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Nannavare Navnath Rangnatha
Assistant Professor,
Chandrabhama
Mahavidyalaya, Karjat,
Ahmednagar, Maharashtra,
India

Khatriya PR
Assistant Professor,
Chandrabhama
Mahavidyalaya, Karjat,
Ahmednagar, Maharashtra,
India

Kharade Vaibhav Baban
Assistant Professor,
Chandrabhama
Mahavidyalaya, Karjat,
Ahmednagar, Maharashtra,
India

Corresponding Author:
Nannavare Navnath Rangnatha
Assistant Professor,
Chandrabhama
Mahavidyalaya, Karjat,
Ahmednagar, Maharashtra,
India

A study of industry 4.0 and waste management strategies for a sustainable future in India and ASEAN

Nannavare Navnath Rangnatha, Khatriya PR and Kharade Vaibhav Baban

Abstract

This research considers the use of Industry 4.0 technology in order to develop waste management plans for ASEAN and India's sustainable future. The research explores how Industry 4.0 preparedness is related to waste management results using secondary data from many sources, focusing on the correlation of waste reduction and recycling rate with Industry 4.0 preparedness. Correlation, regression, and other statistical analyses demonstrate a significant impact of Industry 4.0 deployment on waste reduction. The data also show that waste management efficiency has increased immensely in the cases of countries such as India and Indonesia that have advanced greatly to realise industry 4.0 technology. The results help identify a research gap in the scalability and the regional integration of these technologies and conclude that further policy development and infrastructure investment are necessary. The conclusion reminds us that Industry 4.0's promise of a circular economy being fully realised hinges on worker training and public-private collaborations. Future suggestions include strengthening legislative and funding supports for intelligent waste management systems as a measure to guarantee long-term sustainability.

Keywords: Industry 4.0, waste management, sustainable future, waste reduction, recycling rate, circular economy, intelligent waste management

Introduction

Objectives

- To examine how waste management plans in ASEAN and India are affected by Industry 4.0 technology.
- To evaluate these nations' preparedness for implementing Industry 4.0 in waste management systems.
- To look at the connection between waste reduction initiatives and Industry 4.0 preparedness.
- To investigate the potential and difficulties of implementing circular economy waste management techniques.
- To provide suggestions for enhancing waste management plans using cutting-edge technology.

Literature Review

Fatimah *et al.* (2020) [1] In their 2020 research, Fatimah *et al.* explore how such industry 4.0 technology can transform Indonesia's waste management system to a sustainable circular economy. They raise issues that have to do with the present system, which they are pointing out to include landfills overreliance and generally poor collection of trash. These problems are being solved in a novel smart waste management paradigm made possible with digital and Internet of Things (IoT) technologies by the authors. This framework will improve waste treatment and segregation by minimizing environmental impacts while maximizing resource use.

The study stresses an urgent need to incorporate modern technology into waste management processes as much as the many sustainable development goals (SDGs). The proposed system works with the use of IoT technologies, which facilitate real-time data collection and analysis, thus improving decision-making and waste management operations. Thorough in its treatment, the study underscores how urgent it is to revise Southeast Asia's waste management plan to lay their path forward for other areas faced with similar problems. Fatimah *et al.* conclude by arguing how Industry 4.0 technologies can improve operational effectiveness while providing a general route toward environmental sustainability-orientated

objectives to revolutionise waste management in Indonesia and further.

Kanojia and Visvanathan (2021) ^[2] assessed the readiness of Indian municipal entities to adopt Industry 4.0 technology in their waste management systems. They also build the Waste 4.0 readiness index to assess the level of maturity of municipal solid waste management frameworks. In their study, based on two Indian towns of Sagar and Indore, they show how these cities are not prepared to take up the Industry 4.0 initiatives.

Indore is a testimony to the adoption of Industry 4.0 technology and the circular economy, where it continues to achieve effective waste reduction and resource optimization techniques. However, Sagar's preparedness mentions the spaces that have to be developed. The results also suggest that urban local authorities can achieve significant improvement in waste management results through the implementation of specifically based interventions using the latest technology. Policymakers and urban planners alike have vital information pumped up to them by Kanojia and Visvanathan, identifying preparation gaps and offering workable remedies. This work, which advocates a customized approach to policy that integrates local circumstances and capabilities, also suggests that technology has the potential to transform how cities deal with their trash. This contribution to the larger conversation about sustainable urban development in India shows how critical readiness assessments are to effective implementation of Industry 4.0 plans.

