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Sustainable automation towards productivity
in electronic manufacturing industry: A study in
Negeri Sembilan, Malaysia

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Abstract

The adoption of sustainable automation has been associated with significant transformation in modern manufacturing, especially the electronics manufacturing industry in Malaysia, which is a key contributor to the national gross domestic product, export performance, and industrial competitiveness. However, challenges remain associated with economic volatility, ergonomic constraints, operational instability, workforce issues, and societal requirements. This research empirically evaluated the relationship of five sustainability-related factors, namely physical working environment, economic factor, employee well-being, operational efficiency, and societal impact, on the productivity of the electronic manufacturing industry in Negeri Sembilan, Malaysia, while providing theoretical and practical insights grounded in Deming Theory and the Triple Bottom Line framework. A quantitative research design was employed to analyze the data obtained from 274 respondents across four major electronic manufacturing companies using factor analysis, reliability testing, multiple regression, and analysis of variance. The findings indicate that economic factor, operational efficiency, physical working environment, and societal impact have a significant positive relationship with productivity, with economic factor as the strongest predictor. In contrast, employee well-being shows a positive correlation in preliminary analysis but was not found to be a significant contributor when tested with other variables. The findings enhance existing knowledge by demonstrating that productivity in highly automated manufacturing environments is mainly associated with economic and operational factors rather than human-centric factors. These findings provide valuable insights to other industries undergoing Industry 4.0 transformation, including semiconductor, automotive, and advanced manufacturing. The research highlights that as automation maturity increases, system-level capabilities such as financial readiness, process stability, and technological integration are critically associated with productivity outcomes.

Keywords: Sustainability; Social responsibility; Process innovation; Electronic manufacturing; Automation; Productivity

1. Introduction

Previous research has explored multiple factors associated with productivity in manufacturing environments, such as physical working conditions, economic constraints, workforce-related factors, operational efficiency, and societal expectations. For example, previous research has shown that poor ergonomics is associated with employee fatigue and reduced performance, thereby decreasing productivity (Shafi *et al.*, 2023; Zurnizam *et al.*, 2024).

Other studies highlight that economic factors such as investment capacity, cost pressures, and return on investment are significant factors associated with automation adoption and production outcomes (Jalaludin *et al.*, 2024). Global disruptions such as supply chain interruptions and economic volatility have been associated with decreased production efficiency in manufacturing industries (Jalaludin *et al.*, 2024).

However, previous studies have largely examined the factors independently, without integrating them into a comprehensive framework. While working environment and workforce-related factors have been widely highlighted in the literature, recent research suggests that system-level factors such as operational efficiency and economic factors are strongly associated with productivity in highly automated environments. This suggests a shift in productivity-associated factors as industries move toward Industry 4.0.

Despite previous findings, empirical research has not synthesized these factors into a unified model, especially in the Malaysian electronics manufacturing industry. Therefore, this research addresses this gap by integrating physical working environment, economic factors, employee well-being, operational efficiency, and societal impact into a single analytical framework to evaluate the combined influence on productivity.

The Malaysian electronics manufacturing industry is undergoing an important transformation driven by the integration of sustainable automation technologies that align with national sustainability goals and digitalization initiatives (Santos & Sant'Anna, 2024; Sony *et al.*, 2021). The government's New Industrial Master Plan 2030 aims to convert a substantial number of factories into smart factories by 2030 (Santos & Sant'Anna, 2024; Sony *et al.*, 2021). This will be achieved by emphasizing the adoption of Industry 4.0 technologies such as the Internet of

Things, artificial intelligence (AI), robotics, and advanced automation to improve resource utilization and support sustainability (Javaid *et al.*, 2022; Maddikunta *et al.*, 2022; Ramanujan *et al.*, 2023; Santos & Sant'Anna, 2024).

Nevertheless, challenges such as suboptimal working conditions, operational inefficiencies, and economic constraints continue to hinder productivity improvements. Increasing societal and regulatory demands for sustainable and ethical practices require organizations to balance productivity targets with environmental and social responsibilities.

Global supply chain disruptions, such as the COVID-19 pandemic and the semiconductor shortage, have affected productivity in Malaysia's electronics manufacturing sector. Production delays, increased logistics costs, and uncertain delivery schedules are associated with manufacturers operating below optimal levels, reducing productivity (Belhadi *et al.*, 2021; Jalaludin *et al.*, 2024). Although the Malaysian government has few Industrial 4.0 initiatives, the adoption rate among SMEs remains relatively low. Manual processes, outdated equipment, and poor maintenance practices are often associated with higher cycle times and defect rates (Jalaludin *et al.*, 2024).

A significant increase in consumer and investor demand for ethical labor practices and sustainability standards has encouraged companies to improve working conditions and strengthen environmental responsibilities within the electronic manufacturing industry. While such initiatives are beneficial overall, the transition frequently requires significant investment in training, equipment, and certification processes that temporarily affect output productivity (Santos & Sant'Anna, 2024).

The electronic manufacturing industry in Malaysia is at a critical crossroads. This sector is a major contributor to the economic growth of Malaysia. However, factors such as environmental disruptions, economic factors, worker welfare issues, operational inefficiency, and societal perceptions are key factors in realizing the full potential of the industry. Therefore, this study aims to empirically evaluate the influence of sustainable automation factors on productivity in the electronic manufacturing industry in Negeri Sembilan, Malaysia, by focusing on five key factors mentioned earlier. This study provides a comprehensive evaluation of factors associated with productivity and offers insights into improving automation implementation

strategies.

Based on identified research gaps, our study aims to clarify the following research question:

- To what extent do the physical working environment, economic factors, employee well-being, operational efficiency, and societal impact associate with productivity in the electronics manufacturing industry in Negeri Sembilan, Malaysia?

