

Article

Determinants of Youths' Behavioural Intention Towards Hydrogen Energy Adoption in Kuching, Sarawak: An Extended Theory of Planned Behaviour Approach

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Abstract

The emergence of hydrogen energy as a key part of the global decarbonization agenda and energy transition plans has gained traction in recent years. As one of the earliest states to adopt policies promoting hydrogen development, such as the Post COVID-19 Development Strategy (PCDS 2030) and the Sarawak Hydrogen Economy Roadmap (SHER 2025), Sarawak has paved the way for hydrogen development in Malaysia. Although the state's commitment to invest in technology and infrastructure to support hydrogen development has been promising, the successful implementation of hydrogen energy depends not only on technological development but also on public acceptance and behavioural intention (BI), particularly among youths who will become future users and decision-makers. This study therefore aims to examine the predictive relationships between attitudes (ATTI), social norms (SN), perceived behavioural control (PBC), personal norms (PN), and behavioural intention (BI) towards hydrogen energy adoption among youths in Kuching, Sarawak. A cross-sectional survey using convenience sampling was conducted among 345 youths in Kuching, Sarawak, between 13 September and 17 December 2025, and the data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM). The results indicate that all four constructs exhibited significant positive predictive relationships with behavioural intention, with Personal Norms exhibiting the largest standardized path coefficient ($\beta = 0.246, p < 0.001$). These findings suggest the value of incorporating Personal Norms into the Theory of Planned Behaviour to enhance the understanding of behavioural intention towards hydrogen energy adoption. The study contributes to the growing body of literature on hydrogen energy adoption and offers practical insights that may assist policymakers in developing youth-focused awareness initiatives, strengthening environmental responsibility, and supporting hydrogen energy awareness and acceptance among youths in Kuching.



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Keywords: hydrogen energy adoption; behavioural intention; theory of planned behaviour; personal norms; youths; Sarawak

1. Introduction

Across Asia, renewable energy development has increased as nations seek to balance rapid economic growth with the urgency of decarbonization. Countries such as China, Japan, and South Korea have made significant investments in solar, wind, and hydrogen technologies, while emerging economies, including Indonesia, Vietnam, and India, are

progressively expanding their renewable energy portfolios to ensure energy security and sustainability [1]. However, the scale of the transition varies widely between developed and developing countries, largely due to differences in technological capacity, financial resources, and policy commitment [2].

In developing Asian nations, renewable-energy adoption has become both an environmental necessity and an economic opportunity. With an ever-increasing energy demand and dependency on fossil fuels, many of these countries see renewables as the way forward to achieve energy independence and inclusive growth [2]. For example, Malaysia is positioning itself as a regional leader in the energy transition by developing the National Energy Transition Roadmap (NETR) and the Hydrogen Economy and Technology Roadmap (HETR), both with the aim of achieving net-zero emissions by 2050 [3]. In Malaysia, Sarawak is playing an active role in the energy transition by tapping into its wealth of hydropower resources to be at the forefront of the hydrogen-energy revolution, supported by the Sarawak Hydrogen Economy Roadmap (SHER 2025) and the Post COVID-19 Development Strategy (PCDS 2030). These frameworks place Sarawak at the forefront of Malaysia's transition towards a green economy. They make it the first state in the country to include hydrogen as part of its clean energy plans, aligning it with the international trend towards renewable energy [4,5].

Figure 1 illustrates Sarawak's PCDS 2030, which provides the policy framework guiding the state's economic transformation toward 2030. The strategy is anchored on six economic sectors such as Manufacturing, Commercial Agriculture, Tourism, Forestry, Mining, and Services. It is supported by seven enablers, namely Digital Transformation, Innovation, Education and Human Capital, Basic Infrastructure, Utilities, Transport, and Renewable Energy. These enablers collectively drive Sarawak's vision of achieving a prosperous, inclusive, and sustainable economy by 2030, in alignment with Malaysia's broader NETR and HETR [6].

Economic Sectors	Enablers
1. Manufacturing	1. Digital Transformation
2. Agriculture	2. Innovation
3. Tourism	3. Education and Human Capital
4. Forestry	4. Basic Infrastructure
5. Mining	5. Utilities
6. Services	6. Transport
	7. Renewable Energy

Figure 1. Framework of the Post COVID-19 Development Strategy (PCDS) 2030, illustrating the six economic sectors and seven strategic enablers. Source: Adapted from the Post COVID-19 Development Strategy (PCDS) 2030 [6].

