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Emissions in pharmaceutical distribution: A systematic literature review of accounting methodologies in supply chains

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Background: The pressure to meet sustainability goals in the pharmaceutical industry has resulted in significant obstacles, one of which is accurately calculating greenhouse gas (GHG) emissions across the supply chain.

Objectives: This systematic literature review (SLR) aims to identify the frameworks or methodological approaches for calculating logistics emissions in pharmaceutical supply chains (which includes software), as well as the available energy consumption values and emission intensity factors that are needed to calculate emissions.

Method: This SLR follows the nine-step PRISMA 2020 protocol. Keywords were used to form three different search strings to search for frameworks, energy and emission factors. The review encompassed an analysis of a total of 33 documents.

Results: The findings highlight that no standardised methodological approach is used to calculate the emissions of pharmaceutical distribution. Furthermore, no emission factors specific to pharmaceutical products and few benchmarked energy consumption values are available.

Conclusion: The current lack of a standardised methodological approach within the pharmaceutical industry makes it challenging to quantify the emissions associated with the distribution of pharmaceutical products.

Contribution: This SLR identifies the need for a standardised emission framework and associated emission intensity factors in the pharmaceutical industry. It shows that the distribution of pharmaceutical products produces substantial emissions. Shipping 1 kg of ARV pills from a manufacturer in India to a hospital in South Africa emits 0.88 kg CO_2e, while shipping 1 kg of snake antivenom ampoules from a manufacturer in India to a hospital in South Africa emits 207.78 kg CO_2e.

Keywords: greenhouse gas emissions; pharmaceutical; supply chain; sustainable; systematic literature review.

Introduction

The continuous degradation of human health standards, coupled with an increase in life expectancy, has resulted in a heightened demand for pharmaceutical products (Ahmad et al. 2022). Over 30 million tonnes of pharmaceuticals are consumed globally per annum (Kumar et al. 2023), and figures from 2017 indicate that the global market for health care was estimated to be worth $7.7 trillion (Deloitte n.d.). Without access to pharmaceutical products, good health is unattainable, and an endless cycle of preventable misery and suffering is caused for billions of people (World Health Organization 2017).

The 2030 Agenda for Sustainable Development, adopted by the United Nations (2023), has placed considerable pressure on the pharmaceutical industry to meet certain sustainability goals by 2030. In particular, the third sustainability goal, which focusses on ensuring good health and well-being for all (United Nations 2023), is likely not going to be achieved. Therefore, it is essential that steps are taken to improve the ability of the pharmaceutical industry to adhere to the rising criteria needed to support improved levels of sustainability.

Note: Additional supporting information may be found in the online version of this article as Online Appendix 1.

Pharmaceutical supply chains and logistics

A typical pharmaceutical supply chain consists of multiple different actors or role players, such as raw material production, pharmaceutical production (primary and secondary manufacturing), distribution centres, retail pharmacies or hospitals and patients (Moosivand, Ghatari & Rasekh 2019). Over the past few decades, the level of complexity and fragmentation in pharmaceutical supply chains has increased significantly because of production fragmentation across multiple countries and the number of stakeholders (Blossey, Hahn & Koberstein 2021). There are many challenges in these supply chains, such as operational costs, timely delivery of medicines, product availability and the perishable nature of the medicine (Pathy & Rahimian 2023). Thus, the logistics process is critical in health supply chains. Any disruption to the pharmaceutical supply chain has the potential to impair health systems' effectiveness and impede the flow of medications (Marrone et al. 2023).

Globally, over 30 million tonnes of pharmaceutical products need to be shipped per year by various modes of transportation (Kumar et al. 2023). Klopott (2021) states that the more valuable, temperature and time-sensitive pharmaceutical products are more likely to be transported by air because of speed and flexibility. The primary manufacturing of the active pharmaceutical ingredient generally takes place at a small number of large facilities, frequently located in India and China, while secondary manufacturing of the final pharmaceutical product is conducted at multiple facilities that are closer to the customer (Blossey et al. 2021). Thus, the extensive hub-and-spoke nature of the pharmaceutical supply chain means that successful logistics is critical. For example, India is the world's largest provider of generic medications and produces 60% of vaccines used worldwide Government of India (2023). However, it is uncertain what the emissions of pharmaceutical distribution are and how these emissions are calculated. Therefore, this paper aims to conduct a systematic review to:

- Identify the frameworks or methodological approaches for calculating logistics emissions in pharmaceutical supply chains (including software).
- Establish the available energy consumption values for different logistical activities.
- Determine emission intensity factors that are needed to calculate emissions.

The remainder of this section discusses and evaluates the emissions of pharmaceutical product distribution. Thereafter, the methodology of the systematic literature review is explained in 'Methods and data' section, followed by the results and a discussion thereof. The last section presents a conclusion to the paper.

Emissions of pharma supply chains and logistics process

Globally, all sectors are under pressure to reduce carbon emissions to become carbon neutral by 2050 (Yang et al. 2023), with an increasing expectation of companies to track, report and manage emissions in their respective supply chains (World Economic Forum 2023). The Greenhouse Gas Protocol has been used as a methodology to manage emissions on a corporate level (WBCSD & WRI 2015). The greenhouse gas (GHG) Protocol allocates emissions into three different scopes for reporting. Logistics has been neglected in these emission assessments and reduction efforts because it is a Scope 3 emission (AstraZeneca 2023) in the majority of corporate emissions reports, and is therefore not often reported on.

Logistics process emissions and example scenarios

Previous studies have assessed the carbon emissions from logistics operations for various commodities. In a doctoral thesis written by Du Plessis (2023), the scenario-specific distribution of fresh fruit via deep-sea ocean transportation emitted between 0.31 and 0.84 kg CO_2e/kg of fruit, and up to 11.35 kg CO_2e/kg of fruit if air transportation was used. In a journal article written by Aragão et al. (2022) that analysed the carbon footprint of hake in Spain, results indicated that 15.85 kg CO_2e/kg of hake was emitted through air transportation and 0.3385 kg CO_2e/kg of hake was emitted through deep-sea transportation.

To illustrate the extent of possible emissions when distributing pharmaceutical goods, two example scenarios were developed and analysed, as shown in Figure 1. The scope of these scenarios is from factory gate to a hospital door. The first one represents a lower emissions scenario example where an ambient pharmaceutical product is distributed in bulk via maritime transportation. The second scenario represents a higher emissions scenario where a temperature-controlled pharmaceutical product is distributed in smaller quantities, requires air transportation and is stored under refrigerated conditions for an average of 180 days until usage. The two scenarios have the same country of origin (India) and destination country (South Africa), as shown in Figure 1. Both scenarios use the Cape Medical Depot (CMD) as a transshipment or storage point.

The first scenario utilises ambient road transport and deep-sea ocean transport, and it pertains to antiretroviral (ARV) HIV drugs being exported via the Port of Mormugau in India to Tygerberg Hospital, Cape Town, in South Africa, with the Port of Cape Town as a discharge port. The second scenario utilises refrigerated road transportation and air transportation, and it pertains to ampoules of snake antivenom being exported via Chhatrapati Shivaji Maharaj International Airport (BOM), in Mumbai, India, to Tygerberg Hospital in South Africa, with a connecting flight at Dubai International Airport. Figure 1 visually summarises the distribution process and vehicles used in both the antivenom and ARV scenarios.