To address this research question, we developed and tested five hypotheses derived from Deming Theory (Fonseca *et al.*, 2021) and the Triple Bottom Line framework (Bhatti *et al.*, 2025). The hypotheses examine the individual relationship between each sustainability-related factor and productivity in highly automated manufacturing environments.

2. Literature review

The productivity of the electronic manufacturing industry is a crucial factor in ensuring the competitiveness and profitability of the sector and is influenced by technological, operational, and managerial factors (Kamal & Rahman, 2024). Kamal and Rahman (2024) examined recent research on productivity optimization in the sector, including key associated factors and methodologies. They used simulation-based modeling to optimize productivity in the electronics manufacturing industry. This involved creating virtual replicas of real manufacturing processes that enable testing various scenarios without interfering with actual operations. Their approach identified bottlenecks related to resource allocations, machine utilization, and process flow. Using discrete-event simulations, the evaluation reported measurable improvements in production throughput and utilization rates, together with a significant reduction in delay time. This method is associated with enhanced decision-making, increased accuracy, reduced downtime, and support for continuous process improvement and strategic planning in the electronics manufacturing sector (Kamal & Rahman, 2024).

Productivity increases when inputs produce more output in terms of quantity and quality. This can also be explained as achieving the same output with fewer inputs. Regarding theoretical perspectives on productivity improvement, recent research highlighted a systems approach to manufacturing productivity (Santos & Sant'Anna, 2024). This approach emphasized the complex interrelationships among various factory elements. Productivity management involved multidimensional responsibilities, including managerial decisions and engineering control mechanisms across various manufacturing system components. Santos and Sant'Anna (2024) showed that productivity

improvements are linked to orchestrating interactions among resources, processes, and management controls. Leaders must navigate multiple categories of elements and their relationships to enhance productivity. Understanding these interrelationships helps identify barriers and develop effective productivity improvement strategies.

Sustainable automation uses technologies such as robotics, AI, and control systems to perform tasks with minimal or no human effort (Maddikunta *et al.*, 2022; Xu *et al.*, 2021). This technology is categorized as fixed, programmable, and flexible automation, reflecting its adaptability in operations (Shabur *et al.*, 2025). Sustainable automation in the Malaysian electronic manufacturing industry relates to factors associated with productivity while ensuring environmental and social responsibilities (Ivanov, 2023; Maddikunta *et al.*, 2022; Nasir *et al.*, 2025; Shabur *et al.*, 2025). These factors are the physical working environment ensuring comfort and safety, economic factors such as cost impact and investment, employee well-being related to morale and retention, operational efficiency through reduced waste and energy consumption, and societal impact based on its role in community and environmental stewardship (Setyadi *et al.*, 2025; Shabur *et al.*, 2025).

The physical working environment is potentially significant because a well-designed environment is associated with employee comfort and fewer musculoskeletal disorders, reflecting enhanced productivity and effective human-automation interactions (Mohd Nizam & Ramlee, 2024). Ergonomic interventions such as adjustable workstations and sufficient lighting have been associated with lower workplace injuries and better performance in Malaysian manufacturing plants. The high incidence of work-related disorders in the sector underscores the need for sustainable workplace design. However, context-specific studies on the Malaysian electronics manufacturing industry remain limited. Research in Batu Pahat and Penang has highlighted a significant correlation between workplace stressors and low productivity.

As for economic factors, Malaysia's New Industrial Master Plan 2030 focuses on Industry 4.0 technology adoption, including automation intended to enhance productivity and competitiveness in the electronics industry (Ministry of Investment, Trade, and Industry, 2021). The government supports organizations through incentives and funding to facilitate the shift toward smart factories, which support sustainable economic growth. Investments in automation infrastructure have been associated with operational improvements and cost efficiencies (Bag *et al.*, 2021; Jalaludin *et al.*, 2024).

Employee well-being and job satisfaction have been associated with automation systems, including AI, through their influence on workloads, physical demands, and repetitive tasks (Miah *et al.*, 2024). Training and upskilling programs help employees adjust to change and encourage acceptance of automation as a productivity tool by fostering a culture of acceptance and collaboration and framing automation as a productivity enhancer rather than a risk (Margherita & Bua, 2021; Miah *et al.*, 2024).

Automation can enhance operational efficiency by enabling predictive maintenance, real-time data monitoring, and resource optimization (Marinagi *et al.*, 2023; Sam *et al.*, 2021). Tools such as smart manufacturing and the Internet of Things can reduce energy use and waste generation, promoting both environmental and economic sustainability (Sam *et al.*, 2021). Sustainable automation can help meet societal objectives by reducing carbon footprints through renewable energy adoption and carbon reduction projects (Setyadi *et al.*, 2025). Malaysia's electronics industry is increasingly aligning with ESG principles by promoting community resilience and environmental stewardship (Setyadi *et al.*, 2025).

Employment quality is also linked to workload and psychological stress when not managed properly (International Labour Organization, 2024). Automation can improve occupational health and safety by reducing exposure to hazardous tasks, but it can also increase work intensification and psychological stress if not managed properly. To mitigate negative social impacts, decent work conditions, job security, and worker involvement in decision-making are important.

In our study, productivity is the dependent variable, while the physical working environment, economic factors, employee well-being, operational efficiency, and societal impact are selected as independent variables. The framework proposes a direct relationship between independent and dependent variables, where improvements in these sustainability-related elements are hypothesized to be associated with improvements in productivity outcomes in the electronic manufacturing environment.