Human-induced climate change has triggered a cascade of environmental and societal challenges both globally and in Malaysia. For Sarawak, which relies heavily on hydropower and is positioning itself as a regional leader in clean energy, the challenge is not only technological but also behavioural. Despite hydropower's dominance, Sarawak remains a net carbon emitter, referring to a condition where the total carbon dioxide (CO₂) emissions

released into the atmosphere exceed the amount removed through natural processes such as forest absorption or other carbon sinks. The imbalance continues to contribute to the buildup of greenhouse gases and inhibits efforts towards achieving climate neutrality. Figure 2 illustrates the average annual net CO₂ emissions, CO₂ removals, and CO₂ emissions in Sarawak between 2001 and 2023. During this period, the state averaged emissions of 110 million metric tons of CO₂ each year, with 39.8 million metric tons removed on average, resulting in a net emission of around 69.9 million metric tons per year [7].

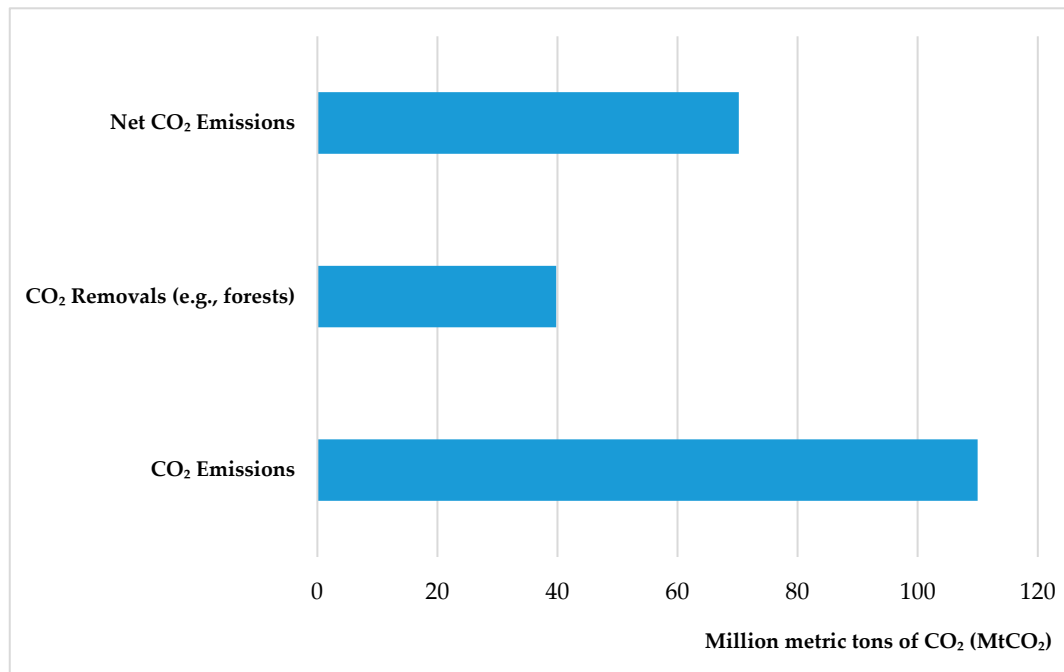


Figure 2. Average annual net CO₂ emissions, CO₂ removals, and CO₂ emissions in Sarawak (2001–2023). Source: Adapted from Global Forest Watch [7].

The challenge of Sarawak's hydrogen economy is not just about reducing carbon emissions but also addressing wider energy security issues. In a world where global fossil fuel supplies are falling, and Malaysia's reserves are projected to run out in the coming decades at its current rate of demand [8], it is becoming increasingly evident that there is a need for energy diversification and for sustainable energy sources like hydrogen. However, despite progress on the supply side, including hydrogen production, refuelling facilities, and storage technologies, the long-term success of the hydrogen economy will also depend on the development of sufficient demand. This will be important for the long-term success of Sarawak's hydrogen economy. Ensuring stable and sustained demand is important to ensure the commercial viability and scalability of hydrogen solutions. Unless there is sufficient uptake across various industries including transportation, industrial, residential and commercial, hydrogen investments are at risk of being underutilized and hence not economically sustainable. Understanding the public's perceptions and their willingness to adopt hydrogen technologies is crucial because societal acceptance will be a significant driver of demand [4]. At the national level, Malaysia has pledged to achieve net zero emissions by 2050 [9]. In line with this ambitious goal, the government launched the HETR, which outlines a phased strategy for hydrogen development. As shown in Figure 3, the roadmap illustrates key milestones from 2005 to 2030, beginning with research and pilot projects, followed by infrastructure expansion, and ultimately progressing towards cost reductions and large-scale deployment by 2030 [3]. These national developments form the broader policy framework within which this study is situated, highlighting the importance

