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A Study for Analysing the Framework for Solvent Recovery, Reuse and Recycling in the Pharmaceutical Sector

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***Abstract*— This research uses empirical statistical approaches to quantitatively analyse a structured framework for solvent recovery, reuse, and recycling (RRR) in the pharmaceutical industry. A standardised 5-point Likert scale questionnaire measuring environmental effect, operational efficiency, cost savings, investment levels, and regulatory compliance was utilized to gather information from 399 respondents in 20 stratified pharmaceutical organisations. T-tests, regression, and correlation analyses were performed using SPSS, which validated each of the four hypotheses that were put out. The findings showed that businesses using advanced solvent RRR methods benefited economically, operationally, and environmentally. These advantages included lower costs, more efficiency, and less of an effect on the environment. High reliability (Cronbach's Alpha, Composite Reliability) and validity (AVE, KMO, Bartlett's test) assessments corroborated the data's resilience. The research provides a useful framework for improving operational and environmental performance in the pharmaceutical business and emphasises the strategic importance of structured solvent management in advancing sustainability.**

***Keywords*— Solvent Recovery, Solvent Reuse, Solvent Recycling (RRR), Pharmaceutical Industry, Environmental Impact, Operational Efficiency.**

I. INTRODUCTION

The pharmaceutical and fine chemical sectors' waste creation from inefficient processing and poor solvent selection has raised apprehensions regarding ecological and health safety. Up to 90% of the process by mass may be attributed to the use of solvents, which are often discarded after just one use. Laws have been passed to assist the environmental effort because of unintentional harmful emissions into the environment and risks to workplace safety [1]. Because of the potential for contamination, the pharmaceutical sector generally does not reuse solvents. Rather, the Used solvents are sold to fuel blending companies, incinerators, and businesses with laxer restrictions [2]. The most popular way of disposing of solvents, incineration, is not seen as "green." Accordingly, recovery techniques are being explored to enhance the sustainability and environmental friendliness of operations in the fine chemical and pharmaceutical sectors. In order to find economic, environmental, and process efficiency indicators, many novel greenness analysis techniques were created in the last ten years [3]. There hasn't been an integrated approach that takes into consideration aspects related to the environment, safety, and economy, despite the fact that these techniques may finally result in sustainability and increase process efficiency and cost.

The pharmaceutical industry contributes. gigatons of carbon dioxide (CO_2), or 4.4% of world net emissions. The largest contributors to these emissions are the United States, China, and the constituent nations of the European Union (EU). The pharmaceutical industry is seen as an above-average emitter per capita, accounting for 4.8% of the national net emissions when considering the local situation. The pharmaceutical sector was predicted to have created 52 million metric tonnes of CO_2 emissions worldwide as of 2015 [4].

Since the 1970s, it has been known that drugs are present in the environment. One of the main causes of pharmaceutical contamination is the pharmaceutical industry. The identification regarding active pharmaceutical ingredients (APIs) and their by-products in soil, water, including surface and ground water, and the atmosphere is referred to as environmental pharmaceutical pollution. The impact of pharmaceutical goods is contingent upon their type, toxicity, half-life, duration of exposure, and environmental concentrations [5]. The issue of cross contamination is one of the main reasons solvent recoveries is seldom carried out in pharmaceutical manufacture. Up until the early 1990s, solvent

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recovery was carried out at the Snäckviken location.
It was carried out at a solvent recovery facility known locally as "The church." Five batch distillation columns were used to recover the main solvents. There could be remnants of other compounds in the recovered solvents that might contaminate the API [6]. The solvent recovery was halted because API production requires rigorous quality compliance.

II. Literature Review

[7] emphasised the need of sustainable development, switching to renewable energy, and using environmentally friendly chemicals in the pharmaceutical industry. Among the primary elements affecting the healthcare sector's severe environmental problems are energy used and chemical used. Adopting green chemistry concepts, putting process intensification strategies into practice, and switching to continuous manufacturing platforms are all examples of process optimisation options. However, there are still unanswered questions about supply chain tactics, biopharmaceuticals, and medication recycling.

[8] purposed, this study introduced a comprehensive methodology at the systems level, including many approached that may be used to develop and assess effective solvent recovery paths. Reclaiming waste solvent for reuse was a very effective option for enhancing the environmental sustainability of industrial operations. In light of the growing emphasis on sustainability to advance a circular economy, it is essential to use solvent recovery techniques in the chemical sector. Nevertheless, the methodical development of recovery procedures was a formidable challenge because of the intricacies linked to the composition of waste streams, technological-economic evaluation and ecological evaluation. Moreover, the difficulties to meet the required product criteria, especially in the pharmaceutical and specialised chemical sectors, might further discourage the rehabilitation and reusing of solvents.