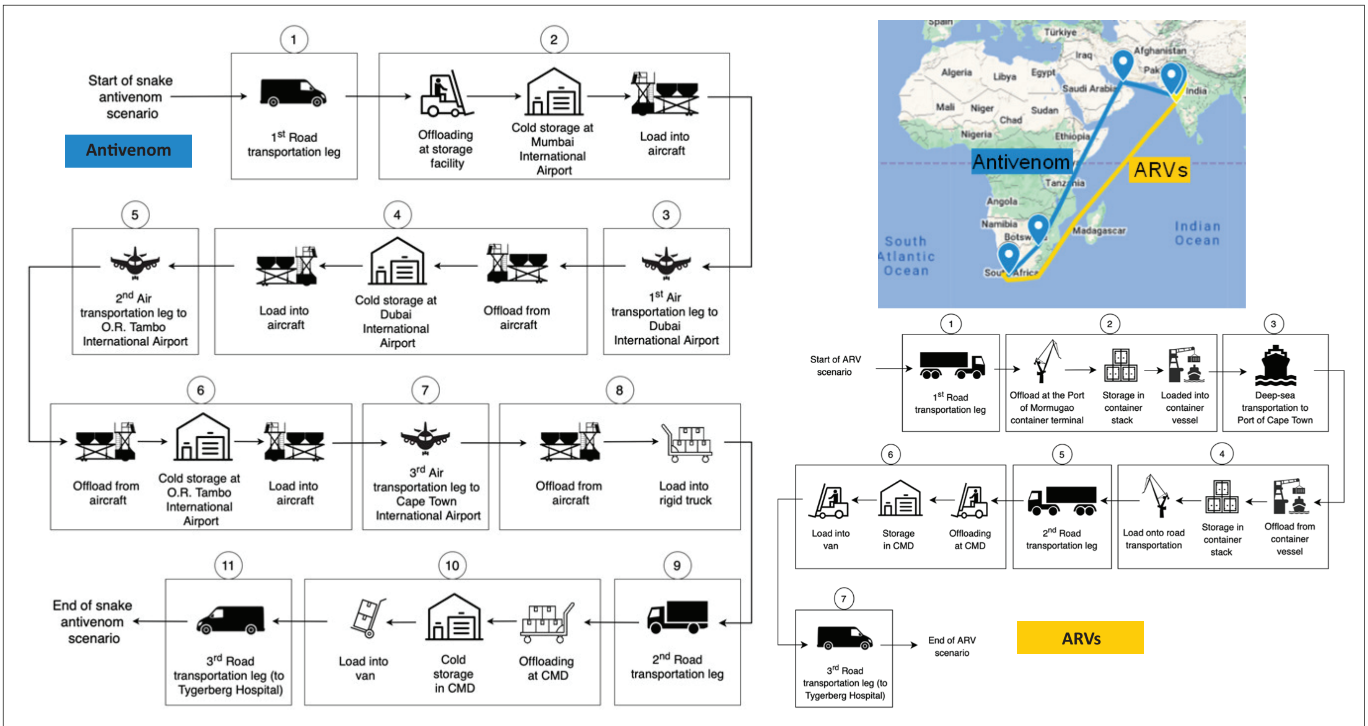
The Global Logistics Emissions Council (GLEC) Framework, developed by the Smart Freight Centre (2023), was used as the methodology for calculating the carbon footprint of each scenario under investigation. Emission intensity factors from the GLEC Framework (Smart Freight Centre 2023) and Du Plessis (2023) were used to quantify emissions. Du Plessis (2023) developed a framework and emission intensity factors to calculate emissions for the international distribution of fresh fruit produced in South Africa. This was used as a starting point for the development of the two pharmaceutical distribution example scenarios, as the methodology of Du Plessis (2023) has been validated, peer-reviewed and published. Although fresh fruit and pharmaceutical products are different in nature, both are cold chain products; therefore, the methodology of Du Plessis (2023) was used for calculating the pharmaceutical distribution emissions. The description of each scenario's distribution process, detailed calculations and emission intensity factors for each scenario are presented in Online Appendix 1.

The results show that logistics is a carbon-intensive process. Shipping 1 kg of ARV pills, not including the packaging, from a manufacturer in India to a hospital in South Africa emits 0.88 kg CO_2e. The proportional contribution of each emission-generating activity in the distribution of ARVs is shown in Figure 2. The maritime transportation leg is the largest contributor of emissions (70% of the total emissions) to the carbon footprint of ARVs. Losses of ARVs throughout the entire distribution chain contribute 20% to the total carbon footprint. In terms of the three road transportation legs, the last mile leg from the Cape Medical Depot (CMD) to Tygerberg Hospital has the most significant contribution (3.4% of the total emissions) to the carbon footprint of ARVs. Further, the ambient storage of ARVs in the CMD contributes 5.5% to the total carbon footprint, while the total handling and storage at ports contribute only 0.7% to the end-to-end emissions.

The distributional emissions of temperature-sensitive goods are significantly larger. Shipping 1 kg of snake antivenom ampoules, not including the packaging, from a manufacturer in India to a hospital in South Africa emits 207.78 kg CO_2e. The proportional contribution of each emission-generating activity in the distribution chain of antivenom is shown in Figure 2. Air transportation is responsible for 46.85% of the emissions in the carbon footprint of the antivenom. However, the 180-day cold storage in the CMD is also a significant emissions contributor (32.76% of total emissions) to the carbon footprint of the antivenom. Losses of antivenom throughout the entire distribution chain contributes 20% to the total carbon footprint, while the total refrigerated road transportation legs contributes 0.37% to the carbon footprint of antivenom.

The results of this analysis highlight the significant variation in different pharmaceutical supply chains' GHG emissions, as it can range from 0.88 kg CO_2e/kg pharmaceutical product to 207.78 kg CO_2e/kg pharmaceutical product. The reason for the variation is because of multiple factors that need to be taken into consideration, some of which include:

- the type and characteristics of the pharmaceutical good
- the mode of transport
- the weight of goods (nett vs gross)
- the volume of goods
- the calculation of emissions based on weight or volume, or the combination thereof
- transportation distance
- storage durations
- emission intensity factors used
- repositioning of empty vehicles and containers
- losses during transportation



ARV, antiretroviral.

FIGURE 1: The distribution routes of the antiretroviral and snakevenom scenarios from India to a hospital in South Africa.

