

# **THESIS OF THE DOCTORAL (Ph.D.) DISSERTATION**

**EMA ADOPTION AND SUSTAINABILITY REPORTING:  
Exploring the Impact of Industry 4.0 on Financial Performance of  
SMES in Eastern Indonesia's Manufacturing and Agriculture  
Sectors**

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## 1. INTRODUCTION

The text discusses the impacts of the COVID-19 pandemic and environmental crises on global businesses, particularly focusing on small and medium enterprises (SMEs). The global pandemic and war have led to worldwide shortages, pushing many businesses to prioritize profit maximization, often neglecting environmental conservation. This approach has resulted in violations of key economic principles such as economic cost, accounting cost, and opportunity cost.

The environmental damage caused by businesses, especially due to the overconsumption of natural resources, is linked to the emergence of the COVID-19 pandemic, with studies by Jones et al. (2008), O'Callaghan-Gordo & Antó (2020), and Rahman et al. (2020) highlighting these connections. The pandemic significantly impacted the global economy, causing income issues and layoffs, and challenging economic recovery (Ibn-Mohammed et al., 2021; Olivia et al., 2020). Government responses such as lockdowns and work-from-home policies, have affected various sectors, including tourism, manufacturing, and agriculture (Hidayatullah et al., 2020; Muhyiddin, M., & Nugroho, 2021; Purnama & Susanna, 2020).

Despite some positive environmental impacts like reduced air pollution, these government measures are seen as insufficient for long-term environmental sustainability. The necessity of balancing the 'triple bottom line' of people, planet, and profit, as proposed by Elkington (1998), is emphasized. The current accounting practices, critiqued for being inadequate for addressing long-term challenges (Cho et al., 2021; Tregidga & Laine, 2021).

The text advocates for Environmental Management Accounting (EMA) as a critical tool for businesses to manage environmental costs and impacts (Burrit & Saka, 2006; Latan et al., 2018). The advancement in managerial accounting, aligned with the industrial revolution 4.0, is also discussed (Romanovs, 2017; Tiwari & Khan, 2020). The impact of Fintech in the financial sector and the need for adapting accounting practices to technological advancements are highlighted (Batunanggar, 2019; Hsueh & Kuo, 2017; Suryono et al., 2019).

In Indonesia, data from Statista and IQAir reveals a contrasting scenario in terms of air quality and environmental challenges. Western Indonesia, particularly urban centers like Jakarta, faces significant pollution issues, compromising air quality. In contrast, Eastern Indonesia is known for its clean and fresh air. This disparity is further highlighted by forest coverage statistics: as of 2020, Indonesia had 92 million hectares of forest, ranking it 8th worldwide. However, the loss of 230 hectares of forest in 2022 places Indonesia as the fourth highest globally in terms of net forest area lost that year.

Geopolitical factors add complexity to these environmental challenges. Many polluting companies in Western Indonesia are foreign-owned, and tightening environmental regulations could lead to international legal disputes and potential compensation claims against the Indonesian Government. In response, the government is considering relocating the capital from Western to Eastern Indonesia, underscoring the urgency for strong environmental policies and emphasizing the critical need for effective environmental regulations to address immediate air quality issues and ensure long-term environmental sustainability.

The integration of long-term environmental sustainability with Industry 4.0 poses significant challenges and opportunities for SMEs. These advancements, while potentially threatening traditional business models, also offer substantial opportunities for job creation and innovation within SMEs (Tuegeh et al., 2021; Vasin et al., 2018) and the complexity of the production process in the era of Industry 4.0, both at micro and macro levels (C. L. Chen, 2020). SMEs face uncertainties about large investment costs required for new technologies and their impact on business models. Schumacher et al. (2016) reveal that many companies struggle to understand and integrate the concept of Industry 4.0 into their specific domains and strategies.

For SMEs, the challenge is formidable, encompassing issues like lack of capital, managerial skills, and technological adoption (Baron & Armstrong, 2008; Deegan, 2002; Moeuf et al., 2018). Rahman et al. (2011) point out that SMEs' difficulty in applying industrial technology 4.0 is compounded by the lack of a qualified workforce and the high costs and risks associated with new technology investments.

The presence of disruptive technology in Industry 4.0, offers opportunities for small businesses (Akhter & Sultana, 2018). Müller, et al. (2018) discuss the challenges and hopes for the agricultural sector in adapting to these technological advancements, particularly highlighting the lack of skilled workers in information and technology as a major challenge.

The role of SMEs in Indonesia's economy is significant, with SMEs contributing substantially to the national economy in terms of company numbers, employment, and GDP (Tumiwa & Nagy, 2021; Tumiwa & Tuegeh, 2019). However, as indicated by the Indonesian Central Bank (2020), SMEs also contribute to environmental damage. This issue is exacerbated by challenges related to the Industrial Revolution 4.0, geopolitical issues, and the COVID-19 pandemic (Bonacini et al., 2021; Djalante et al., 2020).

