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Sustainability in the Pharmaceutical Industry: Solutions to Reduce Environmental Impact in Drug Production

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ABSTRACT

The increase in pharmaceutical waste is a global concern due to its impact on the environment and public health. Pharmaceutical waste comes from a variety of sources, including households, healthcare facilities, and the pharmaceutical industry. This research aims to analyze the solutions needed to reduce the environmental impact in drug production. This study uses the Systematic Literature Review (SLR) method using a database from scopus. There are three stages carried out in mapping the analysis of solutions needed to reduce environmental impact in drug production, namely 1) harvesting data, 2) screening data and 3) Data Analysis and Visualization. Based on this step, seven scopus articles were analyzed. Based on research with the SLR method that has been carried out, it can be concluded that the solution to reduce environmental impact in drug production is 1) The Use of Environmentally Friendly Raw Materials, 2) Optimization of the Production Process, 3) More Effective Treatment of Pharmaceutical Waste, 4) Increased Distribution and Packaging Efficiency, 5) Stricter Environmental Regulations and Policies, and 6) Public Education and Awareness. The implications of this research are aimed at researchers and the pharmaceutical industry being more sustainable.

INTRODUCTION

The increase in pharmaceutical waste is a global concern due to its impact on the environment and public health. Pharmaceutical waste comes from a variety of sources, including households, healthcare facilities, and the pharmaceutical industry. Sources and Causes of Pharmaceutical Waste: 1) Household: Many unused or expired medicines are disposed of carelessly, often along with regular household waste, which can pollute the environment (Hiew & Low, 2024; Pibul et al., 2025). The main causes of this waste are non-compliance with prescriptions, oversized packaging sizes, and limited shelf life of drugs after opening. (Louhisalmi et al., 2024; Pibul et al., 2025). 2) Health Facilities: Pharmaceutical waste in hospitals is often caused by changes or cancellations of drug orders, resulting in prepared drugs becoming wasted (Doshi et al., 2025). In hospitals, anesthetic and anti-infective waste is also a significant problem (Doshi et al., 2025; Habte et al., 2024). 3) Pharmaceutical Industry: Waste from the pharmaceutical industry,

including pharmaceutical effluents, contributes to environmental pollution and requires better management (Adetunde et al., 2025; Haque et al., 2024). Therefore the increase in pharmaceutical waste requires serious attention from all parties, including the public, health professionals, and industry. Education, drug return programs, and technological innovation are important steps to reduce the negative impact of pharmaceutical waste on the environment and public health.

Environmental pollution has a wide and significant impact on human health, ecosystems, and the economy. Here are some of the main impacts of environmental pollution, which have an impact on health, economy, ecosystem, and society. Health Impacts in the form of 1) Cardiovascular Disease: Air, water, and soil pollution contributes to an increased risk of cardiovascular diseases such as hypertension, coronary artery disease, and stroke. Mechanisms involved include oxidative stress, inflammation, and endothelial dysfunction(Kumar et al., 2025; Scimeca et al., 2024), 2) Respiratory Problems: Air pollution worsens respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD) (Chen et al., 2024; Iram et al., 2025), 3) Mental Health: Exposure to air, soil, and water pollution can exacerbate mental disorders such as anxiety, depression, and schizophrenia (Tota et al., 2024). For economic impacts in the form of; 1) Economic Losses: Environmental pollution causes significant economic losses, including health costs and decreased productivity (Chen et al., 2024; Fatima et al., 2024). 2) Influence on Economic Growth: Economic growth and the use of natural resources can increase the damage caused by carbon dioxide, which requires policies to minimize its impact (Fatima et al., 2024). For Ecosystem Impact in the form of; 1) Ecosystem Damage: Pollution from the energy and industrial sectors causes ecosystem damage, including a decrease in air and water quality (Rauner et al., 2024). 2) Climate Change: Emissions from the energy sector contribute to climate change, which impacts human health and ecosystems (Rauner et al., 2024). For Social Impact in the form of; 1)Global Inequality: The impact of pollution is heavier felt by developing countries, exacerbating global inequality (Rauner et al., 2024).2) Public Awareness: Increased public awareness and green technology innovation can reduce air pollution (Wang et al., 2024; Yuan et al., 2024). Therefore, environmental pollution has a far-reaching impact on human health, the economy, and ecosystems. Mitigation efforts through public policy, technological innovation, and increased public awareness are essential to reduce these negative impacts.