Each independent variable is conceptualized as a multidimensional construct based on previous research. The physical working environment factor includes sub-dimensions such as lighting conditions, temperature, noise level, ergonomic design, and workstation layout (Shafi *et al.*, 2023; Zurnizam *et al.*, 2024). Economic factors consist of investment capability, cost efficiency, and return on investment (Jalaludin *et al.*, 2024; Malaysian Investment Development Authority, 2023).

Employee well-being is presented through dimensions

such as job satisfaction, workload, work-life balance, career growth, and working environment (Margherita & Bua, 2021; Miah *et al.*, 2024; Narkhede *et al.*, 2025; Zakaria *et al.*, 2024). Operational efficiency includes process optimization, equipment utilization, and yield achievement (Kamal & Rahman, 2024; Sam *et al.*, 2021). Societal impact covers sub-elements such as ethical labor practices, social impact, and sustainability awareness (Setyadi *et al.*, 2025; Shaharudin *et al.*, 2022).

The questionnaire operationalizes these sub-elements by using multiple items for each variable to ensure the construct is grounded in established literature and measured empirically. The proposed framework illustrates structured relationships where multiple sustainability-driven independent factors are hypothesized to be associated with productivity in the electronic manufacturing industry. Figure 1 illustrates the proposed conceptual framework, where the independent variables are hypothesized to have a significant relationship with productivity and the sub-elements are derived from previous studies.

3. Data and methods

3.1. Study settings

The study was conducted in non-contrived, natural settings, with no manipulative or controlled conditions (Greenhalgh & Manzano, 2022). The questionnaires were provided to employees who work as engineers/executives, managers, and supervisors in the electronic manufacturing industry. Participants completed the questionnaires without researcher interference to ensure the data accurately reflected participants' genuine information. This method supports greater realism and a more comprehensive understanding of the research context.

3.2. Time horizon

We used a cross-sectional survey to collect data at a single point in time (Taris, 2021). This method suits the research goals, as it investigates the current state of productivity in the electronic manufacturing sector and its associated factors. The questionnaire was distributed and completed over four months. This period provided sufficient time for data collection and helped capture responses reflecting current conditions and industry trends.

3.3. Sample size

The study utilized a non-probability convenience sampling method, as the respondents were selected based on accessibility and willingness to participate. This approach is suitable for exploratory research within a particular industrial context where access to respondents is limited. The Slovin formula was utilized for calculation,

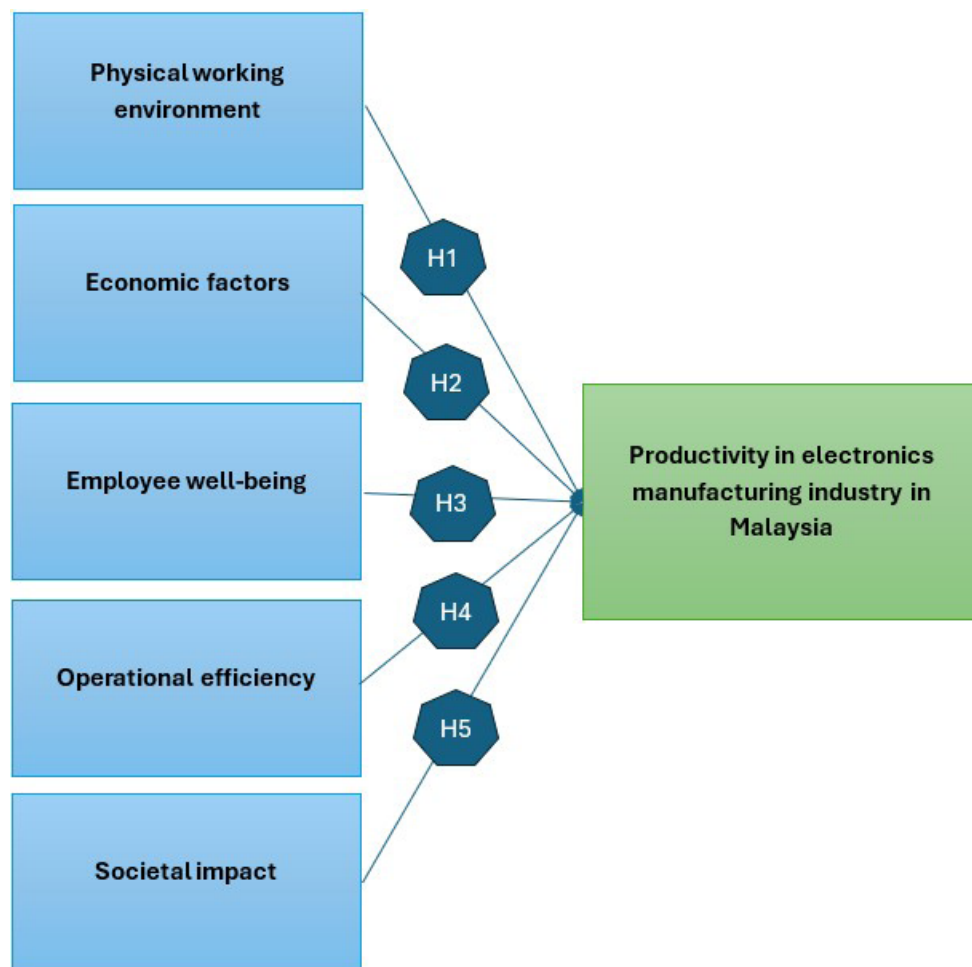


Figure 1. Theoretical framework of independent variables associated with productivity

with a 95% (0.95) confidence level and a 5% margin of error (Anugraheni *et al.*, 2023). We targeted at least 257 participants using the Slovin formula (**Equation 1**) to ensure a balanced representation of companies across various sizes and industry segments within Malaysia's electronic manufacturing sector.

$$n = \frac{N}{1 + Ne^2} = \frac{717}{1 + 717(0.05)^2} \approx 257 \quad (1)$$

where,

- n : Number of samples;
- N : Total population;
- e : Error tolerance.