In the era of Industry 4.0, the maturity of companies is determined not by size but by the mastery and use of information technology (Müller, Buliga, et al., 2018). This situation necessitates SMEs' investment in IT infrastructure and human resources to capitalize on

opportunities and address threats. The benefits of Industry 4.0 for business environments include improved data quality and transparency (R. L. Burritt et al., 2019; Carey, 2015).

Finally, the potential for SMEs to offset environmental costs by selling waste as a product is discussed, emphasizing the role of Environmental Management Accounting (EMA) in controlling environmental costs and creating added value for businesses (Datsii et al., 2021; Meidiana & Gamse, 2010). The legitimacy theory, suggests that environmental disclosure through financial reports is crucial for businesses to gain legitimacy and ensure their survival (Bonsón et al., 2020; Cho & Patten, 2007).

In the contemporary business landscape, marked by rapid technological advancements and heightened environmental consciousness, small and medium-sized enterprises (SMEs) face a complex array of challenges and opportunities. The intersection of economic principles, environmental sustainability, and the advent of Industry 4.0 technologies necessitates a nuanced understanding of how these factors coalesce to impact business practices. The following **Table 1** synthesizes key findings from recent research, identifies existing gaps in our understanding and practice, and proposes strategies to bridge these gaps. It particularly emphasizes the role of Environmental Management Accounting (EMA), the integration of Industry 4.0 technologies, and the importance of sustainability reporting in enhancing financial performance and meeting the evolving demands of stakeholders. This table serves as a roadmap for SMEs navigating the intricacies of modern business environments, balancing profitability with environmental stewardship, and leveraging technological innovations for sustainable growth.

Table 1. **Research Gap**  
Empirical and Theoretical

No	Previous Findings	Research Gaps	Addressing the Gaps
1	Violation of economic, accounting, and opportunity cost principles leading to environmental damage.	Lack of comprehensive strategies integrating economic, environmental, and social sustainability.	Implementing Environmental Management Accounting (EMA) and adapting to Green Accounting principles.
2	Geopolitics and pass global pandemic direct impact on the economy and businesses, especially SMEs.	Insufficient attention to the environmental impact of pandemic response measures.	Balancing economic recovery with environmental sustainability, leveraging lockdowns to reduce pollution.

No	Previous Findings	Research Gaps	Addressing the Gaps
3	Rapid technological advancements in Industry 4.0 affecting business processes and SMEs.	SMEs facing challenges in adapting to new technologies and environmental sustainability requirements.	Training and investment in IT infrastructure for SMEs, focusing on environmental sustainability in the Industry 4.0 era.
4	The emergence of Industry 4.0 technologies transforming business operations and management.	Difficulty in quantifying the impact of Industry 4.0 on financial performance and sustainability.	Developing a new PLS-SEM model to analyze the relationships between Industry 4.0 technology adoption, EMA practices, financial performance, and sustainability reporting in SMEs.
5	Growing awareness and demand for environmental sustainability in business practices.	Lack of effective tools and models for SMEs to integrate sustainability into their business strategies.	Utilizing EMA as a strategic tool for SMEs to align their operations with environmental sustainability goals.
6	Increasing role of digital finance and fintech in the business sector.	Need for SMEs to adapt to digital financial technologies while maintaining sustainability.	Encouraging SMEs to adopt fintech solutions that support sustainable business practices and reporting.
7	The importance of environmental disclosure for legitimacy and stakeholder trust.	SMEs struggle with transparent and effective environmental reporting.	Implementing comprehensive sustainability reporting frameworks that enhance transparency and stakeholder trust.

Sources: Author archives data processing, 2022.

### 1.1. Research Questions

In this section, we try to reveal the intricacies of integrating Environmental Management Accounting (EMA) and Industry 4.0 technologies within Small and Medium-sized Enterprises (SMEs) to achieve sustainability, particularly in the wake of economic challenges posed by economic recovery due to the past global pandemic and the geopolitical issue. We employed Partial Least Squares Structural Equation Modeling (PLS-SEM) to quantitatively assess the impact of EMA and Industry 4.0 technologies on SME sustainability, aiming to empirically demonstrate the relationship between these variables and their collective influence on sustainability outcomes in SMEs. Therefore, in a connection with analysis, we formulate the research objectives as follows:

1. How do SMEs utilize technology industry 4.0 to gain sustainability?
2. What conceptual model could SMEs use to achieve sustainability?

3. What factors affect SMEs' sustainability based on confirmatory analysis?
4. What is EMA, Industry 4.0's effect on SMEs' financial performance and Sustainability using PLS-SEM?

## **1.2. Research Objectives**

The objectives of this dissertation are as follows:

1. To investigate the utilization of Industry 4.0 technologies by SMEs to achieve sustainability, examining the specific technologies employed and their impact on sustainable practices.
2. To develop a conceptual model that SMEs can utilize to achieve sustainability, focusing on integrating various elements of business operations and technology.
3. To identify and analyze the factors affecting SMEs' sustainability, utilizing confirmatory analysis to establish key influences and their impacts.
4. To examine the effects of Environmental Management Accounting (EMA) and Industry 4.0 on the financial performance and sustainability of SMEs, utilizing Partial Least Squares Structural Equation Modeling (PLS-SEM) for a comprehensive analysis.