The need for environmentally friendly solutions is increasingly urgent as awareness of the negative impacts of pollution and climate change increases. Various studies have proposed innovative solutions to address this challenge. Eco-Friendly Solutions in Various Fields in the form of; 1) Textile Waste Treatment: The use of electron mediators from the Rubia cordifolia plant in microbial fuel cells shows improved efficiency of textile waste treatment and bioelectricity production, offering a sustainable solution to reduce water pollution (Tan et al., 2024). 2) Hydrogen Energy Storage: The process of coupling methanol and amine dehydrogenatives offers an environmentally friendly solution for energy storage, although it still faces thermodynamic challenges that need to be overcome (Zhang et al., 2024), 3) Point-of-Care Diagnostic Devices: The development of biodegradable and sustainable diagnostic devices is becoming important to reduce the environmental impact of medical device waste (Gabriel & Batet, 2024), 4) Carbon Capture: Carbon capture, utilization, and storage (CCUS) technologies offer a promising method for reducing CO2 emissions, although challenges related to cost and scalability still exist (Carrascal-Hernández et al., 2025), 5) Graphene-Based Supercapacitors: The use of biodegradable materials such as paper and cork to make graphene-based supercapacitors

demonstrates potential in environmentally friendly energy storage (Silvestre et al., 2024), 6) Mycelium-Based Green Composites: The use of paper waste to improve the properties of mycelium-based green composites shows potential in reducing waste and creating more sustainable materials (Teeraphantuvat et al., 2024), 7) Eco-Friendly Desalination: The use of eco-friendly organic mixtures in desalination systems shows increased efficiency and reduced electricity consumption (Hai et al., 2024). 8) Green Artificial Intelligence: Green AI focuses on reducing computing costs and energy consumption, supporting more sustainable AI practices (Bolón-Canedo et al., 2024) . A variety of eco-friendly solutions have been proposed in various fields, from waste treatment to energy storage and AI technology. While many of these solutions still face challenges in terms of cost and scalability, they offer great potential to reduce environmental impact and support long-term sustainability.

Pharmaceutical waste treatment is an important global issue because of its impact on human health and the environment. Pharmaceutical waste can come from healthcare facilities, including expired drugs, unused doses, and contaminated materials. This waste management requires coordinated efforts from various parties, including policymakers, healthcare providers, pharmaceutical manufacturers, waste management companies, and consumers. Pharmaceutical waste management faces a variety of challenges, including a lack of consumer education regarding proper waste disposal and institutional and behavioral barriers that affect the effectiveness of waste management (Ionescu & Cazan, 2024). In Australia, for example, there is a lack of knowledge among health professionals regarding the environmental impacts of improper disposal of pharmaceutical waste (MacDonald et al., 2024). In addition, inadequate infrastructure also hinders the proper disposal of medications (Hiew & Low, 2024). Various methods have been used to treat pharmaceutical waste, including advanced and biological oxidation processes that can remove pollutants from the aquatic environment(Adeoye et al., 2024) . Valorization techniques, such as the use of pharmaceutical process residues to produce biofuels and biofertilizers, have also been explored to reduce environmental impact and create value-added products (Haque et al., 2024). In addition, research shows the potential for reuse of pharmaceutical waste in other industrial processes, such as the development of cosmetic products (Ciriaco et al., 2024). The use of advanced technologies, such as machine learning, has been implemented to improve pharmaceutical waste management. For example, machine learning models are used to predict waste production profiles and enable preventive measures (Honti et al., 2024). In addition, the pyrolysis-gasification process has been explored to convert pharmaceutical blister waste into fuel gas, demonstrating potential in more efficient waste management (Yao et al., 2024). It can be concluded that pharmaceutical waste management requires a comprehensive and sustainable approach, involving various waste treatment and utilization techniques as well as improving education and infrastructure. By addressing institutional and behavioural barriers, as well as leveraging innovative technologies, pharmaceutical waste management can be improved to reduce negative impacts on the environment and human health (Ionescu & Cazan, 2024; Adeoye et al., 2024; MacDonald et al., 2024).

Environmental regulations and policies play an important role in managing the negative impact of human activities on the environment. These policies are designed to reduce pollutant emissions, encourage innovation, and increase corporate environmental responsibility. Recent studies explore various aspects of environmental regulation, including its impact on corporate operational risk, productivity growth, and social welfare. Well-designed environmental regulations can reduce the operational risks of companies

