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Evaluating the Impact of Sufficiency Economy Philosophy on Sustainable Innovation: A Data-Driven Analysis

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Abstract

This study investigates the factors affecting sustainable innovation within Thailand's Provincial Electricity Authority, a nonprofit organization committed to sustainable energy solutions. With a focus on the Sufficiency Economy Philosophy as a developmental framework, the study examines how SEP principles of moderation, prudence, and resilience contribute to reducing greenhouse gas (GHG) emissions and achieving Sustainable Development Goals (SDGs). The research adopts a quantitative approach to analyze how SEP influences SI in PEA's operations alongside internal and external factors like disruptive leadership, digital transformation, and national sustainability initiatives. Through a series of correlation and regression analyses, the study identifies SEP as a critical component in fostering SI, with values of virtue, risk management, and informed decision-making emerging as influential elements. The findings indicate that integrating SEP's balanced approach to production and consumption facilitates organizational resilience, enabling the PEA to navigate internal and external shocks effectively. Furthermore, the results underscore the necessity of a holistic framework where internal initiatives align with broader cultural and ecological goals. The study highlights SEP's applicability beyond the energy sector, as seen in sustainable efforts in regions like Krabi and Koh Samui, which exemplify SEP-driven approaches toward low-carbon transitions. By leveraging SEP's sufficiency principles, organizations can strengthen sustainable practices contributing to Thailand's environmental and social well-being. The research calls for further exploration into SEP's role across sectors, positing that SEP could be a foundational pillar alongside economic, social, and environmental dimensions to drive sustainable innovation across diverse contexts.

Keywords: Sufficiency Economy Philosophy, Sustainable Innovation, Provincial Electricity Authority, Greenhouse Gas Reduction, Sustainable Development

1. Introduction

This study explores the factors influencing sustainable innovation (SI) at Thailand's Provincial Electricity Authority (PEA), a nonprofit entity providing electrical services. It examines the internal and external drivers of greenhouse gas (GHG) emission reductions, aiming to identify key factors contributing to Thailand's Sustainable Development Goals (SDGs). By understanding how these factors intersect, the study provides valuable insights for organizations globally working toward sustainable development [1]. PEA's alignment with Thailand 4.0 demonstrates its commitment to digital and clean energy technologies, crucial for SI. This includes implementing smart grids, renewable energy (RE) sources, and low-carbon operations. Smart grids help reduce energy consumption and decentralize power generation, while PEA's Smart Meter enables residents to manage energy use more responsibly. The PEA Care and Service and Smart Plus programs, including EV charging stations at hotels, apartments, and resorts, further promote sustainable energy practices. RE technologies like solar and wind are essential for reducing emissions in the electricity sector, a

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major CO_2 emitter. In Asia, a 1% increase in energy innovation correlates with a 0.67% decrease in GHG emissions [2]. According to the IEA, by 2050, 90% of global electricity could come from renewables, with solar and wind contributing 70% [3], [4].

Developing SI requires aligning economic, environmental, and social goals to maximize positive impacts. This includes integrating clean technologies and eco-innovation to foster SI [5], [6]. SI goes beyond technical solutions, involving ideation, prototyping, and creative exploration to develop new products, business models, and strategies [7], [8]. Addressing institutional gaps and managing resource limitations further enables SI by ensuring scalability and long-term sustainability, even in resource-constrained environments. In the PEA, both internal and external factors influence SI, highlighting areas for improvement and strategies to overcome barriers. Thailand's SEP effectively balances economic, social, and environmental dimensions, emphasizing moderation, competitive advantage, and risk reduction. SEP's principle of the "middle path" promotes knowledge, prudence, and ethical integrity at all levels of society. SI within the PEA also intersects with technologies like machine learning, data analysis, and blockchain. Research on clustering techniques [7], [8] and predictive modeling [9], [10] shows how data-driven approaches improve customer experience and digital marketing strategies. Blockchain's potential for creating decentralized, resilient systems [11], [12], along with advancements in processing efficiency [13], [14], further enhances sustainability efforts. These technologies support integrating SEP principles with SI, demonstrating their role in advancing sustainable practices within the PEA. Integrating the SEP with SI offers a promising path for advancing sustainability, but research on their combined impact is limited. This study aims to explore how SEP principles can align with SI to foster sustainable practices. The key research questions are: What is the relationship between SEP and SI within the PEA? How does SEP influence SI adoption? What challenges and opportunities arise from implementing SEP for SI? And how can PEA leverage SEP to achieve long-term sustainability? By addressing these questions, the study seeks to provide insights into how SEP can strengthen SI practices and contribute to Thailand's sustainability goals.

2. Literature Review

2.1. Micro and Macro Environmental Factors

SI is influenced by both micro- and macro-environmental factors. The micro-environment includes internal aspects such as relationships, organizational structure, and communication. Trust and cooperation among supply chain actors enable resource exchange, while internal frameworks can either support or hinder sustainability. Effective communication ensures alignment across stakeholders, which is essential for achieving SI. The macro-environment, on the other hand, comprises broader external factors such as legal, political, social, economic, and technological conditions. Legal frameworks may mandate environmental standards, while economic incentives and political support can drive or limit SI initiatives. Technological advancements provide tools to enhance productivity and reduce environmental impacts.

The interdependence between micro- and macro-environmental factors highlights the need for a holistic approach to SI. Organizations must adapt internal practices to align with external pressures and opportunities to achieve long-term sustainability. For instance, organizational culture (micro-level) must respond to regulatory changes (macro-level), ensuring agility and competitiveness. This interconnectedness emphasizes the complexity of SI, where balancing internal efficiencies with external compliance and innovation is key. In the context of the PEA, both internal factors (like structure and communication) and external factors (such as regulatory frameworks and technological advancements) must be carefully managed to promote sustainability. Technological changes can impact organizational structure, which, in turn, affects relationships and communication within the supply chain. This integrative perspective aligns with the SEP's principles of moderation, prudence, and resilience, promoting a balanced approach to sustainability in both organizational and environmental practices.