We focused on electronic manufacturing companies in Negeri Sembilan, Malaysia because the region is a growing industrial hub with a concentration of semiconductor,

electronic device, and battery manufacturing companies. We justified this selection by the region's active involvement in the Malaysian electronic manufacturing supply chain and its accessibility for data collection, enabling the researcher to obtain dependable, industry-specific participation from relevant practitioners.

Participants were selected based on defined professional criteria to ensure the reliability and relevance of the data obtained. Specifically, respondents were required to hold technical or managerial roles such as supervisors, engineers, executives, or managers; have direct involvement in manufacturing operations, automation projects, systems, and processes; be process engineers or in production management; and have work experience in the electronic manufacturing sector. These criteria were designed to select respondents with relevant practical exposure to automation practices and productivity-related processes. A total of 274 participants, including engineers/executives,

managers, and supervisors, completed the questionnaire survey. Population refers to the total set of observations that are made. This comprises all the individuals within a specified group that the researcher examines to gather data from and make informed decisions. By defining knowledge and experience in terms of roles, involvement in respective processes, and minimum industry exposure, the research aimed to obtain data that were dependable, relevant, and reflective of actual industrial practices within the electronic manufacturing industry.

3.4. Data collection method

We provided questionnaires to the defined participants through online surveys. The online surveys were conducted on a secure platform, Google Forms, and respondents were given a link to access and complete the questionnaire. The responses were exported directly to an Excel file for analysis purposes. This helped to reduce data entry errors and improve data management efficiency.

3.5. Measurement scales

The survey questionnaires used two types of scales: the nominal scale and the Likert scale (Table 1) (Taherdoost, 2022).

To ensure proper operationalization of constructs, this research evaluated each variable using multiple attributes obtained directly from a structured questionnaire. Each attribute corresponds to a statement in the survey instrument and reflects the underlying dimensions of the constructs. For instance, the physical working environment was evaluated by attributes such as lighting and temperature conditions, equipment ergonomic design, repetitive tasks, noise level, and workplace layout. Economic factors were

measured by budget allocation, cost efficiency, investment planning, prioritization of productivity improvement, and return on investment. Employee well-being was captured by workload, training and upskilling opportunities, work-life balance, work efficiency support, and career growth chances.

Operational efficiency was evaluated through attributes such as production yield, manual task reduction, manufacturing target achievement, waste reduction, and downtime reduction. Societal impact consists of sustainability considerations, corporate social responsibility, societal impact awareness, job security, and alignment with sustainable societal well-being. The dependent variable, productivity, was evaluated using attributes such as increased productivity, reduced operational errors, enhanced process control, level of automation, and compliance with Industry 4.0 standards. These attributes, as summarized in Table 2, were measured using a five-point Likert scale and were clearly defined.

3.6. Data analysis

The collected survey data were analyzed using a quantitative research approach. Quantitative methods, including descriptive statistics, correlation analysis, multiple regression analysis, and analysis of variance, were used to analyze the relationship between the independent and dependent variables. Data were collected through online survey forms, which are known for efficient data collection (Taherdoost, 2022). The questionnaire was distributed online through platforms such as email, WhatsApp, and other relevant channels. The questionnaire was distributed using a non-probability convenience sampling approach to reach relevant participants in the electronics manufacturing

Table 1. Source of questionnaire

Section	Variables	No of item	Source	Adapt/ adopt	Measurement scale
I	Demographic	5	Age, gender, position, working experience, education level	–	–
II (dependent variable)	Productivity in the electronic manufacturing industry	5	(Abu Bakar <i>et al.</i> , 2022)	Adapted	Likert scale
	Physical working environment	5	(Ispășoiu <i>et al.</i> , 2023)	Adapted	Likert scale
III (independent variables)	Economic factor	5	(Miah <i>et al.</i> , 2024)	Adapted	Likert scale
	Employee well-being	5	(Vorma <i>et al.</i> , 2024)	Adapted	Likert scale
	Operational Efficiency	5	(Panigrahi <i>et al.</i> , 2023)	Adapted	Likert scale
	Societal Impact	5	(Dzage <i>et al.</i> , 2024)	Adapted	Likert scale

industry. The questionnaire was administered in English and consisted of three primary sections. We used a variety of measurement methods, including a pilot test, factor analysis, reliability testing, descriptive analysis, multiple regression analysis, and beta coefficient (Nieminen, 2022). The measurement scaling method compared ratings across variables and used the variable with the highest rating scale.

Table 2. Variable and attribute

Variable	Attributes
Productivity (dependent variable)	Productivity increase
	Operational error reduction
	Improve process control
	Automation level
	Industry 4.0 compliance
Physical working environment	Lighting and temperature
	Equipment ergonomic design
	Repetitive task requirement
	Noise level comfort
	Workplace layout
Economic factor	Automation budgets allocation
	Investment cost efficiency
	Economic planning
	Productivity improvement prioritization
	Return on investment
Employee well-being	Workload balance
	Training and upskilling
	Work-life balance
	Efficient working environment
	Career growth opportunity
Operational efficiency	Product yield enhancement
	Manual task reduction
	Production target achievement
	Waste reduction
	Downtime reduction
Societal impact	Consideration of sustainability
	Corporate social responsibility
	Social impact
	Job security
	Long-term alignment with social well-being

4. Results

4.1. Demographic profile

Table 3 presents the demographic profile of participants and provides a detailed summary of the sample population, showing diversity and representativeness. The age distribution showed a mixed population, with most respondents in the 30–39 age range (41.2%). The gender distribution showed more male than female respondents, with males comprising 58.8% and females 41.2%. Most respondents were in engineer/executive positions, representing 55.5%. In terms of work experience, most respondents had 6–10 years and more than 15 years of experience, each accounting for 26.6%. Most respondents held a bachelor's degree (57.7%); 20.4% held a diploma/certificate, 18.6% held a master's degree, and a small group held a doctorate.