that pollute the environment a lot. Studies show that the implementation of the New Environmental Protection Law in China in 2015 reduced the operational risks of companies by encouraging innovation and better environmental management. More innovative companies tend to be better able to develop green technologies and build a positive reputation in the market (Li & Li, 2024). Research in the Eurozone shows that stricter environmental policies can have a negative impact on productivity growth, especially for companies that pollute the environment a lot. However, this negative impact is smaller on large companies that have easier access to financing and innovation (Benatti et al., 2024). On the other hand, environmentally-based taxation in China was found to increase corporate productivity by encouraging investment in research and development (Cao et al., 2024). Strict environmental regulations encourage companies to meet their environmental responsibilities. However, economic growth targets can reduce the effectiveness of these environmental policies, especially in state-owned enterprises and companies that face high profit pressures (Wu et al., 2024). Therefore, it is important for governments to balance economic and environmental policies to achieve sustainable green growth. Environmental regulations also have a positive impact on public health and social welfare. Studies show that these regulations can improve public health by increasing individual happiness and employment opportunities, especially among low-educated groups and rural communities (Gao et al., 2024). In addition, these regulations can reduce energy security risks by encouraging the energy transition and the use of renewable energy sources (Aslam et al., 2024). Based on some of the sources above, it can be concluded that environmental regulations and policies have a wide and diverse impact on companies, productivity, and social welfare. While challenges remain, such as balancing economic growth and environmental protection, well-designed regulations can encourage innovation, increase productivity, and improve social well-being. These policies are essential to achieve sustainable development and address global environmental challenges. Therefore, this study was conducted to analyze the solutions needed to reduce the environmental impact in drug production.

METHODOLOGY

This study uses the Systematic Literature Review (SLR) method. SLR is a synthesis of literature studies that are carried out systematically, clearly, and thoroughly. SLRs are often used to conduct thematic analysis, identify key themes and subthemes in the existing literature, and explore current trends and developments (Oladimeji et al., 2020). The purpose of this method is to help researchers understand more deeply about the research being studied, including why and how the results can be used as a reference for new research. In this study, researchers analyzed the solutions needed to reduce the environmental impact in drug production. This study uses a database from scopus. There are three stages carried out in mapping the analysis of solutions needed to reduce environmental impact in drug production, namely:

1. Harvesting Data.. At this stage, the researcher harvested data by collecting articles that had been published and indexed by the Scopus indexing agency. To collect publications from this Scopus indexing institution, researchers directly went to the Scopus database. The search for publications was carried out using keywords in this study, including: "reduce OR the environmental OR impact AND in OR drug OR production" with a time span of 2023-2025. In harvesting this data, it is also based on several countries in Southeast Asia, such as Indonesia, Malaysia, and Singapore.

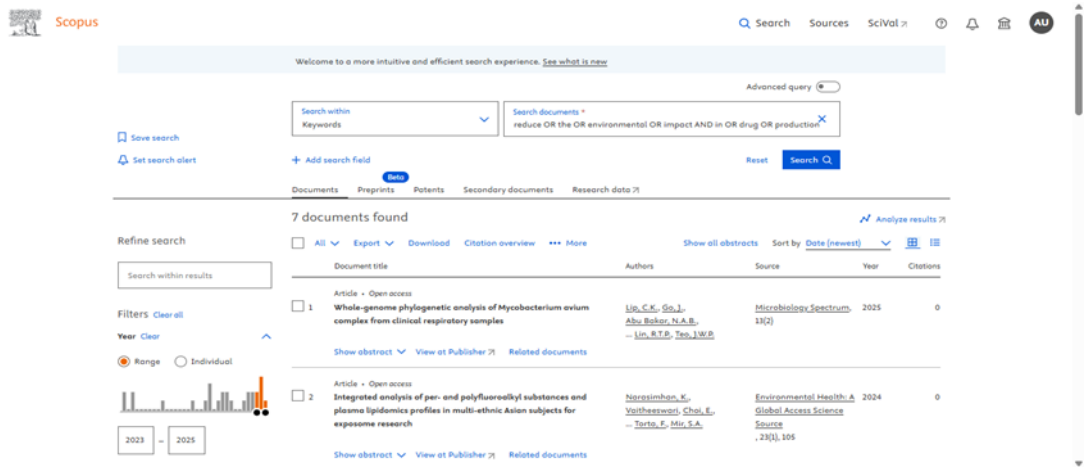

Figure 1. Results of data harvesting 7 articles

From the results of data harvesting, 7 articles were published. Furthermore, the researcher downloads all scientific papers in the form of RIS. Click "Select All", then click "Export" and select "RIS Format". Then it will go to the page as below