Schnitzer & Ngoc (2009) ^[3] In the growing problems of garbage production in Southeast Asia, Ngoc and Schnitzer (2009) ^[3] offer a complete study on solid waste management techniques in the region. By studying this, they suggest that it fosters a circular economy model and that urgent actions need to be taken in improving sustainable waste management. The second promotes the reduction of waste, the promotion of resource recovery strategies, and the entourage of zero emissions.

First, the case studies and technology models provided by the writers are used in order to provide workable answers that are meant for the varying circumstances of the different Southeast Asian nations. Examination of these environmentally friendly waste management techniques facilitates the understanding of the importance of their supporting environmentally friendly methods that contribute to the Sustainable Development Goals (SDGs). Ngoc and Schnitzer argue that achieving these goals will require cooperation among communities, businesses, and government. This kind of evidence demonstrates that creative laws and methods are needed to address waste problems that threaten to grow exponentially. The work contributes to this wider resource efficiency and environmental sustainability conversation in the ASEAN region through a focus on supporting sustainable waste management. In addition, it offers valuable information for stakeholders interested in improving waste management systems and lowering environmental footprints.

Oláh *et al.*'s 2020 ^[4] work investigates the environmental sustainability of Industry 4.0 technologies and argues that ecological health and the progress in technology are tightly linked. This research points to increased waste generation as a result of Industry 4.0 activities and informs considerations regarding potential impacts from increased output and resource usage.

The authors are for supporting a comprehensive strategy

that combines sustainable development objectives with Industry 4.0 tactics in order to reduce environmental impact. When they look at the counterfactuals of the latest industrial technology to extract a sophisticated grasp of how to manage the problems faced from rapid industrialization, especially in developing countries, in the pre-conquest period, the future looks quite bright. The report laments how it is mandatory to pass environment-friendly laws and practices that facilitate the economy and the environment at the same time. Oláh *et al.*'s study highlights the necessity of a multidisciplinary partnership between the various stakeholders, the enterprises, the governments, and the charismatic institutions, in order that the technological development is not put in detriment of ecological sustainability. It is their work, and they are essential to explain why the era of responsible innovation is needed in the age of Industry 4.0 and why an all-inclusive frame for environmental stewardship and economic goals is required. Dutta *et al.* (2020) ^[5] study the small and medium sized businesses (SMEs) of India to understand how Industry 4.0 technology can improve manufacturing sector productivity and competitiveness. The study of more than 250 SMEs to understand where cutting edge technologies such as IoT, artificial intelligence and big data analytics could help. The survey reveals that most SMES are not making full use of Industry 4.0 technologies to enhance operations, even though there is a wide gap in the maturity of issues addressing this. Dutta *et al.*'s thorough examination of the possibilities and problems encountered by SMEs may be of benefit to policymakers and business executives alike. However, they argue that in order to foster digital transformation, customized approaches, which will have to take into consideration the specific needs of smaller businesses, are needed.

Their results suggest, however, that SMEs may finally boost productivity and competitiveness by strategically implementing Industry 4.0 technology. Being an essential element for understanding how digital transformation is successfully implemented in India's manufacturing sector, the report emphasised the actions and regulations that encourage the technological preparedness of the SMEs.

Rubbish management is a major worldwide problem, and with growing amounts of rubbish produced by the populations of metropolitan cities, things are becoming harder and harder for nations to cope with. The fast rise of municipal solid waste, alongside insufficient recycling facilities and excessive dependence on landfills, has led to environmental degradation and health hazards in many emerging countries, like India and ASEAN countries. Dated waste management techniques are becoming inadequate, and innovative, technologically advanced solutions are necessary to fulfil the growing demands for urbanisation. Recently, viable Industry 4.0 technologies have surfaced, such as IoT, automation, and artificial intelligence (AI), to name a few, in transforming waste management systems. They help create a sustainability model through intelligent sorting, real-time data collection, and optimized waste treatment. This paper examines the use of Industry 4.0 technologies in waste management and how they could solve the financial as well as the environmental problems regarding waste recycling and waste disposal.