2.2. Internal Factors Affecting SI

Internal factors within an organization can significantly influence employee performance and organizational outcomes. Research [15] distinguishes between two core types of purpose within organizations: inside-out and outside-in. Inside-out purpose channels employees' passion and commitment toward fulfilling internal goals and stakeholder needs, driving alignment with organizational values and objectives. Outside-in purpose, in contrast, arises from external pressures such as societal expectations, stakeholder demands, and regulatory requirements, compelling organizations to adapt and respond to external needs and challenges [15]. Together, these internal dynamics shape organizational change, influence company culture, and drive shifts in management practices [16].

2.2.1. Disruptive Leadership (DIL)

DIL is a complex, multidimensional approach to leadership that aligns with the demands of 21st-century organizations [17]. Dumas and Beinecke describe DIL behaviors as encompassing many competencies, including motivation, effective communication, and team-building skills—all critical predictors of successful organizational change [18]. Leaders who excel in these areas tend to be more effective in guiding teams through transformation, fostering resilience, and achieving positive outcomes. Developing this leadership style requires a comprehensive internal and external focus within the organization [15], [19]. Disruptive leaders are encouraged to adopt practices emphasizing inclusiveness, collaboration, and a dedication to serving others [20]. These values promote social good and ecological sustainability, enhancing individual well-being and contributing to a broader organizational purpose. This leadership approach prioritizes quality of life, livability, and environmental aesthetics, aiming to create a work environment that balances social and ecological responsibilities [21]. By embedding these principles, organizations can develop a leadership model responsive to modern business's complex demands while fostering a culture of innovation and responsibility.

2.2.2. PEA Digital Utility (PDU)

The PEA's strategic vision aims to become a leading, sustainability-driven energy provider, transitioning toward a "value-based economy" that emphasizes eco-friendly practices and energy efficiency. Through the PDU initiative, PEA integrates sustainable principles to improve service quality, support economic growth, and reduce environmental impact. This includes the implementation of key technologies, such as smart grids, advanced metering infrastructure, and EV charging stations, which enhance operational efficiency and promote sustainable energy practices. These technologies not only improve energy management but also decentralize power generation, contributing to a reduction in Thailand's carbon footprint [22], [23]. In addition to technological innovation, PEA focuses on customer engagement and workforce development as part of the PDU. The "connected customer service initiative" allows consumers to monitor and manage their energy usage, encouraging energy-saving behaviors aligned with PEA's sustainability goals. Meanwhile, the "workforce of the future initiative" prepares employees for the demands of a digital, tech-driven energy sector, ensuring they have the skills needed to support PEA's long-term sustainability mission. Overall, the PDU initiative demonstrates PEA's commitment to sustainable innovation by combining digital transformation, customer involvement, and workforce development, aligning closely with the SEP's principles of prudent resource management and resilience [22], [23].

2.3. External Factors Impacting SI

2.3.1. Thailand 4.0 (THAI)

THAI is a strategic industrial model designed to transform the country's economy into one that is value-based, innovation-driven, and aligned with sustainable practices. THAI emerged in response to the limitations of previous economic frameworks that focused on low-cost manufacturing and heavy industry, which provided limited support for technology-driven and environmentally sustainable growth. The model aims to transition Thailand from a middle-income to a high-income nation, fostering a knowledge-based economy that prioritizes value creation over sheer production volume. By promoting green technologies, research, and development in clean energy, agriculture, and digital sectors, THAI encourages industries to adopt environmentally friendly practices and innovate in ways that support both economic and environmental goals [24], [25]. Incorporating the social, economic, and environmental pillars of sustainability, THAI aligns with the three-pillar sustainability model, where these interconnected elements form the foundation of development. This holistic approach emphasizes inclusive growth, ensuring that the benefits of economic development extend beyond urban industrial sectors to include rural areas and address social disparities. THAI's focus on people-centered development aims to improve quality of life and reduce inequality, particularly in rural regions. By integrating these sustainability pillars, THAI supports long-term resilience, economic progress, and social well-being while promoting environmentally conscious practices. The model's emphasis on adaptability in policy, where societal values and norms guide decision-making, has positioned THAI as a potential framework not only for Thailand but also for other nations facing similar sustainability challenges. In the Thai energy sector, the PEA has adopted THAI principles, demonstrating how this model fosters sustainable innovation and provides a foundation for integrating ecological, social, and economic objectives in policy and practice [26], [27].

2.3.2. Industry 4.0 (IND)

IND has transformed manufacturing by integrating advanced technologies like the Internet of Things (IoT), artificial intelligence, and big data to enhance sustainability and efficiency. These technologies enable real-time monitoring of resource use, reducing waste and promoting energy-efficient production. By optimizing processes and minimizing resource consumption, IND supports sustainable manufacturing practices that conserve resources and reduce environmental impact [28]. A key feature of IND is its promotion of closed-loop production systems, which recycle materials and reduce dependency on raw resources, aligning with circular economy goals and lowering GHG emissions [28], [29]. IND's core principle is to achieve superior quality and efficiency, summarized by the motto "Better, not cheaper." This approach encourages manufacturers to focus on innovation and sustainability rather than just cost-cutting. Instead of reducing costs at the expense of quality, IND aims to create value through high-quality production, improved efficiency, and reduced environmental impact. This shift from cost-driven to value-driven strategies positions companies to meet the demand for eco-friendly products while contributing to sustainable development. IND offers a comprehensive framework for balancing economic performance with environmental responsibility, fostering SI in manufacturing and other industries [30], [31].