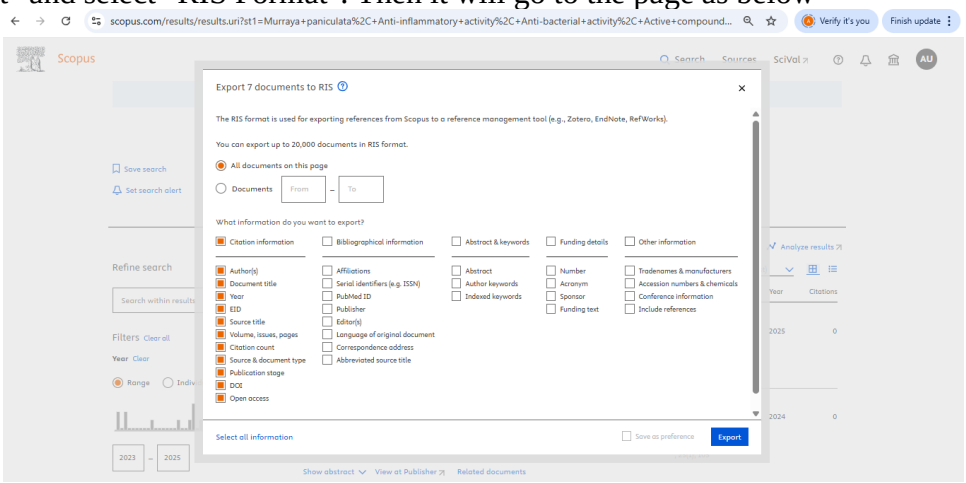

Figure 2. Results of RIS 7 articles

Data Screening. Based on the results of data collection obtained from the Scopus indexing agency, there are 7 article publications related to the analysis of solutions needed to reduce environmental impacts in drug production during the 2023-2025 period. Data Analysis and Visualization.. In this data analysis stage, the researcher conducted an analysis of the publications obtained from Scopus at the time of data harvesting. There are several data related to publications that are analyzed, such as the development of publications per year during the 2023-2025 period. Of the three stages, namely the stages of data harvesting, data filtering and data analysis and visualization, can be described as follows:

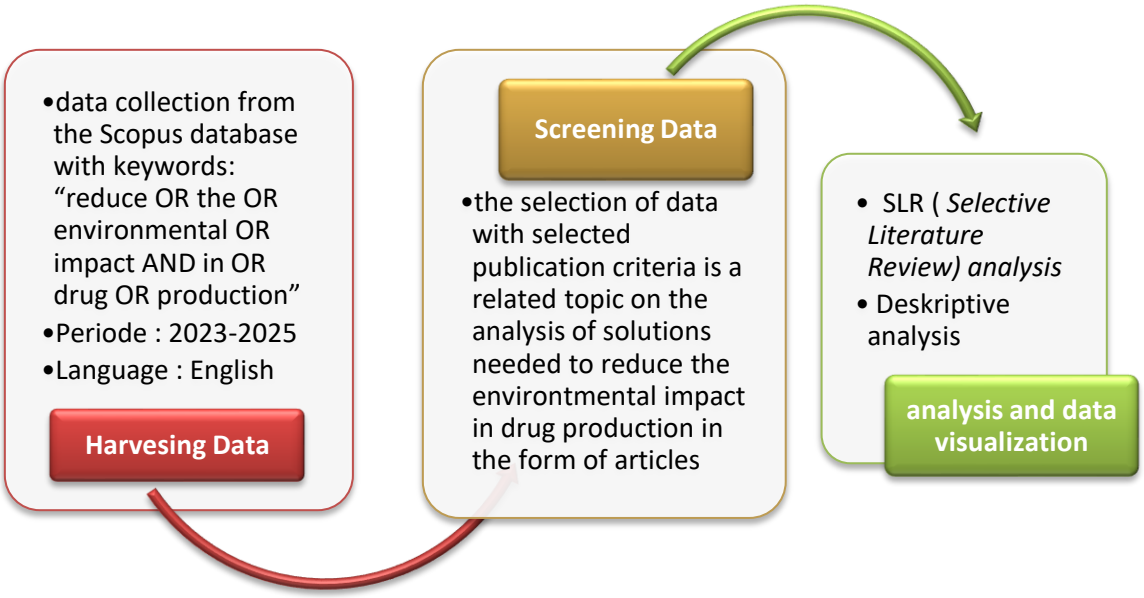

Figure 3. Draft SLR Methodology on Research related to the analysis of solutions needed to reduce environmental impact in drug production

RESULTS AND DISCUSSION

1. Publication Development

The development of publications in the Scopus journal related to the analysis of solutions needed to reduce the environmental impact in drug production during the 2023-2025 period. In 2023, there are 2 journals published. In 2024, there will be a significant increase to 4 journals, indicating a peak in the number of publications in this time span. By 2025, the number of publications will decrease drastically to 1 journal, indicating a possible decline in interest or a shift in research focus. indicates fluctuations in the number of publications...

