EV Battery Recycling Adoption: Insights from Dealers and Workshops in Yogyakarta

Manuscript received March 16, 2026; revised July 7, 2026

Ichsanul Fikri Umar Irawana
Department of Industrial Engineering,
Ahmad Dahlan University
Yogyakarta, Indonesia
ichsanul2100019102@webmail.uad.ac.id

Annie Purwani*
Department of Industrial Engineering,
Ahmad Dahlan University
Yogyakarta, Indonesia
annie.purwani@ie.uad.ac.id

***Abstract*— The rapid growth of electric vehicles in Indonesia has intensified battery waste management challenges, while the participation of informal repair businesses in battery recycling services remains limited. Existing studies have largely focused on consumers' recycling behavior, providing little understanding of how informal actors develop the intention to provide recycling services. This study develops a TPB-based behavioral framework by incorporating environmental, social, economic, and technological dimensions as contextual determinants of intention. Survey data from informal repair businesses in Yogyakarta were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results show that the environmental and technological dimensions significantly influence intention, whereas the social and economic dimensions do not. Intention, in turn, significantly increases willingness to provide battery recycling services. These findings indicate that the underlying behavioral mechanisms of recycling service providers are driven primarily by environmental awareness and technological readiness. This study contributes by elucidating the mechanisms that shape the intentions of recycling service providers, an underexplored stakeholder group in developing countries, and offers practical suggestions for designing interventions that strengthen battery recycling services through environmental education, the provision of appropriate technology, and clear institutional support to encourage participation.**

Keywords*— *Behavioral Intention, Circular Supply Chain, Electric Vehicle Battery Waste, Informal Recycling Service, PLS-SEM

I. INTRODUCTION

The electric vehicle industry has become one of the main focuses in supporting efforts to create environmentally friendly transportation solutions in various countries, including Indonesia [1]. The adoption of electric vehicles in Indonesia has increased significantly in recent years, driven by growing public awareness of sustainable technologies and strong government support. Based on data from the Ministry of Industry, the population of electric vehicles in Indonesia continues to increase, from 1,437 units in 2019 to 116,438 units in 2023 [2]. This growth is inseparable from government incentives and regulations, including Presidential Regulation Number 55 of 2019, which aims to accelerate the electric motor vehicle development program in Indonesia [3].

Electric vehicles have significant advantages over fossil fuel vehicles, especially in terms of energy efficiency and low emissions. By using rechargeable lithium-ion batteries, electric vehicles are able to reduce dependence on fossil fuels and offer an energy-efficient and environmentally friendly transportation solution [4]. However, despite being rechargeable, lithium-ion batteries have a limited-service life. In the automotive context, these batteries generally have a lifespan of 8-10 years, after which their performance will drastically decline [5]. This raises concerns about the increasing volume of electric vehicle battery waste. Based on research by the BPPT Material Technology Center, it is estimated that by 2025, Indonesia will produce around 250,000 tons of battery waste [6]. If not properly managed, this waste can endanger human health, pollute the environment, and threaten ecosystems due to its content of hazardous chemicals such as nickel, copper, and cobalt [7].

The importance of electric vehicle battery waste management has attracted widespread attention. Various research projects have been developed, including battery life-cycle environmental impact assessments [8], determining production and recycling sites [9], battery material recycling technology and the reuse of chemical elements contained therein [10], government-regulated management mechanisms [11], and the selection of treatment options for informal battery waste managers [12]. The resulting solutions not only reduce negative environmental impacts but also increase the sustainability of electric vehicle technology.

Various studies on the battery life cycle and the management of vehicle waste and e-waste have clearly demonstrated that informal actors in the supply chain play a crucial role. A study of lead-acid batteries in Brazil shows that despite official regulations, most collection and recycling processes still rely on informal networks that are not always monitored, posing risks to environmental contamination and public health [11]. A similar situation is found in the management of end-of-life vehicles (ELVs), where dismantling and recovery are carried out by small workshops or informal actors operating outside the official system [9]. Even in the context of battery swaps for electric motorcycles in Indonesia, recent research emphasizes the need for recycling classification before EoL because many batteries end up in informal channels that lack adequate technical standards [12]. Thus, the presence of informal actors remains a crucial node that impacts the effectiveness and risks of the overall system.

A review of these references found that electric vehicle dealers and workshops play a strategic role as centers for the maintenance and management of used batteries. However, a field survey conducted in July 2024 in the Special Region of Yogyakarta, specifically in Sleman, Bantul, and Yogyakarta City, found that dealers and workshops were not yet prepared to effectively handle and recycle battery waste [13]. Challenges identified include technological readiness, technical knowledge, availability of facilities and infrastructure, and high recycling costs.

Across studies, several factors consistently emerge as determinants of both success and challenges in battery and e-

 EISSN: 2961-872X ●PISSN: 2961-8924●DOI: 10.56741/IISTR.esl.002076

waste management. First, regulatory aspects and institutional incentives are consistently cited as key drivers, both in studies of circular economy-based lithium-ion battery recycling and Industry 4.0 in India [14] and in Brazil's national policy for lithium-ion battery recycling (LABs) [11]. Second, environmental and public health factors are a common thread: all studies highlight the impact of heavy metal toxicity (lead, cobalt, nickel) and the risk of ecotoxicity if improperly managed [8], [15]. Third, socioeconomic factors such as consumer awareness, attitudes toward recycling, and economic incentives emerged in e-waste research in India and China, where household behavior is heavily influenced by financial motivation and public information [16], [17], [18]. Michael [19]adds the importance of social factors and actual behavior in recycling practices. Fourth, technological factors and process efficiency—whether through hydrometallurgical recycling, reverse logistics, or SoH cut-off classification for battery swaps—are key to closing the material loop sustainably [14], [15], [20]. The similarities between these factors suggest that despite differences in country contexts and battery types, the success of a circular supply chain system always depends on a combination of regulations, incentives, social awareness, and technological innovation.