## **4.1. Research Approach and Structure of the Dissertation**

This dissertation methodically explores the integration of Environmental Management Accounting (EMA) and Industry 4.0 technologies in Small and Medium-sized Enterprises (SMEs) to enhance financial performance and sustainability. The introduction sets the stage by outlining key concepts such as EMA, Industry 4.0, financial performance, and sustainability in SMEs, along with specific research questions and objectives. It also provides an overview of the dissertation's structure. The literature review delves into relevant theories like agency, legitimacy, and institutional theories, and how they relate to EMA, Industry 4.0, and sustainability in SMEs. It encompasses a thorough examination of Environmental Management Accounting, advancements in Industry 4.0, the relationship between sustainability practices and financial performance, the importance of sustainability reporting, and hypothesis formulation based on the literature.

The dissertation proceeds with the material and method section, detailing the research methodology, population and sample selection, variable definitions and measurements, and data analysis techniques, focusing on Partial Least Squares Structural Equation Modeling (PLS-SEM). The research findings and evaluations section presents descriptive statistics and

the results of the PLS-SEM analysis, discussing their implications in the context of existing literature. The conclusion summarizes the key findings and provides research-based recommendations, highlighting novel discoveries. Appendices include a comprehensive list of sources, tables, figures, publications, and supplementary materials, aiding in navigating the complexities of integrating EMA and Industry 4.0 in SMEs for sustainability. Each section is designed to build upon the previous, ensuring a complete understanding of the topic.

## **2. THEORETICAL REVIEW AND HYPOTHESIS DEVELOPMENT**

This dissertation explores the relationship between Environmental Management Accounting (EMA) and financial performance (FP) in Small and Medium-sized Enterprises (SMEs), revealing a consistently positive correlation. Studies by Deb et al. (2023); Nguyen and Phan et al. (2019); and Nuleg et al. (2021) highlight that EMA significantly enhances both environmental and financial efficiency, especially when supported by government policies. Additionally, Yuniarti et al. (2023) found that EMA mediates the relationship between innovation and FP in Indonesia's manufacturing sector.

The research also investigates the connection between EMA and Sustainability Reporting (SR), with studies like Jasch and Lavicka (2006), Maughan (2022), and Mihai & Aleca (2023) showing that EMA is crucial in assessing sustainability's financial impacts and improving investment appraisals. This is further supported by Bennett et al. (2003) and Nyahuna & Swanepoel (2022), who note the positive correlation between EMA adoption and return on equity. The hypothesis developed in this study posits that effective EMA implementation, influenced by various factors, significantly boosts SMEs' financial performance and enhances the quality of their SR. This is in line with the principles of the Global Reporting Initiative and frameworks that stress the importance of integrating economic, environmental, and social dimensions into corporate decision-making and sustainability reporting. The dissertation concludes that adopting EMA and SR practices can drive business sustainability and financial efficiency in SMEs. Consequently, based on the development of this hypothesis, we have organized the following group of hypotheses:

H<sub>1.1</sub>: EMA has positive relationship on FP.

H<sub>1.2</sub>: EMA has positive relationship on SR.

H<sub>1.3</sub>: EMA indirectly enhances SR through its positive relationship on FP.

Research shows a significant and positive relationship between Industry 4.0 and Environmental Management Accounting (EMA) adoption, with EMA playing a key role in

leveraging Industry 4.0's technologies to enhance environmental performance. Studies by Rasit et al. (2022a) and Burritt and Christ (2016) illustrate how EMA acts as a catalyst in this process, suggesting its potential to revolutionize environmental accounting. In SMEs, the positive influence of Industry 4.0 on EMA is evident (Mohamed, 2018). These studies highlight that advanced Industry 4.0 technologies boost EMA, leading to enhanced sustainability-related strategies and higher-order sustainability outcomes in SMEs. Čečević et al. (2021) also emphasize the need for EMA to evolve alongside Industry 4.0 to improve environmental and company performance, establishing EMA as an indispensable tool for organizational sustainability.

Further, the impact of Industry 4.0 on financial performance is also substantial (Atif et al., 2021; Gyurák Babel'ová et al., 2022; Sevinç et al., 2018). These studies indicate that adopting Industry 4.0 technologies enhances revenue, profitability, and overall organizational performance, particularly in SMEs. Asmolov and Ledentsov (2022) and Haseeb et al. (2019) found that components like big data and the Internet of Things improve long-term business performance by promoting efficient resource utilization. Additionally, research by Chonsawat and Sopadang (2020) and Chen (2021) link Industry 4.0 adoption to increased production efficiency, reduced energy consumption, and improved internal business process performance, ultimately influencing financial outcomes.

