1.12	0.87	1.41	1.61	1.17		
particulates	0.23	0.16	0.06	2.37	1.58	0.7		
nitrogen_oxides	2.42	2.36	1.52	4.36	4.7	2.9		
sulphur_dioxide	1.17	0.99	0.92	1.36	2.31	0.65		
water_withdrawn	346	330						
water_cosumed	110	93	98	42	59	57	55	53
organic_matter_after_treatment (t)								
heavy_metals_after_treatment (kg)								

H. Novozymes:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
total_scope_1_2	408	413	447	437	330	234	218	161
scope_1_co2								
scope_2_co2								
scope_3_co2				715	655	626	684	734
energy_consumption	4148	4380	4760	4831				
VOCs								
particulates								
nitrogen_oxides								
sulphur_dioxide								
water_withdrawn								
water_cosumed	6965	7225	8106	8205	7845	7998	8638	8720
organic_matter_after_treatment (t)								
heavy_metals_after_treatment (kg)								

I. Lonza Group:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
scope_1_co2	400	498	656	574		324	325	321
scope_2_co2	250	235	389	348		209	199	198
scope_3_co2							1733	1792
energy_consumption	4.065	3.98	3.6	3.29	2.89			
VOCs	249	220		213.8				
particulates	32	36		58.5				
nitrogen_oxides	344	390		477.5				
sulphur_dioxide	37	50		36.4				
water_withdrawn								
water_cosumed	1900	1780	1637	1432				
organic_matter_after_treatment (t)								
heavy_metals_after_treatment (kg)								

J. Genmab:

A	B	C	D	E	F	G	H	I
type_emissions	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
scope_1_co2							341.2	283.1
scope_2_co2							297.5	110.7
scope_3_co2								
energy_consumption							10.53	11.2572
VOCs								
particulates								
nitrogen_oxides								
sulphur_dioxide								
water_withdrawn								
water_cosumed								
organic_matter_after_treatment (t)								
heavy_metals_after_treatment (kg)								

Appendix 3: a. defining variables and UI part of R Shiny application. Implemented in R language

```
# Define static colors for each emission type
emission_colors <- c("deeppink2", "darkolivegreen2", "cornflowerblue",
                     "darkmagenta", "coral", "darkgrey", "yellow", "aquamarine",
                     "darkseagreen2", "brown1", "skyblue", "darkgreen",
                     "deepskyblue2", "maroon", "cornsilk")

# Create a mapping between emission types and colors
emission_types <- unique(unlist(sapply(data_list, function(x) x$type_emission)))
emission_color_mapping <- setNames(emission_colors[1:length(emission_types)],
                                   emission_types)

# Ui part
ui <- fluidPage(
  titlePanel("Footprint Assessment"),
  sidebarLayout(
    sidebarPanel(width = 3,
                 selectInput(
                   inputId = "company",
                   label = "Select Company",
                   choices = companies
                 ),
                 checkboxGroupInput(
                   inputId = "emission_type",
                   label = "Select Emission Type",
                   choices = unique(unlist(sapply(data_list,
                                                  function(x) x$type_emission))))
    ),
    mainPanel(
      plotOutput("barPlot"),
      tableOutput("data_table")
    )
  )
)
```

Appendix 3: b. server part of R Shiny application. Implemented in R language

```r
# Server part
server <- function(input, output, session) {
  data <- reactive({
    get(paste0(input$company, "_data"))
  })

  observe({
    updateCheckboxGroupInput(session,
                             "emission_type",
                             choices = unique(unlist(sapply(data_list,
                                                            function(x) x$type_emission))))
  })

  filtered_data <- reactive({
    data_subset <- data()
    emission_types <- input$emission_type

    if (length(emission_types) > 0) {
      data_subset <- data_subset[data_subset$type_emission %in% emission_types, ]
    }

    data_subset[, c("type_emission", "2015", "2016",
                    "2017", "2018", "2019", "2020",
                    "2021", "2022")]
  })

  output$barPlot <- renderPlot({
    scope_data_long <- melt(filtered_data(),
                            id.vars = "type_emission",
                            variable.name = "year",
                            value.name = "emission")

    # Convert year to factor with original order
    scope_data_long$year <- factor(scope_data_long$year,
                                   levels = colnames(filtered_data())[2:ncol(filtered_data())])
```

Appendix 3: c. continues server part of R Shiny application. Implemented in R language

```r
    # Create a bar plot with different colors for different emission types
    ggplot(scope_data_long, aes(x = year,
                                y = emission,
                                fill = type_emission)) +
      geom_bar(stat = "identity") +
      labs(title = paste("Emission Over Years for", input$company),
           x = "Year",
           y = "Emission Value",
           fill = "Emission Type") +
      scale_y_continuous(labels = scales::comma) +
      scale_fill_manual(values = emission_color_mapping) +
      theme_minimal()
  })

  output$data_table <- renderTable({
    filtered_data()
  })
}

shinyApp(ui, server)
```