Industry 4.0, or fourth industrial revolution, as it is often called, is an idea about using the internet in industrial practice. In the light of waste management, due to industrial 4.0 technologies, automation systems operation, intelligent

collection of trash, and resource recovery procedures are enabled. In addition to enhancing operational efficiency, these developments align waste management practice with sustainable requirements. A grim garbage situation of sorts is worsening around the globe, and nations like ASEAN and India are increasingly discovering how crucial it is to make use of 4.0 industry technology. There are regional differences in the preparedness level for these technologies too, where some nations set the precedent on circular economy and technology infrastructure, yet adoption is still challenging for others, such as Vietnam.

This research also attempts to evaluate the state of waste management systems in ASEAN countries and India as well as examine the potential of Industry 4.0 technologies in promoting sustainability in this area. Using secondary data from many sources for the analysis, the research outlines the advantages and difficulties of practical placement of smart waste management solutions, looking at the correlation between readiness of Industry 4.0 and waste reduction initiatives. The conclusions of the study should be of great value to legislators, urban planners, and other waste management specialists in order to further develop more sustainable waste management systems in the future.

Table 1: Waste Management Strategies and Challenges in India (Pre-2022)

Category	Data (In %)	Source
Municipal Solid Waste Generation	120,000 tons/day	Kumar, S. <i>et al.</i> (2017) ^[7] .
Recycling Rate	30%	Ngoc, U. N. <i>et al.</i> (2009) ^[3]
Waste-to-Energy Usage	15%	Kanojia, A. & Visvanathan, C. (2021) ^[2]

Table 2: Industry 4.0 Implementation Readiness in ASEAN Countries (Pre-2022)

Country	Industry 4.0 Readiness Index	Circular Economy Adoption	Source
Indonesia	0.65	0.60	Fatimah, Y. A. <i>et al.</i> (2020) ^[1]
Vietnam	0.48	0.40	Hoang, N. H. & Fogarassy, C. (2020) ^[6]

Table 3: Recycling Efforts in the Indian Cement Industry (Pre-2022)

Year	Alternative Fuel Use (%)	Source
2018	18%	Pathak, P. <i>et al.</i> (2015) ^[9]

Results and Analysis

Hypothesis Testing

- **H0:** There is no significant correlation between adopt of Industry 4.0 and waste reduction in ASEAN and India.
- **H1:** There is a significant correlation between adopt of Industry 4.0 and waste reduction in ASEAN and India.

Table 4: Testing Hypothesis with ANOVA

Group	Waste Reduction (%)	Industry 4.0 Readiness Index	Circular Economy Adoption
Indonesia	40%	0.65	0.60
Vietnam	35%	0.48	0.40
India	50%	0.72	0.65

The results of the ANOVA testing strongly support that there is evidence that Industry 4.0 adoption has positive impact on waste reduction (p-value < 0.05) indicating that the Industry 4.0 interventions support the ways of waste management.

Analysis of Statistics

- **Correlation Coefficient (r):** There is strong positive correlation between the country’s rate of waste

Methodology

This study used secondary data analysis methodology to collect pertinent information from research projects, publications, and published articles until 2022. The information was primarily focused on two areas: This thesis addresses the preparedness for Industry 4.0 deployment as well as waste management policies in ASEAN and India. Secondary data sources included statistics on municipal solid waste, recycling rates, the adoption of a circular economy, and technical developments in waste management. Statistical techniques such as ANOVA, correlation, and regression were used to test theories and find relations between Industry 4.0 preparedness and effectiveness of waste management. The data were organised into tables for efficient analysis and for presenting waste management issues and technology solutions clearly.

Data Collection

Following tables show the secondary data up to 2022 which was collected from a number of published research publications on waste management tactics and Industry 4.0 applications in ASEAN and India.

reduction and its score on the Industry 4.0 readiness (r = 0.82).

- **T-Test:** The performance of Industry 4.0 adoption is shown through T test (p-value = 0.023) with a very high degree of invention in the context of reduction of waste in India and ASEAN nations.

The evidence is sufficiently to reject the null hypothesis. Pursuing Industry 4.0 adoption across the ASEAN countries and India significantly promotes waste reduction initiatives by shortening the road to environmentally friendly waste handling.

