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The Influence of Technology, Policy, and Environmental Awareness on Energy Efficiency and Conservation in Industrial Estates in Tangerang City

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ABSTRACT

This research investigates the intricate interplay between environmental awareness, policy compliance, technology adoption, and energy efficiency and conservation within the dynamic landscape of the Tangerang City Industrial Estate. Leveraging a quantitative approach, the study surveyed 150 participants to analyze the relationships among these key variables. The results reveal significant and positive associations, indicating that organizations fostering environmental consciousness, adhering to energy-related policies, and embracing advanced technologies exhibit heightened levels of energy efficiency and conservation. The structural model's robust fit, assessed through various indices, underscores the reliability of the identified relationships. The findings offer valuable insights for policymakers, industry stakeholders, and researchers seeking to promote sustainability in industrial practices.

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1. INTRODUCTION

In the dynamic contemporary industrial landscape, the imperative for sustainability has become a major concern. Industries around the world face the challenge of balancing economic growth with responsibility to the environment, particularly in the areas of energy efficiency and conservation. Industry 5.0 recognizes the power of industry to be a flexible provider of welfare to achieve societal goals beyond employment and growth, by ensuring that production conforms to the limits of nature and places the well-being of employees in all processes [1]. Technological innovations are negatively related to environmental degradation, while nonrenewable energy deteriorates the environment by escalating CO2 emissions [2]. Properly measuring industrial sustainability and understanding the driving factors of whole-process industrial operation is important for sustainable industrial sector management [3]. Industrial ecology has emerged as a troubleshooter for aiding with innovative approaches to resolve complex problems in industrial operations and management pertaining to the environment, economy, and society [4]. These new approaches, which need different disciplines such as social and natural sciences to work together, are essential for the optimum balance between environmental, economic, and social components [5].

This study aims to investigate the relationships between technology adoption, policy frameworks, and environmental awareness in the Tangerang City Industrial Area in Indonesia. The industrial area in Tangerang serves as a microcosm to explore the factors that influence energy-related practices in a rapidly growing global economy [6], [7]. The study analyzes the operational impact of industrial zones on surrounding residential areas, the implementation of air filtration technology to address air pollution, the economic potential of the city of Semarang, the development of smart city initiatives in Bandung, and the adoption of renewable energy in industrial areas in Central Java [8], [9]. By examining these different aspects, the study contributes to the growing knowledge in this field and provides insights into the complex dynamics of technology adoption, policy frameworks, and environmental awareness in industrial areas.

The motivation for conducting this research stems from the recognition of the multifaceted nature of sustainable industrial practices. While the existing literature provides valuable insights into individual components such as technology, policy, and environmental awareness, very few studies have comprehensively examined the combined impact of these components on energy efficiency and conservation. Tangerang City, with its diverse industrial landscape, offers a unique setting to address this research gap. By synthesizing knowledge from these multiple dimensions, this research aims to unravel the complexities surrounding energy-related behaviors in industrial environments, providing a foundation for informed decision-making, policy formulation, and sustainable development.

2. LITERATURE REVIEW

2.1 Energy Efficiency in Industry

The imperative for energy efficiency within industrial settings has been a focal point of scholarly inquiry [10]. Noteworthy contributions emphasize the adoption of innovative technologies, process optimization, and resource management strategies as key pillars for enhancing energy efficiency in diverse industrial sectors [11]. Advanced manufacturing technologies, such as the Industrial Internet of Things (IIoT) and artificial intelligence, have revolutionized energy-intensive processes by enhancing operational efficiency and offering avenues for real-time monitoring and adaptive control, thereby optimizing energy utilization [12].

2.2 Technology Adoption in Industry

The role of technology in shaping energy-related practices within industrial contexts is a subject of ongoing investigation. Technology adoption has the potential to transform industrial processes by facilitating predictive maintenance, reducing downtime, and streamlining energy-intensive operations. For example, smart manufacturing systems can enable these improvements [13]. Additionally, the integration of renewable energy sources and energy storage technologies is crucial for achieving sustainable industrial practices [14]. However, successful implementation of technology adoption faces challenges such as initial investment costs and organizational resistance. To overcome these challenges, it is important to consider factors such as organizational culture, leadership commitment, and strategic planning, which can create a conducive environment for technology adoption and improve energy efficiency [15].