Moreover, Industry 4.0 technology significantly impacts sustainability reporting, improving transparency and control over sustainability and circular economy aspects (da Costa Tavares & do Carmo Azevedo, 2021; Takhar & Liyanage, 2020). The integration of digital technologies, as highlighted by Portna (2021) and Jonak et al. (2020), facilitates sustainable reporting development and enhances sustainability across various sectors. In the SME sector, the role of Industry 4.0 in promoting information technology use and sustainable business performance is emphasized (Alyusha Asmolov & Avraam Ledentsov, 2022), and the adoption of smart technologies in production systems, aiding SMEs in achieving sustainability and competitive advantage (Jayashree et al., 2020; Philbin et al., 2022). These findings indicate that as Industry 4.0 technologies evolve, their role in enhancing sustainability reporting and overall business performance becomes increasingly significant. Following an in-depth analysis of the existing research presented in our literature review, we have formulated the subsequent hypotheses:

- Hypothesis 2.1 : Industry 4.0 exhibits a positive relationship with Environmental Management Accounting.
- Hypothesis 2.2 : Industry 4.0 has a positive relationship with Financial Performance.

Hypothesis 2.3 : Industry 4.0 has a positive relationship with Sustainability Report.

In Industry 4.0, there is an indirect positive relationship between the adoption of advanced technologies and financial performance, with Environmental Management Accounting (EMA) playing a vital mediating role. This linkage underscores EMA's significant role in enhancing the financial outcomes of Industry 4.0's technological advancements. Studies by Rasit et al. (2022a) and Kumar and Bhatia (2021) indicate that EMA facilitates the utilization of Industry 4.0 technologies, improving environmental information and influencing organizational and technological factors.

Financial Process Automation (FPA) in Industry 4.0 is crucial for enhancing financial operations and strategies. Bisht et al. (2022) highlight the contribution of FPA to production process automation and its challenges to financial security and the importance of employee digital skills in this context is crucial (Bolek et al., 2021; Karacay, 2018), with EMA providing essential decision-making information. EMA's benefits, as noted by Burrit & Saka (2006) and Burritt et al. (2019), include compliance, eco-efficiency, and strategic positioning, aligning environmental and financial goals. The adoption of EMA at the corporate level is influenced by various factors, including human capital (Chathurangani & Madhusanka, 2019; Imtiaz Ferdous et al., 2019).

Kamble et al. (2020) observed that Industry 4.0 technologies have direct and indirect impacts on sustainable organizational performance, with lean manufacturing practices playing a strong mediating role. This suggests a potential mediating role for EMA. Contrarily, Saeidi et al. (2018) found a negative moderating effect of EMA on the relationship between process innovation and financial performance, illustrating EMA's complex role in Industry 4.0 dynamics.

In sustainability reporting, Rasit et al. (2022b) and Burritt and Christ (2016) indicate that Industry 4.0 positively influences EMA and environmental performance, with EMA acting as a crucial intermediary for sustainability reporting. The Global Reporting Initiative (GRI) framework sets standards for sustainability reporting, emphasizing corporate responsibility and transparency (Jasch & Lavicka, 2006; Mihai & Aleca, 2023). This is particularly relevant for SMEs, where GRI standard adoption enhances legitimacy and reputation, aligning operations with sustainable practices (Arena & Azzone, 2012; Rodríguez-Gutiérrez et al., 2021).

Oláh et al. (2020) and Bonilla et al. (2018) discuss how Industry 4.0 integrates with sustainable development goals, suggesting a mediating role for EMA. Rasit et al. (2022a) also

found that Industry 4.0 technology relates indirectly to EMA adoption in SMEs, indicating EMA's mediating role. Kamble et al. (2020) and Burritt and Christ (2016) further support the significant effects of Industry 4.0 on sustainable organizational performance, highlighting EMA's role in this process. As a result, the empirical evidence sourced from prior scholarly studies corroborates and substantiates our formulated hypotheses in the following manner:

- Hypothesis 3.1 : Industry 4.0 has an indirect positive relationship with Financial Performance through EMA.
- Hypothesis 3.2 : Industry 4.0 has an indirect positive relationship with Sustainability Report through EMA.
- Hypothesis 3.3 : Industry 4.0 has an indirect positive relationship with Sustainability Report through Financial Performance.
- Hypothesis 3.4 : Industry 4.0 has an indirect positive relationship with Sustainability Report through EMA and Financial Performance.