Several previous studies have identified environmental, social, technological, and economic factors influencing battery recycling [18], [20], [21], [22], [23]. While most of these studies are based on the TPB, they focus on consumer recycling intentions [23], [24], [25]). The role and availability of formal EV dealers and repair shops are highly anticipated as providers of waste battery recycling services. However, despite their crucial role in the battery recycling supply chain, their availability remains very limited. The TPB theory, as a behavioral-based framework for explaining behavioral intentions among recycling service providers, remains underexplored. This study addresses this gap by examining the behavioral intentions of EV dealers and repair shops to provide battery recycling services.

This research is rooted in the Theory of Planned Behavior (TPB) developed by Ajzen [24], in an adapted form. The TPB emphasizes that behavioral intentions are influenced by three key constructs: attitude toward the behavior, subjective norms, and perceived behavioral control. Based on a literature review, this study identifies four relevant contextual factors: environmental, social, technological, and economic in battery waste management. Social factors directly represent the subjective norm dimension, while technological and economic factors are positioned as operationalizations of perceived behavioral control because they are related to perceived ease of use and resource constraints. Environmental factors are viewed as part of attitudes toward behavior, as they reflect positive evaluations of environmentally friendly behavior.

Unlike previous TPB studies that primarily focused on consumer recycling behavior, this study extends the application of the TPB by examining behavioral intentions from the perspective of EV dealers and repair shops as recycling service providers. This perspective is crucial because these actors operate under different operational conditions, where technological readiness, environmental awareness, and economic capacity directly influence their willingness to provide battery recycling services.

This study focuses on dealers and repair shops due to their limited availability and strategic role in the supply chain as centers for the maintenance and management of electric vehicle batteries. The selected method is Partial Least Squares Structural Equation Modeling (PLS-SEM). PLS is a structural equation modeling analysis method used to test or develop theories for predictive purposes. This method is not only used to confirm existing theories but is also useful for explaining the relationships between latent variables [26].

The results of this study are expected to provide a basis for formulating appropriate policy strategies and interventions to encourage the mapping of behavioral mechanisms that are prerequisites for the involvement of informal actors in the circular supply chain system for electric vehicle battery waste. The study's primary contribution lies in its empirical examination of business actor behavior from the perspective of recycling service providers, a topic rarely explored in the Indonesian context.

II. METHODS

A. Population and Sample

In theory, population includes all elements with specific characteristics, including subjects and objects [27], [28] The population for this study consisted of electric vehicle dealers and workshops located in the Special Region of Yogyakarta. The sampling technique was selected based on predetermined criteria [29], [30]. Respondent qualifications included electric vehicle dealers and repair shops that did not yet offer electric vehicle battery recycling services. Respondent selection was based on information regarding the location of electric vehicle repair shops in the Special Region of Yogyakarta obtained through an online search using Google Maps.

In this study, the indicator used was a five-category Likert scale (strongly agree, agree, neutral, disagree, and strongly disagree), with four paths addressing the main factors of intention and willingness to manage battery waste: environmental, social, technological, and economic.

B. Variables

The variables in this study were identified through two main approaches. First, questionnaires were distributed to several electric vehicle dealers and workshops in Yogyakarta to explore the factors influencing their decision to recycle electric vehicle batteries. Second, a literature review was conducted to examine factors that affect the intention to recycle electric vehicle batteries. Based on this approach, this study employs several key variables that are considered influential in the decision-making process related to recycling electric vehicle batteries. The framework of this research model is presented in Fig. 1, while the the measurement indicators for each variable in the study are listed in Table 1. The questionnaire items were adapted from previously validated instruments reported in prior studies related to EV battery recycling, e-waste recycling, and the Theory of Planned Behavior (TPB). The selected indicators were adjusted to fit the context of EV dealers and workshops as recycling service providers. Each construct was operationalized into measurement items while preserving the conceptual meaning of the original instruments. The corresponding sources for each construct are presented in Table 1. The instruments in this study have been validated through face validity tests by lecturers who have expertise in related fields.

 EISSN: 2961-872X ●PISSN: 2961-8924●DOI: 10.56741/IISTR.esl.002076

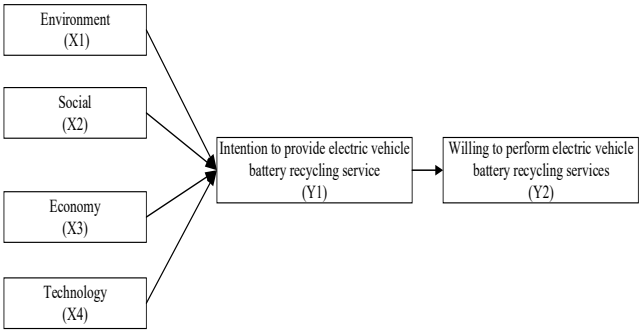


Fig. 1. Research model framework

1. Independent variable

The independent variable is the variable whose value affects the dependent variable [31]. In this study, the independent variables are environment (X1), social (X2), economy (X3), and technology (X4).

The research hypothesis used is as follows:

H1 : Environmental factors have a significant effect on the intention of electric vehicle battery recycling services

H2 : Social factors have a significant effect on the intention of electric vehicle battery recycling services

H3 : Economic factors have a significant effect on the intention of recycling services for electric vehicle batteries.

H4 : Technological factors have a significant effect on the intention of electric vehicle battery recycling services

H5 : Recycling service intention factors have a significant effect on willing to do electric vehicle battery recycling services.

2. Mediating variable

A mediating variable is a variable that explains the relationship between the independent and dependent variables. In this study, the mediating variable used is the intention to provide recycling services. Intention is a cognitive representation of a person's readiness to perform a certain behavior or action, and this intention can be used as a measure of a person's behavior or action [32].