Table 3. Respondents' demographic profile summary

Group	Sub-group	Frequency	Percent (%)
Age group	20–29	59	21.5
	30–39	113	41.2
	40–49	51	18.6
	50–59	49	17.9
	60+	2	0.8
Gender	Male	161	58.8
	Female	113	41.2
Position	Supervisor	52	19.0
	Engineer/executive	152	55.5
	Manager	70	25.5
	<1	10	3.7
Working experience	1–5	55	20.1
	6–10	73	26.6
	11–15	63	23.0
	>15	73	26.6
	Bachelor's degree	158	57.7
Education level	Diploma/certificate	56	20.4
	Master's degree	51	18.6
	PhD	9	3.3

Note: Total 274 participants

4.2. Factor analysis

Factor analysis was performed to assess the construct structure and evaluate whether the measurement elements appropriately represent the respective variables. The Kaiser–Meyer–Olkin (KMO) measure was used to assess sampling adequacy, while Bartlett’s Test of Sphericity was used to determine whether the correlation matrix was adequate for factor analysis. As shown in Table 4, the KMO value was 0.913, which indicates that the sample is adequate for factor analysis. This value is categorized as “Outstanding,” indicating that the data were suitable for analysis. Bartlett’s test of sphericity showed a χ^2 of 1,027.593 with 15 degrees of freedom and a significance level of less than 0.001. This result showed that the correlation between variables is significantly different from zero, reflecting that the data were appropriate for factor analysis. The high KMO and Bartlett’s test of sphericity values suggest that the data collected were adequate for factor analysis and support the validity of the constructs utilized in the research.

Table 4. Kaiser–Meyer–Olkin and Bartlett’s test

Kaiser–Meyer–Olkin measure of sampling adequacy	Bartlett’s test of sphericity		
	χ^2	Degree of freedom	Significance
0.913	1,027.59	15	<0.001

4.3. Reliability analysis

Table 5 shows the results of the reliability analysis, confirming that the scales used were reliable. The dependent variable, productivity, showed good internal consistency with a Cronbach’s Alpha of 0.814 across all five items. For the independent variables, the physical working environment showed acceptable internal consistency, with a Cronbach’s Alpha of 0.703. However, the other independent variables, such as economic factor, employee well-being, operational efficiency, and societal impact, showed Cronbach’s Alpha values greater than 0.8, which indicates good internal consistency for the five items of the respective variables. Overall, the results show that the measurement instrument used in this study is reliable, with all variables at acceptable levels of internal consistency.

4.4. Multiple regression analysis

The R value in Table 6 (0.705) showed a strong positive correlation between observed and predicted productivity values in the electronic manufacturing industry in Negeri Sembilan, Malaysia. The R^2 value of 0.496 indicates that

49.6% of the variance in the dependent variable is explained by the independent variables, namely physical working environment, economic factor, employee well-being, operational efficiency, and societal impact. The adjusted R^2 value was 0.487, slightly lower than R^2 . This shows that the model explained 48.7% of the variance in productivity when accounting for the number of predictors. This difference accounts for the number of predictors and the sample size, which gives a more realistic measure of model performance.

Table 5. Reliability test

Variables	Cronbach’s alpha	No of Items
Productivity	0.814	5
Physical working environment	0.703	5
Economic factor	0.814	5
Employee well-being	0.860	5
Operational efficiency	0.841	5
Societal impact	0.841	5

Table 6. Model summary result

Model ^a	R	R^2	Adjusted R^2	Standard error of the estimate	Durbin–Watson
1	0.705 ^b	0.496	0.487	0.52917	1.781

Notes: ^aDependent variable: Productivity; ^bPredictors: (Constant), physical working environment, economic factor, employee well-being, operational efficiency, societal impact

4.5. Regression analysis of variance

The analysis of variance in Table 7 for the regression model showed that the model was statistically significant. The regression sum of squares is 73.990 with 5 degrees of freedom and mean square 14.798. The residual sum of squares is 75.045 with 268 degrees of freedom, and the mean square is 0.280. The F -statistic was 52.847 with a significance level less than 0.001. This indicates that the overall regression model was statistically significant, indicating that at least one of the independent variables was significantly associated with productivity in the electronic manufacturing industry in Negeri Sembilan, Malaysia (Hassan *et al.*, 2024).

Table 7. Analysis of variance summary

Model ^a	Sum of squares	Degree of freedom	Mean square	F	Significance
Regression	73.990	5	14.798	52.847	<0.001 ^b
Residual	75.045	268	0.280		
Total	149.034	273			

Notes: ^aDependent variable: Productivity; ^bPredictors: (Constant), physical working environment, economic factor, employee well-being, operational efficiency, societal impact

4.6. Multicollinearity and beta coefficient

The hypothesis testing in Tables 8 and 9 showed that employee well-being did not have a statistically significant positive relationship with productivity in the electronic manufacturing industry in Negeri Sembilan, Malaysia, with a *p*-value of 0.833. However, the physical working environment, economic factor, operational efficiency, and societal impact were significant, with *p*-values of 0.031, 0.000, 0.007, and 0.039, respectively. The regression analysis further supports these findings, showing that the stated variables had a significant positive relationship with productivity. The standardized coefficients showed that economic factors were the strongest unique predictor ($\beta = 0.303$), followed by operational efficiency ($\beta = 0.213$), societal impact ($\beta = 0.148$), and physical working

environment ($\beta = 0.134$). Overall, the results highlighted the significant role of physical working environment, economic factors, operational efficiency, and societal impact in influencing productivity in the electronic manufacturing industry in Negeri Sembilan, Malaysia. Ideally, a variance inflation factor value above 10 indicates high multicollinearity, which is undesirable. In our study, the variance inflation factor values were lower than the threshold, indicating that multicollinearity was not a severe problem in this model.