2.3.3. ICT and Digital Innovation (ICT)

ICT plays a crucial role in driving SI by enhancing productivity, optimizing resources, and reducing waste. In Thailand, ICT is integral to the THAI initiative, which supports the country's transition to a value-based economy focused on sustainability and innovation. Through the integration of ICT in industrial practices, Thailand seeks to align economic growth with environmentally responsible practices [30]. Digital innovations in sectors like energy are particularly impactful, with technologies such as smart grids, energy management systems, and real-time monitoring reducing energy consumption and carbon emissions. The PEA, recognizing the importance of digital transformation, has adopted ICT solutions to improve energy operations, ensuring that its sustainability goals are met while addressing growing consumer demands [23].

Globally, ICT and digital innovation are reshaping industries and fostering smart, connected communities that prioritize sustainability. Cross-cultural considerations are vital, as digital leadership varies across regions based on cultural, economic, and social factors. In Thailand, the integration of ICT within the THAI framework reflects a locally adapted approach to digital transformation, emphasizing both technological advancement and cultural alignment with sustainable practices. These ICT-driven innovations support the creation of eco-friendly societies by encouraging responsible behaviors at both the individual and organizational levels. Through its digital energy initiatives, the PEA not only strengthens its commitment to sustainability but also contributes to Thailand's broader goal of establishing an eco-conscious society, offering a model for other countries seeking to balance economic growth with environmental stewardship [32], [33].

2.3.4. Sufficiency Economy Philosophy (SEP)

The SEP, introduced by King Bhumibol Adulyadej, emphasizes moderation, reasonableness, and prudence as core principles for sustainable development. Moderation encourages organizations to operate within their means, promoting resource efficiency and waste reduction. In the PEA, this is reflected in energy-efficient practices such as reducing unnecessary consumption. Reasonableness focuses on the long-term impacts of decisions, guiding ethical and responsible innovation. Prudence, combined with resilience, supports risk management and long-term planning, ensuring the organization can adapt to challenges like market fluctuations and regulatory changes. SEP's principles are closely aligned with SI. Moderation supports the adoption of resource-efficient technologies like smart grids and RE solutions, minimizing environmental impact. Reasonableness ensures that innovations are developed with long-term sustainability in mind. Prudence and resilience enable innovations to adapt to regulatory and environmental changes, ensuring their sustainability. For example, PEA's use of smart meters allows consumers to monitor and reduce energy consumption in real time. SEP's focus on both economic and social sustainability strengthens PEA's role as a sustainable organization. SEP has also been applied successfully in other regions, like Krabi and Koh Samui, where it has guided sustainable practices in agriculture and tourism, demonstrating its broader applicability.

2.4. Sustainable Innovation (SI)

SI refers to the development of products, services, and processes that enhance environmental, economic, and social performance over time. Unlike traditional innovation, which focuses primarily on profit, SI integrates environmental and social considerations, ensuring that innovation efforts contribute to long-term sustainability. The goal is to create solutions that fulfill organizational objectives while respecting natural resources and regeneration capacities. SI encourages organizations to balance profitability with environmental stewardship and social responsibility, addressing global challenges such as climate change, resource depletion, and social inequality. By adopting eco-friendly technologies and sustainable practices, organizations can reduce their environmental footprint and enhance social responsibility, leading to greater public trust and stakeholder loyalty [34], [35]. The SI model includes several key elements essential for fostering sustainable development. It starts with idea generation and execution, where creative solutions are developed and implemented to address pressing environmental and social issues. The attributes of SI, such as originality and practical usefulness, ensure that innovations are not only unique but also applicable to real-world challenges. The outcomes of SI include innovative products, business models, and strategies that create value for organizations, customers, communities, and the environment. By promoting practices like closed-loop systems and circular economies, SI reduces dependency on finite resources and encourages long-term ecological health. For organizations like PEA, SI aligns with sustainability goals by integrating eco-efficiency and social responsibility into energy infrastructure, helping to build resilience against external challenges and foster a more sustainable future [36], [37].

3. Methodology

3.1. Participants

The participants in this study were employees of the PEA, representing a diverse sample from the organization's nationwide workforce. With a total population of 17,170 employees, the study aimed to ensure accurate representation through an appropriate sample size. Using Yamane's formula, the required sample size was determined to be 390 employees at a 95% confidence level, accounting for population variability and ensuring a statistically reliable analysis [38]. To strengthen the study's reliability and validity, the final sample comprised 419 employees, exceeding the minimum required sample size. This sample was randomly selected across PEA's four main operational areas (Areas 1, 2, 3, and 4), ensuring representation from different geographical locations and functional segments within the organization. The sampling method aimed to mitigate potential biases by capturing a broad spectrum of perspectives across various roles and regions. However, the gender imbalance, with a higher proportion of male respondents, could influence the findings related to gendered perceptions of SEP and SI. The study's demographic characteristics were diverse, reflecting PEA's workforce composition, including employees from varying age groups, professional levels, and departments. This diversity allowed for a comprehensive understanding of employee views on SI and SEP implementation, providing insights across different hierarchical levels. By including both management and non-management employees, the study ensured the representation of different perspectives within the organization. The random sampling strategy aimed to minimize bias, ensuring that the findings could be generalized to the broader PEA workforce, thus offering valuable insights to inform organizational practices and policies related to SI and SEP adoption.