3. Dependent variable

The dependent variable is the variable whose value is influenced by the independent variable [31]. The dependent variables used in this study are the willingness to do recycling services. Willingness is defined as the actual readiness or commitment of dealers and repair shops to implement recycling services in practice.

TABLE 1. RESEARCH VARIABLES AND MEASUREMENT INDICATORS

Variable	Indicator	Measurement item	Adapted from
Enviroment	EVM1	Recycling reduces pollution and hazardous waste	[18], [20], [21]
	EVM2	Recycling can reduce the need for mining new raw materials	
	EVM3	Recycling programs contribute to environmental sustainability	
Social	SCL1	Community influenced to participate in recycling program	[20], [22]
	SCL2	Recycling is a responsibility for businesses	
	SCL3	Recycling programs provide social benefits to the community	
Economy	ECM1	The use of recycled materials provides an affordable price	[20], [22]
	ECM2	Recycling can increase profits and revenue	
	ECM3	High investment cost	
Technology	TCG1	Technology is available and accessible	[20], [21]
	TCG2	Possess knowledge and skills	
	TCG3	Use of modern tools and devices is essential	
Intention	ITN1	Intention to recycle waste	[18], [22]
	ITN2	Participate in government-provided recycling programs	
	ITN3	Willing to take the time to recycle waste	
Willingness	WLS1	Willing to recycle	[23]
	WLS2	Willing to invest in equipment	
	WLS3	Willing to improve knowledge and skills	

4. Data Analysis Technique

The questionnaire used in this study was developed by the authors, based on a review of several articles (Table 1). The development process began with identifying research constructs and measurement indicators from previous studies related to pro-environmental behavior, technology adoption, and battery recycling. Based on these indicators, questionnaire items were independently formulated in Indonesian to reflect the operational characteristics and terminology commonly understood by EV repair business actors in Yogyakarta.

The data collected in this study used questionnaires. Question items on the assessment measure used the Likert scale from "1" to "5. The data in this study were analyzed using the Partial Least Squares (PLS) method with the aid of SmartPLS 4.1 software to test the formulated hypotheses. PLS-SEM is a multivariate statistical method that allows simultaneous analysis of the relationship between several independent and dependent variables. This method is widely used in research involving small sample sizes and complex models [33], [34].

In this analysis, the validity and reliability of research instruments were evaluated through the measurement model, which included tests of convergent validity, discriminant validity, and composite reliability [35]. Hypothesis testing was conducted using a structural model to measure the causal relationship between variables in the study. With this approach, the research can generate more accurate insights in understanding the factors that influence the intention of dealers and repair shops to provide electric vehicle battery recycling services.

III. RESULTS

A. Evaluation of Measurement Model

Validity and reliability tests in this study were conducted using the measurement model in PLS-SEM, as presented in Table 2. The analysis results show that all loading factor (LF) values are above 0.70, indicating that each indicator is valid in representing the measured variables [30]. This suggests that each indicator has a strong contribution in explaining the latent variable it represents. In addition, all constructs in the model also have an Average Variance Extracted (AVE) value above 0.50. This value indicates that more than 50% of the indicator variance can be explained by the construct being measured.

TABLE 2. RELIABILITY AND VALIDITY

Variable	Indicator	Loading Factor	CR	AVE	Alpha Cronbach
EVM	EVM1	0.902	0.926	0.807	0.881
	EVM2	0.917			
	EVM3	0.876			
SCL	SCL1	0.851	0.926	0.807	0.881
	SCL2	0.914			
	SCL3	0.928			
ECM	ECM1	0.920	0.930	0.817	0.888
	ECM2	0.913			
	ECM3	0.878			
TCG	TCG1	0.898	0.931	0.819	0.891
	TCG2	0.912			
	TCG3	0.904			
INT	INT1	0.908	0.897	0.744	0.828
	INT2	0.862			
	INT3	0.816			
WLS	WLS1	0.852	0.919	0.790	0.868
	WLS2	0.910			
	WLS3	0.902			

In addition, reliability was assessed using composite reliability (CR) and Cronbach's alpha. The analysis results show that all constructs have CR and Cronbach's Alpha values > 0.70, which indicates that the data has met the reliability criteria [36], [37]. This suggests that the research instrument demonstrates a good level of internal consistency in measuring the variables studied so that the data obtained can be trusted and consistent for use in further analysis.

The discriminant validity results presented in Tables 3 and 4 indicate that each indicator has the highest loading value on the construct it is supposed to measure, and no indicator has a higher loading on any other construct. This indicates that the discriminant validity in this model has been met well. Thus, based on the results of the validity and reliability tests, all indicators and constructs in this study can be considered valid and reliable. Consequently, further data analysis can be conducted to test the hypothesis and understand the relationship between the study variables.

TABLE 3. CROSS LOADING

	Enviroment	Social	Economy	Technology	Intention	Willingness
EVM1	0.902	0.449	0.078	0.075	0.709	0.405
EVM2	0.917	0.252	0.114	0.102	0.612	0.303
EVM3	0.876	0.211	0.053	0.252	0.596	0.357
SCL1	0.420	0.851	0.454	0.093	0.388	0.311
SCL2	0.205	0.914	0.458	0.106	0.316	0.404
SCL3	0.297	0.928	0.561	0.151	0.494	0.518
ECM1	0.040	0.426	0.920	0.372	0.371	0.415
ECM2	0.074	0.626	0.913	0.087	0.283	0.387
ECM3	0.135	0.480	0.878	0.384	0.334	0.275
TCG1	0.126	0.023	0.176	0.898	0.379	0.461
TCG2	0.188	0.229	0.355	0.912	0.406	0.329
TCG3	0.086	0.097	0.371	0.904	0.268	0.219
INT1	0.632	0.517	0.383	0.298	0.908	0.613
INT2	0.746	0.387	0.226	0.358	0.862	0.598
INT3	0.446	0.268	0.357	0.385	0.816	0.584
WLS1	0.279	0.227	0.339	0.374	0.490	0.853
WLS2	0.382	0.528	0.376	0.350	0.670	0.910
WLS3	0.383	0.447	0.346	0.314	0.661	0.902