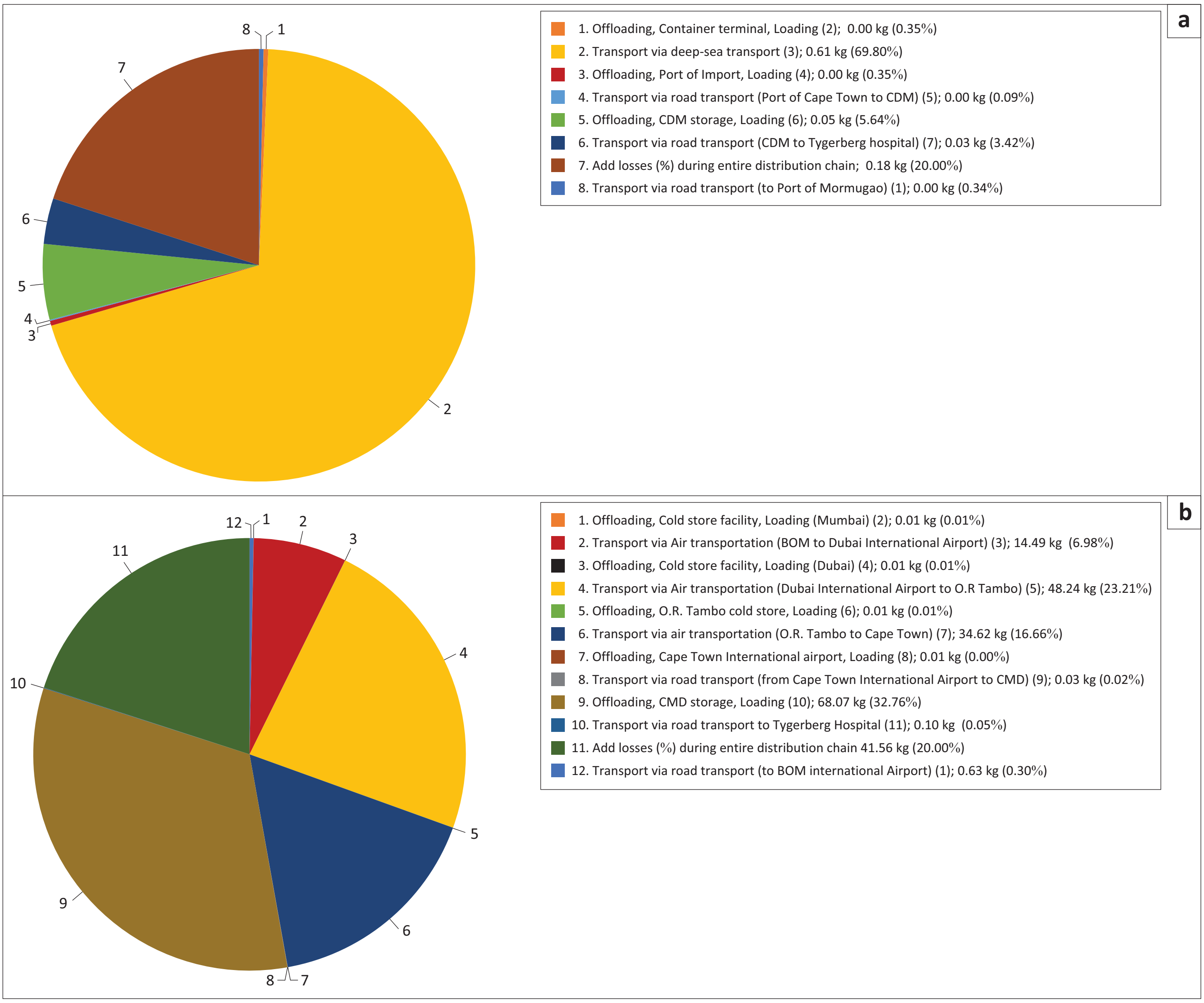


FIGURE 2: Carbon footprint (kg CO_2e/kg pharmaceutical goods) and percentage of each phase in the distribution scenario for antiretrovirals and snake antivenom from India to South Africa: (a) antiretrovirals and (b) antivenom.

- type of packaging used
- type of containers and pallets used during transportation
- equipment in a storage facility (i.e. refrigerator).

Ultimately, the significant variation in different pharmaceutical supply' GHG emissions emphasises the need for an emission intensity framework in the pharmaceutical industry to improve the accuracy of calculated and reported results. Based on the large emissions values for the above scenarios and the range of emissions, the remainder of this paper seeks to find suitable methodologies that can be used to calculate GHG emissions of pharmaceutical distribution.

Methods and data

This systematic literature review (SLR) follows the *nine-step PRISMA 2020* protocol outlined by Page et al. (2021) as methodology. Each step served as a guide in the SLR and is discussed in more detail in the remainder of this section.

Defining the research question

The question that is assessed by this systematic literature review (SLR) is: 'What are the existing frameworks, energy consumption values, and emission intensity factors related to logistical activities in pharmaceutical supply chains?'. This research question serves as the basis for the paper.

Literature search

The literature search strategy began with identifying databases such as *Scopus*, *Web of Science*, *EBSCOHost* and *Google Scholar*, which were then searched in a structured way to retrieve literature. Keywords and synonyms with Boolean operators were then defined and used to form a search string. The multiple keyword synonyms used ensured that all literature related to the research question was retrieved.

Keywords were used to form three different search strings based on the search for the primary concepts of the SLR: *frameworks*, *energy* and *emission factors*. Because of the applied nature of logistics and supply chain management, it is important to consider literature published in industry reports and Master's and PhD theses and dissertations, also known as grey literature. Google Scholar was utilised as a search engine to search for grey literature. However, the number of sources retrieved from each search string was too large (over 7 million), and a scan of the first 100 results for each search string showed no relevance for this study. Subsequently, the researchers decided to exclude grey literature and Google Scholar as a search engine option. The three search strings used in Scopus, Web of Science and EBSCOHost are as follows:

- **Search string 1:** ('Pharmaceutical Products' OR Medicine OR Vaccines OR Medication) AND (Distribution OR Transport OR Movement OR Storage OR Shipping OR Logistics OR Warehousing OR DC) AND (Emissions OR GHG OR 'Carbon footprint' OR Carbon OR 'Greenhouse gases') AND (Framework OR Methodology OR Calculation OR Method OR Standard OR Guideline OR Protocol OR Toolkit).
- **Search string 2:** ('Pharmaceutical Products' OR Medicine OR Vaccines OR Medication) AND (Distribution OR Transport OR Movement OR Storage OR Shipping OR Logistics OR Warehousing OR DC) AND (Energy OR Electricity OR Diesel OR Fuel OR Solar OR Petrol OR LNG OR Consumption).
- **Search string 3:** ('Pharmaceutical Products' OR Medicine OR Vaccines OR Medication) AND (Distribution OR Transport OR Movement OR Storage OR Shipping OR Logistics OR Warehousing OR DC) AND (Emissions OR GHG OR 'Carbon footprint' OR Carbon OR 'Greenhouse gases') AND (Factors OR 'Emission intensity factors' OR 'Emission factors' OR Multiplier).

Specific search operators are given in Online Appendix 1. Further filtering of results in each database was conducted by only including certain subjects or research areas. Some examples of exclusions are agriculture, psychology, biochemistry, genetics and molecular biology. Fields of research included in the study include environmental science, transportation and carbon emissions. Consult Online Appendix 1 for a complete set of subject areas included and excluded during the literature search. Note that results were not filtered by year of publication. Following the refinement process in each database, the search using keywords and search strings yielded a total of 2264 resources, as shown in Figure 3.

Selection and screening of literature

Various software was utilised during the selection and screening of literature, the first of which was Zotero, an open-source reference management software. Search outputs from the three databases were exported into Zotero, where the software assisted in removing duplicate resources. A total of 385 duplicate resources were excluded from the SLR, which left 1879 resources, as shown in Figure 3. The 1879 resources were then transferred over to *Rayyan*, software that helps expedite the initial screening of abstracts and titles (Ouzzani et al. 2016). Rayyan was used as the first step of the screening process because of the large number of resources.

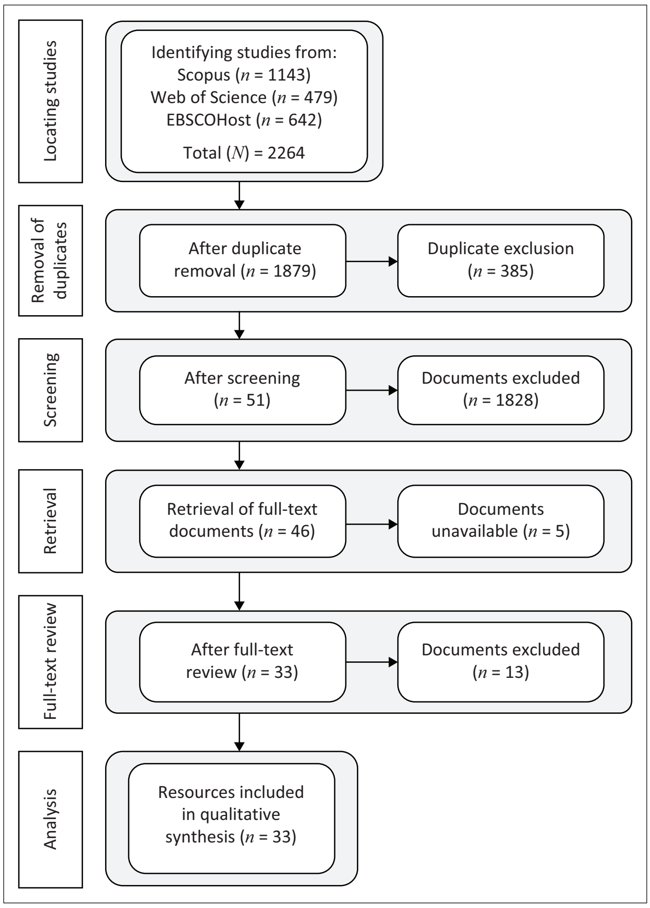


FIGURE 3: Study selection and evaluation steps.

Screening of the resources was manually reviewed in Rayyan, and certain inclusion and exclusion criteria were applied by the primary researcher to retrieve only relevant resources. This manual process ensured that no studies related to the research question in 'Defining the research question' section were wrongfully removed. Note that any resources not in English were excluded from the SLR. In the first iteration of the screening process, resources were excluded if any word in the title could be classified under the specific title themes and sub-themes described in Online Appendix 1. Examples of excluded title sub-themes are animals, social issues, diseases and conditions. In the second iteration of the screening process, resources were excluded if any keyword in the resource could be classified under any of the keyword themes. Examples of excluded keyword themes are industry and manufacturing, agriculture and food industry, economics and business. In the third iteration of the screening process, resources were excluded if the abstract indicated a purpose that can be classified under any of the abstract themes. See Online Appendix 1 for more details. Examples of excluded abstract themes are physics and astronomy, biology and biotechnology, computer science and data analysis.