5. Discussion

The overall results show that four out of five factors, namely physical working environment, economic factor, operational efficiency, and societal impact, had a statistically significant and positive relationship with productivity in the electronic manufacturing industry in Negeri Sembilan, Malaysia. This result aligns with previous research emphasizing the importance of system-based and technological factors in improving productivity in Industry 4.0 and automated manufacturing environments (Sam *et al.*, 2021). However, we extended the literature by empirically evaluating this relationship in the context of sustainable automation in Malaysia's manufacturing industry, which remains underexplored.

The dominance of economic factors as the strongest predictor of productivity is consistent with previous studies that emphasize the importance of financial readiness, investment capability, and cost efficiency in adopting automation (Bag *et al.*, 2021; Jalaludin *et al.*, 2024). While previous studies have acknowledged the role of economic considerations, we contributed by

Table 8. Coefficients and collinearity results

Model ^a	Unstandardized coefficients		Standardized coefficients	<i>t</i>	Significant	Collinearity statistics	
	<i>B</i>	Standard error	β			Tolerance	VIF
(Constant)	0.649	0.205		3.173	0.002		
Physical working environment	0.151	0.069	0.134	2.172	0.031	0.497	2.012
Economic factor	0.308	0.067	0.303	4.607	0.000	0.434	2.302
Employee well-being	0.012	0.058	0.014	0.211	0.833	0.411	2.431
Operational efficiency	0.211	0.077	0.213	2.737	0.007	0.311	3.214
Societal impact	0.152	0.073	0.148	2.075	0.039	0.371	2.695

Notes: ^aDependent variable: Productivity.
Abbreviation: VIF: Variance inflation factor.

Table 9. Hypothesis result

Hypothesis	β coefficient	p -value	t -value	Results
H1: The physical working environment factor has a significant positive relationship with productivity.	0.134	0.031	2.172	Accept
H2: Economic factor has a significant positive relationship with productivity.	0.303	0.000	4.607	Accept
H3: Employee well-being has a significant positive relationship with productivity.	0.014	0.833	0.211	Reject
H4: Operational efficiency has a significant positive relationship with productivity.	0.213	0.007	2.737	Accept
H5: Societal impact has a significant positive relationship with productivity.	0.148	0.039	2.075	Accept

quantitatively demonstrating that economic factors are the primary predictor of productivity outcomes in sustainable automation environments. This outcome supports the argument that automation is not only a technological approach but is also closely tied to economic capabilities, especially in developing manufacturing environments.

The strong link between operational efficiency and productivity supports existing literature highlighting process optimization, predictive maintenance, and real-time monitoring as critical factors in productivity enhancement (Kamal & Rahman, 2024; Sam *et al.*, 2021). The current study contributed by integrating these operational elements into a sustainability-oriented framework, demonstrating that operational efficiency appears as an important element associated with sustainable automation and measurable productivity gains.

The results also explain the continued significance of the physical working environment, supporting previous research that focused on ergonomics and workplace layout as predictors of productivity even in automated environments (Mohd Nizam & Ramlee, 2024). In contrast to the traditional view that focuses primarily on manual labor conditions, the current study suggests that ergonomic and environmental elements remain important for effective human-machine interaction, extending their relevance to highly automated manufacturing environments.

Moreover, societal impact was observed to have a significant positive relationship with productivity, which is consistent with previous research on social sustainability and corporate responsibility in manufacturing, indicating the notion that community acceptance, workforce readiness, and responsible labor practices play important

roles in organizational performance (Setyadi *et al.*, 2025; Shaharudin *et al.*, 2022). The current study contributed to the literature by empirically evaluating whether societal factors, such as workforce readiness and ethical labor practices, are significantly associated with productivity rather than only being indirect or long-term predictors.

In contrast, employee well-being did not show a statistically significant independent relationship with productivity when evaluated with other variables, although it showed positive correlations in earlier analysis. The results differ from earlier studies that highlight employee well-being as a major contributor to productivity (Zakaria *et al.*, 2024). The current study offers the latest insight by suggesting that, in highly automated environments, employee well-being is indirectly associated with productivity and mediated by system-level and operational factors, reflecting a shift from a human-centric productivity framework to a system-driven one.

This non-significant effect of employee well-being can be explained by the increasing automation maturity within electronic manufacturing environments. In traditional, labor-intensive manufacturing settings, employee well-being is often directly linked to productivity because operator performance directly influences productivity outcomes. However, in highly automated conditions, automated systems control many operational tasks, reducing productivity's direct dependence on operator effort. Therefore, productivity is more closely associated with process stability, equipment capacity, financial capability, and system integration than with individual employee-controlled factors.

The significance value indicates that employee well-

being was not strongly associated with productivity. This shows that employee well-being affects productivity indirectly through organizational practices, workforce readiness, technology adaptability, and operational systems. Therefore, while employee well-being remains significant for organizational sustainability, its contribution to productivity in highly automated environments is mediated by system-level factors rather than being a direct independent factor associated with productivity.