TABLE 4. DISCRIMINANT VALIDITY CONSTRUCT (HTMT)

	EVM	SCL	ECM	TCG	INT	WLS
EVM						
SCL	0.378					
ECM	0.104	0.629				
TCG	0.717	0.151	0.361			
INT	0.821	0.513	0.429	0.455		
WLS	0.445	0.502	0.452	0.427	0.805	

B. Structural Model Evaluation

The structural model test in this study was used to evaluate the research hypothesis and test the relationship between latent variables in the research model. Hypothesis testing was conducted using an alpha significance level of 5% so that if the T-statistic value is greater than 1.96 or the p-value is less than 0.05, it indicates that the hypothesis is accepted or there is a significant effect [38][39].

The results of hypothesis esting presented in Table 5 show that two hypotheses are accepted, while three are rejected. Specifically, environmental variables have a positive and significant effect on the intention of dealers and repair shops to provide battery recycling services. In addition, the intention variable also has a positive effect on the willingness of dealers and repair shops to offer battery recycling services. Fig. 2 presents the structural model in Smart-PLS. Table 5 shows that the structural model yields a coefficient of determination (R^2) of intention of 0.651 and willingness of 0.510. This study shows that environmental, social, economic, and technological factors can explain 65.1% of the intention to provide recycling services. Furthermore, this intention also contributes 51% to the willingness to provide recycling services.

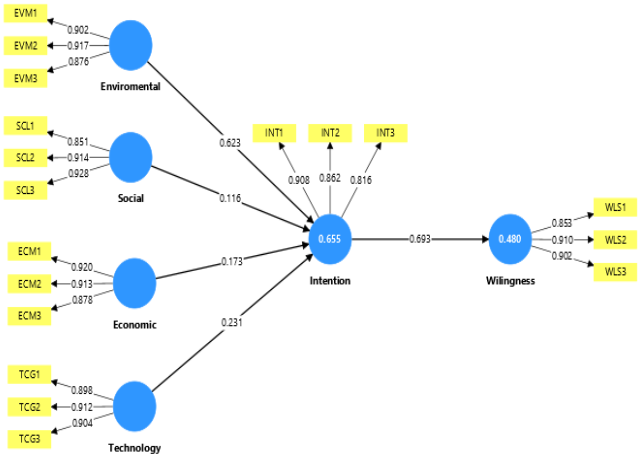


Fig. 2. Structural Model

The proposed behavioral model explains 65.5% of the variance in intention and 48.0% of the variance in willingness (Table 5). These findings indicate that environmental, technological, economic, and social factors capture a substantial proportion of the behavioral mechanisms underlying informal workshops' decisions to provide battery recycling services. Nevertheless, 34.5% of the variance in intention and approximately half of the variance in willingness remain unexplained. This suggests that other factors, such as organizational, regulatory, and institutional aspects, may also influence future participation in battery recycling systems.

TABLE 5. R-SQUARE

Endogenous Construct	R-Square	R-Square adjusted
Intention	0.655	0.609
Willingness	0.480	0.465

Table 6 presents the effect sizes (f^2) of the exogenous constructs, indicating their practical contributions to the explanatory power of the endogenous variables. The environmental variable exhibits a large effect size ($f^2 = 0.947$), indicating that environmental awareness makes a substantial contribution to the formation of intention. Similarly, intention has a large effect on willingness ($f^2 = 0.925$), confirming its central role in translating behavioral intention into willingness to provide battery recycling services. In contrast, technology ($f^2 = 0.134$), economic ($f^2 = 0.053$), and social ($f^2 = 0.023$) factors exhibit only small effect sizes, indicating that their practical contributions to the model's explanatory power are

EISSN: 2961-872X ●PISSN: 2961-8924●DOI: 10.56741/IISTR.esl.002076

relatively limited. These results suggest that although technological factors contribute to the formation of intention, their practical influence remains considerably weaker than that of environmental awareness, while the contributions of social and economic factors are marginal.

TABLE 6. EFFECT SIZE (f^2)

Construct	Intention	Wilingness
Enviromental	0.947	-
Social	0.023	-
Economic	0.053	-
Technology	0.134	-
Intention	-	0.925

The hypothesis testing results are presented in Table 7. Environmental factors have a significant positive effect on intention ($\beta = 0.623$, $t = 5.367$, $p < 0.001$), thereby supporting H1. Technology also has a positive and significant effect on intention ($\beta = 0.231$, $t = 1.984$, $p = 0.047$), supporting H4, although its practical impact is relatively small, as reflected by its effect size. In contrast, social ($\beta = 0.116$, $p = 0.394$) and economic factors ($\beta = 0.173$, $p = 0.215$) do not have significant effects on intention; therefore, H2 and H3 are not supported. Finally, intention has a significant positive effect on willingness ($\beta = 0.693$, $t = 6.015$, $p < 0.001$), supporting H5 and confirming that intention serves as the primary behavioral mechanism linking contextual factors to willingness among informal repair businesses.