3.2. Data Collection Instruments

The data collection for this study involved a carefully designed questionnaire, developed with guidance from 17 experts across various PEA departments. These experts were selected from a pool of 82 and contributed to shaping the questionnaire's conceptual framework. The initial design phase featured open-ended questions and a Cmap system, a tool that organizes complex ideas hierarchically, helping to visualize connections between six key factors influencing SI: DIL, THAI, IND, PDU, ICT, and the SEP. Experts assessed the content validity of 37 items using the Item Objective Congruence (IOC) method, ensuring the relevance and clarity of each item [39], [40]. After this formative stage, the questionnaire evolved into a structured checklist with 40 closed-ended items based on the SI model, designed to assess how these factors align with PEA's sustainability goals. The feedback from open-ended responses refined the items further, and all Cmap-based questions achieved an IOC score of 0.5 or higher, validating their inclusion in the final survey. Once the content was finalized, the questionnaire was distributed to PEA employees, segmented into three sections: demographic information, SI-related factors, and attitudes toward SI. The demographic section collected data on gender, age, and position, offering context for analyzing variations in SI perspectives across employee profiles. The second section included 54 items across nine subcategories, covering the six internal and external SI factors. The third section, composed of 24 SI-related statements, used a five-point Likert scale to gauge employee agreement from 1 (strongly disagree) to 5 (strongly agree). This structured approach allowed for both quantitative and qualitative insights into employees' perceptions of SI. The questionnaire was distributed between April and May 2022, with online and mailed versions available to accommodate the COVID-19 pandemic. Of 525 questionnaires sent, 419 were returned, yielding a response rate of 79.8%, ensuring the study's reliability and representativeness [41].

3.3. Analysis Methods

The analysis of the study's data consisted of two primary components: Confirmatory Factor Analysis (CFA) for instrument validation and Multiple Regression Analysis (MRA) to assess relationships between the SEP, SI, and other influencing factors. To ensure construct validity, CFA was performed using AMOS 21.0, which enabled the examination of the data collection instrument's ability to accurately represent the theoretical constructs with empirical data. This analysis helped confirm the alignment of the questionnaire's items with the underlying theoretical model based on expert input. Following CFA, Cronbach's alpha was calculated to measure the internal consistency and reliability of the instrument, ensuring that the factors used in the study consistently measured the components of SEP and SI [42], [43]. For the relationship analysis, Stepwise MRA was employed to explore the influence of SEP, DIL, THAI, IND, PDU, and ICT on SI. This method allowed for the identification of the most significant predictors of SI by systematically adding variables based on their statistical significance. By examining the strength and significance of these relationships, MRA revealed the key factors contributing to SI within the PEA, controlling for the impact of other variables. The study also tested key assumptions of MRA to ensure the validity of results. Variance Inflation Factor (VIF) values for each predictor were well below 4, indicating no multicollinearity, and tolerance values exceeded the recommended threshold of 0.25 for all variables. The Durbin-Watson statistic of 1.891 indicated no significant autocorrelation in the residuals, confirming the independence of errors. Additionally, the distribution of residuals met the assumption of multivariate normality, supporting the use of MRA in this context. Further analysis using Pearson's product-moment correlation coefficients assessed the relationships among the factors. Stepwise MRA highlighted SEP as a significant predictor of SI outcomes. The analysis was further enriched using a large language model (LLM) to interpret contextual examples related to SEP, providing deeper insights into the application of SEP principles within the data analysis framework [44], [45].

4. Results and Discussion

4.1. Demographic Profile of Respondents

Table 1 presents the demographic characteristics of the 419 respondents, including gender, age, and job position, which help contextualize perceptions of SI and the SEP within PEA.

Table 1. Summary of Respondents' Demographic

Demography	Demographic	N	%
Gender	Males	353	84.25
	Females	66	15.75
Age	25–29	151	36.04
	30–39	140	33.41
	40–49	81	19.33
	50 or more	47	11.22
Position	Level 2–3	92	21.96
	Level 4–7	273	65.16
	Level 8–10	54	12.89

A significant gender imbalance is observed, with 84.25% of respondents (353 males) and 15.75% (66 females). This gender disparity reflects the male-dominated workforce typical of technical sectors like PEA. The underrepresentation of women may influence perceptions of SEP and SI, as gender differences can shape views on sustainability and resource use. A more balanced gender distribution might provide a broader range of perspectives on SEP's implementation and SI practices. The respondents' age distribution indicates a younger workforce, with 36.04% aged 25–29, 33.41% aged 30–39, and 19.33% aged 40–49. Only 11.22% were aged 50 or older. Younger employees are often more open to progressive environmental practices, which may impact their approach to SI and SEP. In terms of job positions, 65.16% were in mid-level roles (Levels 4–7), 21.96% in entry-level positions (Levels 2–3), and 12.89% in higher-level roles (Levels 8–10). This distribution suggests that the majority of insights were gathered from operational and mid-management employees, providing a grounded perspective on SEP and SI within the organization.

4.2. Validity and Reliability

4.2.1. Reliability or Internal Consistency Using Cronbach's Alpha

The questionnaire demonstrated excellent reliability with a Cronbach's alpha of 0.975, confirming internal consistency. Factor-wise reliability was also strong, with values ranging from 0.864 (DIL) to 0.954 (SI), all within the acceptable range of 0.70 to 0.95. These results indicate that each factor consistently measured its intended concept, with the SI and SEP factors showing particularly high reliability ($\alpha = 0.954$ and $\alpha = 0.926$, respectively). The strong internal consistency across factors supports the robustness of the questionnaire as an effective tool for capturing the nuances of each construct in the organizational context.