These findings suggest that sustainable automation success is associated with strong economic capacity, robust operational conditions, an ergonomically supportive physical working environment, and a positive societal ecosystem. Employee well-being has appeared to play a more complementary than direct role in productivity. This supports the argument that productivity in the electronic manufacturing industry is more closely linked to system-based factors than to workforce-related factors alone.

From the perspective of Deming Theory, the results reinforce the argument that productivity improvement is driven more by system optimization than by individual performance alone. Deming highlights that organizational output is highly influenced by the effectiveness of the production system, management practices, and process control mechanisms. The importance of economic factors, operational efficiency, and the physical working environment supports this perspective by showing that productivity is closely linked to system-level factors. The non-significant role of employee well-being further aligns with Deming's theory that organizational performance should be attributed not only to individual employees but also to the design and effectiveness of the overall operational system.

The results also provide important information regarding the Triple Bottom Line framework. While the framework suggests that economic, social, and environmental elements should support sustainable organizational performance, the findings show that these elements contribute differently within automated manufacturing environments. The economic factor emerged as the strongest predictor among the other factors of productivity, highlighting the continued importance of financial capacity and investment capability. On the other hand, societal impact and physical working environment remained important contributors, indicating that social and environmental considerations continue to influence performance. However, the non-significant association of employee well-being suggests that not every social factor equally contributes to productivity under Industry 4.0 environments. This finding extends the Triple Bottom Line framework by suggesting that each sustainability

factor may vary in influence depending on technological maturity and operational mechanisms.

Our study contributed to the existing body of knowledge in three significant ways. Firstly, this research develops and validates a multi-factor productivity model that incorporates sustainability dimensions such as economic, operational, environmental, and social elements. Secondly, it provides empirical evidence from the Malaysian electronics manufacturing industry, addressing a contextual gap in previous research. Thirdly, this research highlights a theoretical change in productivity determinants, showing that system-based and structural elements play a more dominant role than human-centric factors in automated manufacturing conditions.

Recommendations to enhance the demographic profile of the respondents potentially increase the robustness and generalizability of this study on sustainable automation towards productivity in the electronic manufacturing industry in Negeri Sembilan, Malaysia. Primarily, department-based representation should be further considered within the electronic manufacturing industry. For instance, the study should include roles from departments such as process, quality, manufacturing teams, and others. This could provide a more comprehensive overview across multiple backgrounds.

To implement this recommendation, targeted recruitment strategies can reach the desired groups. This includes reaching through professional events, social media campaigns, and collaborating with educational institutions. Providing incentives to encourage participation from diverse demographic backgrounds can help improve response rates and maintain sample balance. To do this, the language and questions should be clear and relevant to a wide range of participants. By implementing these recommendations, the study can improve participant demographics, resulting in more comprehensive outcomes. This could enhance the overall quality and generalizability of research on sustainable automation and productivity in the electronic manufacturing industry in Negeri Sembilan, Malaysia. A diversified and representative sample supports a robust understanding of factors associated with productivity in the electronic manufacturing industry and helps develop effective strategies for sustainable automation. This approach strengthens the reliability and applicability of the research outcomes in a wider context, supporting the advancement of sustainable automation towards productivity in the electronic manufacturing industry.

As a limitation, this study focused on sustainable automation towards productivity in the electronic manufacturing industry in Negeri Sembilan, Malaysia,

which limits the generalizability of the findings to other regions and countries. Automation conditions and other associated factors can vary by region, depending on local context such as economic factors, technological capacity, and regulations. For instance, a policy that is locally effective may not be effective in regions with different economic and technological structures. Future research can expand the scope to include comparative research across regions and countries to provide a broader perspective on sustainable automation in the electronics manufacturing industry. Comparative analysis can identify best practices and common challenges that provide useful insights for adapting to different contexts.

A key contribution of this study is that the findings show economic strength and operational efficiency as the two main predictors of productivity, as noted in Triple Bottom Line theory (Bhatti *et al.*, 2025). This emphasizes the need for continued support from the government through incentives, funding schemes, and capacity-building initiatives that support organizations' financial readiness and process stability. By indicating the societal impact, such as workforce ecosystem preparedness and ethical labor practices, observed to be significantly associated with productivity, the study emphasizes the importance of national policies in promoting responsible, inclusive, and sustainability-based automation adoption. It is subject to continuous improvement, as mentioned in Deming Theory (Fonseca *et al.*, 2021). These findings provide the policymakers with valuable evidence for developing targeted initiatives in training, digital infrastructure, and regulatory frameworks that assist both industry efficiency and long-term social resilience.

This study contributes to industrial stakeholders by providing actionable insights by determining the specific areas that should be focused on when implementing sustainable automation. Because economic factors, operational efficiency, and the physical working environment were significantly associated with productivity, organizations can use these findings to guide investment decisions, prioritize process optimization, adopt predictive maintenance, reconsider plant layouts, and enhance ergonomics for better human-machine interaction. The results also show that employee well-being, while important, does not directly affect productivity in automated environments, suggesting organizations should shift their direction towards system stability, talent upskilling, and ensuring workforce adaptability rather than relying only on conventional well-being initiatives. This potentially assists managers, engineers, and automation project planners to design an effective digital transformation strategy aligning with organizational

requirements, resource constraints, and sustainability aims.

For future researchers, this study provided a reliable measurement framework, including a statistically evaluated five-factor productivity model, and a high-quality dataset from the southern regions of the Malaysian electronic manufacturing industry, which has not been explored previously. In addition, the finding that employee well-being was not significantly associated with productivity in an automated environment creates opportunities for new theoretical discussion and research, particularly on changing job roles, automation maturity, and cognitive demand reshaping the relationship between humans and productivity. The study also identified gaps for future work, such as cross-regional comparisons, deeper investigation of specific factors, and cost-benefit modeling.