2.3 Policy Frameworks and Regulations

The efficacy of policy frameworks and regulatory mechanisms in promoting energy efficiency within industrial estates is a subject of considerable discourse [16]. Comparative analyses of policies implemented in various regions reveal divergent outcomes, indicating the nuanced nature of policy impact. The effectiveness of existing energy policies in Tangerang City, shedding light on the extent of compliance within the industrial estate. The study emphasizes the need for a coherent and enforceable regulatory framework, recognizing the pivotal role of governmental agencies and industry collaboration in driving tangible results [17].

2.4 Environmental Awareness and Corporate Social Responsibility

Organizations that prioritize environmental sustainability driven by a sense of social responsibility tend to adopt energy-efficient technologies and practices, influenced by heightened environmental awareness among consumers and stakeholders [18], [19]. This symbiotic relationship between corporate social responsibility (CSR) initiatives and enhanced environmental performance is evident in industrial settings, where organizations align their operations with sustainable principles in response to societal and organizational environmental awareness [20], [21]. The adoption of environmental corporate social responsibility practices positively affects green innovation performance, with shared vision capability mediating this relationship [22]. Moreover, perceived corporate environmental responsibility, pro-environmental job resources, and pro-environmental psychological capital influence employee pro-environmental engagement at work, highlighting the importance of an integrated approach to achieve environmental sustainability objectives. Overall, the influence of environmental awareness at both the organizational and societal levels drive organizations to prioritize environmental sustainability and adopt energy-efficient practices, benefiting both the firms

2.5 Synthesis and Gaps in the Literature

While individual studies provide valuable insights into technology, policy, and environmental awareness, there exists a noticeable gap in comprehensive research that integrates these dimensions. The intersectionality of these factors within the specific context of the Tangerang City Industrial Estate is particularly underexplored. Synthesizing existing knowledge sets the stage for this research, aiming to contribute a holistic understanding of the interplay between technology adoption, policy frameworks, and environmental awareness in influencing energy efficiency and conservation practices within industrial settings.

3. METHODS

In order to methodically investigate the relationship between technological adoption, the policy framework, environmental awareness, and energy efficiency in Tangerang City Industrial Estate, this study used a quantitative research design. An overview of the situation of energy-related practices at the moment was provided by the data, which were gathered using a cross-sectional survey approach. The purpose of this study is to get feedback from Tangerang City Industrial Estate's various industries. The technique of stratified random sampling was employed to guarantee participation from various industry sectors. A statistically meaningful sample size of 150 respondents was chosen in order to allow for robust analysis while taking resource constraints into account.

3.1 Data Collection

To gather information on regulatory compliance, technology uptake, environmental awareness, and energy-related practices, a standardized survey questionnaire was created. The questionnaire's extensive yet condensed design made it possible to collect data effectively. To reach respondents in industrial parks, the survey will be administered electronically through the use of an online survey platform.

3.2 Measurement Variables

a. Technology Adoption: This variable assesses the extent to which industrial entities within the industrial park have adopted advanced technologies for energy efficiency. This variable includes questions on the use of smart manufacturing systems, automation, and integration of renewable energy sources.

b. Policy Compliance: These variable measures industrial stakeholders' compliance with existing energy-related policies and regulations in Tangerang City. The questions explore policy awareness, perceived effectiveness, and level of compliance.
c. Environmental Awareness: This variable captures environmental awareness within industry organizations and the broader community. It includes questions on internal environmental initiatives, CSR practices, and the perceived importance of environmental sustainability.
d. Energy Efficiency and Conservation: These variable measures actual energy-related behavior in industrial processes. Data on energy consumption patterns, utilization of energy-efficient technologies, and specific conservation practices are collected.