A total of 1828 resources were excluded as they did not meet the screening criteria, and a total of 51 relevant documents remained after the screening process, as shown in Figure 3. During the retrieval of full texts, five (5) documents were unavailable via interlibrary loans; therefore, those resources were excluded. After the screening and full-text retrieval steps, a total of 46 full-text resources were meticulously reviewed and subjected to stringent exclusion criteria, which resulted in a further 13 being excluded. This process led to the inclusion of 33 resources relevant to the SLR. These resources are assessed in the remainder of this paper.

Analysis and synthesis

The 33 resources were individually analysed and carefully assessed during the data extraction process. During this step, *Microsoft Excel* was utilised to organise the data, with sub-theme headings created based on the primary themes or concepts of the SLR being:

- **Frameworks:** Framework(s) mentioned, frameworks or tools used and methodology.
- **Energy:** Distribution – transport mode, storage facility, cooling (packaging), energy type, energy consumption values and energy consumer.
- **Emission factors:** Fuel emission factor, emission type, emission producer and emission intensity factors.

Relevant data from each resource were extracted and categorised under sub-theme headings in Excel, facilitating the visualisation of trends and similarities across the 33 articles. In addition, several headings not directly related to the primary themes were included to capture essential information. These headings comprised the year of publication, the country of research, the type of product analysed, whether the study had a pharmaceutical focus or holistic supply chain focus, life cycle assessment (LCA), scope of the LCA, case study, whether the study was a literature review and document type.

Reporting results

The final step involved reporting on the results of the SLR. Three main areas of discussion involve the frameworks or methodological approaches, energy consumption and emission intensity, which are discussed in the subsequent sections.

Ethical considerations

Ethical clearance to conduct this study was obtained from the Stellenbosch University, Social, Behavioural and Education Research Ethics Committee (Project No. 30241).

Results and discussion

The results obtained from the SLR are discussed in two separate sections. The first provides an overview of the SLR resources, while the second analyses the contents of the resources based on general findings, methodological approaches, software packages mentioned, energy consumption and emission intensity. This is followed by 'Suitable quantification methods' section, which discusses suitable quantification methods based on the analysis of the results. Lastly, 'Need for emission intensity framework in the pharmaceutical industry' section discusses the need for an emission intensity framework in the pharmaceutical industry.

Overall review of systematic literature review resources

This section reviews the different database sources, resource types, time range and literature sources.

Database source

Assessing the three databases that were used to obtain resources for the SLR, it is evident that the Web of Science search produced the largest number of resources (17), followed by Scopus (15), while EBSCOhost produced the least number of resources, identifying only one relevant resource. Note that this was based on the order of reviewed sources.

Resource type

Various resource types were retrieved in the literature search; however, the results of the SLR returned three types of resources: journal articles, conference proceedings and book sections. Of the three, journal articles (28) were the largest type of resource, representing 85% of the overall resources. The SLR analysed three conference proceedings (9%) and two book sections (6%) of the total resources.

Time range

The systematic review analysed resources over a timeframe of 26 years. No dates were excluded in this SLR, and all time periods were considered. The earliest publication date was in 1998 when (Kattakayam & Srinivasan 1998) explored the development and performance of a refrigeration system powered by photovoltaic panels and a generator backup. The most recent publications explored the development of a phase change material to maintain ultra-low temperatures for vaccine transportation without the use of dry ice (Schmit et al. 2024) and the optimisation of an ultra-low temperature cascade refrigeration system for the effective storage of vaccines (Ji et al. 2024). From the time range evaluation, it is evident that there was a significant increase in publications after 2021, most likely because of the coronavirus disease 2019 (COVID-19) pandemic. In total, 69.7% of the retrieved resources were published after 2021, showing a keen interest in pharmaceutical-related studies.

Literature sources

The systematic review retrieved 33 resources from 27 sources of literature. Of the 27 different sources, five journals contained two or more relevant resources:

- **Renewable and Sustainable Energy Reviews:** Mostafaeipour et al. (2014), Nkwetta and Sandercock (2016) and Klemeš et al. (2021).

- **Building and Environment:** Dillion and Colton (2014) and Pudleiner and Colton (2015).
- **Energies:** Santos, Gaspar and De Souza (2021) and Maiorino, Petruzziello and Aprea (2021).
- **Journal of Cleaner Production:** Sajid, Ali and Santibanez Gonzalez (2022) and Chowdhury et al. (2022).
- **Springer:** Sindhwani and Saddikuti (2023) and Morais et al. (2022).

Renewable and Sustainable Energy Reviews produced the highest number of resources (3), while approximately 81.5% of the literature sources only produced one relevant resource to the SLR. This indicates that no specific source of literature is dominant in the field of pharmaceutical supply chains or emission intensity research; rather, multiple different literature sources cover these fields. The remainder of the sources all yielded one resource only.

Results of the systematic literature review

This section of the SLR results analyses the different contents of the resources in terms of general findings, methodological approaches, software packages mentioned, energy consumption and emission intensity to identify similarities among resources and discuss the impact on the pharmaceutical industry.

General findings

The analysis of transport modes used for product distribution showed that 55% (18 out of 33) of the reviewed resources mentioned using specific transport modes. Road transportation emerged as the most frequently mentioned mode, encompassing a range of vehicle sizes, as well as diesel and electric options, as detailed in Online Appendix 1. Seven of the resources mentioned refrigerated road transportation (Klemeš et al. 2021; Li 2023; Maiorino et al. 2021; Oliveira et al. 2023; Santos, Gaspar & De Souza 2022; Sun, Andoh & Yu 2021; Wu et al. 2023), while eight resources mentioned non-refrigerated road transportation (Bassani et al. 2022; Erdogan et al. 2017; Guilbert & Vitale 2021; Lloyd et al. 2015; Maloney 2003; Sindhwani et al. 2023; Sprague et al. 2011; Wenyu et al. 2023). Air transportation, primarily involving airplanes, as well as an interesting study by Sun et al. (2021) that utilised unmanned aerial vehicles for the distribution of vaccines, was identified as the second most common mode, followed by rail and maritime transportation. In addition, the examination of storage facility types, also presented in Online Appendix 1, showed that 55% (18 out of 33) of the resources referred to various storage facilities such as warehouses, distribution centres, depots, or vaccine cold storage facilities. Nine of the resources mentioned that the storage facility was temperature controlled (Dillion et al. 2014; Erdogan, Kannan & Cheng 2012; eds. Leholo, Owolawi & Akindeji 2022; Lloyd et al. 2015; Maloney 2003; Mostafaeipour et al. 2014; Pudleiner et al. 2015; Sun et al. 2021; Wu et al. 2023).

Another analysis was conducted on the type of packaging that required cooling before being used in the distribution process. The results indicated that only 10 of the 33 (30%) resources mentioned cooled packing, such as ice bricks or dry ice, used to maintain the cold chain during product distribution. As shown in Online Appendix 1, dry ice emerged as the most frequently referenced cooling method, cited by Sajid et al. (2022), Klemeš et al. (2021) and Santos et al. (2021). This was closely followed by ice packs (mentioned by Gebretnsae et al. [2022] and Pambudi et al. [2022]) and gel packs (mentioned by Pambudi et al. 2022 and Vamza et al. 2021).

In terms of the products analysed in this SLR, 21 of the 33 (64%) resources mention vaccines as the type of product under investigation, while the second largest product type was from four resources that referenced pharmaceuticals or medicine. Seventeen of the 33 (52%) resources included a form of a case study, while only one full life cycle assessment assessed pharmaceutical packaging from cradle to grave (Bassani et al. 2022). Three resources were identified as full literature reviews, with Maiorino et al. (2021) investigating the current systems, technical issues, innovations and challenges for sustainability in refrigerated transport; Pambudi et al. (2022) assessing cold storage technology and management; and Nkwetta et al. (2016) studying the current methods and technologies used in solar air-conditioning systems.