of incorporating youth perspectives into policies that strengthen demand and ensure that hydrogen adoption is both technologically feasible and socially accepted.

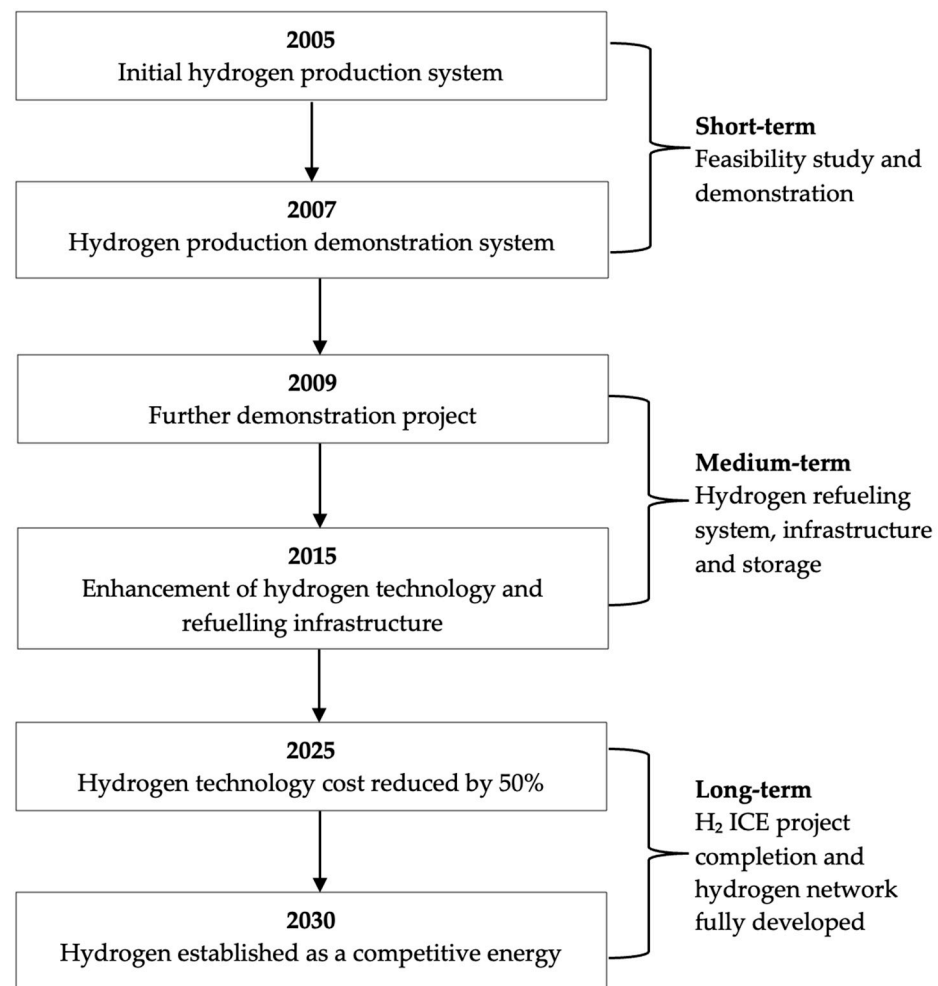


Figure 3. Malaysia hydrogen energy development roadmap (2005–2030). Source: Adapted from Ambrose et al. [10].