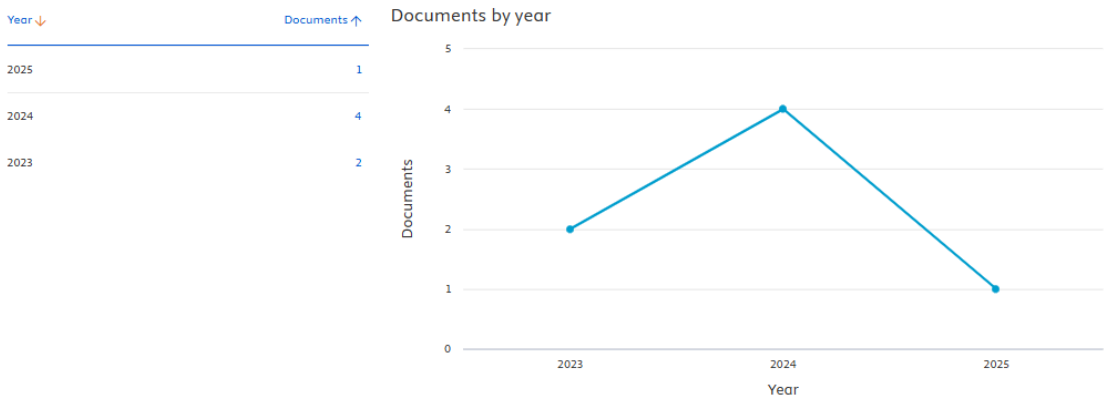

Figure 4. Publication Development Based on Scopus Data for the Period 2023-2025 Data Source : Scopus 2025

The graph above illustrates the list of significant increases (in 2023 to 2024): The surge in the number of journals in 2024 could be due to increased attention to certain research topics or the existence of funding programs that support more research. In addition, there has also been a sharp decline (in 2024 to 2025): A decline in the number of

publications in 2025 may indicate that research in this field has begun to be saturated, resources are reduced, or the focus shifts to other fields. This pattern may reflect dynamics within the area of research being analyzed, such as a temporary increase in interest or a peak in research productivity before stabilizing again.

2. Afiliation of the Country Producing Scientific Work

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The affiliation of the countries producing this scientific work is within the scope of countries in Southeast Asia, such as Indonesia, Malaysia, and Singapore. Based on the graph produced, it shows the distribution of documents based on affiliation. National University became the institution with the highest number of publications, far surpassing any other institution. Institutions such as the NUS Yong Loo Lin School of Medicine and the Sorbonne Université have also made significant contributions to publications. Other institutions such as Folkhalan, Radboud University, and a few others have a smaller number of publications, but still contribute to the research in question.

National University dominates publications, which could indicate that the institution has a strong research focus in a related field, most likely with the support of adequate resources and funding. Several other universities such as NUS Yong Loo Lin and Sorbonne Université also show considerable presence, indicating a strong concentration of research in certain countries or regions. Institutions with a smaller number of publications may still be in the early stages of research development or have limited resources in scientific publications. This indicates that the research related to the documents being analyzed involves international collaboration or has a global scope.

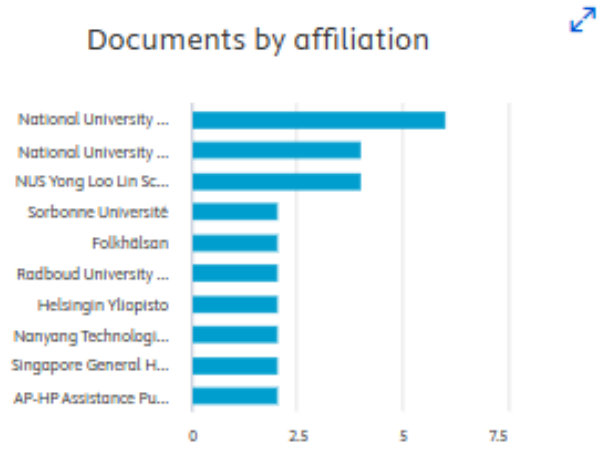

Figure 5. Affiliation of Scientific Paper Producing Countries Based on Scopus
Data Source: Data Scopus 2025

Based on the graph image above, it can be concluded that this graph shows that National University is the institution with the highest number of publications, while other institutions contribute a smaller amount. This pattern indicates the existence of major research centers in a particular topic, as well as opportunities for other institutions to enhance their role through collaboration and research strengthening.

3. Most Cited Articles

Based on the results of harvesting data, data selection (screening data) and data processing on publications related to the analysis of solutions needed to reduce environmental impact in drug production in the Scopus database. During the period 2023 to 2025, there are 7 journal publications related to the analysis of solutions needed to reduce environmental impacts in drug production. From Table 1 below, there are seven journal publications related to the analysis of solutions needed to reduce the environmental impact in drug production.