TABLE 7. HYPOTHESIS TEST RESULTS

	Hypothesis	Coefficient	T-Value	P-Value	Conclusing
H1	EVM→INT	0.623	5.367	0.000	Sig
H2	SCL→INT	0.116	0.852	0.394	Not sig
H3	ECM→INT	0.173	1.241	0.215	Not sig
H4	TCG→INT	0.231	1.984	0.047	Sig
H5	INT→WLS	0.693	6.015	0.000	Sig

IV. DISCUSSION

This study develops a TPB-based behavioral framework to explain the behavioral mechanism through which informal EV repair businesses become willing to provide battery recycling services. The framework positions environmental [40], [41], [42], social [43], economic [9], [11], and technological [14], [24], [41], [44] dimensions as contextual determinants shaping intention [24], while intention subsequently predicts willingness to provide recycling services. Rather than merely testing statistical relationships. the proposed framework explains how contextual conditions influence behavioral decisions that are essential for establishing battery recycling services. In this respect. the study views informal actors [11], [14] not simply as waste handlers but as key participants whose behavioral decisions determine whether reverse material flows can emerge within a circular battery supply chain.

The number of respondents who qualified as electric vehicle dealers and repair shops that did not yet offer electric vehicle battery recycling services in the Special Region of Yogyakarta was 35. The number of respondents available aligns with the more flexible nature of PLS-SEM. which is more flexible to small sample sizes compared to covariance-based SEM. Hair et al. (2017) [37] emphasize that the 10-fold rule of thumb allows for the use of a relatively small minimum sample size. namely ten times the largest number of indicators in a construct or the number of paths leading to a particular construct. In this study. there were four entry points. so the minimum required sample size (Hair) was 40. making 35 slightly below the threshold. However. Kock and Hadaya (2018) [45] stated that. considering expected effect sizes and statistical significance. stable estimates can still be produced in samples under 50. especially when the research model is not too complex. The models tested in this study had large path coefficients ($\beta = 0.623$ and 0.693). very large effect sizes ($f^2 = 0.947$ and 0.925). and adequate R^2 and Q^2. making the use of PLS-SEM with 35 respondents still justified.

The findings reveal that environmental and technological dimensions significantly influence intention. whereas social and economic dimensions do not. Furthermore. intention significantly predicts willingness to provide battery recycling services. indicating that intention functions as the central behavioral mechanism linking contextual conditions with service provision. These findings suggest that informal repair businesses evaluate participation in battery recycling primarily from the perspectives of environmental responsibility and technological feasibility rather than social expectations or anticipated economic benefits [24], [40]-[42], [44] In the context of Yogyakarta. where informal repair businesses operate independently and battery recycling systems remain underdeveloped. practical capability appears to outweigh normative or financial considerations [9], [11], [43].

The empirical findings indicate that environmental awareness and technological readiness are the primary behavioral conditions influencing informal repair businesses' intention to provide battery recycling services [24], [40]-[42]. [44], [46] The empirical findings indicate that environmental awareness and technological readiness are the primary behavioral conditions influencing informal repair businesses' intention to provide battery recycling services. This is also in line with studies conducted in consumer or formal organizational context [47] which highlight the importance of contextualizing behavioral theory according to stakeholder characteristics. This interpretation is consistent with the current situation in Yogyakarta. where battery waste volumes remain limited. formal collection networks are still emerging. and institutional support mechanisms have yet to become fully established. Consequently. economic incentives and social norms have not yet matured sufficiently to influence behavioral intention. This phenomenon aligns with a literature review that highlights that aligning technology with local cultural values. engaging stakeholders. and promoting capacity building through culturally relevant training and education are crucial for enhancing the effectiveness of sustainability practices [48].

The principal theoretical contribution of this study lies in explaining the behavioral mechanism through which informal repair businesses develop the intention and willingness to provide battery recycling services. Previous behavioral studies have predominantly examined consumers' recycling intentions. whereas this study focuses on informal actors who enable recycling services within the reverse flow of end-of-life batteries. By employing a TPB-based behavioral framework. the study shifts the analytical focus from explaining individual recycling behavior to identifying the behavioral conditions required for integrating informal actors into circular battery waste management systems. As summarized in Table 8. the empirical findings can be synthesized into four sequential stages. beginning with contextual determinants. followed by behavioral mechanism. stakeholder integration. and system implication. This synthesis demonstrates that environmental awareness and technological readiness constitute the primary contextual conditions supporting intention formation. while intention subsequently translates into willingness that facilitates informal actor participation in reverse logistics activities [49]. Consequently. the proposed framework broadens the application of behavioral theory to an

underexplored stakeholder group and provides a behavioral foundation for understanding how informal actors contribute to the development of circular battery supply chains.

Beyond its behavioral contributions. the proposed framework provides insights into the conditions needed for the gradual emergence of a circular battery supply chain through the participation of informal actors [11], [14], [21]**)**. The findings suggest that behavioral motivation alone is insufficient to build an effective reverse logistics system. Although informal repair businesses have shown a willingness to participate when supported by environmental awareness and technological readiness. the absence of significant social and economic influence suggests that stakeholder networks and market mechanisms remain underdeveloped. Consequently. building a circular battery supply chain should be seen as a progressive process rather than an immediate outcome. Effective implementation also requires communication and coordination between informal repair businesses. licensed recyclers. manufacturers. and local governments to facilitate battery collection. information exchange. technical assistance. and safe handling practices [12]. Consequently. policy interventions should not focus solely on regulatory enforcement but also on strengthening institutional support that protects and empowers informal actors through repair shop associations [14], [49], collaborative collection networks. technical training. and accessible financial incentives.

TABLE 8. POLICY FOR CIRCULAR BATTERY SUPPLY CHAIN FORMATION

Development Stage	Empirical Evidence	Interpretation	Policy alternative
Environmental readiness	Environment significantly influences intention	Environmental responsibility has emerged	Strengthen environmental education
Technological readiness	Technology significantly influences intention	Workshops require practical technological capability	Provide modular technologies and technical assistance
Institutional readiness	Intention significantly predicts willingness	Informal actors are ready to participate	Build communication. repair shop associations. and collection partnerships
Market readiness	Social and economic factors are not yet significant	CSC ecosystem remains in an early developmental stage	Create direct financial incentives. EPR mechanisms. and community engagement

Similar collaborative approaches have been successfully implemented through community-based e-waste initiatives in Malaysia [47], accessible recycling technologies in Brazil and India [41], and financial support mechanisms for informal recyclers in Nigeria and Kenya [9], [11], [46] demonstrating that institutional support is essential for sustaining informal sector participation. Therefore. policies should focus not only on regulation but also on strengthening communication platforms. repair shop associations. technical training. and direct incentives that enable informal actors to participate as long-term partners within circular battery supply chains.