Sarawak, the largest state in Malaysia, has emerged as a frontrunner in the development of hydrogen in the country. Taking advantage of its abundance of renewable hydropower resources, Sarawak has been one of the leaders in the development and use of hydrogen. As part of the initiatives under the PCDS 2030, hydrogen has been discovered as a new growth area in the energy sector. This focuses on the diversification of the energy sector through renewable energy and the green economy agenda. This is complemented by SHER 2025, which identifies the strategies to produce, develop infrastructure, certify, and engage in export partnerships, including the setting up of Southeast Asia's first hydrogen refueling station in Kuching, hydrogen-powered buses, as well as engagement with international partners such as Japan and South Korea [4]. Figure 4 reveals the proposed action plan under SHER 2025 divided into three phases: 2025–2030, 2031–2035 and 2036 onwards. In the first phase, Sarawak aims to establish hydrogen hubs in Bintulu and Kuching, find industry clusters for hydrogen use, engage in international offtake partnerships and set up a certification platform for exports. Enabling measures include setting up a Clean Hydrogen Working Committee under the Sarawak Economic Council (SEC), rolling out domestic incentives, developing infrastructure and targeted skilling programs. In 2031–2035, the plan expands with the rollout of hydrogen hubs, securing the first international offtake, establishing certification standards, and strengthening governance. The phase emphasizes

scaling up industrial applications through innovation partnerships, infrastructure consolidation, and workforce readiness. From 2036 onwards, Sarawak will focus on downstream applications, ensuring sustained offtake agreements, and continuing to review certification standards. The long-term vision is to anchor Sarawak as a competitive hydrogen exporter, backed by ongoing research, domestic integration, and the development of a skilled workforce.

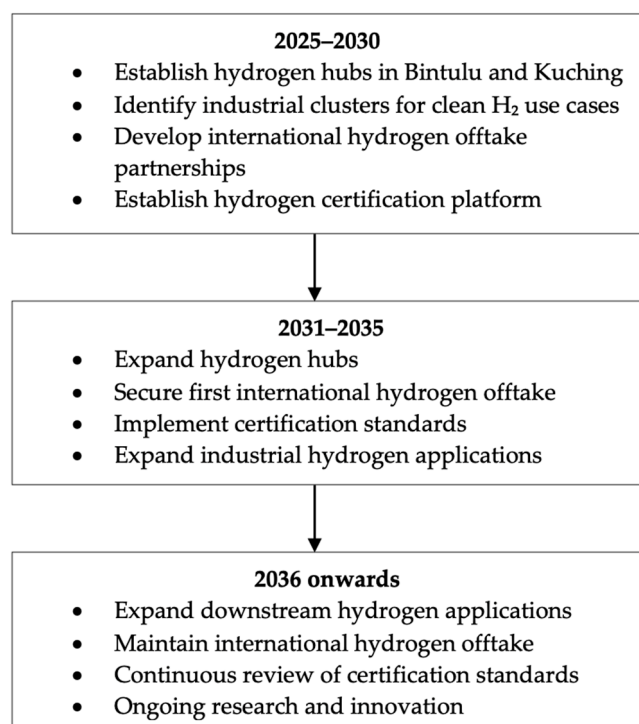


Figure 4. Simplified implementation phases of the Sarawak Hydrogen Economy Roadmap (SHER) 2025. Source: Adapted from the Sarawak Hydrogen Economy Roadmap (SHER) [4].

The efforts are in line with the Sustainable Development Goals (SDGs) of the United Nations, particularly SDG 7: Affordable and Clean Energy and SDG 13: Climate Action. These call for more uptake of renewable and low-carbon energy systems [11]. As of 2023, Malaysia's energy mix was still heavily reliant on fossil fuels. Natural gas and coal accounted for more than 80% of electricity generation [12]. While Sarawak's hydropower capacity has allowed it to outpace the rest of the country in terms of renewable generation, hydrogen is seen as a new frontier to expand its exports, increase energy security and lower greenhouse gas emissions [3,5]. Despite these policy developments, several challenges remain. Hydrogen adoption continues to face infrastructural constraints, affordability concerns, and low public awareness, particularly among youths [13,14]. These challenges suggest that although the state may be technologically prepared, the behavioural aspect of hydrogen energy adoption remains insufficiently understood, particularly regarding the factors associated with public acceptance and behavioural intention [13,15]. In addition, most previous studies have applied the Theory of Planned Behaviour (TPB) without considering the integration of moral and normative factors that may also be associated with sustainable energy behaviours [16–18].

These limitations reveal a research gap in the current literature regarding the relationships between rational and moral factors and youths' behavioural intention towards hydrogen energy adoption in Sarawak. Furthermore, empirical evidence focusing on youths remains limited, despite their important role as future users, decision-makers, and key stakeholders in Sarawak's hydrogen economy. Accordingly, the primary aim of this

study is to examine the relationships between perceived behavioural control (PBC), social norms (SN), attitudes (ATTI), personal norms (PN), and youths' behavioural intention (BI) towards hydrogen energy adoption in Kuching, Sarawak.