Tabel 2. Literatur Review Summary

No	Referensi	Judul	Fokus Studi	Metode dan sampel	Hasil
1	(Lip et al., 2025)	Whole-genome phylogenetic analysis of Mycobacterium avium complex from clinical respiratory samples	Whole-genome phylogenetic analysis	Methods and samples: Phylogenomic analysis identified eight subspecies and species.	The study revealed that Mycobacterium avium subspecies hominissuis (MAH) was the most prevalent species, accounting for 72.9% (148 out of 203) of the isolates. The remaining identified species included M. intracellulare subsp. yongonense (8.9%, 18/203), M. intracellulare subsp. chimaera (4.9%, 10/203), M. colombiense (5.4%, 11/203), M. paraintracellulare (3%, 6/203), M. marseillense (2.5%, 5/203), M. intracellulare (1.5%, 3/203), and M. avium subspecies paratuberculosis (1%, 2/203). A notable genetic clustering was identified among the MAH isolates, particularly a large group of 76 isolates sharing the same sequence type and differing by fewer than 12 SNPs. This clustering within hospital environments raises potential concerns about transmission pathways, possibly involving environmental sources.

					Regarding antimicrobial resistance, phenotypic testing based on established breakpoints showed very low resistance rates to clarithromycin (0.5%, 1/203) and amikacin (1.5%, 3/203). However, resistance to linezolid and moxifloxacin was higher, at 25.6% (52/203) and 46.3% (94/203), respectively. Genetic analysis for resistance-associated mutations revealed that only one isolate had the A2059G mutation in the 23S rRNA (rrl) gene, which is linked to macrolide resistance.
2	(Narasimhan et al., 2024)	Integrated analysis of per- and polyfluoroalkyl substances and plasma lipidomics profiles in multi-ethnic Asian subjects for exposome research	Integrated analysis of per- and polyfluoroalkyl substances and plasma lipidomics	Method type: Integrated PFAS and lipidomic analysis. A targeted LC-MS/MS method was developed for the quantification of 14 PFAS from human plasma samples (n = 96)	The findings showed that women exhibited lower PFAS levels than men, and among the ethnic groups studied, Asian-Indians had lower PFAS concentrations compared to both Chinese and Malay participants. Positive correlations were identified between PFAS and several lipid species, particularly those belonging to the lysophospholipid, ceramide, and triacylglycerol classes. In contrast, PFAS levels were inversely associated with phosphatidylinositol, acylcarnitine, and sphingosine-1-phosphate.
3.	(Zhao et al., 2024)	A real-world prospective observational study of eptinezumab in Asian patients with migraine	study of eptinezumab in Asian patients	Methods: This was a non-interventional, prospective, multisite cohort study of adults with migraine	Of the 30 patients enrolled, 29 completed the study. On average, participants had previously tried 3.4 preventive treatments (SD 2.9), with nearly all (29 out of 30) having attempted at least one preventive therapy without success. The

				(International Classification of Headache Disorders, 3rd edition criteria) in Singapore who were prescribed eptinezumab (100 mg at baseline and Month 3, administered intravenously) and were followed until Month 6	majority had used oral preventives (87%, 26/30), and 70% (21/30) had tried anti-CGRP treatments. Compared to baseline, the average number of monthly migraine days (MMDs) significantly decreased by 4.3 days at Month 3 (95% CI: 2.1–6.4; $p < 0.001$) and by 4.9 days at Month 6 (95% CI: 2.1–7.7; $p < 0.001$).
4.	(Dong et al., 2024)	A machine-learning exploration of the exposome from preconception in early childhood atopic eczema, rhinitis and wheeze development	A machine-learning exploration of the exposome	a combined analysis of two multi-ethnic Asian birth cohorts, the Growing Up in Singapore Towards healthy Outcomes (GUSTO) and the Singapore PREconception Study of long Term maternal and child Outcomes (S-PRESTO) cohorts. Interviewer-administered questionnaires were used to collect information on demography,	The final analysis included 1,151 mother-child pairs. The results indicate that childhood diseases may be influenced as early as in the womb, shaped by maternal exposures before and during pregnancy via inflammatory mechanisms. Notably, maternal alcohol intake prior to conception and depressive symptoms during pregnancy emerged as significant modifiable risk factors linked to increased likelihood of eczema and rhinitis in children. The mechanistic model also suggested that elevated levels of maternal blood neopterin and child blood dimethylglycine were associated with reduced risk of early childhood wheezing. Postnatally, early-life infections were identified as major contributors to the