This study provides a description of information actors in Yogyakarta. which urgently requires further validation for interpretation in other regions. Although the proposed TPB-based behavioral framework demonstrates satisfactory explanatory and predictive capabilities. future studies should validate the framework using a larger and more geographically diverse sample. Future research should investigate how the behavioral readiness identified in this study translates into actual participation as battery waste volumes increase and institutional arrangements mature. Longitudinal studies examining the transition from environmental motivation to economically sustainable recycling practices would provide valuable insights into the evolution of the circular battery supply chain. Further research is also encouraged to integrate governance-related variables. including stakeholder collaboration. communication mechanisms. government support. and extended producer responsibility. to better explain how willingness among informal actors translates into effective reverse logistics systems.

V. CONCLUSION

This study developed a TPB-based behavioral framework to explain how informal repair businesses develop the intention and willingness to provide battery recycling services. The findings indicate that environmental awareness and technological readiness constitute the primary behavioral conditions supporting intention formation. whereas social and economic considerations have not yet become significant drivers within the current context. Rather than indicating the irrelevance of these factors. the results suggest that the battery recycling ecosystem in Yogyakarta is still at an early stage of development. where environmental responsibility precedes market formation and institutional integration.

The study further demonstrates that willingness among informal repair businesses provides an essential behavioral foundation for integrating these actors into future reverse logistics systems. However. willingness alone is insufficient to establish a circular battery supply chain. Sustained development will require stronger communication among stakeholders. supportive institutional arrangements. accessible recycling technologies. and concrete economic incentives that enable informal actors to participate as long-term partners in battery waste management. In this sense. the present study represents an initial step toward understanding the behavioral conditions necessary for developing circular battery supply chains in emerging electric vehicle markets.

ACKNOWLEDGMENT

The author team would like to thank the Muhammadiyah Central Leadership Higher Education Research and Development Council for the Mu Research Program grant Wave VIII in 2024. This research was funded by the Funding and Implementation of the Muhammadiyah National Research Grant Batch VIII in 2024 Number: 0258.227/I.3/D/2025. I would like to thank Wandhansari Sekar Jatiningrum for his valuable suggestions and insightful feedback during the completion of this research. I would also like to thank Aufha Rafhika. Salsabiela Nurul Alisyah. and Dea Maulivia. who supported the writing of this article.

REFERENCES

[1] F. Hidranto, "Industri kendaraan berbasis listrik: Menyongsong masa depan transportasi ramah lingkungan," *Indonesia.go.id*. [Online]. Available: https://indonesia.go.id/kategori/editorial/8646/industri-kendaraan-berbasis-listrik-menyongsong-masa-depan-transportasi-ramah-lingkungan

[2] Shiddiq, "Populasi kendaraan listrik April 2024 capai 133.225 unit," *Media Nikel Indonesia*. [Online]. Available: https://nikel.co.id/2024/06/20/stafsus-menteri-esdm-populasi-kendaraan-listrik-april-2024-capai-133-225-unit/

[3] K. P. Pramono and S. M. Nur, "Business model canvas pada usaha penjualan box baterai motor listrik," *Jurnal Informatika Teknologi dan*

 EISSN: 2961-872X ●PISSN: 2961-8924●DOI: 10.56741/IISTR.esl.002076

Sains (JINTEKS), vol. 6, no. 2, pp. 171–177, May 2024, doi: 10.51401/jinteks.v6i2.4001.

[4] F. Nurfadlilah, A. Malika, A. Naufal, and R. Wikansari, "Peran sepeda listrik dalam mewujudkan mobilitas berkelanjutan," *HUMANITIS: Jurnal Homaniora, Sosial dan Bisnis*, vol. 2, no. 1, pp. 136–141, 2024.

[5] L. Putri, A. Rachmaddi, A. Pradana, and R. Sasue, "Analisis penanganan limbah baterai mobil listrik untuk mendukung pengembangan kendaraan listrik di Indonesia," *Prosiding Forum Studi Transportasi antar Perguruan Tinggi*, vol. 10, no. 1, pp. 379–385, 2023.

[6] G. Satria and A. Ferdian, "Pentingnya pengolahan limbah baterai mobil listrik untuk lingkungan," *Komps*. [Online]. Available: https://otomotif.kompas.com/read/2019/09/05/192900215/pentingnya-pengolahan-limbah-baterai-mobil-listrik-untuk-lingkungan

[7] S. Apriani, "5 jenis limbah elektronik yang dihasilkan oleh motor listrik," *Radar Banyumas*. [Online]. Available: https://radarbanyumas.disway.id/read/101851/5-jenis-limbah-elektronik-yang-dihasilkan-oleh-motor-listrik

[8] J. Porzio and C. D. Scown, "Life-cycle assessment considerations for batteries and battery materials," *Adv. Energy Mater.*, vol. 11, no. 33, 2021, doi: 10.1002/aenm.202100771.

[9] S. Karagoz, N. Aydin, and V. Simic, "End-of-life vehicle management: A comprehensive review," *J. Mater. Cycles Waste Manag.*, vol. 22, no. 2, pp. 416–442, 2019, doi: 10.1007/s10163-019-00945-y.