To achieve this aim, the study addresses two central research questions: (1) What are the relationships between PBC, SN, ATTI, PN, and youths' BI towards hydrogen energy adoption in Kuching? and (2) What policy recommendations can be developed to support hydrogen energy adoption in Kuching, Sarawak, based on the study findings regarding youths' BI towards hydrogen energy adoption? The study has three main objectives: (1) to examine the predictive relationships between PBC, SN, ATTI, PN, and youths' BI towards hydrogen energy adoption; (2) to identify the construct that exhibited the largest standardized path coefficient in relation to BI; and (3) to provide theoretical and practical insights relevant to hydrogen energy policy in Kuching, Sarawak, with particular emphasis on youths as key stakeholders.

The remainder of this paper is organised as follows. Section 2 reviews the relevant literature and presents the theoretical framework and research hypotheses. Section 3 describes the research methodology, including the data collection procedures, sampling approach, questionnaire development, and data analysis. Section 4 presents the empirical findings, while Section 5 discusses the findings, presents the policy recommendations, and outlines the study limitations and directions for future research. Finally, Section 6 concludes the study by summarising the key findings and contributions.

2. Literature Review and Theoretical Framework

2.1. Theory of Planned Behaviour

One of the most widely used models in behavioural science is the TPB, proposed by Ajzen [16]. It posits that intention is the proximal determinant of behaviour and is shaped by ATTI towards the behaviour, SN and PBC. ATTI are the individual's evaluation of the behaviour as favourable or unfavourable. SN captures perceived social pressure to engage in the behaviour, and PBC reflects the ease or difficulty of performing the behaviour (i.e., considering both internal abilities and external resources). These three constructs have been widely used to explain pro-environmental and energy-related behaviours in previous studies. Figure 5 illustrates the relationships proposed by the TPB.

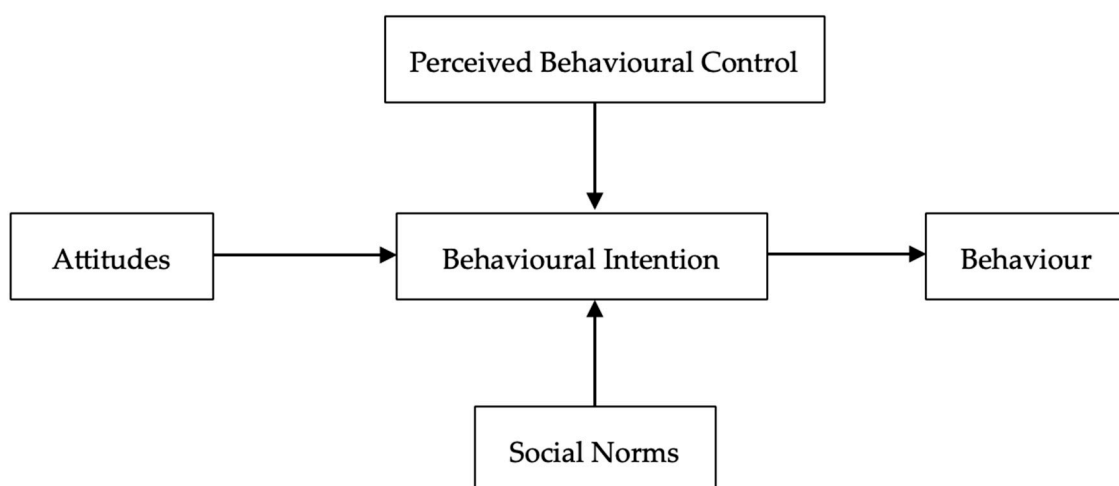


Figure 5. Simplified Theory of Planned Behaviour (TPB) model illustrating the relationships among attitudes (ATTI), social norms (SN), perceived behavioural control (PBC), behavioural intention (BI), and behaviour. Source: Adapted from Ajzen [16].