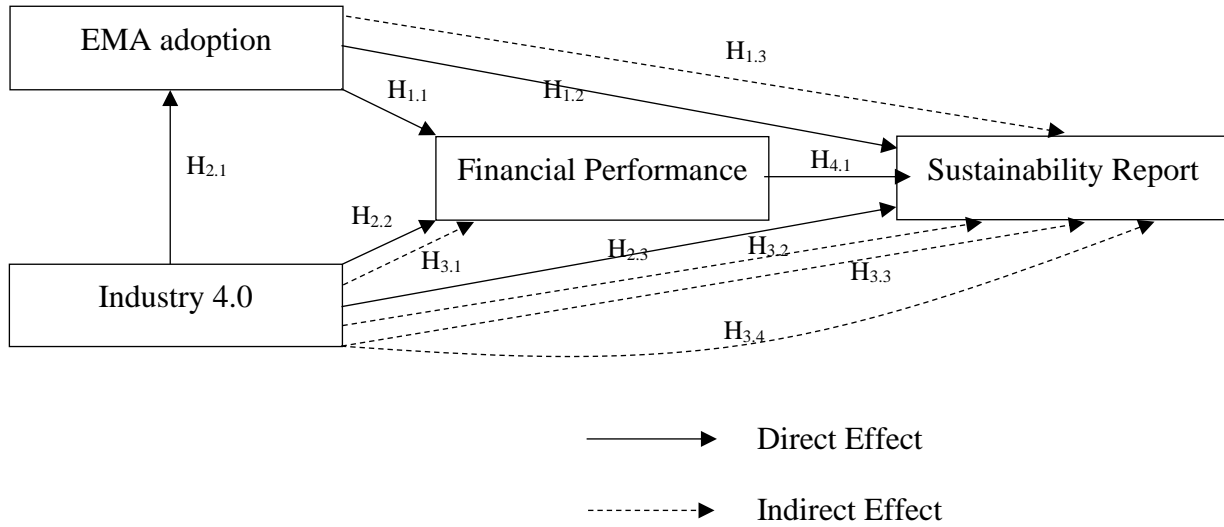
Recent research reveals a significant positive correlation between sustainability reporting and financial outcomes in businesses. Buallay (2022) and Buallay et al. (2021) find that firms engaged in sustainability and Environmental, Social, and Governance (ESG) reporting, especially in smart cities, often see improved financial performance. Lee and Hu (2018) and Zhou et al. (2022) support this, showing that corporate financial performance (CFP) enhances corporate social responsibility (CSR) and mediates the relationship between corporate reputation and CSR. Zhou et al. (2022) also discover that ESG performance improvements in listed companies lead to higher market value, with financial performance playing a crucial mediating role.

In the context of SMEs, studies by Malesios et al. (2018) and Masocha (2019) indicate a direct positive link between sustainability practices and financial performance. McMahon (2001) and Otieno et al. (2021) report that improved financial reporting practices and adherence to international financial reporting standards significantly affect financial performance in SMEs. Furthermore, Burlea-Schiopoiu and Mihai (2019) suggest that SMEs can increase profitability through training and innovation in CSR, indicating a direct relationship between sustainability practices, including reporting, and financial performance. Consequently, the empirical data derived from previous academic research validates and reinforces our proposed hypothesis as follows:

- Hypothesis 4.1 : Financial Performance has a direct positive relationship with

Figure 2. **Research Model**

Conceptual Framework of EMA Adoption, Industry 4.0, Financial Performance, and Sustainability Reporting in SMEs



### 3. METHODOLOGY

Our research employs quantitative methods, specifically partial least squares structural equation modeling (PLS-SEM) and descriptive analysis. PLS-SEM is chosen for its ability to model complex relationships and adaptability to small sample sizes, essential for our theory-driven exploratory research. Alongside, descriptive analysis helps examine SMEs and environmental issues in Indonesia. The research unfolds in three stages: initial data collection from various sources to form a foundational understanding, development and refinement of a questionnaire distributed to SMEs, and primary data collection through structured interviews.

The research focuses on SMEs in manufacturing and agriculture sectors in Eastern Indonesia, involving collaboration with local government bodies for field data collection. Purposive sampling targets SME owners or managers familiar with Environmental Management Accounting (EMA) or environmental cost considerations. Challenges in determining the study population size led to adopting the "10 times rule" for sample size, resulting in a minimum recommended size of approximately 260. However, based on a more robust power analysis using G\*Power software, the required minimum sample size is set at 119. Out of 1,000 distributed questionnaires, 543 final data sets were suitable for statistical analysis after eliminating issues like missing values and incomplete answers.

Table 2. **Variable Measurement**

Latent and Manifest Variables with Corresponding Items in the PLS-SEM Model

<b>Latent Variable</b>	<b>Manifest Variable</b>	<b>Items</b>
Industry 4.0	Technology Adoption Rate	Ind4_1
	Data Quality	Ind4_2
	Financial Process Automation	Ind4_3
	Employee Digital Skill	Ind4_4
	Management Approach	Ind4_5
Environmental Management Accounting (EMA) adoption	Compliance	EMA1
	Eco-efficiency	EMA2
	Strategic Position	EMA3
	Coercive Pressures	EMA4
	Normative Pressures	EMA5
	Memetic Pressures	EMA6
Financial Performance	Operating cash flow	FP1
	Financial Ratios	FP2

	Sales Turnover	FP3
	Net Profit	FP4
	Asset	FP5
	Working Capital	FP6
Sustainability Report	Economic Outcomes Report	SR1
	Environmental and Social Aspects Report	SR2
	Employee Attractiveness	SR3
	Product Quality and Innovation	SR4
	Transparency and Governance	SR5
Sustainable competitive advantage (SCA)		SCA1
	1. Focus	SCA2
	2. Inimitable	SCA3
	3. Resources	SCA4
	4. Capabilities	SCA5

## 4. RESULT

### 4.1. Outer Model Measurement

In our data analysis using SmartPLS, we evaluated the outer model with three standards: Convergent Validity, Discriminant Validity, and Composite Reliability. Convergent validity was assessed through the correlation between item scores and component scores. We observed strong correlations, typically above 0.70, indicative of high validity. Analyzing the outer loadings across constructs EMA, FP, Ind4, and SR, each demonstrated strong relationships between individual items and their constructs, with EMA and SR showing particularly high loadings.