A. Development of Hypothesis

H1: Pharmaceutical companies that implement advanced solvent recovery and recycling practices experience significantly lower environmental impact compared to those that do not**.**

[9] examined the effectiveness of Romanian chemists in gathering, getting rid of, and recycling pharmaceutical waste. Effective waste management was also impacted by behavioural and institutional constraints, which are identified. Exploratory factor analysis, cross-tabulation, Pearson's chi-square test, and qualitative analysis utilising the Delphi approach were among quantitative and qualitative methodologies employed in the study. According to the research, technical, financial, and regulatory factors, as well as organisational and human attitudes, had a major role in choosing effective waste management strategies. In addition to offering useful implications for creating sustainable pharmaceutical waste policy, the study proposed a thorough strategy for removing obstacles that combines institutional and community-focused behavioural tactics.

[10] Sustainable materials development was becoming more and more important to the pharmaceutical business in an effort to reduce environmental effects over their life cycle. There aren't many chances to lessen the negative effects that drug used and disposal had on the environment, however. Because of environmental concerns and legal obligations, the sector was under pressure to incorporate sustainable practices. A crucial component of this change was materials sustainability, which emphasises sparing the environment and utilising resources responsibly. Adopting green chemistry concepts, utilising biodegradable materials, and creating environmentally friendly package designs are important tactics. Regulatory complexity and the need for cooperation between parties are obstacles. A comprehensive strategy that incorporates supply chain management and product development is necessary to attain sustainability, support global climate objectives, and guarantee long-term profitability.

H2: The adoption of a structured framework for solvent recovery, reuse, and recycling leads to increased operational efficiency and cost savings in pharmaceutical industries.

[11] provided a summary of methods that had the potential to be helpful when choosing solvents for the first phases of developing a process to synthesise APIs. Features of the approached are examined, as was their suitability for early phases. It was acknowledged that the best time to identify advantages and problems with solvent usage was in the early phases of development. For the purpose of evaluating and choosing solvents in pharmaceutical processes, the "system" idea was presented; nevertheless, it appears not to be extensively used in the speciality chemicals and pharmaceutical sectors at this time. System analysis has been regarded as a crucial instrument for taking a comprehensive approached to solvent selection.

[12] Pharmaceutical trash comprises leftover drugs, non-prescription personal care products, as well as intermittently sharps, test strips, and various provisions. Concerns arise because it threatens human and environmental health. Pharmaceutical waste from hospitals, clinics, pharmacies, and households must be handled carefully due to its risks. Pharma waste management has several issues. covered waste categories, regulatory agencies, and waste management strategies in this study. Heavy metals, endocrine disruptors, and other substances in certain medications harm animals and the environment. People who abuse drugs might potentially get their hands on inadequately regulated trash. To securely handle and disposed of garbage, you must understand its dangers and how a disposal method may handle them.

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H3: The level of investment in solvent recovery technologies is positively correlated with the effectiveness of solvent reuse and recycling efforts in pharmaceutical industries

[13] A software toolkit has been created to lower operational expenses and the environmental effect of producing active pharmaceutical ingredients (APIs). In order to separate binary waste mixes, fractional distillation and pervaporation were taken into consideration while evaluating the viability of a compact, flexible skid that could recover numerous solvent waste streams. To optimise operational cost savings and environmental impact reductions, the ideal distillation reflux ratio and intake stage were identified. Compared to conventional heuristics, ideal reflux ratio was much higher, leading to cost and emissions savings of up to 59% and 43%, respectively. Increasing profitability depends on the skid's capacity to recover solvent waste streams with varying volumes and thermodynamic types. To illustrate the tool's potential in green engineering decision making, Pfizer provided four case examples.

[14] presented a Computer Aided Molecular Design (CAMD) framework that evaluates both the solute extraction and solvent recovery processes concurrently in the solvent design. The selection a solvent possesses a crucial function not solely in determining efficiency regarding procedure, but also in its implications for safety, well-being, and ecological consequences. Furthermore, the power needed for the renewal of solvents is contingent upon both the selected solvent and the methods used for its recovery. Hence, we have included physicochemical characteristic objectives, safety, health, and environmental (SHE) considerations, the necessary utility expenses for solvent recovery in the design phase.