Overall, the results of this research contribute meaningfully to the existing body of knowledge on sustainable automation and productivity. While previous research across various industries has established that automation is associated with productivity enhancement through efficiency and technological advancement, this research highlights a deeper understanding within highly automated manufacturing environments. Particularly, it shows that productivity is highly associated with system-based and structural factors, especially economic capacity and operational efficiency, rather than human-centric factors only.

These findings advance existing knowledge by suggesting a change in productivity determinants in Industry 4.0 conditions, where human-centric factors become indirect and mediated by technology. Additionally, the study contributes empirical evidence from the Malaysian electronic manufacturing industry, a context that remains unexplored in existing studies. This assists in the broader application of the sustainable automation framework while highlighting the importance of contextual and industry-based factors associated with productivity outcomes.

The results directly address the research question regarding the extent to which physical working environment, economic factors, employee well-being, operational efficiency, and societal impact are associated with productivity in the electronic manufacturing sector in Negeri Sembilan, Malaysia. The results demonstrate that four factors, namely economic factors, operational efficiency, physical working environment, and societal impact, significantly influence productivity. Employee well-being does not exhibit a statistically independent relationship when evaluated with the other factors. These results show that productivity in highly automated manufacturing conditions is highly associated with

system-level and structural factors rather than individual-level factors. Consequently, the research gives empirical evidence clarifying the relative impact of multiple sustainability-based factors on productivity within an integrated framework.

Furthermore, the results address the research gap identified in the introduction. Previous research has largely examined physical working environment, economic factors, workforce factors, operational efficiency, and societal impact independently. Limited research has integrated these factors into one empirical framework from the Malaysian electronic manufacturing perspective. By evaluating all factors simultaneously, this research finds that economic and operational factors are more strongly associated with productivity than employee well-being in highly automated manufacturing environments. This presents new contextual evidence from a Malaysian electronic manufacturing perspective and enhances understanding of productivity-determining factors within Industry 4.0 and sustainable automation.

6. Conclusion

The findings suggest that productivity in fully automated and semi-automated manufacturing conditions is primarily associated with structural and system-based factors. Economic factors emerged as the strongest predictor of productivity, emphasizing that financial readiness, investment capability, and cost-benefit alignment are associated elements of successful automation. Operational efficiency showed a strong positive association with productivity, reinforcing the importance of process stability, predictive maintenance, and digitalized operational control in achieving the desired productivity levels.

The physical working environment showed a meaningful relationship with productivity despite the rise of automation, highlighting the crucial role of ergonomics, comfortable workplace layouts, and human-machine interaction. This suggests that automation itself does not enhance productivity; rather, human factors matter, especially in roles that require oversight, adjustment, and technical modification.

Societal impact also showed a significant positive relationship with productivity, pointing to community acceptance, ethical labor practices, and workforce adaptability for long-term operational sustainability. Organizations that align automation initiatives with social responsibility, upskilling programs, and environmental awareness are better positioned to achieve sustainable productivity improvement.

In contrast, employee well-being, while showing a

positive correlation with productivity, did not exhibit a significant independent relationship in the regression model, suggesting that in highly automated environments, well-being is associated indirectly through other factors such as operational stability, technological adaptation, or workforce engagement, rather than being a primary factor on its own.

The results also provide significant theoretical implications for both Deming Theory and the Triple Bottom Line framework. The findings support Deming's system-based perspective by showing that productivity is more strongly associated with organizational systems, operational structures, and resource capabilities than with individual-level factors. Furthermore, while the Triple Bottom Line framework remains relevant for understanding sustainable productivity, the findings propose that sustainability-related factors do not contribute equally within highly automated manufacturing conditions. Economic and operational factors exhibit stronger relationships with productivity than human-centric factors, indicating that the significance of sustainability-related factors varies according to the level of automation adoption and technological integration.

In relation to the research question, the study demonstrates that productivity in the electronic manufacturing industry is not equally associated with all sustainability-related factors. Economic factors emerged as the strongest predictor, followed by operational efficiency, societal impact, and physical working environment. Employee well-being was not a significant independent predictor in the regression model. Therefore, the research concludes that productivity in highly automated manufacturing environments is primarily associated with structural and operational dimensions rather than human-centric factors only.

Overall, the findings suggest that sustainable automation is most effective when supported by strong economic capability, efficient operational structure, an ergonomically comfortable physical working environment, and social responsibility. The results highlight that productivity enhancement through automation requires more than technology adoption alone; it demands strategic planning, investment stability, well-structured workplace conditions, and holistic ecosystem support.

By integrating five sustainability-related factors into a single analytical framework, this study addresses a significant gap in the existing literature on sustainable automation in the Malaysian electronic manufacturing sector. The results provide empirical evidence that enhances current understanding of productivity determinants in Industry 4.0 environments and provide a

foundation for future research to evaluate the interaction between sustainability, automation, and organizational performance.

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Conflict of interest

The authors declare that there is no conflict of interest.

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Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of INTI International University (Reference no: INTI/UEC/2026/017 and date of approval 11/8/2026).

Consent for publication

Informed consent was obtained from all participants prior to their participation in the study. Consent was obtained electronically through the online survey, with participation being voluntary and consent implied through completion and submission of the questionnaire. Permission to publish the collected data was obtained, as only anonymized, non-identifiable information was collected and reported. No images or personally identifiable information of

participants were included in this study.

Availability of data

The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

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