Discriminant validity was assessed through cross-loading tables and the Fornell-Larcker Criterion. While EMA and FP showed high loadings with their items, some cross-loadings with other constructs were noted, particularly with SR. The Ind4 construct displayed strong discriminant validity with clear distinctions from other constructs. The SR construct also exhibited strong loadings and discriminant validity with some overlap with FP. The Fornell-Larcker Criterion further supported discriminant validity, with the square root of AVE for each construct being greater than its correlations with any other construct.

Composite reliability was assessed using Cronbach's Alpha, rho\_A, and Average Variance Extracted (AVE). All constructs displayed high values in these metrics, indicating excellent reliability and validity. EMA, FP, and SR had notably high Cronbach's Alpha and rho\_A values, indicating robust internal consistency. Composite reliability values for all constructs were well above the recommended threshold, affirming precision and consistency. The AVE values for each construct were also above the standard acceptability threshold, demonstrating strong explanatory power and confirming the constructs as valid measures of their respective concepts.

Overall, our evaluation indicated that the constructs used in the study – EMA, FP, Ind4, and SR – exhibit high reliability and validity. The measures of internal consistency and composite reliability significantly exceeded the recommended thresholds, ensuring accurate and consistent measurement. High AVE values across all constructs affirmed their substantial explanatory power, contributing to the credibility and integrity of the study's outcomes.

### 4.2. Inner Model Evaluation

In the analysis of the inner model using PLS-SEM for this research, several key aspects were evaluated to ensure the model's reliability and validity. The Variance Inflation Factor

(VIF) was used to assess multicollinearity among the constructs, which include Environmental Management Accounting (EMA), Financial Performance (FP), Industry 4.0 (Ind4), and Sustainability Reporting (SR). The VIF results indicated that multicollinearity was not a significant concern for any of the constructs, as all VIF values were comfortably below the common threshold of 5 or 10. This suggests that each construct in the model contributes distinct information without undue influence from correlations with other constructs.

The study also looked at the Coefficient of Determination ( $R^2$ ) to measure the predictive accuracy and explanatory power of the inner model. The  $R^2$  values for EMA and FP constructs were around 0.63, indicating that approximately 63% of the variance in these constructs was explained by the model. This was further validated by the close alignment of  $R^2$  with the adjusted  $R^2$  values, indicating a well-sized model for these constructs. The SR construct, in particular, showed an impressively high  $R^2$  and adjusted  $R^2$  value of 0.96, suggesting that the model has a very strong predictive accuracy for this construct, and it effectively captures the relationships within the SR construct.

The effect size ( $F^2$ ) values provided additional insights into the relative impact of each construct within the model. EMA demonstrated a moderate to large effect on both FP and SR, highlighting its significant role in influencing these constructs. FP showed a very strong influence on Ind4, while Ind4's impact on EMA was large, but its effect on FP was minimal. This variation in effect sizes illustrates the varying degrees of influence each construct has within the model.

Furthermore, the Predictive Relevance ( $Q^2$ ) of the constructs was assessed, with EMA, FP, and SR all showing strong predictive relevance. This was evident from their  $Q^2$  values, which were significantly above the threshold for strong predictive relevance. Such high  $Q^2$  values underscore the model's robustness in predicting these constructs, reinforcing the practical significance and applicability of the model in real-world scenarios.

Lastly, the model fit was evaluated using several metrics, including SRMR,  $d_{ULS}$ ,  $d_G$ , Chi-Square, and NFI. The congruence of values between the Saturated and Estimated models across these metrics indicated a good model fit. The SRMR values, in particular, were indicative of a model that accurately represents the observed data. While the NFI value didn't meet the ideal threshold of 0.9, it still denoted a reasonably good fit.

Thus, the inner model evaluation in this dissertation using PLS-SEM demonstrated that the constructs EMA, FP, Ind4, and SR are measured with precision, show distinctiveness, and the model overall possesses strong explanatory and predictive power. The high  $R^2$  values, particularly for the SR construct, and the strong predictive relevance indicated by the  $Q^2$

values, validate not only the statistical significance of the model but also its practical significance in forecasting and decision-making processes. The model fit assessment further reinforces the adequacy of the model in capturing and representing the observed data.

#### 4.3. Hypothesis Test

To substantiate the statistical significance of relationships between constructs, we conduct further analysis using bootstrapping to examine the direction and impact of both direct and indirect effects on our hypotheses (Alshebami & Murad, 2022; Klein & Todesco, 2021). This analysis is essential for validating the relationships within our PLS-SEM model, which encompasses constructs such as Environmental Management Accounting (EMA), Financial Performance (FP), Industry 4.0 (Ind4), and Sustainability Reporting (SR), to accept or reject each hypothesis.