4.2.2. Construct Validity Using CFA Through AMOS 21.0

Construct validity was assessed using Confirmatory Factor Analysis (CFA) via AMOS 21.0. Factor loadings ranged from 0.556 to 0.811, indicating strong correlations between items and their respective factors, confirming the alignment with the theoretical model. Model fit indices, including chi-square ($\chi 2/df = 1.522$), RMSEA (0.035), and SRMR (0.024), supported a good fit with the observed data. The high values for GFI (0.945), AGFI (0.936), and CFI (0.948) further validated the model, confirming that the questionnaire effectively measures the relationships between SEP, SI, and related factors. These findings establish the questionnaire's construct validity, ensuring it is a credible tool for assessing the influence of SEP on SI within the PEA framework. [46].

4.3. Employees' Perceptions of Internal and External Factors Affecting SI in the PEA

4.3.1. Correlations

Correlation analysis was used to examine the relationships between SI and several internal and external factors at PEA, as shown in table 2.

Table 2. Correlations between Dependent Variable and Independent Variables

	SI	PDU	DIL	THAI	IND	ICT	SEP
SI	1.000	0.715**	0.660**	0.680**	0.713**	0.704**	0.662**
PDU		1.000	0.744**	0.765**	0.843**	0.794**	0.577**
DIL			1.000	0.772**	0.765**	0.685**	0.551**
THAI				1.000	0.767**	0.721**	0.600**
IND					1.000	0.763**	0.596**
ICT						1.000	0.568**
SEP							1.000

The results indicate statistically significant correlations ($p < 0.01$) between SI and each of the six independent variables, with correlation coefficients ranging from 0.660 to 0.715. These values suggest moderate to high associations, demonstrating that these factors strongly influence employees' perceptions of SI. The strongest correlation was found between SI and PDU, with a coefficient of 0.715, indicating that employees perceive digital transformation and sustainable energy initiatives as critical drivers of SI within the organization. This aligns with PEA's focus on modernizing its energy infrastructure and implementing environmentally responsible solutions. DIL also showed a significant correlation (0.660) with SI, emphasizing the role of leadership in fostering innovation and adaptability, which are key to achieving SI goals. Additionally, the other factors—THAI, IND, ICT, and SEP—all displayed positive correlations with SI, ranging from 0.662 to 0.713. These findings suggest that a holistic approach, integrating technological innovation, national policy, and cultural values, is seen as essential for driving SI within PEA. The results highlight the interconnected nature of these factors and reinforce the importance of combining internal and external elements to support PEA's sustainability objectives [47].

4.3.2. Model Summary

A model summary analysis was performed to assess the predictive power of internal and external factors on SI perceptions within PEA, as presented in table 3. The analysis focused on five key predictors: PDU, SEP, ICT, DIL, and IND, and measured their combined influence on SI perceptions among employees.

Table 3. Prediction of Internal and External Factors Affecting SI in the PEA

Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	R^2 Change	Sig. F Change	Durbin–Watson
PDU	0.715a	0.512	0.511	8.530	0.512	0.000	
PDU, SEP	0.778b	0.605	0.603	7.682	0.093	0.000	
PDU, SEP, ICT	0.794c	0.631	0.628	7.437	0.026	0.000	
PDU, SEP, ICT, DIL	0.800d	0.640	0.637	7.348	0.010	0.001	
PDU, SEP, ICT, DIL, IND	0.803e	0.645	0.641	7.309	0.005	0.021	1.891

The results show that PDU alone accounted for 51.2% of the variance in SI perceptions ($R^2 = 0.512$), highlighting its significant role as a driver of SI within PEA. When SEP was added, the R^2 increased to 0.605, suggesting that SEP further shapes employee perceptions by integrating cultural and philosophical elements that align with organizational sustainability objectives. Adding ICT, DIL, and IND to the model led to a cumulative increase in the R^2 to 0.645, explaining 64.5% of the variance in SI perceptions. This incremental rise indicates that while PDU and SEP are strong predictors, ICT, DIL, and IND also play important roles in shaping SI at PEA. The addition of each factor was statistically significant ($p < 0.05$), reinforcing the idea that a variety of organizational, technological, and policy factors collectively influence SI. The Durbin-Watson statistic of 1.891 indicates no significant autocorrelation, confirming the reliability of the model. Overall, the R^2 value of 0.645 suggests that the combination of these internal and external factors explains a substantial portion of the variance in SI perceptions, underlining the importance of a comprehensive approach to fostering SI within PEA, integrating technological, leadership, and policy dimensions [48].

4.3.3. Coefficients

Stepwise multiple regression was applied to assess the impact of internal and external factors on SI within PEA. Table 4 presents the regression coefficients, with the constant value of 17.034 representing the baseline level of SI when all predictors are held at zero.

Table 4. Coefficients

	B	SE B	β	t	p
(Constant)	17.034	3.285		5.186	0.000
PDU	0.436	0.161	0.167	2.702	0.000
SEP	0.614	0.079	0.294	7.761	0.000
ICT	0.507	0.121	0.215	4.187	0.000
DIL	0.327	0.134	0.118	2.441	0.015
IND	0.358	0.154	0.142	2.321	0.021

Among the predictors, SEP had the strongest influence on SI, with a coefficient of B = 0.614 and a standardized beta (β) of 0.294, both statistically significant at the 0.01 level. This underscores SEP's central role in driving SI within PEA. ICT also demonstrated a significant effect, with B = 0.507 and β = 0.215, indicating that digital advancements are crucial for enhancing SI. PDU, with B = 0.436 and β = 0.167, further supports the importance of PEA's digital transformation efforts in shaping perceptions of sustainability. DIL and IND were also statistically significant, though at the 0.05 level. DIL had B = 0.327 and β = 0.118, signifying the positive impact of leadership that supports adaptability and change. IND showed B = 0.358 and β = 0.142, highlighting the importance of advanced manufacturing principles in fostering SI. The overall model demonstrated a strong explanatory power, with an R^2 of 0.645, meaning that 64.5% of the variance in SI perceptions was explained by the combination of PDU, SEP, ICT, DIL, and IND. This confirms the model's effectiveness in capturing key factors influencing SI within PEA. The Durbin-Watson statistic of 1.891 indicated no significant autocorrelation. These findings emphasize the important roles of SEP, ICT, and PDU in advancing SI at PEA, while also highlighting the contributions of leadership and technological advancements in supporting sustainability goals. Figure 1 illustrates these influences, categorizing the factors into internal (PDU and DIL) and external (SEP, ICT, and IND) groups, with standardized coefficients and significance levels indicating their respective contributions to SI.