H4: Companies that follow best practices in solvent management are more likely to achieve compliance with environmental regulations and sustainability goals.

[15] examines two ideas that are used to lessen the effects on the environment and enhance the environmental performance of industrial operations. In many nations, the Best Available Techniques (BAT) idea serves as the primary regulatory one, but the European Union (EU) promotes the Best Environmental Management Practices notion as a voluntary approach. In order to attain the highest environmental performance, BEMP is thought to be the most efficient method of implementing the Environmental Management System (EMS). The European Commission (EC) determines the priority sectors for SRD, which include public administration, tourism, and telecommunications in addition to "heavy" industry sectors governed by BAT-related laws. There are several instances of BEMP being used by Russian businesses. Several of them create BEMP as voluntary EMS processes that are pertinent to the Sustainable Development Goals (SDGs).

[16] examined the environmental management strategies, goals, and attitudes of the pharmaceutical industry in Lebanon. It also looked at the factors that encourage, hinder, and motivate the voluntary application of the ISO 14001 Environmental Management System. The industries' notable ignorance of the norm was discovered during a semi structured in-depth interview. The primary motivations for implementing ISO 14001 are enhancing the company's reputation and navigating global commerce. However, obstacles include a lack of legal enforcement and government assistance. The pharmaceutical businesses in Lebanon do not see prioritising the adoption of the ISO 14001 standard; instead, they place more emphasis on quality and safety concerns. In emerging nations, the research highlights the need of regulatory frameworks and enforcement.

B. Research Gap

Significant research gaps still exist despite the fact that solvent recovery, green chemistry, and sustainability in the pharmaceutical sector have been the subject of several studies. A comprehensive paradigm that integrates solvent recovery, reuse, and recycling with quantifiable gains in operational efficiency, financial savings, and regulatory compliance is lacking. Although studies have been conducted on individual strategies like solvent selection, environmental management systems, and sustainable materials, little is known about how these strategies work together to affect sustainability as a whole. There is also a dearth of empirical data relating real environmental results to monetary investments in solvent recovery systems. Although institutional, behavioural, and regulatory constraints are acknowledged, there is a lack of work on developing integrated policy or organisational methods to address them. It is also necessary to investigate the function of early solvent selection and its long-term effects on recovery efficiency. The absence of a comprehensive, scalable model that is suited to various pharmaceutical settings impedes the industry's advancement towards attaining sustainability and circular economy objectives.

III. METHODOLOGY

A. Research Design

The methodology of the research utilized a quantitative analysis to investigated A study for analyzing the structure for solvent reclamation, reutilization and recycling within the pharmaceutical sector by statistical empirical analysis. To guarantee statistical analysis was used to methodically gather and examine data from a representative sample of 399 respondents. A standardized questionnaire with 5-Likert-scale questions to evaluate respondents' structured Environmental impact, Adoption of a structured framework for solvent RRR, Operational efficiency, Cost savings, Level of investment in solvent recovery technologies, Effectiveness of solvent reuse and recycling efforts, Practices in solvent management, Environmental regulations and sustainability goals was employed to gather data. The Statistical Package for the Social

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Sciences, commonly referred to as SPSS, was utilized in study to analyze the data. For T-test, Regression Analysis and Correlation was utilised to evaluate the proposed hypotheses and examined the correlations between the primary variables.

B. Objective

1) To evaluate the strengths and limitations of the current solvent reclamation, reusing, and recycling practices in pharmaceutical sectors.
2) To evaluate the economic and ecological consequences regarding pharmaceutical solvent reclamation and recycling initiatives.
3) To identify and document the most effective methods and innovative technologies for solvent management that are employed by the most prominent pharmaceutical companies.
4) To suggest a structured framework that pharmaceutical industries can implement to improve their solvent recovery, reuse, and recycling initiatives.
5) To validate the proposed framework through expert feedback and case studies, ensuring its practical applicability.

C. Sample Selection

The research employed a sample size of 399 respondents, ensuring a representative dataset for analysis. A purposive A stratified random sampling method approached could be employed to choose a pattern of 20 pharmaceutical organizations based on their size, production ability, and geographic area. Companies could be selected to ensure a consultant mix of these presently working towards solvent restoration and recycling and people no longer yet enforcing such techniques.