2.2. Norm Activation Model

Although the TPB has been widely applied to explain BI, it has been criticised for its limited ability to explain behaviours that are strongly associated with moral and normative considerations. Pro-environmental behaviours often involve ethical responsibility and concern for societal welfare that extend beyond rational cost–benefit evaluations. To address this limitation, Schwartz [17] proposed the Norm Activation Model (NAM), which explains pro-social and pro-environmental behaviour through three interrelated constructs: Awareness of Consequences (AC), Ascription of Responsibility (AR), and Personal Norms (PN). AC refers to an individual's recognition of the environmental and social consequences of failing to act responsibly, whereas AR reflects the extent to which an individual accepts personal responsibility for those consequences. Together, AC and AR activate PN, which represents an individual's internalised moral obligation to perform environmentally responsible behaviour [18,19].

2.3. Extended Theory of Planned Behaviour

Building upon the TPB, the Extended Theory of Planned Behaviour (ETPB) incorporates moral considerations into the original TPB framework to provide a more comprehensive understanding of pro-environmental BI. Among the constructs derived from the NAM, PN has received considerable attention because it represents an individual's internalised moral obligation to engage in environmentally responsible behaviour. Empirical studies have shown that incorporating PN into the TPB framework enhances the understanding of BI by considering both rational and moral aspects of decision-making [20,21]. Consequently, incorporating PN into the TPB framework provides an additional moral perspective while retaining the rational constructs proposed by Ajzen [16].

The original NAM proposes that AC and AR activate PN, which is subsequently associated with behaviour [17]. While the present study acknowledges this theoretical structure, it adopts PN as the representative moral construct because the primary objective is to examine youths' BI towards hydrogen energy adoption rather than to test the complete activation mechanism proposed by the NAM. Unlike studies that operationalise the complete NAM mediation structure by modelling AC and AR as antecedents of PN, the present study adopts a theoretically parsimonious approach by focusing on PN as the moral construct incorporated into the TPB framework. This approach is consistent with the study objective and enables the examination of both rational and moral considerations within a conceptually focused and empirically manageable framework. Within the original NAM, PN represents the construct most directly associated with behaviour, whereas AC and AR function as its antecedent constructs [18,19].

Previous studies have shown that incorporating PN alongside ATTI, SN, and PBC enhances the understanding of sustainable behaviours, including green product consumption, recycling, renewable energy adoption, and environmentally responsible consumption [20–23]. These findings suggest that environmentally responsible decisions are associated with rational evaluations, perceived social expectations, and individuals' moral obligations towards environmental sustainability.

Hydrogen energy adoption represents not only a technological decision but also an environmentally responsible choice that contributes to climate change mitigation and sustainable development. Therefore, incorporating PN into the TPB framework provides a theoretical foundation for examining the predictive relationships between rational evaluations, moral obligations, and youths' BI towards hydrogen energy adoption in Kuching, Sarawak.

Accordingly, this study proposes that PBC, SN, ATTI, and PN have significant positive predictive relationships with youths' BI towards hydrogen energy adoption. The conceptual framework developed for this study is presented in Figure 6.