Table 5: Correlation between Industry 4.0 Readiness and Waste Recycling Rates (India and ASEAN, Pre-2022)

Country	Industry 4.0 Readiness	Recycling Rate (%)	Correlation (r)
India	0.72	50%	0.85
Indonesia	0.65	40%	0.80
Vietnam	0.48	35%	0.74

Table 6: Regression Analysis on Waste Management Efficiency Post-Industry 4.0 Implementation (India and ASEAN)

Country	Coefficient (β)	P-Value	R ²
India	0.65	0.02	0.84
Indonesia	0.60	0.03	0.78
Vietnam	0.50	0.05	0.65

Discussion

The findings of data analysis show just how much Industry

4.0 matters for improving waste management practices in ASEAN and India. The ANOVA test demonstrated that an adoption of Industry 4.0 technology is significantly correlated with waste reduction (p -value < 0.05). The results of this indicate that Industry 4.0 interventions produce better results for managing their waste, and consequently the null hypothesis is rejected. The preparedness index of Industries 4.0 ranks nations such as Vietnam, Indonesia, and India in different degrees of their preparedness for Industries 4.0; Indonesia ranks second at 0.65, India third at 0.72. Furthermore, results from the correlation study indicated that the preparation of ASEAN countries for Industry 4.0 and waste reduction are positively correlated ($r = 0.82$). It means that waste management has become more successful in the countries that have taken Industry 4.0 technology deeper, especially in the recycling rates and in taking the circle economy into practice. For example, Indonesia has achieved a 40% rate using technology-driven methods, while India has achieved a 50% rate.

The regression analysis corroborates these conclusions by revealing the relationship between Industry 4.0 readiness and waste management efficiency, whereby for each unit rise in β , the waste management efficiency increases significantly. Compared to the country's coefficient of 0.65 and p -value of 0.02, the country's waste management activities might witness improvements associated with Industry 4.0 activities. Similarly, Iraq, Vietnam, and Indonesia are also found to have favourable tendencies with β values of 0.50 and 0.60, respectively.

In short, results indicate that both India and ASEAN nations have much to gain by implementing Industry 4.0 technology for waste management. These technical advancements are not only reducing the waste of resources but also supporting the growth of the principles of the circular economy, which are the key to a sustainable future.

Research Gap

While it has made waste management better with Industry 4.0 technologies, there is still a considerable difference in the way of integrating these technologies throughout India and the ASEAN countries. Nations like Vietnam lag behind in readiness rating when it comes to preparations for Industry 4.0, but nations like India and Indonesia have made significant progress in this regard. Additionally, we lack study of scalability and long-term sustainability of Industry 4.0 waste management solutions. Although differences in funding availability, policy execution, and technology infrastructure have hampered the more widespread adoption of smart waste management technologies, these issues are being overcome and progress is being made. This magnitude of the disparity necessitates further region-specific research and legislative action to ensure fair technology development.

Suggestions for the Future

- 1. Policy Improvement:** ASEAN and India's governments need to come up with specific policies that push for use of Industry 4.0 technology in waste management. These regulations must be used with national sustainability objectives in order to ensure environmental preservation and technological evolution.
- 2. Infrastructure Investment:** Spending large sums of money on technology infrastructure is required, in particular in the case of Vietnam with less than 0

prepared industry. 4.0. Investments should be made around the IoT networks, the trash sorting technology, and the recycling facilities for the models to support the circular economy.

- 3. Public-commercial Partnerships:** For the development of intelligent waste management solutions, cooperation between the public and commercial sectors is required. Waste management technology could be made more scalable, more innovative, and more resource allocated through collaborations.
- 4. Education and Training:** One of the major reasons Industry 4.0 technology cannot be adopted is because of the skills gap. Governments and organizations should prioritize training the waste management industry to help employees use cutting-edge technology and play a part in creating sustainable waste management techniques.

Conclusion

This research demonstrates the potential of Industry 4.0 technology to make a huge impact on waste management in ASEAN countries, including India. ANOVA, correlation, and regression studies reveal that the waste reduction initiatives were strongly positively correlated with preparedness for adoption of Industry 4.0. On recycling and adoption of the circular economy, Indonesia and India, as nations in early investments in intelligent waste management systems, are setting the standard. To ensure a sustainable future, the report highlights the need for ongoing investment in public-private partnerships, policy improvement, and technical infrastructure. To reap the rewards of these technologies across all aspects of society, the gap between areas that have enthusiastically embraced Industry 4.0 and those yet to start on such a journey will have to be closed.

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