Analysis of the geo context of the resources resulted in seven of the 33 (21%) resources representing a global study. On a country level, China was referenced the most from five individual resources, namely Ji et al. (2024); Wenyu, Xinru and Yunrui (eds. 2023); Chen et al. (2021); Li (2023); and Wu et al. (2023).

Methodological approaches mentioned

The SLR identified a total of 43 distinct frameworks, methodologies, methods, standards, models, algorithms, or guidelines across the 33 resources. It is important to clarify that this analysis focuses on the mention of methodological approaches within the resources rather than their practical application in the research studies.

The Vehicle Routing Problem (VRP) was the most frequently mentioned methodological approach in the SLR, with four references, as shown in Table 1. This was closely followed by the Total Equivalent Warning Impact (TEWI) Framework that was referenced three times. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) multi-criteria decision analysis method was also referenced three times. Seven methodological approaches were referenced twice in individual resources, while the remaining 33 approaches, constituting 77% of the total, were mentioned only once. This variety of different methodological approaches underscores the lack of a standard method or approach for quantifying logistics emissions in the pharmaceutical supply chain.

Software packages used

An analysis was conducted on the various software packages mentioned in the resources to determine if there was a standard software of choice within the pharmaceutical industry to calculate emissions. Among the 19 types of

TABLE 1: Methodological approaches mentioned in the systematic literature review.

Methodological approaches mentioned	Number of occurrences	References
Vehicle Routing Problem (VRP)	4	Li (2023) Sun et al. (2021) Oliveira et al. (2023) Maiorino et al. (2021)
Total Equivalent Warming Impact (TEWI) Framework	3	Ji et al. (2024) Santos et al. (2022) Santos et al. (2021)
Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method	3	Chowdhury et al. (2022) Vamza, Valters, Dzalbs, Kudurs and Blumberga (2021) Mokrini, Benabbou and Berrado (2018)
Life Cycle Assessment (LCA) Methodology	2	Jiang et al. (2021) Guilbert and Vitale (2021)
Sensitivity analysis	2	Leholo et al. (2022) Sajid et al. (2022)
Energy, exergy, economic and environmental (4E) analysis framework	2	Ji et al. (2024) Jiang et al. (2021)
Air Conditioning, Heating, and Refrigeration Institute (AHRI) 210/240-2017 standard	2	Santos et al. (2022) Santos et al. (2021)
American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ANSI/ASHRAE) 72-2018 standard	2	Santos et al. (2021, 2022)
World Health Organization (WHO) Guidelines	2	Santos et al. (2021) Klemeš et al. (2021)
Genetic algorithm (GA)	2	Dillon and Colton (2014) Wenyu et al. (2023)
Mixed integer optimisation model	1	Sun et al. (2021)
Centre for Environmental Science CML method	1	Bassani et al. (2022)
Design of Experiments (DOE) is a systematic method	1	Dillon and Colton (2014)
Elimination and Choice Translating Reality (ELECTRE) – It is a family of multi-criteria decision analysis (MCDA) methods	1	Mokrini et al. (2018)
Emergency Supply Emission Estimation Methodology (ESEEM)	1	Sajid et al. (2022)
Preference Ranking Organisation Method for Enrichment Evaluations (PROMETHEE)	1	Mokrini et al. (2018)
Monte Carlo Analysis (MCA)	1	Pudleiner et al. (2015)
Multi-Sector Partnership Framework	1	Sprague and Woolman (2011)
Good Practices to Address Pandemic Risks (framework by the European Commission)	1	Pambudi et al. (2022)
ASHRAE 90.1-2019 Standard	1	Santos et al. (2021)
ASHRAE Standard 90.1-2007	1	Pudleiner et al. (2015)
Energy Standard for Buildings, Excluding Low-Rise Residential Buildings (ASHRAE2-019)	1	Santos et al. (2022)
AHRI 1201-2013 standard	1	Santos et al. (2022)
Worldwide harmonised Light duty Test Cycle (WLTC) standard	1	Maiorino et al. (2021)
International Organization for Standardization (ISO) 14040 Standard	1	Bassani et al. (2022)
ISO 14044 Standard	1	Bassani et al. (2022)
ISO 16440-1:2015 Standard	1	Maiorino et al. (2021)
National Fire Protection Association (NFPA) 2 standard – for hydrogen technologies	1	Guilbert and Vitale (2021)
International Fuel Gas Code (IFGC) – set of codes	1	Guilbert and Vitale (2021)
Bottom of the Pyramid (BOP) Model	1	Sprague et al. (2011)
Environmental Impact = Population × Affluence × Technology (IPAT Model)	1	Sajid et al. (2022)
multi-objective model	1	Sun et al. (2021)
LC model – life cycle model	1	Bassani et al. (2022)
Multi-Objective Feasibility Enhanced Particle Swarm Optimisation (MOFEPSO) model	1	Chowdhury et al. (2022)
Optimisation Models	1	Jiang et al. (2021)
Multi-Objective Social Engineering Optimiser (MOSEO) model	1	Chowdhury et al. (2022)
Fruit Fly Optimisation Algorithm (FFO)	1	Li (2023)
Monte Carlo Simulation (MCM) – it is a computational algorithm	1	Sajid et al. (2022)
Simulated Annealing Algorithm (SAA)	1	Li (2023)
Multi-objective Evolutionary Algorithm based on Decomposition (MOEA/D)	1	Li (2023)
Ant colony algorithm	1	Wenyu et al. (eds. 2023)
Capacitated Multiple Allocation Hub Location Problem (CMAHLP)	1	Sindhwani et al. (2023)
Principles of Optimum Conditions for Storing Non-Refrigerator Medicines	1	Mostafaeipour et al. (2014)

Please see the full reference list of the article. Ashworth B., Plessis M.J., Goedhals-Gerber L.L. & Eeden J., 2025, 'Emissions in pharmaceutical distribution: A systematic literature review of accounting methodologies in supply chains', *Journal of Transport and Supply Chain Management* 19(0), a1150. https://doi.org/10.4102/jtscm.v19i0.1150.

software identified, as illustrated in Table 2, *Anylogistix* software (Sindhwani et al. 2023; Sun et al. 2021), *Chemours Refrigerant Expert 1.0* software (Santos et al. 2021, 2022) and the *EnergyPlus* tool (Dillon & Colton 2014; Pudleiner et al. 2015) emerged as the most frequently mentioned, each appearing twice. The remaining software packages and tools were referenced only once by a limited number of resources. The low frequency of references underscores the absence of a standardised software choice in the pharmaceutical industry.

Energy consumption results

To gain more insight into the energy consumption values that exist in the pharmaceutical supply chain, the analysis of each resource had to focus on three aspects. These aspects are the consumer of energy (what was the energy used for), the type of energy consumed (the type of fuel) and the relevant mention of energy consumption values as shown in Table 3. The assessment showed that the most referenced energy consumer was transportation, as it was referenced by thirteen of the 31 resources (42%) that discussed energy. General storage activities and refrigeration systems were noticeable energy consumers, as referenced by the resources. Interestingly, when the type of energy consumed is analysed, electricity was referenced by 19 individual resources (61%), followed closely by fossil fuels, which were referenced by 17 resources (55%) of the 31 resources that discuss energy.

TABLE 2: Software types mentioned in the resources.