D. Data Collection

This study utilizes a quantitative methodology, implementing systematic data gathering techniques to guarantee precision and dependability. The questionnaire encompasses essential characteristics such credit approval experience, evaluated through several Likert-scale statements to thoroughly capture respondent impressions. Conducting interviews with key stakeholders in pharmaceutical industries, including environmental managers, manufacturing supervisors, and nice control experts, to gather insights on current solvent management practices. Participants were requested to assess factors like data structured Environmental impact, Adoption of a structured framework for solvent RRR, Operational efficiency, Cost savings, Level of investment in solvent recovery technologies, Effectiveness of solvent reuse and recycling efforts, Practices in solvent management, Environmental regulations and sustainability goals. The questionnaire was disseminated online by email, Google Forms, and fintech lending platforms to guarantee extensive participation and accessibility. secondary data from government publications, published studies, and institutional records will be added to the main data. Distributing the questionnaires to a broader variety of industry professionals to acquire quantitative statistics on the effectiveness, demanding situations, and fees related to present day solvent healing and recycling tactics. Reviewing research of pharmaceutical agencies which have effectively implemented solvent restoration and recycling applications to pick out elements contributing to their fulfilment.

E. Measures

Information has been gathered using a structured questionnaire. Questionnaire has been prepared using 5 Likert-scale (Strongly disagree to Strongly agree) where respondents will be asked to share their opinions regarding various research questions under study. Questionnaire has a set of both open ended and closed ended questions. Questions have been carefully crafted so as to gather meaningful information with respect to identified research variables. There are five categories of respondents in the survey and a separate questionnaire has been designed for each category of respondents.

IV. RESULTS

A. Demographic Variables

The demographic background of the study's respondents indicates a proportional gender representation, with 51.1% male, 48.9% female participants from a total of 399 respondents. The age cohort of 36–45 years comprised the predominant segment at 37.3%, followed by 25–35 years at 32.8%, and 46–55 years at 29.8%, reflecting a balanced representation among mid-career professionals. The majority had doctorate degrees (34.8%), followed closely by bachelor's degree holders (34.3%) and master's degree holders (30.8%), indicating a highly educated group. In terms of professional duties, 53.9% of respondents identified as production managers, whilst 46.1% identified as environmental managers, so providing views from both operational and environmental compliance viewpoints within the pharmaceutical industry.

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TABLE I
DEMOGRAPHIC VARIABLES

Demographic Variable	Category	Frequency	Percentage (%)
Gender	Male	204	51.1
	Female	195	48.9
	Total	**399**	**100.0**
Age	25-35 Years	131	32.8
	36-45 Years	149	37.3
	46-55 Years	119	29.8
	Total	**399**	**100.0**
Educational Qualification	Bachelor's	137	34.3
	Master's	123	30.8
	Doctorate	139	34.8
	Total	**399**	**100.0**
Designation/Role	Production Manager	215	53.9
	Environmental Managers	184	46.1
	Total	**399**	**100.0**

B. Factor Analysis

TABLE II
KMO AND BARTLETT'S TEST

Test	Statistic	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.913
Bartlett's Test of Sphericity	Approx. Chi-Square	6571.019
	df	435
	Sig.	.000

KMO and Bartlett's tests evaluate the appropriateness for factor analysis. The KMO value obtained was 0.913, signifying high sampling adequacy, and the Bartlett's test was highly significant (P = 0.00), corroborating the factor analysis.

TABLE III
RELIABILITY AND VALIDITY OF CONSTRUCTS

Construct	Cronbach's Alpha	Composite Reliability	AVE
Environmental impact	0.893	0.834	0.692
Adoption of a structured framework for solvent RRR	0.920	0.744	0.527
Operational efficiency	0.851	0.813	0.644
Cost savings	0.800	0.825	0.671
Level of investment in solvent recovery technologies	0.869	0.764	0.800
Effectiveness of solvent reuse and recycling efforts	0.873	0.832	0.688
Practices in solvent management	0.914	0.856	0.755
Environmental regulations and sustainability goals	0.883	0.826	0.673

The research confirmed good construct validity and internal consistency by assessing the reliability and validity of measuring constructs using Composite Reliability (CR), Average Variance Extracted (AVE), and Cronbach's Alpha. All Cronbach's Alpha values were higher above the acceptable level of 0.7, ranging from 0.800 for cost savings to 0.92 for structured solvent recovery, reuse, and recycling (RRR) approaches, showing good reliability. All constructs had CR values more than 0.7, including 0.856 for solvent management approaches and 0.833 for environmental effect, which confirmed internal consistency. Additionally, AVE values above the 0.5 threshold, indicating convergent validity. Notably, investment in solvent recovery technology had the greatest AVE (0.800), indicating that the construct explained a considerable percentage of the variation. These findings support the measurement model's robustness, providing a solid framework for additional structural analysis and interpretation of correlations between variables linked to solvent recovery and sustainability in the pharmaceutical business.