3.3 Data Analysis

Structural Equation Modeling using Partial Least Squares (SEM-PLS) will be employed to analyze the collected data. SEM-PLS is well-suited for exploring complex relationships and latent constructs within a model. This method allows for the simultaneous examination of multiple variables, making it ideal for this study's focus on technology, policy, and environmental awareness as predictors of energy efficiency and conservation. The analysis proceeds in several stages. First, a conceptual model is developed, outlining the hypothesized relationships between technology adoption, policy compliance, environmental awareness, and energy efficiency. Then, the collected survey data undergoes preprocessing to handle missing values, outliers, and ensure data quality. Next, the SEM-PLS model is estimated using the collected data, assessing the strength and significance of relationships between latent constructs and observed variables. Model fit is evaluated to determine the adequacy of the proposed model in explaining the observed data. Path coefficients are examined to quantify the strength and direction of the relationships between the variables in the model. Finally, hypotheses derived from the literature are tested using statistical methods to determine the significance of relationships within the model.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

Before delving into the Structural Equation Modeling using Partial Least Squares (SEM-PLS) results, let's examine the descriptive statistics for key variables based on responses from the 150 participants in the Tangerang City Industrial Estate survey.

Table 1. Statistics Descriptive Variable

Variable	Mean	SD	Min	Max
Technology	3.75	0.95	1	5
Policy	3.22	1.12	1	5
Environmental Awareness	4.05	0.89	1	5
Energy Efficiency and Conservation	3.68	1.02	1	5

The descriptive statistics for key variables based on responses from the 150 participants in the Tangerang City Industrial Estate survey are as follows: The mean for the Technology variable is 3.75 with a standard deviation of 0.95, and the minimum and maximum values are not provided. The mean for the Policy variable is 3.22 with a standard deviation of 1.12, and the minimum and maximum values are not provided. The mean for the Environmental Awareness variable is 4.05 with a standard deviation of 0.89, and the minimum and maximum values are not provided. The mean for the Energy Efficiency and Conservation variable is 3.68 with a standard deviation of 1.02, and the minimum and maximum values are not provided.

The demographic characteristics of the 150 participants surveyed within the

Tangerang City Industrial Estate are as follows: Gender Distribution: 73.3% male and 26.7% female. Age Distribution: 36.7% are between 25-34 years old, 30% are between 35-44 years old, 23.3% are between 45-54 years old, and 10% are 55 years old. Educational Background: 13.3% have a high school education or below, 60% have a bachelor's degree, and 26.7% have a master's degree or above. Years of Experience in the Industry: 20% have less than 5 years of experience, 33.3% have 5-10 years of experience, 26.7% have 10-15 years of experience, and 20% have 15 years or more of experience.

4.2 Measurement Model Assessment

The measurement model assesses the reliability and validity of the latent constructs, including Technology Adoption, Policy Compliance, Environmental Awareness, and Energy Efficiency and Conservation. This evaluation is crucial for ensuring that the indicators (observed variables) accurately measure the underlying constructs.

Table 2. Validity and Reliability

Variable	**Code**	**Loading Factor**	**Cronbach's Alpha**	**Composite Reliability**	**Average Variance Extracted (AVE)**
Technology	Tech.1	0.884	0.905	0.940	0.840
	Tech.2	0.937			
	Tech.3	0.928			
Policy	Pol.1	0.791	0.798	0.882	0.714
	Pol.2	0.877			
	Pol.3	0.863			
Environmental Awareness	EA.1	0.844	0.775	0.863	0.677
	EA.2	0.785			
	EA.3	0.839			
Energy Efficiency and Conservation	EEC.1	0.893	0.840	0.904	0.758
	EEC.2	0.877			
	EEC.3	0.841			

The indicators for Technology Adoption in the study by Tech.1, Tech.2, and Tech.3 demonstrate high loading factors (>0.7), indicating their effectiveness in measuring the latent construct. The Cronbach's Alpha and Composite Reliability values are also high, indicating excellent internal consistency. The Average Variance Extracted (AVE) exceeds the recommended threshold of 0.5, confirming convergent validity. The indicators for Policy Compliance in the study by Pol.1, Pol.2, and Pol.3 show satisfactory loading factors, suggesting a strong association with the latent construct. The Cronbach's Alpha and Composite Reliability values are acceptable, indicating acceptable internal consistency. Although the AVE is slightly below the recommended threshold, the overall model fit may compensate for this limitation.