Software packages	Number of occurrences	References
Anylogistix software	2	Sindhwani et al. (2023) Sun et al. (2021)
Chemours Refrigerant Expert 1.0 Software	2	Santos et al. (2021) Santos et al. (2022)
EnergyPlus tool	2	Pudleiner et al. (2015) Dillon and Colton (2014)
PVWatts Tool	1	Dillon and Colton (2014)
ARTEMIS software tool	1	Maiorino et al. (2021)
MOBILE software tool	1	Maiorino et al. (2021)
The Passenger Car and Heavy-Duty Emission Model (PHEM)	1	Maiorino et al. (2021)
HOMER software	1	Leholo et al. (2022)
Gurobi 6.5 software	1	Erdogan et al. (2017)
Coolpack Software	1	Santos et al. (2021)
COPERT	1	Maiorino et al. (2021)
AirCalculator tool	1	Bassani et al. (2022)
Effective Vaccine Management (EVM) tool	1	Lloyd et al. (2015)
The Handbook Emission Factors for Road Transport (HBEFA)	1	Maiorino et al. (2021)
Consumption-based emissions accounting approach (CBA)	1	Sajid et al. (2022)
TRNSYS Simulation Model	1	Nkwetta et al. (2016)
The Motor Vehicle Emission Simulator (MOVES)	1	Maiorino et al. (2021)
SIM-OPT software tool	1	Sun et al. (2021)
SimaPro (v.8.0.2) software	1	Bassani et al. (2022)

Please see the full reference list of the article. Ashworth B., Plessis M.J., Goedhals-Gerber L.L. & Eeden J., 2025, 'Emissions in pharmaceutical distribution: A systematic literature review of accounting methodologies in supply chains', *Journal of Transport and Supply Chain Management* 19(0), a1150. https://doi.org/10.4102/jtscm.v19i0.1150.

While many of the resources analysed in the SLR mentioned the type of energy and the consumer of energy, it is evident that there is a lack of literature when it comes to energy consumption values, as there were only 17 of the 31 resources (55%) that provided numerical values for energy consumption. Of the 17 resources that referenced transportation as an energy consumer, only five provided energy consumption values related to fuel, as shown in Table 3. Wenyu et al. (eds. 2023) provided fuel consumption coefficient values that were relative to the load being transported: 1 l/km (No-Load) and 2 l/km (Full-Load). Similarly, Bassani et al. (2022) provided fuel consumption values between 25.4 and 31.4 l/100 km (depending on the weight load transported). Oliveira et al. (2023) mentioned the average fuel consumption of vans to be 9 km/litre. On the other hand, Klemeš et al. (2021) considered the refrigeration aspect of road transportation and discussed fuel consumption values of both the refrigeration (5 L of fuel per hour) and engine (0.3 litres per kilometre) components. Li (2023) provided a fuel consumption cost function equation, which is valuable in calculating energy consumption values in the industry. Electricity was referenced by 19 resources as a type of energy; however, only seven resources provided energy consumption values in kilowatt-hour (kWh).

The relationship between energy consumption and emissions depends on the source of the energy, the regulatory frameworks in place and the efficiency of use. The lack of literature on energy consumption values, as shown in the SLR, results in less accurate relationships being drawn between energy consumption and emissions in the pharmaceutical industry.

Emission intensity results

Analysis of emission intensity in the SLR shows that 24 out of the 33 resources (73%) discussed emissions. Table 4 indicates the different types of emissions, the producers of emissions, the mention of fuel emission factors and the emission intensity factors found in the SLR. In the case of emission producers, transportation was the most referenced by twelve of the 24 resources (50%). Other emission producers that stand out from the results shown in Table 4 include refrigeration (equipment, cold rooms and chillers), storage facilities and generators. The most common emission type referenced by 18 of the 24 resources (75%) was carbon dioxide (CO_2), followed by other emissions such as GHG, nitrous oxides (NO_x) and sulphur oxides (SO_x).

Investigating the fuel emission factors in the SLR indicates a significant gap in the literature, as only four of the 24 resources (17%) mentioned any factors in the study. According to (Du Plessis et al. 2024), an emission factor for fuel is a number that indicates how much carbon dioxide equivalent (CO_2e) is released into the atmosphere for every unit of fuel that is consumed. For example, a well-to-wheel (WTW) fuel emission factor for diesel of 3.24 kg CO_2e/l means that, for every litre of diesel burnt, 3.24 kg CO_2e emissions are released. Lloyd et al. (2015) provided the most fuel emission factors, including 2.7 kg of CO_2 per litre of

TABLE 3: Energy type, consumer and consumption values found in the systematic literature review.

Authors	Energy type	Energy Consumption values	Energy Consumer
Lloyd et al. (2015)	Electricity (Solar)	None	Storage, transport
Wu et al. (2023)	None	None	Storage, transport, IoT gateways and devices
Kattakayam et al. (1998)	Electricity (Solar), Fossil Fuel (Diesel: generator backup)	Yes – 1300 Wh per day electricity	Battery discharge, energy collection and demand
Dillon and Colton (2014)	Electricity (solar), Fossil Fuel (natural gas generators)	Yes – Buenos Aires: 44 948 kW h; Mombasa: 54 974 kW h; Asunción: 51 774 kW h; Bangkok: 57 385 kW h; Tunis: 50 221 kW h	Refrigeration systems, HVAC, lighting
Pudleiner et al. (2015)	Electricity (solar, grid)	Yes – Total distribution range. Buenos Aires: 69 926 kW h; Mombasa: 69, 506 kW h; Asunción: 77 593 kW h; Bangkok: 86 027 kW h; Tunis: 108 325 kW h	Refrigeration systems, fans, lighting
Li (2023)	Fossil fuel	Mention of the fuel consumption cost function equation	Transportation, refrigeration
Sajid et al. (2022)	Fossil fuel (aviation fuel)	None	Air transportation
Chowdhury et al. (2022)	Electricity, Fossil fuels	None	Storage, transport, facility operations
Mostafaeipour et al. (2014)	Electricity, Fossil fuel (natural gas), Renewable (Wind)	Yes – 200 m^3/h natural gas (consumed by boiler)	Absorption chiller system
Nkwetta et al. (2016)	Electricity (Solar PV), Thermal (Solar), Fossil fuel (Natural Gas)	Yes – Absorption chiller 125 kWh; mgas consumption values of 2.51 m^3/h and 2.67 m^3/h	Absorption and compression chillers, GAHP-AR-type heat pump
Klemeš et al. (2021)	Electricity (solar, grid), fossil fuel (diesel, gasoline)	Yes – 5 L of fuel per hour for refrigeration and engine's fuel consumption of 0.3 litres per kilometre, 11.96 L per kilometre for air cargo transportation, 0.14 kWh per kilogram of dry ice, Total estimated energy consumption: 2.5×10^8 kWh global estimate for sufficient vaccination. 0.69 kWh per dose global estimate	Refrigerated transport and storage, dry ice manufacturing
Pambudi et al. (2022)	Electricity (mention of solar generation system)	None	None
Sun et al. (2021)	Fossil fuel (nothing stated for UAV)	None	Road transport, UAV (drone batteries)
Oliveira et al. (2023)	Fossil fuel	Yes – average fuel consumption of the vans is set at 9 km/litre	Road transport
Guilbert and Vitale (2021)	Electricity	None	Hydrogen production process
Vamza et al. (2021)	Heat (thermal conductivity)	Yes – 0.04 W/m/K (threshold) for thermal conductivity	Packaging materials
Santos et al. (2021)	Electricity	Yes – Vaccine refrigeration system for Brazil and USA – EUED (kWh/yr), MWh/year, energy consumption per year (kWh p.a.)	Refrigeration systems
Maiorino et al. (2021)	Thermal, electricity (solar PV on vehicle rooftop), LCO_2, LNG, fossil fuel (diesel)	Yes – Using a battery to replace the diesel engine can reduce fuel consumption by 3105 kg/year, 0.3 kg/100 km (hydrogen consumption), consumption required is 64.3 kg/h for LCO_2	Refrigeration systems, VCR systems, PCMs, auxiliary power units, cryogenic systems, electric power systems
Maloney (2003)	Electricity (direct current)	None	Coolers require refrigeration, voltage DC-operating conveyors, DC-powered rollers, sliding-shoe shipping sorter (DC motor)
Gebretnsae et al. (2022)	Electricity	None	Refrigerators
El Mokrini et al. (2022)	None	None	Storage, transport
Santos et al. (2022)	Electricity	Yes – energy consumption [kWh/day], kWh/yr., energy consumption per year (kWh p.a.), 2294.80 kWh, vaccine EUED [MWh/yrs]	Vaccine coolers, cold rooms used for refrigeration
Bassani et al. (2022)	Electricity, fossil fuel	Yes – 16 Wh per packaging, between 25.4 and 31.4 ℓ/100 km, was calculated (depending on the weight load transported).	Packing process, production of PVC sheet and aluminium foil, transportation, train
Sprague et al. (2011)	Fossil fuel (liquefied petroleum gas [LPG])	None	Health clinics (refrigeration, lighting, sterilisation), households, commercial and industrial consumers
Chen et al. (2021)	Electricity (solar, wind, grid), gas (LMG, LO2, LN2), fossil fuel (diesel)	None	Generators, batteries, HVAC, chiller/cooler units
Erdogan et al. (2017)	None	None	Transport
Leholo et al. (2022)	Electricity (solar, wind), fossil fuel (diesel)	Yes – 50 kWh/m^3/year (for the facility), daily energy consumption 240 kWh	Evaporator fans, condensers, electric defrost, lighting, compressors, generators, batteries, other refrigeration
Wenyu et al. (eds. 2023)	Fossil fuel	Yes – 1 ℓ/km (No- Load fuel consumption coefficient), 2 ℓ/km (full-load fuel consumption coefficient)	Transport, refrigeration
Ji et al. (2024)	Electricity, thermal	Equation that mentions electric energy consumed by annual operation of CRS in TEWI analysis, kWh; power consumption for different refrigerant pairs (kW)	HTC and LTC compressors
Sindhwani et al. (2023)	None	None	Transport
Morais et al. (2022)	Fossil fuel	Yes – bioplastics: energy content of diesel around 45 MJ/kg	Steam cracking (production of plastics)