C. Hypothesis Development

H1: Pharmaceutical companies that implement advanced solvent recovery and recycling practices experience significantly lower environmental impact compared to those that do not.

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TABLE IV
INDEPENDENT SAMPLES T-TEST FOR ENVIRONMENTAL IMPACT (H1)

Variable	Implement advanced solvent recovery and recycling practices	N	Mean	F	Sig.	t	df
Environmental impact	Have adopted advanced solvent recovery and recycling practices.	241	3.795	51.742	0.000	5.916	242.74
	Have not adopted advanced solvent recovery and recycling practices.	158	3.2652				

Table IV presents the group data, which indicate that companies using advanced solvent recovery and recycling techniques (N = 241) had a superior mean score for reduced environmental effect (Mean = 3.795) relative to those without such practices (N = 158; Mean = 3.2652). The F-value recorded was 51.742, with a significance level (Sig.) of 0.000, denoting a statistically significant disparity in environmental effect among the 2 groups. The independent samples t-test yielded a t-value of 5.916 with 242.74 degrees of freedom, so confirming the statistical significance of the difference. The findings indicate that enterprises using modern solvent recovery and recycling methods have markedly reduced environmental effect. Consequently, Hypothesis H1 is fulfilled.

H2: The adoption of a structured framework for solvent recovery, reuse, and recycling leads to increased operational efficiency and cost savings in pharmaceutical industries.

TABLE V
REGRESSION ANALYSIS FOR OPERATIONAL EFFICIENCY AND COST SAVINGS (H2)

Independent Variable	Dependent Variable	R Value	R Square	F	Unstandardized Coefficients	t	Sig.	Hypothesis
Adoption of a structured framework for solvent RRR	Operational efficiency	0.261	0.068	29.06	1.094	5.391	0.000	**ACCEPTED**
	Cost savings	0.302	0.091	39.937	1.126	6.32	0.000	

Table V illustrates the regression analysis, which indicated a favourable association between the implementation of the structured RRR framework and the dependent variables. The R value for operational efficiency was 0.261, with a R Square of 0.068, denoting about 6.8% of the variance in operational efficiency is attributable to the implementation of the structured framework. The F-value of 29.06 and a substantial p-value (Sig. = 0.000) validate the model's overall relevance. The unstandardized coefficient (B = 1.094) and a t-value of 5.391 reinforce the robustness of this association. For cost savings, the R value was 0.302, R Square was 0.091, and the F-value was 39.937, with a coefficient of 1.126, a t-value of 6.32, all statistically significant at the 0.000 level. The data demonstrate that the systematic use of solvent RRR techniques enhances operational efficiency and reduces costs. Consequently, Hypothesis H2 is fulfilled.

H3: The level of investment in solvent recovery technologies is positively correlated with the effectiveness of solvent reuse and recycling efforts in pharmaceutical industries.

TABLE VI
CORRELATION BETWEEN INVESTMENT IN SOLVENT RECOVERY TECHNOLOGIES AND EFFECTIVENESS OF REUSE AND RECYCLING (H3)

Correlation		
	Level of investment in solvent recovery technologies	**Effectiveness of solvent reuse and recycling efforts**
Level of investment in solvent recovery technologies	1	
Effectiveness of solvent reuse and recycling efforts	.552**	1
**. Correlation is significant at the 0.01 level (2-tailed).		

Table VI displays the correlation analysis, which indicated a Pearson correlation value of 0.552, denoting a moderate to strong favourable correlation between the two variables. This represents that an increase in investment in solvent recovery technology enhances the efficacy of solvent reuse and recycling initiatives. The relation is statistically significant at the 0.01 level (two-tailed), demonstrating dependability of this relationship. These data corroborate the premise that increased investments in solvent recovery technology improve the efficacy of solvent reuse and recycling efforts. Consequently, Hypothesis H3 is fulfilled.