Table 13. **Bootstrapping Result**

	<b>Hypotheses</b>	<b>Original Sample (O)</b>	<b>T Statistics ( O/STDEV )</b>	<b>P Values</b>	<b>Decision</b>
<b>H<sub>1.1</sub></b>	EMA -> FP	0.646	19.267	0.000	Accepted
<b>H<sub>1.2</sub></b>	EMA -> SR	0.301	12.964	0.000	Accepted
<b>H<sub>1.3</sub></b>	EMA -> FP -> SR	0.471	16.988	0.000	Accepted
<b>H<sub>2.1</sub></b>	Ind4 -> EMA	0.794	29.843	0.000	Accepted
<b>H<sub>2.2</sub></b>	Ind4 -> FP	0.181	4.879	0.000	Accepted
<b>H<sub>2.3</sub></b>	Ind4 -> SR	-0.007	0.477	0.634	Rejected
<b>H<sub>3.1</sub></b>	Ind4 -> EMA -> FP	0.513	15.43	0.000	Accepted
<b>H<sub>3.2</sub></b>	Ind4 -> EMA -> SR	0.239	11.58	0.000	Accepted
<b>H<sub>3.3</sub></b>	Ind4 -> FP -> SR	0.132	5.006	0.000	Accepted
<b>H<sub>3.4</sub></b>	Ind4 -> EMA -> FP -> SR	0.374	14.237	0.000	Accepted
<b>H<sub>4</sub></b>	FP -> SR	0.730	35.352	0.000	Accepted

Source: Author Data Processing, 2023

Table 3, which presents the results of our hypothesis testing, reveals a diverse array of direct and indirect relationships among the constructs in our study: Environmental Management Accounting (EMA), Financial Performance (FP), Industry 4.0 (Ind4), and Sustainability Reporting (SR).

The first hypothesis, H<sub>1.1</sub>, posits that EMA positively influences FP. This is accepted, evidenced by a substantial effect size of 0.646, a very high T statistic of 19.267, and a P value

of 0.000. This result indicates a strong and statistically significant relationship between EMA practices and financial performance. Similarly,  $H_{1,2}$ , which examines the effect of EMA on SR, is also accepted. With an effect size of 0.301, a T statistic of 12.964, and a P value of 0.000, it suggests a significant positive relationship between EMA practices and sustainability reporting.

The indirect effect of EMA on SR through FP, denoted as  $H_{1,3}$ , is accepted as well, highlighting a significant mediating role of financial performance. The effect size stands at 0.471, complemented by a T statistic of 16.988 and a P value of 0.000.

In hypotheses  $H_{2,1}$  and  $H_{2,2}$ , the impact of Industry 4.0 on EMA and FP is explored.  $H_{2,1}$  is strongly supported with an effect size of 0.794, a T statistic of 29.843, and a P value of 0.000, indicating a significant influence of Industry 4.0 on EMA.  $H_{2,2}$ , examining Industry 4.0's effect on FP, is also accepted, albeit with a more modest effect size of 0.181.

However,  $H_{2,3}$ , which tests the direct effect of Industry 4.0 on SR, is rejected. This is due to a negligible effect size of -0.007, a low T statistic of 0.477, and a non-significant P value of 0.634, indicating that the direct influence of Industry 4.0 on sustainability reporting is not supported.

Hypotheses  $H_{3,1}$  to  $H_{3,4}$  assess various indirect effects involving Industry 4.0. All these hypotheses are accepted, demonstrating significant relationships and confirming different pathways through which Industry 4.0 influences FP and SR, either directly or mediated through EMA.

Finally,  $H_4$ , which posits a direct effect of FP on SR, is strongly supported with a high effect size of 0.730, a T statistic of 35.352, and a P value of 0.000, pointing to a very significant relationship.

Thus, based on the interpretation of Table 15, most of our hypotheses are accepted, confirming significant relationships among the constructs, except for  $H_{2,3}$ . These findings provide a nuanced understanding of the interactions between EMA, FP, Industry 4.0, and SR, offering valuable insights for both theoretical and practical applications.

Our research confirms a significant indirect relationship between Industry 4.0 and both Financial Performance (FP) and Sustainability Reporting (SR), mediated through Environmental Management Accounting (EMA). Studies like Rasit et al. (2022a) and Kumar and Bhatia (2021) indicate that EMA is pivotal in harnessing Industry 4.0's benefits for FP. Additionally, the role of EMA in enhancing SR is supported by research from Burritt and Christ (2016) and Kamble et al. (2020). The disparity in environmental conditions across Indonesia, particularly between more and less industrialized areas, underscores the importance

of our study in the SME sector. Our findings highlight EMA's significance in improving environmental performance and reporting in SMEs, thereby contributing to better air quality and environmental standards, especially in regions like Western Indonesia.