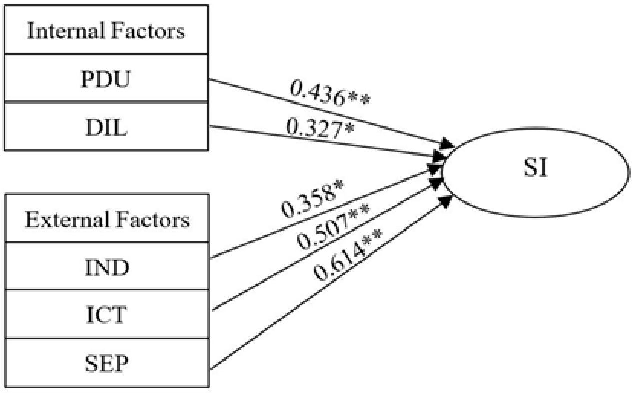

Figure 1. Influence of Internal and External Factors on SI

4.4. Employees' Perceptions of the SEP Affecting SI in the PEA

4.4.1. Correlations

Correlation analysis was conducted to understand how various aspects of the SEP influence SI within the PEA, with results summarized in table 5. This analysis examined the relationship between SI and nine specific components of SEP, labeled SEP1 through SEP9. All correlations were statistically significant at the 0.01 level, with coefficients ranging from 0.454 to 0.590, indicating moderate associations across the SEP factors.

Table 5. Correlations Between Dependent and SEP Variables

	SI	SEP1	SEP2	SEP3	SEP4	SEP5	SEP6	SEP7	SEP8	SEP9
SI	1.000	0.510**	0.454**	0.494**	0.548**	0.505**	0.530**	0.542**	0.554**	0.590**
SEP1		1.000	0.656**	0.643**	0.502**	0.578**	0.607**	0.548**	0.494**	0.505**
SEP2			1.000	0.642**	0.485**	0.567**	0.595**	0.504**	0.511**	0.441**
SEP3				1.000	0.593**	0.619**	0.682**	0.611**	0.569**	0.539**
SEP4					1.000	0.588**	0.584**	0.514**	0.562**	0.586**
SEP5						1.000	0.694**	0.606**	0.574**	0.557**
SEP6							1.000	0.634**	0.586**	0.593**
SEP7								1.000	0.663**	0.638**
SEP8									1.000	0.643**
SEP9										1.000

The strongest correlation was observed between SEP9 and SI (r = 0.590), suggesting that SEP9 is crucial in shaping employees' perceptions of SI. This moderate correlation implies that specific elements within SEP9, which may involve

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resilience, resourcefulness, or adaptability, are perceived as highly relevant to driving sustainable practices within the organization. The relatively high correlation with SI highlights SEP9 as a potential focus area for future strategies to enhance SI within the PEA. In contrast, SEP2 exhibited the lowest correlation with SI (r = 0.454), indicating a moderate association. This result suggests that the factors encompassed by SEP2—potentially involving aspects like moderation or cautious resource management—are perceived as less directly impactful on SI than other SEP components. While still statistically significant, the lower correlation implies that employees may see SEP2 as supportive but not as critical in driving SI outcomes compared to other SEP variables. Other SEP components, such as SEP8 (r = 0.554), SEP7 (r = 0.542), and SEP4 (r = 0.548), also demonstrated moderate correlations with SI. These results collectively indicate that employees perceive multiple facets of SEP as relevant to fostering SI, with SEP9 having the strongest impact, followed closely by SEP8 and SEP4. This pattern underscores the role of SEP as a multi-dimensional framework that contributes to SI through a blend of resilience, ethical principles, and thoughtful resource management.

4.4.2. Model Summary

Table 6 presents the model summary, highlighting the predictive power of five SEP components in explaining SI within the PEA. These components—virtue (SEP9), positive impacts (SEP4), negative impacts (SEP1), knowledge (SEP8), and risk management (SEP7)—were added incrementally to evaluate their collective contribution to SI perceptions.

Table 6. The Prediction of SEP Affecting SI in the PEA

Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	R^2 Change	Sig. F Change	Durbin–Watson
SEP9	0.590a	0.348	0.346	9.860	0.348	0.000	
SEP9, SEP4	0.641b	0.410	0.407	9.386	0.063	0.000	
SEP9, SEP4, SEP1	0.665c	0.443	0.439	9.135	0.032	0.000	
SEP9, SEP4, SEP1, SEP8	0.678d	0.460	0.455	9.005	0.017	0.000	
SEP9, SEP4, SEP1, SEP8, SEP7	0.682e	0.465	0.459	8.970	0.006	0.039	1.801

The model begins with SEP9 (virtue), which explains 34.8% of the variance in SI perceptions ($R^2 = 0.348$), indicating that ethical behavior, integrity, and social responsibility are significant drivers of SI within PEA. The strong influence of SEP9 highlights the importance of values-based principles in fostering sustainability. Adding SEP4 (positive impacts) increases the model's explanatory power, with R^2 rising to 0.410, explaining 41% of the variance. This suggests that proactive environmental practices and sustainable contributions further enhance employees' perceptions of SI. The R Square Change of 0.063 indicates a meaningful improvement with the inclusion of SEP4. Including SEP1 (negative impacts) increases the R^2 to 0.443, explaining 44.3% of the variance in SI. This highlights the importance of minimizing negative environmental and social impacts, emphasizing the balanced approach of SEP. When SEP8 (knowledge) and SEP7 (risk management) were added, the R^2 value increased to 0.465, meaning these five components together explain 46.5% of the variance in SI perceptions. The final model was statistically significant, with each additional component contributing to the model's robustness. The Durbin-Watson statistic of 1.801 confirms no autocorrelation in the residuals, indicating reliable results.