				lifestyle and childhood atopic eczema, rhinitis and wheeze development.	development of atopic eczema and rhinitis.
5.	(Agarwal et al., 2024)	Revised ISHAM-ABPA working group clinical practice guidelines for diagnosing, classifying and treating allergic bronchopulmonary aspergillosis/ mycoses	allergic bronchopulmonary aspergillosis /mycoses	Method: a modified Delphi method (two online rounds and one in-person meeting).	Based on the findings, it is recommended to screen all newly diagnosed adult asthma patients in tertiary care settings for Aspergillus fumigatus sensitization using fungus-specific IgE testing. However, such screening is advised only for children with difficult-to-treat asthma. A diagnosis of allergic bronchopulmonary aspergillosis (ABPA) should be considered in individuals with underlying risk factors or consistent clinical and radiological features, along with confirmed fungal sensitization, a total serum IgE level ≥500 IU/mL, and at least two of the following: positive fungus-specific IgG, elevated peripheral eosinophil count, or indicative imaging results. Allergic bronchopulmonary mycosis (ABPM) should be considered in patients presenting with symptoms resembling ABPA but who test negative for A. fumigatus-specific IgE. For an ABPM diagnosis, repeated isolation of the causative fungus from sputum is necessary. Routine treatment of

					asymptomatic ABPA is not recommended. For acute ABPA cases—whether newly diagnosed or during flare-ups—monotherapy with oral prednisolone or itraconazole is advised. Combination therapy with both drugs is reserved for managing recurrent exacerbations. An objective, multidimensional set of criteria has been developed to evaluate treatment response.
6.	(Chew et al., 2023)	Genomic epidemiology of human candidaemia isolates in a tertiary hospital	Genomic epidemiology of human candidaemia isolates	Method: The resistance mechanisms towards the two most commonly administered antifungals, fluconazole and anidulafungin, were determined. Blood culture isolates between 1 January 2018 and 30 June 2021 positive for Candida spp. were included. Susceptibility testing was performed using Etest.	Whole-genome sequencing was conducted using the Illumina NovaSeq platform, followed by bioinformatics analysis. A total of 203 Candida isolates were sequenced, comprising 56 C. glabrata, 53 C. tropicalis, 44 C. albicans, 36 from the C. parapsilosis complex (including C. parapsilosis, C. orthopsilosis, and C. metapsilosis), six C. krusei, five C. dubliniensis, and three C. auris. Analysis revealed a single cluster of azole-resistant C. tropicalis and four clusters of C. parapsilosis, indicating potential ongoing transmission over multiple years. Notably, 11.3% of C. tropicalis and 52.7% of C. parapsilosis isolates were part of clusters, pointing to a significant role of exogenous sources in transmission, especially for C. parapsilosis. The

					prolonged time span of these clusters suggests environmental reservoirs may be contributing to the spread. In contrast, C. albicans showed minimal clonality, and although certain sequence types were more common in C. glabrata, the wide range of SNP differences suggests no evidence of persistent transmission.
7.	(De Luca et al., 2023)	Gender Difference in the Effects of COVID-19 Pandemic on Mechanical Reperfusion and 30-Day Mortality for STEMI: Results of the ISACS-STEMI COVID-19 Registry	Gender Difference in the Effects of COVID-19 Pandemic on Mechanical Reperfusion and 30-Day Mortality for STEMI	Methods: This retrospective multicenter registry was performed in high-volume primary percutaneous coronary intervention (PPCI) centers on four continents and included STEMI patients undergoing PPCIs in March–June 2019 and 2020.	The primary outcomes assessed were the frequency and timing of primary percutaneous coronary interventions (PPCIs), defined by ischemia duration ≥12 hours and door-to-balloon time ≥30 minutes, along with in-hospital or 30-day mortality. A total of 16,683 STEMI patients who underwent PPCI across 109 centers were analyzed. During the COVID-19 pandemic in 2020, there was a significant decline in PPCI procedures compared to 2019, with an incidence rate ratio (IRR) of 0.843 (95% CI: 0.825–0.861, $p < 0.0001$). No significant gender differences were observed in the pandemic's impact on the number of STEMI cases or mortality rates, as both male and female patients experienced a similar reduction from 2019 to 2020.