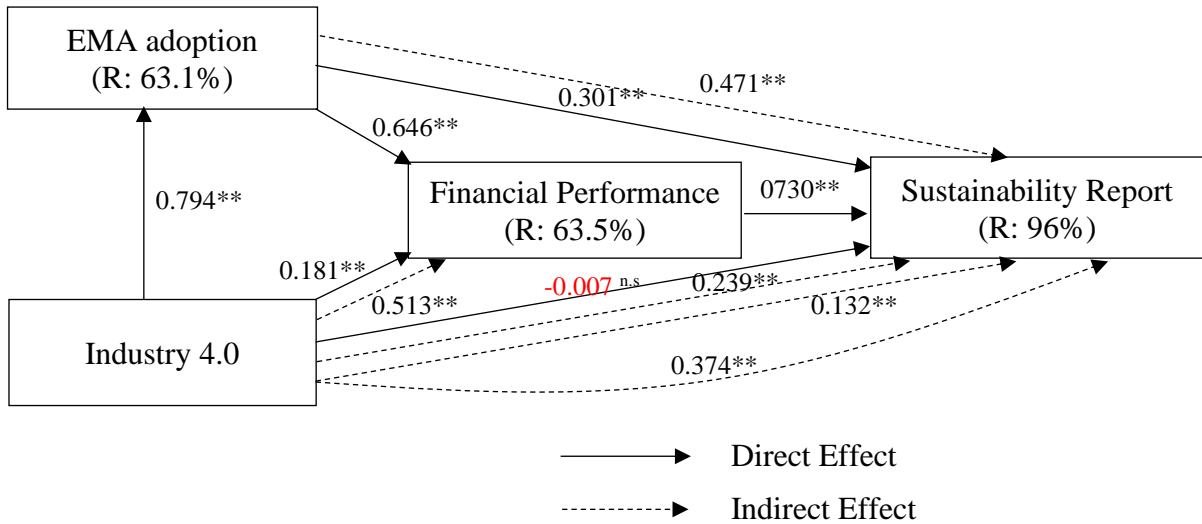
Our hypotheses, demonstrating the indirect relationship between Industry 4.0 and SR through EMA and FP, is corroborated by studies highlighting EMA's role in enhancing corporate sustainability and its influence on SR. The positive relationship between FP and SR is further affirmed by research from Buallay (2022) and Buallay et al. (2021), showing that firms engaged in sustainability reporting often experience improved financial outcomes. Similarly, Lee and Hu (2018) and Zhou et al. (2022) suggest that financial performance directly influences sustainability-related endeavors like CSR, further implying a strong connection between sustainability reporting and financial performance, particularly in SMEs. Thus, our research substantiates the significant indirect impact of Industry 4.0 on SR via both EMA and FP, emphasizing the multifaceted influence of technological advancements on sustainable practices and reporting in the SME sector.

## 5. CONCLUSION AND RECOMENDATIONS

Following the analysis of the data, this dissertation presents its conclusions as depicted in the final research model figure:

Figure 2. **Final Research Model**

With original sample effect size, coefficient determination, and sig. level



Source: Author data processing, 2023

Our study in this dissertation has explored the intricate dynamics between Industry 4.0, Environmental Management Accounting (EMA), Financial Performance (FP), and Sustainability Reporting (SR) in the context of Partial Least Squares Structural Equation Modeling (PLS-SEM). The key findings and conclusions drawn from our analysis are as follows:

1. **Significance of EMA and FP as Mediators:** This dissertation has strongly supported the hypotheses that EMA and FP play crucial mediating roles in the relationship between Industry 4.0 and SR. This indicates that while Industry 4.0 has indirect effects on sustainability practices, these effects are significantly channeled through improvements in environmental management accounting and financial performance.
2. **Complex Dynamics of Industry 4.0:** Our finding suggests a more complex relationship between Industry 4.0 and SR than previously understood. Our findings emphasize that the impact of Industry 4.0 is not straightforward and is contingent on various factors, including the specific nature of Industry 4.0 technologies and organizational contexts, especially in SMEs.

3. **Direct Relationship between FP and SR:** We found a direct and significant relationship between financial performance and sustainability reporting, indicating that firms with better financial outcomes are more likely to engage in comprehensive sustainability initiatives and reporting.
4. **Alignment with Prior Research:** Our findings align with existing literature, underscoring the positive influence of Industry 4.0 on sustainability practices and reporting. However, they also contribute novel insights by highlighting the mediating roles of EMA and FP.

Based on these conclusions, the following recommendations are proposed:

1. **Strategic Integration of Industry 4.0:** Organizations, particularly SMEs, should strategically integrate Industry 4.0 technologies to enhance both EMA and FP. This integration should be tailored to specific organizational needs and contexts to maximize its impact on sustainability reporting.
2. **Investment in EMA and Digital Technologies:** Firms should invest in advanced EMA systems and digital technologies as part of their Industry 4.0 initiatives. This would not only improve environmental and financial reporting but also enhance overall sustainability performance.
3. **Training and Development:** Continuous training and development programs should be implemented to equip employees with the necessary digital skills to adapt to Industry 4.0 technologies, thereby fostering an environment conducive to sustainable practices.
4. **Adherence to Sustainability Reporting Standards:** Companies should adhere to internationally recognized sustainability reporting standards, such as GRI Standards, to ensure comprehensive and transparent reporting of their sustainability initiatives and performance.
5. **Further Research:** Additional research is recommended to explore the variable impacts of Industry 4.0 across different industries and organizational contexts. This would provide deeper insights into how different aspects of Industry 4.0 influence EMA, FP, and SR, particularly in varying SME environments.

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### List of publications related to the dissertation

#### Articles, studies (7)

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