H4: Companies that follow best practices in solvent management are more likely to achieve compliance with environmental regulations and sustainability goals**.**

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TABLE VII
REGRESSION ANALYSIS FOR ENVIRONMENTAL REGULATIONS AND SUSTAINABILITY GOALS (H4)

Independent Variable	Dependent Variable	R Value	R Square	F	Unstandardized Coefficients	t	Sig.	Hypothesis
Practices in solvent management	Environmental regulations and sustainability goals	0.614	0.377	239.904	0.56	15.489	0.000	**ACCEPTED**

Table VII shows the regression analysis, which demonstrated a robust positive correlation, shown by a R value of 0.614, denoting a significant link between the independent and dependent variables. An R Square value of 0.377 indicates that around 37.7% of the variation in adherence to environmental rules and sustainability objectives can be attributed to the use of optimal solvent management methods. The model showed statistical significance, shown by an F-value of 239.904, a p-value (Sig.) of 0.000. The unstandardised coefficient (B = 0.56) and a substantial t-value of 15.489 underscore the robustness and importance of the association. These results affirm that organisations using optimal solvent management strategies are much more likely to attain regulatory compliance and fulfil sustainability objectives. Consequently, Hypothesis H4 is fulfilled.

V. DISCUSSION

This research investigates the processes of solvent reclamation, reuse, and recycling (RRR) in the pharmaceutical business, with a focus on their contribution to environmental sustainability, operational efficiency, and regulatory compliance. Using a robust methodological framework, the research reports a Kaiser-Meyer-Olkin (KMO) value of 0.913 and a substantial Bartlett's Test of Sphericity, indicating that the dataset is appropriate for factor analysis. The constructs were very reliable and valid, with Cronbach's Alpha values above 0.8 and AVE values exceeding 0.5, showing good internal consistency and convergence. All four assumptions were validated by statistically significant findings. Hypothesis H1 revealed that companies that used sophisticated solvent recovery methods had a much lower environmental effect, as shown by an F-value of 51.742 and a t-value of 5.916 ($p = 0.000$). Hypothesis H2 indicated that a structured RRR framework is positively associated with increased operational efficiency and cost savings, as shown by R values of 0.261 and 0.302. Hypothesis H3 revealed a substantial association between financial investment in solvent recovery technology and successful reuse and recycling results, with a Pearson correlation of 0.552, which was significant at the 0.01 level. Hypothesis H4 demonstrated the greatest correlation, with a R value of 0.614 and R^2 of 0.377, showing that optimum solvent management greatly promotes regulatory compliance and sustainability. This is confirmed by an F-value of 239.904 and a t-value of 15.489 ($p = 0.000$). The results strongly urge for pharmaceutical businesses to implement organised solvent RRR systems, which provide advantages in the environmental, economic, and regulatory domains and guide stakeholders towards sustainable industrial practices.

VI. CONCLUSION

The study presents a succinct examination of the strategic significance of solvent recovery, reuse, and recycling (RRR) in the pharmaceutical sector. It confirms a structured solvent management approach based on solid empirical and statistical data. All four hypotheses were validated, indicating that advanced RRR techniques provide considerable environmental, operational, economic, and regulatory advantages. Firms that used novel recovery technology decreased their environmental effect, aligned with sustainability objectives. Systematic RRR deployment was favourably associated to increased operational efficiency and cost reductions, showing both environmental and economic benefits. Investment levels in recovery techniques had a moderate to substantial impact on reuse and recycling efficacy, highlighting the need of ongoing investment. Companies who used best practices also demonstrated improved regulatory compliance. Cronbach's Alpha, CR, AVE, high KMO, and a substantial Bartlett's test all verified the model's dependability and data appropriateness. Overall, the framework provides a viable path for pharmaceutical companies seeking to improve sustainability and performance through solvent RRR initiatives.

REFERENCES

[1] Slater, C. S., Savelski, M. J., Carole, W. A., & Constable, D. J. C. (2010). Green Chemistry in the Pharmaceutical Industry. In Solvent Use and Waster Issue (p. 3). Wiley-VCH, Verlag Gmbh & Co. KGaA.

[2] Chea, J. D., Christon, A., Pierce, V., Reilly, J. H., Russ, M., Savelski, M., Slater, C. S., & Yenkie, K. M. (2019). Framework for Solvent Recovery, Reuse, and Recycling in Industries. In Computer Aided Chemical Engineering (Vol. 47). Elsevier Masson SAS. https://doi.org/10.1016/B978-0-12-818597-1.50032-1

[3] Cavanagh, E. J., Savelski, M. J., & Slater, C. S. (2014). Optimization of environmental impact reduction and economic feasibility of solvent waste recovery using a new software tool. Chemical Engineering Research and Design, 92(10), 1942–1954.