[10] A. Putri, "Peluang dan tantangan daur ulang baterai EV," *Katadata Green*. [Online]. Available: https://green.katadata.co.id/infografik/66e3e62064990/peluang-dan-tantangan-daur-ulang-baterai-ev. Accessed: Jan. 20, 2026.

[11] G. Scur, C. Mattos, W. Hilsdorf, and M. Armelin, "Lead acid batteries (LABs) closed-loop supply chain: The Brazilian case," *Batteries*, vol. 8, no. 10, 2022, doi: 10.3390/batteries8100139.

[12] A. Purwani, S. M. Budijati, and M. H. Asih, "Management of battery waste recycling by electric motorbike workshops: A literature review," *OPSI*, vol. 17, no. 1, pp. 216-233, 2024.

[13] A. Purwani, I. F. U. Irawan, and I. Ramadhan, "Pemetaan potensi pelaku informal (bengkel) sepeda motor listrik yang bersedia melakukan daur ulang limbah baterai," *Venus: Jurnal Publikasi Rumpun Ilmu Teknik*, vol. 3, no. 4, pp. 135–149, Aug. 2025, doi: 10.61132/venus.v3i4.1045.

[14] A. Tripathy, A. Bhuyan, R. K. Padhy, S. K. Mangla, and R. Roopak, "Drivers of lithium-ion batteries recycling industry toward circular economy in Industry 4.0," *Comput. Ind. Eng.*, vol. 179, p. 109157, 2023, doi: 10.1016/j.cie.2023.109157.

[15] A. Purwani, W. Sutopo, M. Hisjam, and A. Widiyanto, "Approach for determining cut-off values for electric motorcycle swap battery before the end-of-life in the recycling classification," *J. Appl. Sci. Eng.*, vol. 28, no. 4, pp. 811–820, 2025, doi: 10.6180/jase.202504_28(4).0013.

[16] Z. Wang, D. Guo, X. Wang, B. Zhang, and B. Wang, "How does information publicity influence residents' behaviour intentions around e-waste recycling?," *Resour. Conserv. Recycl.*, vol. 133, pp. 1–9, 2018, doi: 10.1016/j.resconrec.2018.01.014.

[17] Z. Wang, Q. Wang, S. Zhang, and X. Zhao, "Effects of customer and cost drivers on green supply chain management practices and environmental performance," *J. Clean. Prod.*, vol. 189, pp. 673–682, 2018.

[18] M. Sajid, K. A. Zakkariya, and H. Joy, "Determinants of e-waste recycling intention in India: The influence of environmental concern, attitude and economic incentives," *Colombo Bus. J.*, vol. 13, no. 1, pp. 119–140, Jun. 2022, doi: 10.4038/cbj.v13i1.91.

[19] L. K. Michael, S. S. Hungund, and K. V. Sriram, "Factors influencing the behavior in recycling of e-waste using integrated TPB and NAM model," *Cogent Bus. Manag.*, 2024, doi: 10.1080/23311975.2023.2295605.

[20] Y. Kayikci, Y. Kazancoglu, N. Gozacan-Chase, C. Lafci, and L. Batista, "Assessing smart circular supply chain readiness and maturity level of small and medium-sized enterprises," *J. Bus. Res.*, vol. 149, pp. 375–392, 2022, doi: 10.1016/j.jbusres.2022.05.042.

[21] A. Tripathy, A. Bhuyan, R. Padhy, and L. Corazza, "Technological, organizational, and environmental factors affecting the adoption of electric vehicle battery recycling," *IEEE Trans. Eng. Manag.*, vol. 71, pp. 12992–13005, 2024, doi: 10.1109/TEM.2022.3164288.

[22] H. T. T. Nguyen, R. J. Hung, C. H. Lee, and H. T. T. Nguyen, "Determinants of residents' e-waste recycling behavioral intention: A case study from Vietnam," *Sustainability*, vol. 11, no. 1, Jan. 2019, doi: 10.3390/su11010164.

[23] N. S. Mohamad, A. C. Thoo, and H. T. Huam, "The determinants of consumers' e-waste recycling behavior through the lens of extended theory of planned behavior," *Sustainability*, vol. 14, no. 15, Aug. 2022, doi: 10.3390/su14159031.

[24] I. Ajzen, "The theory of planned behavior," *Organ. Behav. Hum. Decis. Process.*, vol. 50, no. 2, pp. 179–211, 1991, doi: 10.1016/0749-5978(91)90020-T.

[25] N. Afrianty, *Theory of Planed Behavior Mendeteksi Intensi Masyarakat Menggunkan Produk Perbankan Syariah*. Brimedia Global CV, 2021.

[26] J. W. Fernanda, V. Luthifiana, and M. K. Akhyar, "Analisis partial least square structural equation model (PLS-SEM) untuk pemodelan penerimaan Sistem Jaringan Informasi Bersama Antar Sekolah (JIBAS)," *J Statistika: Jurnal Ilmiah Teori dan Aplikasi Statistika*, vol. 15, no. 2, pp. 292–297, Dec. 2022, doi: 10.36456/jstat.vol15.no2.a6436.

[27] P. W. Sulistiyowati and M. C. C. Astuti, *Buku Ajar Statistika Dasar*. Sidoarjo, Indonesia: UMSIDA Press, 2017.

[28] N. F. Amin, S. Garancang, and K. Abunawas, "Konsep umum populasi dan sampel dalam penelitian," *Jurnal Kajian Islam Kontemporer*, vol. 14, no. 1, Jun. 2023.

[29] Sugiyono, *Metode Penelitian Kuantitatif, Kualitatif dan R&D*, vol. 19. Bandung, Indonesia: Alfabeta CV, 2013.

[30] D. R. Rahadi, *Pengantar Partial Least Squares Structural Equation Modeling (PLS-SEM)*. Lentera Ilmu Madani CV, 2023.

[31] Purwanto, "Variabel dalam pendidikan," *Teknodik*, vol. 10, no. 18, pp. 1–20, 2019.