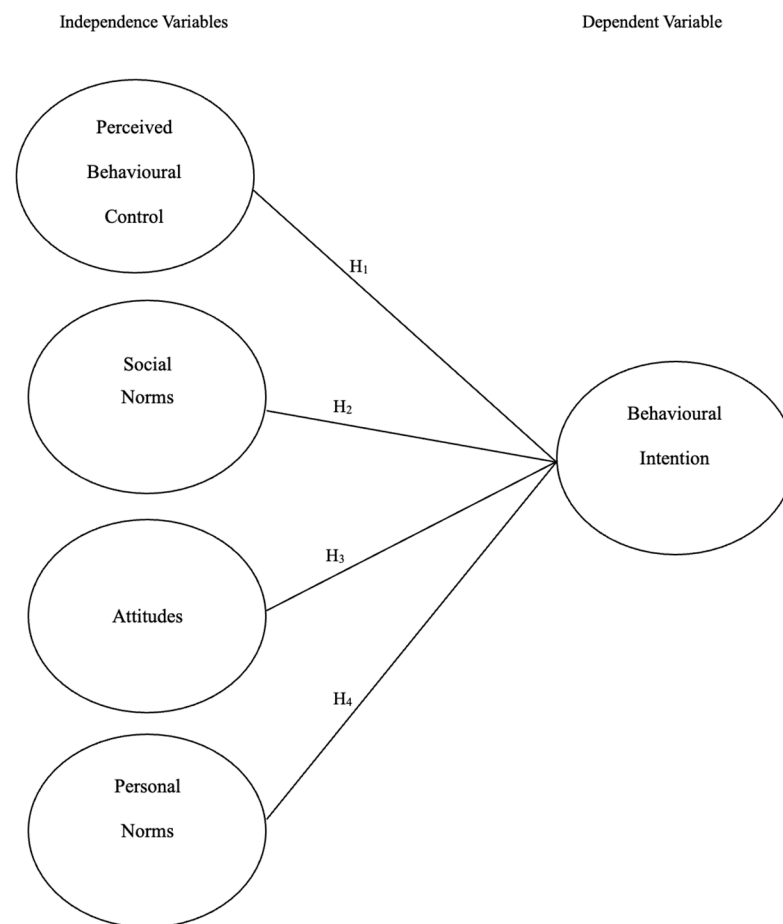


Figure 6. Conceptual Framework. Source: Created by the authors based on the theoretical framework developed for this study.

Hypothesis 1 (H₁). *Perceived behavioural control has a significant positive predictive relationship with youths' behavioural intention towards hydrogen energy adoption.*

Hypothesis 2 (H₂). *Social norms have a significant positive predictive relationship with youths' behavioural intention towards hydrogen energy adoption.*

Hypothesis 3 (H₃). *Attitudes have a significant positive predictive relationship with youths' behavioural intention towards hydrogen energy adoption.*

Hypothesis 4 (H₄). *Personal norms have a significant positive predictive relationship with youths' behavioural intention towards hydrogen energy adoption.*

3. Materials and Methods

3.1. Data Collection

Data were collected using a structured questionnaire comprising primarily closed-ended questions with predetermined response options. The questionnaire was prepared in both English and Bahasa Melayu.

Data were collected between 13 September and 17 December 2025 through a cross-sectional survey using a convenience sampling approach. Eligible respondents were youths aged 18 to 30 years residing in Kuching, Sarawak, who voluntarily agreed to participate in the study. The questionnaire was administered in both paper-based and online formats to improve accessibility and participation.

For the paper-based survey, potential respondents were approached at several accessible locations within Kuching, including Universiti Malaysia Sarawak (UNIMAS), Taman Sahabat (Friendship Park), the Tabuan area (Kuching South), the Petra Jaya area (Kuching North), and cafés in the Saradise commercial area. These locations were selected to facilitate access to eligible respondents from different areas of Kuching. Individuals who met the eligibility criteria and agreed to participate were provided with a printed questionnaire and were requested to complete it on the spot before returning it to the researcher.

For the online survey, potential respondents were contacted individually via WhatsApp, Instagram, and church youth groups. The survey link was distributed only to individuals who agreed to participate and was not publicly posted or shared on any social media platform. The online questionnaire was configured using the “Limit to 1 response” setting to restrict each participant to a single submission, and respondents were instructed to complete the questionnaire only once. Following data collection, all questionnaires were screened for duplicate responses and completeness. No duplicate responses were identified, and any incomplete paper-based questionnaires were excluded from the final dataset. After data screening, a total of 345 valid questionnaires were retained for subsequent statistical analysis.

Figure 7 illustrates the overall research workflow adopted in this study. The study began with identifying the research problem and developing the theoretical framework, followed by questionnaire development, pilot testing, data collection, and data analysis using Partial Least Squares Structural Equation Modelling (PLS-SEM). The final stage involved interpreting the findings to address the research objectives and develop policy recommendations.

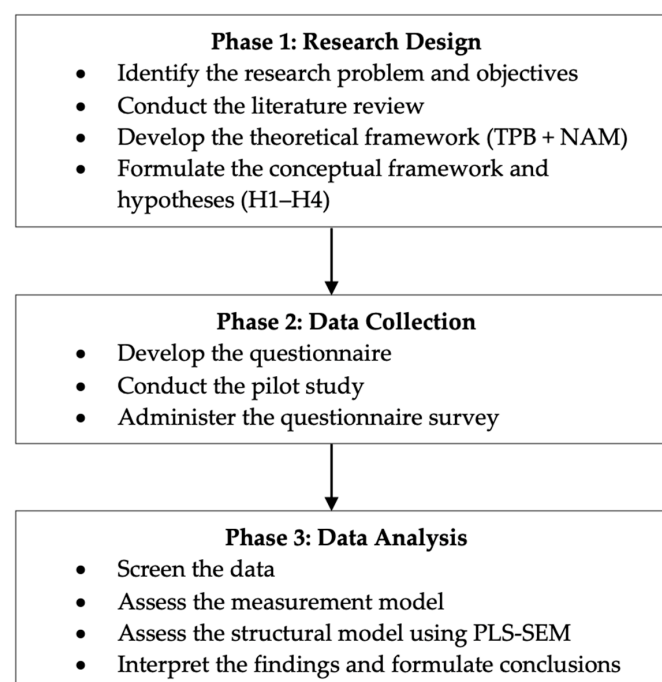


Figure 7. Research workflow of the study. Source: Developed by the authors.