[4] Belkhir, L., & Elmeligi, A. (2019). Carbon footprint of the global pharmaceutical industry and relative impact of its major players. Journal of Cleaner Production, 214, 185–194.

[5] Chen, Z., Lian, J. Z., Zhu, H., Zhang, J., Zhang, Y., Xiang, X., Huang, D., Tjokro, K., Barbarossa, V., Cucurachi, S., & Dong, B. (2024). Application of Life Cycle Assessment in the pharmaceutical industry: A critical review. Journal of Cleaner Production, 459(May), 142550. https://doi.org/10.1016/j.jclepro.2024.142550

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Suresh Gyan Vihar University International Journal of Economics and Management
E-ISSN: 2455-7528
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[6] Shashank Bhandari, Kenneth Jansson, Matthäus U. Bäbler, Stockholm, S. (2016). School of Chemical Science and Engineering Department of Chemical Engineering and Technology MASTER OF SCIENCE THESIS IN CHEMICAL ENGINEERING Design of a Solvent Recovery System in a Pharmaceutical Manufacturing Plant.

[7] Gauci, C. (2024). Green Pharmacy in Pharmaceutical Processes.

[8] Aboagye, E. A., Chea, J. D., & Yenkie, K. M. (2021). Systems level roadmap for solvent recovery and reuse in industries. IScience, 24(10), 103114. https://doi.org/10.1016/j.isci.2021.103114

[9] Ionescu, A. M., & Cazan, C. (2024). Pharmaceutical Waste Management: A Comprehensive Analysis of Romanian Practices and Perspectives. Sustainability (Switzerland), 16(15), 1–19. https://doi.org/10.3390/su16156571

[10] Bhadoriya, A., Patil, B., Vinchurkar, K., Mane, S., Parambath, A., Pradesh, M., & Vishwavidyalaya, D. A. (2024). Materials Sustainability in the Pharmaceutical Industry. 1–18. https://doi.org/10.1055/a-2460-4207

[11] Perez-Vega, S., Ortega-Rivas, E., Salmeron-Ochoa, I., & Sharratt, P. N. (2013). A system view of solvent selection in the pharmaceutical industry: towards a sustainable choice. Environment, Development and Sustainability, 15(1), 1–21. https://doi.org/10.1007/s10668-012-9365-5

[12] Pratyusha, K., Gaikwad, N. M., Phatak, A., & Chaudhari, P. D. (2012). Review on: Waste material management in pharmaceutical industry. International Journal of Pharmaceutical Sciences Review and Research, 16, 121–129.

[13] Digital Works Rowan Digital Works Theses, R. (2013). A new software tool to environmentally and economically evaluate solvent recovery in the pharmaceutical industry. https://rdw.rowan.edu/etd/295

[14] Ooi, J., Ng, D. K. S., & Chemmangattuvalappil, N. G. (2019). A Systematic Molecular Design Framework with the Consideration of Competing Solvent Recovery Processes. Industrial and Engineering Chemistry Research, 58(29), 13210–13226. https://doi.org/10.1021/acs.iecr.9b01894

[15] Tikhonova, I., Guseva, T., Averochkin, E., & Shchelchkov, K. (2021). Best Available Techniques and Best Environmental Management Practices: Collaboration Between Industries and Regions. Procedia Environmental Science, Engineering and Management, 8(2), 495–505.

[16] Massoud, M. A., Makarem, N., Ramadan, W., & Nakkash, R. (2015). Environmental management practices in the Lebanese pharmaceutical industries: implementation strategies and challenges. Environmental Monitoring and Assessment, 187(3). https://doi.org/10.1007/s10661-015-4290-3

[17] Gravitis J., (1987), Theoretical and applied aspects of the steam explosion plant biomass autohydrolysis method, *Khimiya Drevesiny (Wood Chemistry)*, **5**, 3-21.

[18] Gravitis J., (1996), *Material Separation Technologies and Zero Emissions*, Proc. Second Annual UNU World Congress on Zero Emissions, Chattanooga, Tennessee, May 29-31, 168-173.

[19] Gravitis J., Della Senta T., Williams E. D., (1997), *The Conversion of Biomass into Fuels, Fibers and Value-Added Chemical Products from The Perspective of The Zero Emissions Concept*, Proc. Symp. of the Biomass Conversion, Sapporo, Japan, 1-18.