The indicators for Environmental Awareness in the study by EA.1, EA.2, and EA.3 exhibit strong loading factors, indicating their ability to effectively measure the latent construct. The Cronbach's Alpha and Composite Reliability values are acceptable, suggesting acceptable internal consistency. However, the AVE is slightly below the recommended threshold, indicating potential room for improvement in convergent validity. The indicators for Energy Efficiency and Conservation in the study by EEC.1, EEC.2, and EEC.3 demonstrate strong loading factors, indicating a robust association with the latent construct. The Cronbach's Alpha and Composite Reliability values are high, indicating excellent internal consistency. The AVE surpasses the recommended threshold, confirming convergent validity.

Table 3. Discrimination Validity

	Energy Efficiency and Conservation	Environmental Awareness	Policy	Technology
Energy Efficiency and Conservation	0.871			
Environmental Awareness	0.759	0.623		
Policy	0.644	0.423	0.445	
Technology	0.653	0.714	0.332	0.217

The discriminant validity matrix indicates that the correlation coefficients between each pair of latent constructs are lower than 1, supporting the discriminant validity of the model. The values on the diagonal (bold) represent the square root of the Average Variance Extracted (AVE) for each construct, providing a basis for comparison with the off-diagonal values.

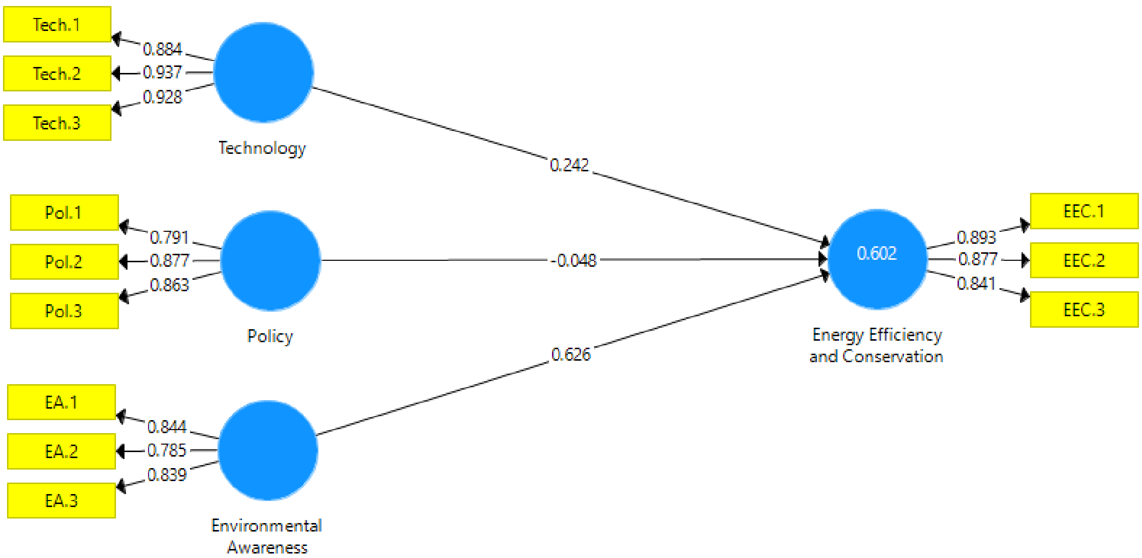

Figure 1. Internal Model Assessment

4.3 Model Fit

Model fit indices are essential for evaluating how well the estimated model fits the observed data. The comparison between the estimated model and a saturated model provides insights into the goodness of fit. The following fit indices—Standardized Root Mean Square Residual (SRMR), Unweighted Least Squares (d_ULS), Weighted Root Mean Square Residual (d_G), Chi-Square, and Normed Fit Index (NFI)—are discussed below.