Based on table 2, it shows that this research covers various aspects of health, ranging from understanding the relationship between the environment and disease, the effectiveness of treatment, to the development of clinical guidelines. Some studies

highlight infectious diseases such as Mycobacterium avium complex, Candidaemia, and Aspergillosis, while others examine how environmental factors, such as PFAS exposure, can affect human health. The researchers used a variety of approaches, including laboratory experiments, direct observation of patients, genetic analysis, and the use of machine learning technology. The data collected came from various ethnic groups and health institutions, so the results better reflect real conditions in society. The results show that there are certain species of bacteria and fungi that are more dominant and have a typical pattern of antibiotic resistance. Several risk factors for the disease have also been successfully identified, for example alcohol consumption before pregnancy which can increase the risk of eczema and rhinitis in children. On the other hand, there are also therapies that have been shown to be effective, such as eptinezumab that can reduce the frequency of migraines, as well as the best therapy recommendations for ABPA patients. The COVID-19 pandemic has also had a major impact, especially in the number and effectiveness of STEMI interventions, although no significant differences were found by gender. Overall, this study provides broader insights into how the environment, lifestyle, and medicine are interrelated in maintaining health. With a diverse and data-driven approach, the results are expected to help medical personnel and researchers in developing more effective solutions to various health challenges in the future

DISCUSSION

Solutions to Reduce Environmental Impact in Drug Production.

Based on the results of the table analysis, some of the main solutions that can be applied to reduce environmental impact in drug production include: 1) The use of environmentally friendly raw materials; Develop a biotechnology-based synthesis process to replace chemical methods that produce toxic waste. Using natural raw materials or recycled materials to reduce carbon emissions and pharmaceutical waste. Another source said that the development of environmentally friendly drugs using a "benign-by-design" approach encourages the development of pharmaceutical active ingredients (APIs) that are environmentally friendly and safe for patients. It involves dialogue between R&D and environmental scientists to develop tools that integrate environmental sustainability in drug development (Vidaurre et al., 2024). 2) Optimization of the Production Process; Apply green chemistry to minimize the use of harmful organic solvents and reduce carbon footprints. Using sustainable manufacturing technologies such as continuous manufacturing to improve energy efficiency and reduce waste. 3) More Effective Treatment of Pharmaceutical Waste; Develop more advanced waste treatment systems, such as biodegradation techniques and the use of microorganisms to decompose pharmaceutical active substances before they enter the environment. Increase regulations on the disposal of pharmaceutical waste so as not to pollute water sources and soil. Another source said that improving waste management and reducing the impact of company operations is an important step. In addition, centralized production in countries with lax environmental regulations needs to be addressed (Riikonen et al., 2024). 4) Improving Distribution and Packaging Efficiency; Use biodegradable or recyclable packaging materials to reduce plastic waste from pharmaceutical products. Optimizing the distribution chain to be more energy-efficient, for example by reducing carbon emissions from transportation. Use of Life Cycle Assessment (LCA): LCA can be used to identify and reduce the environmental impact of energy consumption and the use of chemicals in drug production. This includes the transition to a sustainable manufacturing platform, the application of green chemistry principles, and process intensification (Chen et al., 2024).

In addition, it can also use Deep Eutectic Systems (DES): DES can replace traditional organic solvents in drug discovery, making them more environmentally friendly and recyclable, as well as reducing production costs (Domingues et al., 2024). 5) Stricter Environmental Regulations and Policies, Encouraging the implementation of stricter environmental standards in the pharmaceutical industry to control emissions and waste. Provide incentives for pharmaceutical companies that implement environmentally friendly production practices. Biological production from (semi) synthetic pharmaceuticals can reduce environmental costs, although the high impact of biologically produced monoclonal antibodies needs to be optimized (Etit et al., 2024). 6) Education and Public Awareness: Raising public awareness about the impact of improper disposal of drugs and how to dispose of drugs safely. Encourage further research on therapeutic alternatives that are more sustainable and have lower environmental impacts. In conclusion, a multi-disciplinary approach that includes technological innovation, strict regulation, and industry and public awareness is needed to reduce the environmental impact in drug production.challenges.

CONCLUSION

Based on research with the SLR method that has been carried out, it can be concluded that the solution to reduce environmental impact in drug production is 1) The use of environmentally friendly raw materials, 2) Optimization of the production process, 3) More effective treatment of pharmaceutical waste, 4) Improvement of Distribution and Packaging Efficiency, 5) Stricter environmental regulations and policies, and 6) Public Education and Awareness

Research Implications

The implications of this research are;

1. For Researchers

   The results of the research can be the foundation for future research in exploring new technologies, such as pharmaceutical nanotechnology, pharmaceutical waste bioremediation, or renewable energy-based production systems. Can encourage interdisciplinary research with other fields such as environmental engineering, biotechnology, and public policy
2. The Pharmaceutical Industry is More Sustainable

This research can encourage the pharmaceutical industry to implement more environmentally friendly production methods, such as the use of safer raw materials, production processes that produce less waste, and recycling technology in drug manufacturing.

LITERATURE

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