[20] Gravitis J., (1999), *Biorefinery and Lignocelluloses Economy Towards Zero Emissions*, In: *Biorefinery, Chemical Risk Reduction, Lignocellulosic Economy*, Iiyama K., Gravitis J., Sakoda A. (Eds.), ANESC, Tokyo, 2-11.

[21] Gravitis J., Della Senta T., (2001), *Global Prospects of Substituting Oil by Biomass*, In: *World Forests, Markets and Policies* III, Palo M., Uusivuori J., Mery G. (Eds.), Kluwer Academic Publ., Dordrect, London, Boston, 23-39.

[22] Gravitis J., Vedernikov N., Zandersons J., Kokorevics A., (2001), *Furfural and Levoglucosan Production from Deciduous Wood and Agricultural Wastes*, In: *Chemicals and Materials from Renewable Resources*, Bozell J.J. (Ed.), American Chemical Society, **784**, 110-122.

[23] Gravitis J., Andersons J., Vedernikov N., (2002), *Chemicals and Materials from Integrated Furfural, Steam Explosion and Pyrolysis Technologies*, Proc. 7th European Workshop on Lignocelluloses and Pulp, Turku/Abo, Finland, 503-506.

[24] Gravitis J., (2003), *Sustainability Based on Forestry: Economy, Technology and Integrated Cluster Development Problems*, Proc. Sustainable Development for the Pulp and Paper Industry, Lisbon, 199-205.

[25] Gravitis J., Zandersons J., Vedernikov N., Kruma I., Ozols-Kalnins V., (2004) Clustering of bio-products technologies for zero emissions and eco-efficiency, *Industrial Crops & Products*, 20, 169-180.

[26] Gravitis J., (2006), *Green Biobased Chemistry Platform for Sustainability*, In: *Environmental Education, Communication and Sustainability*, Vol. 23: *Sustainable Development in the Baltic and Beyond*, Peter Lang Publishers House, Frankfurt/Maim, Berlin, Bern, Brussels, New York, Oxford, Vienna, 145-160.

[27] Gravitis J., (2007), Zero techniques and systems – ZETS strength and weakness, *Journal Cleaner Production*, **15,** 1190-1197.

[28] Gravitis J., Abolins J., (2007), *Biomass Conversion to Chemicals and Nano-Materials By Steam Explosion*, 15th European Biomass Conference & Exhibition, 7-11 May, Berlin, Germany.

[29] Gravitis J., (2008), *Biorefinery: Biomaterials and Bioenergy from Photosynthesis, Within Zero Emissions Framework*, In*: Sustainable Energy Production and Consumption. Benefits, Strategies and Environmental Costing. NATO Science for Peace and Security*, Barbir F., Ulgiati S., (Eds.), Springer, 327-337.

[30] Gravitis J., Abolins J., Tupciauskas R., Veveris A., Alksnis B., (2008), Lignin from steam-exploded pulp as binder in wood composites with energy account of steam explosion process, *Computational Materials Science*, in press.

[31] Heitz M., Capek-Ménard E., Koeberle P. G., Gagné J., Chornet E., Overend R. P., Taylor J. D., Yu E., (1991), Fractionation of *Populus tremuloides* at the pilot plant scale: Optimization of steam pretreatment conditions using the STAKE II technology, *Bioresource Technology*, **35**, 23-32.

[32] Kamm B., Kamm M., (2004), Principles of biorefineries, *Applied Microbiology and Biotechnology*, **64**, 137-145.

[33] Kerr R. A., (1998), The next oil crisis looms large- and perhaps close, *Science*, **281**, 1128-1131.

[34] Kokorevics A., Bikovens O., Gravitis J., (1999), *Steam Explosion and Shear Deformation under High Pressure as Methods Providing "self-sufficient" Treatment of Wood and Non-Wood Biomass*, Proc. First Workshop on QITS: Materials Life-Cycle and Environmentally Sustainable Development, March 2-4, 1998, Campinas, Sao Paulo, Brazil, Published by the UNU/IAS, Suzuki C., Williams E. (Eds.), 161-165.

[35] Odum H. T., (1996), *Environmental Accounting*, John Wiley & Sons, New York.

[36] Pauli G., (1998), *Upsizing: The Road to Zero Emissions. More Jobs, More Income and no Pollution*, Greenleaf, Sheffield.

[37] Potter C. S., (1999), Terrestrial biomass and the effects of deforestation on the global carbon cycle, *Bio Science*, **49**, 769–778.