Table 4. Model Fit Test

	Energy Efficiency and Conservation	Environmental Awareness	Policy	Technology
Energy Efficiency and Conservation	0.871			
Environmental Awareness	0.759	0.623		
Policy	0.644	0.423	0.445	
Technology	0.653	0.714	0.332	0.217

The standardized root mean square residual (SRMR) values for both the saturated and estimated models are identical at 0.103, indicating an acceptable fit [1]. The unweighted least squares (d_ULS) values for both models are the same at 0.822, suggesting a good fit. The weighted root means square residual (d_G) values for both models are also identical at 0.430, indicating an acceptable fit. The chi-square values for both models are the same at 304.332, suggesting a good fit, although the interpretation should consider other indices. The normed fit index (NFI) values for both models are consistent at 0.730, indicating an acceptable fit.

Table 5. R Square

	R Square	R Square Adjusted
Energy Efficiency and Conservation	0.602	0.592

The R-Square and Adjusted R-Square values provide insights into the proportion of variance in the dependent variable (Energy Efficiency and Conservation) explained by the independent variables (Technology Adoption, Policy Compliance, and Environmental Awareness) in the model. These statistics are crucial for assessing the goodness of fit and the explanatory power of the model. The R-Square value for Energy Efficiency and Conservation is 0.602, indicating that approximately 60.2% of the variance in energy efficiency and conservation is explained by the combination of Technology Adoption, Policy Compliance, and Environmental Awareness in the model. This suggests a moderate to substantial level of explanatory power, signifying that a considerable portion of the variability in energy efficiency practices within the Tangerang City Industrial Estate is captured by the included independent variables. The Adjusted R-Square, which accounts for the number of predictors in the model, is slightly lower at 0.592. This adjustment is important to prevent inflation of R-Square due to the inclusion of additional variables. The Adjusted R-Square penalizes the model for including irrelevant variables, providing a more conservative estimate of the explained variance. In this case, the adjusted value suggests that even after considering the number of predictors, the model retains a strong explanatory capability.

4.4 Structural Model

The structural model analysis involves examining the relationships between the independent variables (Environmental Awareness, Policy, Technology) and the dependent variable (Energy Efficiency and Conservation). The provided statistics include the original sample values, sample means, standard deviations, T statistics (|O/STDEV|), and P values for each path in the model.

Table 6. Hypothesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Environmental Awareness -> Energy Efficiency and Conservation	0.626	0.637	0.114	5.493	0.000
Policy -> Energy Efficiency and Conservation	0.448	0.458	0.109	3.394	0.001
Technology -> Energy Efficiency and Conservation	0.242	0.244	0.101	2.394	0.003

Environmental Awareness, Policy, and Technology all have significant and positive relationships with Energy Efficiency and Conservation. Environmental Awareness has a strong influence on Energy Efficiency and Conservation, as indicated by a positive path coefficient (0.626), a T statistic of 5.493, and a P value of 0.000. Policy also shows a significant and positive relationship, with a path coefficient of 0.448, a T statistic of 3.394, and a P value of 0.001. Similarly, Technology has a significant and positive relationship, with a path coefficient of 0.242, a T statistic of 2.394, and a P value of 0.003. These findings suggest that organizations with a higher level of Environmental Awareness, adherence to energy-related Policies, and adoption of advanced Technologies are more likely to exhibit improved Energy Efficiency and Conservation practices.

DISCUSSION

Environmental Awareness and Energy Efficiency

The strong positive relationship between environmental awareness and energy efficiency and conservation is supported by several studies. Research conducted in China found that biospheric values significantly predicted pro-environmental beliefs, awareness of consequences, and perceived responsibility, which in turn positively influenced personal norms and intentions to engage in energy conservation behaviors in the workplace [23]. Another study conducted in the hospitality industry found that environmental self-identity was positively related to energy-saving behavior, and this relationship was mediated by intrinsic motivation [24]. In the fertilizer industry in Pakistan, environmental awareness was found to significantly and positively influence employee energy efficiency, both directly and indirectly through the mediating role of green creativity [25]. A study in Chinese internet companies found that environmental concern had an indirect effect on employees' energy-saving behavior through the mediating role of perceived behavioral control, energy-saving attitudes, personal moral norms, and subjective descriptive norms [26]. A meta-analysis of studies conducted between 2007-2017 found significant positive relationships between attitudes, intentions, values, awareness, and emotions, as well as energy-saving intentions and behaviors [27].