4.4.3. Coefficients

Table 7 shows the coefficients from the stepwise Multiple Regression Analysis (MRA), illustrating the impact of five SEP components on SI within PEA. These components are: virtue (SEP9), positive impacts (SEP4), negative impacts (SEP1), knowledge (SEP8), and risk management (SEP7).

Table 7. Coefficients

	B	SE B	β	t	p
(Constant)	48.692	2.852		17.075	0.000
Virtue (SEP9)	3.449	0.798	0.230	4.324	0.000
Positive impacts (SEP4)	2.945	0.731	0.193	4.030	0.000

Negative impacts (SEP1)	2.380	0.657	0.166	3.620	0.000
Knowledge (SEP8)	2.245	0.847	0.142	2.651	0.008
Risk management (SEP7)	1.694	0.818	0.111	2.072	0.039

The constant value of 48.692 represents the baseline SI when all predictors are zero. Virtue (SEP9) has the highest coefficient ($B = 3.449$, $p < 0.01$) with a beta (β) of 0.230, highlighting the key role of ethical principles like integrity in shaping SI. Positive impacts (SEP4) also strongly influence SI ($B = 2.945$, $\beta = 0.193$), emphasizing the importance of proactive environmental and social outcomes. Negative impacts (SEP1) contribute significantly ($B = 2.380$, $\beta = 0.166$), reflecting the importance of minimizing adverse effects on SI. Knowledge (SEP8) ($B = 2.245$, $\beta = 0.142$) and Risk management (SEP7) ($B = 1.694$, $\beta = 0.111$) also support SI, although with smaller coefficients, stressing the need for informed decision-making and risk mitigation in sustainability efforts. The model's R^2 value of 0.465 shows that these SEP components explain 46.5% of the variance in SI perceptions. The model, with an F value of 39.956 ($p < 0.01$), confirms that virtue, positive impacts, and minimizing negative impacts are key drivers of SI. Figure 2 visualizes these relationships, reinforcing the importance of ethical values and proactive management in fostering SI within PEA.

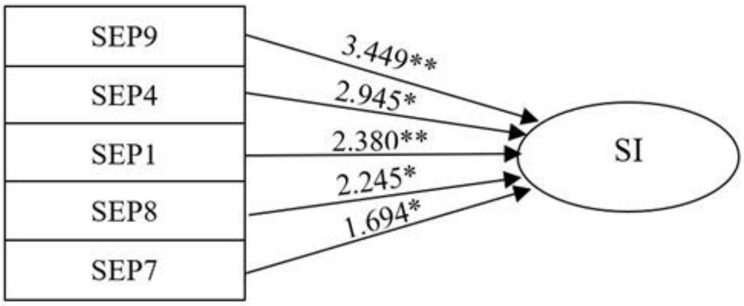

Figure 2. Influence of SEP Variables on SI

4.5. Similarities and Differences between the SEP and SI

The study reveals that while Thailand's SEP and SI both aim to promote responsible, sustainable practices, they differ in their foundational principles. SI is driven by the broader concept of "sustainability," which is framed around the economic, environmental, and social pillars (often referred to as profits, planet, and people). SI focuses on creating innovations that serve both organizational and societal needs, while also contributing to global efforts to reduce carbon footprints. In contrast, SEP's core principle is "sufficiency," emphasizing moderation, prudence, and frugality. SEP advocates for balancing production and consumption, aiming to avoid excess and scarcity in resource use. This philosophy starts with individual behavior and extends to corporate and national levels, encouraging moderation while considering the impact of both internal and external shocks. The "less is more" concept of SEP promotes reducing resource consumption, which leads to a more sustainable, long-term balance benefiting both society and the environment. Integrating SEP's sufficiency with SI's sustainability objectives allows organizations to align with global Sustainable Development Goals (SDGs), particularly SDG 7, which focuses on affordable and clean energy. SEP helps promote responsible consumption and production patterns, supporting the achievement of SDG-related objectives. The positive correlation between SEP and the SDGs ($r = 0.42325$) suggests that incorporating SEP principles into development projects can significantly contribute to advancing SDGs across environmental, economic, and social dimensions. By combining the sufficiency principles of SEP with the structured sustainability framework of SI, organizations like the PEA can enhance their resilience and contribute to the broader goals of sustainable development.

4.6. Relationship between the SEP and SI in the Context of the Electricity Authority

The relationship between SEP and SI at PEA is shaped by SEP's principles of moderation, reasonableness, resilience, knowledge, and virtue. These principles promote responsible resource use and decision-making that aligns with the goals of sustainable innovation. For example, PEA's Green Office project illustrates SEP's influence in fostering a sustainable working environment. This initiative reduces carbon footprints and encourages eco-friendly practices among employees, such as reducing waste, conserving energy, and minimizing resource consumption—all integral to SI. SEP also plays a key role in reducing GHG emissions at PEA by guiding the organization to optimize resource use and reduce waste. SEP's principles of moderation and sufficiency encourage the adoption of practices like using alternative materials and upcycling, which minimize waste generation and environmental impact. These initiatives are part of PEA's broader strategy to reduce resource depletion and lower emissions. Through these efforts, PEA has successfully reduced its GHG emissions by 4,776.81 tCO_2eq, demonstrating how SEP can drive sustainability and foster SI. The integration of SEP into PEA's operations showcases the tangible impact of SEP on environmental performance and its potential to guide sustainable practices within the energy sector.