[32] N. Afrianty, *Theory of Planned Behavior: Mendeteksi Intensi Masyarakat Menggunakan Produk Perbankan Syariah*. Yogyakarta, Indonesia: CV Brimedia Global, 2021.

[33] S. Suriana, R. Rahmawati, and D. Ekawati, "Partial least square-structural equation modeling pada tingkat kepuasan dan persepsi mahasiswa terhadap perkuliahan online," *SAINTIFIK*, vol. 8, no. 1, pp. 10–19, Jan. 2022, doi: 10.31605/saintifik.v8i1.362.

[34] I. Giyanti and E. Indriastiningsih, "Effect of SME food entrepreneurs knowledge on halal certification for certified awareness using partial least square," *Jurnal Teknik Industri*, vol. 20, no. 2, pp. 140–151, Aug. 2019, doi: 10.22219/JTIUMM.Vol20.No2.140-151.

[35] R. Milatalata and A. Hartanto, "Peran ekuitas merek dan persepsi nilai yang dirasakan sebagai mediasi hubungan aktivitas pemasaran media sosial terhadap niat membeli kembali (Studi pada Instagram Erigo)," *Syntax Literate: Jurnal Ilmiah Indonesia*, vol. 7, no. 11, pp. 15606–15625, 2022, doi: 10.36418/syntax-literate.v7i11.9978.

[36] S. Sayyida, "Structural equation modeling (SEM) dengan SmartPLS dalam menyelesaikan permasalahan di bidang ekonomi," *Journal MISSY (Management and Business Strategy)*, vol. 4, no. 1, pp. 6–13, Jun. 2023, doi: 10.24929/missy.v4i1.2610.

[37] J. F. Hair, G. T. M. Hult, C. M. Ringle, M. Sarstedt, N. P. Danks, and S. Ray, "Evaluation of formative measurement models," pp. 91–113, 2021, doi: 10.1007/978-3-030-80519-7_5.

[38] Z. Ulhaq, E. Indriastiningsih, and Y. Primasanti, "Pengaruh sistem reward, digitalisasi, dan metode kampanye audio-visual terhadap tingkat kepedulian keselamatan pekerja," *Jupiter: Publikasi Ilmu Keteknikan Industri, Teknik Elektro dan Informatika*, vol. 2, no. 1, pp. 311–328, 2024, doi: 10.61132/jupiter.v2i2.193.

[39] N. Nilamsari and T. A. Lubis, "Pengaruh kondisi sosial ekonomi keluarga dan lingkungan sosial terhadap keberhasilan wirausaha melalui efikasi diri pada anggota HIPMI di Provinsi Jambi," *Jurnal Manajemen Terapan dan Keuangan (Mankeu)*, vol. 13, no. 3, pp. 733–746, 2024.

[40] A. Bhuyan, A. Tripathy, R. K. Padhy, and A. Gautam, "Evaluating the lithium-ion battery recycling industry in an emerging economy: A multi-stakeholder and multi-criteria decision-making approach," *J. Clean. Prod.*, vol. 331, p. 130007, 2022, doi: 10.1016/j.jclepro.2021.130007.

[41] J. F. de Oliveira Neto, M. M. Silva, *et al.*, "A mini-review of e-waste management in Brazil: Perspectives and challenges," *CLEAN—Soil, Air, Water*, 2019, doi: 10.1002/clen.201900152.

[42] B. Zhang, J. Li, and X. Yue, "Driving mechanism of power battery recycling systems in companies," *Int. J. Environ. Res. Public Health*, vol. 17, no. 21, pp. 1–21, 2020, doi: 10.3390/ijerph17218204.

[43] T. Q. Nguyen and V. Y. Ngo, "Life cycle costing in public building projects in Vietnam," *J. Appl. Sci. Eng.*, vol. 24, no. 6, pp. 861–866, 2021, doi: 10.6180/jase.202112_24(6).0006.

[44] C. L. da Silva, "Proposal of a dynamic model to evaluate public policies for the circular economy: Scenarios applied to the municipality of Curitiba," *Waste Manag.*, vol. 78, pp. 456–466, 2018, doi: 10.1016/j.wasman.2018.06.007.

[45] N. Kock and P. Hadaya, "Minimum sample size estimation in PLS-SEM: The inverse square root and gamma-exponential methods," *Inf. Syst. J.*, vol. 28, no. 1, pp. 227–261, 2018.

[46] S. Sumarsono and N. Muflihah, "The effect of logistical-crossfunctional drivers on the competitive strategy of the supply chain of SMEs: A case study," *Jurnal Teknik Industri*, vol. 22, no. 1, pp. 85–97, Feb. 2021, doi: 10.22219/JTIUMM.Vol22.No1.85-97.

[47] G. Mathew, W. H. Teoh, W. M. A. Wan Abdul Rahman, and N. Abdullah, "Survey on actions and willingness towards the disposal, collection, and recycling of spent lithium-ion batteries in Malaysia," *J. Clean. Prod.*, vol. 421, p. 138394, 2023, doi: 10.1016/j.jclepro.2023.138394.

[48] N. Semiun, I. Ghazali, E. Mohamad, and T. Tanjung, "A systematic review on Industrial 4.0 readiness for environmental sustainability considering cultural influences," *Engineering Science Letter*, vol. 4, no. 1, pp. 23–31, Nov. 2024, doi: 10.56741/iistr.esl.00735.

[49] L. H. Xavier, M. Ottoni, and J. Lepawsky, "Circular economy and e-waste management in the Americas: Brazilian and Canadian frameworks," *J. Clean. Prod.*, vol. 297, May 2021, doi: 10.1016/j.jclepro.2021.126570.

 EISSN: 2961-872X ●PISSN: 2961-8924●DOI: 10.56741/IISTR.esl.002076