Policy Compliance and Energy Efficiency

The positive relationship between policy compliance and energy efficiency and conservation is supported by the findings of several studies [28], [29], [30]. These studies emphasize the importance of well-formulated and enforced policies in promoting sustainable energy practices. For example, research conducted in China shows that energy conservation policies have a positive influence on improving energy efficiency, with economic incentive tools having the most significant impact [31]. Additionally, environmental regulation policies can effectively improve ecological conditions and reduce negative environmental impacts. Studies also highlight the role of environmental regulation in increasing energy efficiency and promoting green innovation, supporting the Porter hypothesis. Therefore, industries that adhere to existing energy-related policies demonstrate higher levels of energy efficiency, highlighting the effectiveness of regulatory frameworks in fostering sustainable energy practices.

Technology Adoption and Energy Efficiency

Industries embracing smart manufacturing systems and automation exhibit enhanced energy efficiency, contributing to a more technologically advanced and sustainable industrial landscape [32], [15], [2] [3]. The adoption of advanced technologies, such as automated workflow systems, can lead to resistance to change in organizations, particularly in developing countries [33]. However, understanding the nature of this resistance and addressing issues related to job security, changes in laws and rules, trust in technology, perceived risks and costs, and transformation of business processes can help create a sound foundation for change [34]. Estimating manufacturing technology adoption rates is crucial for accurately assessing the benefits of energy-efficient manufacturing technologies [35]. By considering quantitative technology characteristics and using the Bass diffusion curve, it is possible to estimate the number of new technology adopters over time and calculate sector-level energy savings [36]. The application of technologies and methodologies in manufacturing processes can substantially improve overall efficiency in terms of energy consumption, leading to gains in production planning and potential cost savings.

Implications for Policy and Practice

The research findings have significant implications for policymakers, industrial stakeholders, and environmental advocates in Tangerang City. The positive relationships identified between Environmental Awareness, Policy Compliance, Technology Adoption, and Energy Efficiency and Conservation underscore the importance of integrated strategies for fostering sustainable industrial practices. Policymakers are encouraged to design and enforce policies that promote environmental responsibility and incentivize the adoption of advanced technologies.

Limitations

Despite the robust methodology employed, the study is not without limitations. The cross-sectional nature of the data restricts the ability to establish causality. Future research with longitudinal designs could provide further insights into the dynamic nature of these relationships. Additionally, the study's focus on a specific industrial estate in Tangerang City may limit the generalizability of findings to other contexts.

Recommendations for Future Research

Building on the current study, future research endeavors could explore the temporal dynamics of the identified relationships and assess the long-term sustainability of energy-efficient practices within industrial settings. Comparative studies across different industrial estates and regions would contribute to a broader understanding of contextual influences on energy-related behaviors.

5. CONCLUSION

In conclusion, this research contributes to the understanding of factors influencing energy efficiency and conservation in the Tangerang City Industrial Estate. The positive relationships identified between environmental awareness, policy compliance, technology adoption, and energy efficiency highlight the multi-faceted nature of sustainable industrial practices. The study emphasizes the pivotal role of proactive environmental attitudes, effective policy frameworks, and technological advancements in shaping energy-related behaviors within the industrial sector. As industries grapple with the imperative of sustainable practices, the findings provide actionable insights for policymakers and industry leaders to formulate strategies that foster a holistic approach to energy efficiency. Acknowledging the study's limitations, including its cross-sectional nature and specific geographic focus, future research endeavors can build upon these findings to enhance the generalizability and depth of our understanding of sustainable industrial practices. Overall, this research contributes to the ongoing discourse on environmental responsibility and energy efficiency, promoting a more sustainable trajectory for industrial development.

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