4.7. Influence of the SEP on SI Adoption in the Electricity Authority

The SEP plays a key role in promoting SI at the PEA by guiding holistic decision-making. PEA leaders incorporate SEP principles, considering societal, environmental, and economic impacts, aligning with the Sustainable Development Goals (SDGs). SEP emphasizes cultural factors like identity, heritage, and creativity, which shape organizational values and sustainability efforts. The philosophy's focus on moral and social norms promotes ethical decision-making, with employees' perceptions of right and wrong guiding responsible actions. Leaders who adopt SEP's ethical approach are better equipped to manage external shocks, ensuring the resilience of sustainability initiatives [49]. SEP also emphasizes the importance of informal institutions in shaping sustainable practices. In Thailand, local customs and traditions help integrate SEP principles into organizational culture. By adopting SEP, PEA fosters diverse perspectives and fair outcomes, particularly for vulnerable groups. SEP's principles are illustrated in Krabi, where the application of moderation and sustainability ensures local energy needs are met through RE and energy security, prioritizing environmental sustainability. While SEP is effective in driving sustainable development, comparing it to other frameworks like the Triple Bottom Line (TBL) and Circular Economy highlights its unique contributions. Both TBL and SEP emphasize a holistic approach to sustainability, but SEP goes further by focusing on moderation, prudence, and resilience, which are not as explicit in TBL. While TBL assesses overall business impact, SEP incorporates cultural and ethical norms, making it particularly suitable for Thailand. The Circular Economy shares SEP's focus on resource efficiency, but SEP's social and cultural dimensions strengthen its long-term resilience and adaptability. This comparison underscores SEP's potential to advance sustainable innovation, particularly in energy, as demonstrated in Krabi's adoption of SEP principles.

4.8. Challenges and Opportunities of Implementing the SEP for SI

A key challenge in implementing SEP for SI is measuring cultural sustainability, which lacks clear, standardized metrics. This complicates integrating cultural aspects into sustainability strategies. For example, in Ghana, while solutions need to be rooted in local culture, there are no universally accepted indicators for cultural sustainability. Developing such metrics requires careful consideration of social, environmental, and economic dimensions. This gap presents an opportunity for innovation, allowing organizations like PEA to create tools that integrate cultural values into sustainability practices, potentially serving as a model for other countries. Balancing modernization with cultural preservation also presents challenges, especially in regions like Krabi, where traditional values must coexist with RE initiatives. Biomass energy offers a sustainable solution but also poses environmental concerns, such as air pollutants. Addressing these issues requires technical solutions, like electrostatic precipitators, alongside community engagement to build trust. Krabi's approach demonstrates how SEP can support the balance between modern energy needs and cultural preservation.

Cultural diversity is a significant asset for innovation. Leveraging diverse perspectives fosters creativity and problem-solving, essential for advancing SI. While managing diversity can be challenging, it strengthens SEP's emphasis on inclusivity and shared values, promoting SI while respecting cultural differences. Empowering local communities is crucial for achieving sustainable development. Involving communities in decision-making and providing them with tools for effective resource management fosters ownership and aligns sustainability efforts with local values. By integrating traditional knowledge into modern sustainability practices, organizations like PEA can create more effective and culturally relevant SI initiatives. Finally, SEP's principles are evident in Koh Samui's low-carbon initiatives, demonstrating SEP's adaptability in diverse contexts. Similar efforts in Krabi show how SEP drives sustainability by balancing environmental, economic, and social objectives. These examples highlight SEP's scalability and its ability to contribute to broader sustainability goals, including those outlined in the UN SDGs.

5. Conclusion

This study emphasizes the role of the SEP in driving SI within the PEA, contributing to Thailand's goal of reducing GHG emissions. SEP's principles of moderation, prudence, and resilience align with environmental sustainability objectives, helping PEA adopt more sustainable operational practices, offering a model for other sectors. However, the study's quantitative approach has limitations. Statistical significance doesn't always equate to real-world impact, and the deterministic nature of quantitative models may not fully capture the complexity of human behavior and organizational dynamics. Additionally, biases and the study's narrow scope suggest caution when applying these findings broadly. SEP can serve as a cultural foundation for sustainability in other sectors, aligning ethical principles with environmental, economic, and social goals. The study highlights the importance of resilience and interconnectedness, emphasizing that shared resources, knowledge, and support are key to overcoming environmental and societal challenges. Future research could further explore SEP's impact across various sectors, using qualitative methods for deeper insights. We recommend several policy initiatives to integrate SEP in the energy sector: embedding SEP into national energy policies, incentivizing companies to adopt SEP principles in their operations, and launching public awareness campaigns to promote sustainable practices. Local development plans in regions like Krabi and Koh Samui should also incorporate SEP principles, strengthening resilience and sustainability. By embedding SEP into national and organizational frameworks, Thailand can foster a more balanced, sustainable development pathway for its energy sector.

6. Declarations

6.1. Author Contributions

Conceptualization: T.R., T.T., K.J., W.S., P.L.; Methodology: P.L.; Software: T.R.; Validation: T.R., P.L., and W.S.; Formal Analysis: T.R., P.L., and W.S.; Investigation: T.R.; Resources: P.L.; Data Curation: P.L.; Writing Original Draft Preparation: T.R., P.L., and W.S.; Writing Review and Editing: P.L., T.R., and W.S.; Visualization: T.R.; All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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