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TABLE 4: Emission type, producer, intensity factors and fuel emission factors in the systematic literature review.

Authors	Fuel emission factor	Emissions	Emission producer	Emission intensity factors (quantity)
Lloyd et al. (2015)	Yes – 2.7 kg CO_2 per litre of fuel, 1.64 kg CO_2 per kWh of grid (STEG) electricity, 0.43 kg CO_2 per kWh of solar generated electricity	CO_2	Road transport	None
Kattakayam et al. (1998)	None	None	Generators	None
Li (2023)	None	CO_2	Transportation, refrigeration	None
Sajid et al. (2022)	None	CO_2, GHG	Transportation (Air)	Yes – 8.1 ± 0.30 metric kilotons (kt) of CO_2 for the global air transport of the COVID-19 vaccine for one dose per capita
Chowdhury et al. (2022)	None	GHG	Transport, storage, handling, production	Yes – Environmental impacts of transporting one unit of each packaged vaccine from source to destination
Mostafaeipour et al. (2014)	None	None	Absorption chiller system	None
Nkwetta et al. (2016)	None	CO_2, GHG	Natural gas boilers, conventional cooling technologies	Yes – 815 g of CO_2/kWh (grid electricity production system)
Klemeš et al. (2021)	Yes – 33 t of CO_2 for 10.7 t of fuel burned in air transportation	CO_2, methane (CH4) and nitrous oxide (N_2O), nitrogen oxides (NO_x) and sulphur oxides (SO_x)	Transportation, storage	Yes – 329 g CO_2 eq per dose globally
Sun et al. (2021)	None	CO_2	Road transport, UAV	Yes – CO_2 emissions of the UAV were set to 40 g/km, CO_2 emissions for small box van 155 g/km, small refrigerated truck 213 g/km
Oliveira et al. (2023)	None	CO_2	Transport	Yes – CO_2 emissions at 200 g/km
Guilbert and Vitale (2021)	None	CO_2	Transport and industry sectors	Yes – 36.4 g CO_2eq/MJ H2, 8 g CO_2eq/kWh for photovoltaic systems.
Vamza et al. (2021)	None	Carbon footprint	Packaging materials	Yes – 64.98 kg of CO_2eq per m^3 expanded polystyrene (polystyrene carbon footprint)
Santos et al. (2021)	None	CO_2	Refrigerant leaks, fossil fuels used to generate electricity, refrigeration equipment	Yes – Brazil: 0.088 kg CO_2/kWh, USA: 0.417 kg CO_2/kWh
Maiorino et al. (2021)	None	CO_2, NO_x, hydrofluorocarbons, particulate matter	Vehicle engines, refrigeration units, auxiliary diesel units, cryogenic systems, thermal energy recovery systems, fuel cell systems	None
Schmit et al. (2024)	None	CO_2	Dry ice	None
Santos et al. (2021)	None	CO_2, GHG, other 'Refrigerant release'	Vaccine coolers, cold rooms used for refrigeration, equipment, fossil fuel systems	Yes – indirect emission factor (kg CO_2/kWh), global warming potential relative to CO_2 (GWP CO_2)
Bassani et al. (2022)	None	None	Transportation	Yes – g CO_2 eq (Global warming)
Sprague et al. (2011)	None	CO_2, other 'air pollutants' from burning of biomass fuels	Households, health clinics	None
Chen et al. (2021)	None	CO_2, GHG	Fossil-fired power plants, diesel generators, natural gas turbines	Yes – 755.86 g of CO_2 per kWh (coal), 61.00 g of CO_2 per kWh (solar), 31.36 g of CO_2 per kWh (wind)
Leholo et al. (2022)	None	CO_2, NO_x	Generator	Yes – kg of CO_2 per kWh
Wenyu, Z., Xinru, L., Yunrui, Y.	Yes – Carbon emission coefficient – 3.21 kg/l	CO_2	Transport (including refrigeration)	None
Jiang et al. (2021)	None	GHG footprints	Transportation, storage	None
Ji et al. (2024)	None	CO_2 (direct and indirect)	Refrigerants, electrical energy	Yes – 0.5810 kg CO_2/kWh, 0.9 kg/kWh (electricity regional conversion factor, kgh CO_2/kWh) TEWI
Morais et al. (2022)	Yes – CO_2 emissions per ton of high-value chemicals (t CO_2/tHVC)	CO_2, methane emissions (CH4), toxic and carcinogenic chemical emissions, chemical CO_2	Production of conventional plastics and bioplastics	Yes – kg CO_2e/kg plastic

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fuel, 1.64 kg CO_2 per kWh of grid electricity and 0.43 kg CO_2 per kWh of solar-generated electricity, while Klemeš et al. (2021) briefly mentioned 33 t of CO_2 for 10.7 t of fuel burned in air transportation. The identification of these fuel emission factors is important for accurate emission tracking, energy management and corporate awareness of the environmental impact of different fuels and energy sources. However, as shown in the SLR, there is an evident lack of fuel emission factors in the resources that assessed the pharmaceutical industry.

Stating emission intensity factors is important for the pharmaceutical industry, as it contributes to achieving sustainability goals and increasing stakeholder transparency, for example. The results from the SLR, as shown in Table 4, indicate that 15 of the 24 resources (63%) discuss emission intensity factors[1] in the study. It is interesting to note how Klemeš et al. (2021), discuss emission intensity factors on the product level

1. Du Plessis (2023), a number that represents the average quantity of greenhouse gas emissions (CO_2e) produced throughout a supply chain activity is called an emission intensity factor.

(e.g. the carbon emitted per dose globally from air transportation), while other resources, such as Sun et al. (2021) discuss the carbon emissions for different transport modes. Chen et al. (2021) discuss emission intensity factors based on different energy sources. This indicates that the emission intensity factors discussed in the SLR are spread out over different parts of the supply chain, while highlighting the lack of literature on emission intensity factors relevant to distribution in the pharmaceutical industry.

Suitable quantification methods

The emissions calculations for two pharmaceutical product distribution chains were illustrated in the 'Introduction' section of this article. Results from the SLR indicated that Klemeš et al. (2021) attempted a similar emissions calculations example; however, this was for the vaccination process. Klemeš et al.'s (2021) initial guess based on statistics estimated the global CO_2 emissions to vaccinate the global population with two doses for each person to be 329 g CO_2e/doses. The scenario for antivenom and the research by Klemeš et al. (2021) both consider air transportation as a mode of transporting pharmaceutical goods. However, the results differ substantially, as the shipment of 1 kg of antivenom from a manufacturer in India to a hospital in South Africa emits 207.78 kg CO_2e. In comparison, the ARV distribution scenario emitted 0.88 kg CO_2e/kg of medicine. This large range of emissions and lack of carbon footprint research emphasises the need for an emission intensity framework in the pharmaceutical industry to improve the accuracy of results.

The results of the SLR indicate a very high level of energy values, as shown in Table 3; however, a key finding is that there are no emission factors specified in the resources to convert energy usage to GHG emissions. This makes it challenging to quantify the emissions associated with the distribution of pharmaceutical products.

Findings from the SLR further indicate that there are not many benchmarked energy consumption values. This limits the ability of organisations and stakeholders to benchmark their environmental performance of pharmaceutical distribution activities over time, which explains the reason for the intense pressure on the pharmaceutical industry to reduce the environmental impacts of supply chain activities.

Need for emission intensity framework in the pharmaceutical industry

The first reason for the necessity of an emission intensity framework is because of the perishable nature of pharmaceutical goods. These products have a limited shelf life and can pose serious health issues to humans if they expire or are compromised because of temperature fluctuations. This inherent characteristic underscores the unique nature of pharmaceutical products and highlights the critical importance of extensive refrigeration and substantial energy demands in their storage and distribution.

The second reason for an emission intensity framework is the inefficient utilisation of storage facilities for pharmaceutical products. Often, a large cold room is used to store only a few boxes of products. This results in unnecessary energy consumption by the refrigeration system and generates more emissions than necessary.

Although there are some similarities between the distribution of pharmaceuticals and other products, the nature or product characteristics of pharmaceutical products are unique. For example, pharmaceutical products require specific cold chain conditions, packaging that results in a different volume–weight ratio compared to other products, different losses in the supply chain, the timely nature of pharmaceutical products, among others. All of these requirements result in the emission intensity of pharmaceutical products' logistics being very different compared to other similar goods, such as fresh fruit.

Recommended framework

Following the SLR, it is evident that there is a lack of a consistent and widely accepted methodology used to assess the emissions of pharmaceutical distribution, resulting in the comparison of emission performances across multiple supply chains becoming an issue. Apart from the GLEC Framework used to quantify emissions in the 'Introduction' section of this article, no other suitable methodology could be found in the SLR for pharmaceutical distribution.

Subsequently, the authors recommended that a framework should account for multiple different factors in the pharmaceutical distribution process, such as:

- The emissions associated with the reverse logistics of empty vehicles and reusable goods containers to their points of origin. These reverse logistics activities are often not accounted for and overlooked in previous literature.
- Tracking the losses from pharmaceutical goods that are disposed of, destroyed, or reprocessed because of temperature breaks in transportation is crucial in the assessment of emissions in the distribution process.
- The storage duration of dry, cooled and frozen pharmaceutical goods impacts energy consumption and emission intensity calculations significantly. The length of time that pharmaceutical goods spend in refrigerated storage facilities and transportation varies depending on the type and urgency of the product.
- The empty movement or partial loading of transport vehicles during deadhead trips or empty repositioning generates higher emissions per unit that should be included in the assessment of pharmaceutical goods distribution.
- The type and amount of packaging used for pharmaceutical goods have an impact on the overall emissions in the distribution process. Some pharmaceutical goods are very temperature-sensitive and require specialised packaging in the form of gel packs during transit, for example. The process of cooling those gel packs impacts the energy

consumption and emissions of the facility and should be included in calculations. Other pharmaceutical products require a significant amount of packing to protect them during transportation, affecting the volume of goods that the relative mode can transport.
- The calculation of emissions based on weight or volume, or a combination thereof, should be considered as no single, universally accepted method is used in the distribution of pharmaceutical goods.
- The differentiation of temperature classes (dry, cooled and frozen) during the distribution of pharmaceutical products should be considered, as energy intensity and emissions vary with the temperature requirements of pharmaceutical goods.

Conclusion

The introductory section illustrated the emissions calculations for two pharmaceutical product distribution chains, one for ARVs and one for snake antivenom. The example analysed that ARVs are exported from the Goa region in India to Tygerberg Hospital in Cape Town, South Africa, while the other example analysed that antivenom is exported from the Mumbai region of India to Tygerberg Hospital in Cape Town, South Africa. The results highlighted the significant variation in different pharmaceutical supply 'chains' GHG emissions, as it can range from 0.88 kg CO_2e/kg pharmaceutical product to 207.78 kg CO_2e/kg pharmaceutical product because of multiple factors that need to be considered. Further, the significant variation in different pharmaceutical supply 'chains' GHG emissions emphasises the need for an emission intensity framework in the pharmaceutical industry to improve the accuracy of results.

A systematic literature review was then conducted to identify the frameworks or methodological approaches that exist for logistics activities in pharmaceutical supply chains, as well as the available energy consumption values and emission intensity factors. Following the SLR methodology in the 'Methods and data' section of this article, a total of 33 resources comprising journal articles, conference proceedings and book sections were included in the qualitative synthesis.

The SLR identified a total of 43 distinct frameworks, methodologies, methods, standards, models, algorithms, problems, or guidelines across the 33 resources. Among the 19 different software packages identified, 16 were referenced only once by a limited number of resources. The low frequency of references underscores the absence of a standardised software choice in the pharmaceutical industry. Investigating the discussion of fuel emission factors in the SLR indicates a significant gap in the literature, as only four of the 24 resources (17%) mentioned any factors in the study, while 63% discussed emission intensity factors in the study. Finally, while many of the resources analysed in the SLR mentioned the type of energy and the consumer of energy, it is evident that there is a lack of literature when it comes to energy consumption values, as there were only 17 of the 31 resources (55%) that provided numerical values for energy consumption.

From the SLR, it is evident that there is no standardised methodology used to assess the emissions of pharmaceutical distribution, as shown by the wide range of methodological approaches mentioned. The absence of specific emission factors to convert energy usage to GHG emissions, along with the lack of an industry-specific standardised framework, makes it challenging to quantify the emissions associated with the distribution of pharmaceutical products, as personal intuition is used. This emphasises the need for future research on developing an emission intensity framework for the pharmaceutical industry.

Future research

Clarity on what the pharmaceutical distribution process looks like and the unique challenges related to the distribution of life-saving pharmaceutical products require future research, as there is increasing pressure to deliver safe and timely products worldwide.

Firstly, future research is needed to assess the uniqueness of the pharmaceutical supply chain with a focus on the urgency of preserving human life as well as the responsiveness and resilience of ensuring the uninterrupted flow of critical medicines.

Secondly, research should be undertaken to assess the storage and handling of pharmaceutical products with a specific focus on the storage durations, as they vary with different products. Research on storage durations will assist researchers in identifying and calculating how emission-intensive specific pharmaceutical products are. Identifying storage conditions alongside the storage duration is also important in ensuring pharmaceutical products maintain their efficacy and quality.

Thirdly, further research should be conducted to assess the modes used in the distribution process of pharmaceutical products and the packaging used to protect these products from environmental factors during transportation.

Lastly, the quantity of pharmaceutical products thrown away or damaged during transport, as a result of improper handling and excursions outside of the required temperature range, requires further research to optimise the distribution process and to minimise waste.

The authors of this paper continued the elements of the proposed research stated above. Ashworth et al. (2025) enable stakeholders in the pharmaceutical supply chain to calculate their carbon emissions because of distribution. The research by Ashworth et al. (2025) developed a methodology for data collection and calculation of company-specific emission intensity factors and recommends typical emission intensity factors for road transport and storage.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

B.A., M.J.d.P., L.L.G.-G. and J.v.E. contributed to the conceptualisation and methodology of the study. Data curation was performed by B.A. and M.J.d.P. Formal analysis was carried out by B.A., M.J.d.P. and L.L.G.-G. Funding acquisition and resources were provided by L.L.G.-G. and J.v.E. The investigation was conducted by B.A., while software development was undertaken by B.A. and M.J.d.P. Project administration, supervision and validation were handled by M.J.d.P., L.L.G.-G. and J.v.E. Visualisation was completed by B.A. The original draft was written by B.A., and all authors, B.A., M.J.d.P., L.L.G.-G. and J.v.E., contributed to the review and editing of the manuscript.

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Data availability

All data used and associated with the study are available in Online Appendix 1.

Disclaimer

The views and opinions expressed in this article are those of the authors and are the product of professional research. It does not necessarily reflect the official policy or position of any affiliated institution, funder, agency or that of the publisher. The authors are responsible for this article's results, findings and content.

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