3.2. Sample Size

This study employed convenience sampling, a non-probability sampling technique where participants are selected based on their availability, accessibility, and willingness to participate. Convenience sampling is widely used in exploratory studies where the primary aim is to identify trends rather than to generalize findings to a larger population [24]. Convenience sampling was considered appropriate for this study for several practical and methodological reasons. Convenience sampling allowed for efficient data collection within the project's timeline and budget [25]. Secondly, the study adopts an exploratory approach to assess the factors associated with youths' perceptions and behavioural intention towards hydrogen energy adoption. In such research, convenience sampling aligns with the objective of obtaining quick, preliminary insights from the target population without the need for full statistical generalizability [26].

To further assess the adequacy of the sample size, an a priori statistical power analysis was conducted using G*Power version 3.1.9.7. The analysis was performed using a linear multiple regression (fixed model) with R^2 deviation from zero. Following Cohen's [27] recommendations, a medium effect size ($f^2 = 0.15$), a significance level (α) of 0.05, a statistical power of 0.80, and four variables (PBC, SN, ATTI, and PN) were specified, resulting in a minimum required sample size of 85 respondents. Although G*Power is based on linear multiple regression rather than a PLS-SEM-specific sample size determination procedure, it provides an appropriate a priori assessment of statistical power. In addition, contemporary PLS-SEM guidelines recommend evaluating sample adequacy by considering statistical power, model complexity, and the prediction-oriented nature of the structural model rather than relying solely on a single heuristic [28]. The final sample of 345 respondents substantially exceeded the minimum sample size estimated by G*Power and was therefore considered adequate for estimating the proposed PLS-SEM model and testing the hypothesised relationships.

This study employed a quantitative, cross-sectional design to investigate youths' perceptions and BI. Data were collected using a structured questionnaire administered in both English and Bahasa Melayu. The target population was youths aged 18 to 30 living in Kuching. A total of 345 valid responses were obtained through convenience sampling. Although the sample was obtained using a non-probability sampling method, the final sample of 345 respondents substantially exceeded the minimum sample size identified through the a priori power analysis and was considered adequate for estimating the proposed PLS-SEM model based on contemporary PLS-SEM guidelines [28]. PLS-SEM was invented by Wold [29] and modified by Lohmoller [30] for the analysis of survey data. The PLS-SEM algorithm is based on an iterative sequence of ordinary least squares regressions used to estimate latent variable scores and path relationships. At convergence, the weight vectors fulfil fixed point equations. The PLS-SEM technique enables researchers to simultaneously estimate relationships among multiple latent constructs, indicator variables, and structural paths. The study makes no assumptions about the distribution of the data [31].

PLS-SEM's primary advantage is that it permits researchers to evaluate complex models with numerous constructs, indicator variables, and structural paths without imposing distributional assumptions on the data. As a prediction-oriented approach to structural equation modelling, PLS-SEM enables researchers to estimate relationships among latent constructs and assess the predictive capability of the proposed model [29,31]. This capability provides useful insights for developing practical and managerial implications [32]. User-friendly software packages such as PLS-Graph and SmartPLS are widely available for conducting PLS-SEM analyses. Additionally, advanced statistical computing environments such as R can also be used to perform PLS-SEM (e.g., *semPLS*) [28,33].

The questionnaire consisted of two sections. The first section captured demographic information, including age, gender, ethnic group, highest academic qualification, household income, and household size. The second section measured the constructs of the extended Theory of Planned Behaviour (ETPB). ATTI, SN, and PBC were measured using items adapted from Ajzen [16]. PN was adapted from Schwartz and Bamberg and Möser [17,34], while BI was adapted from Paul et al. [23]. All items were measured using a five-point Likert scale ranging from strongly disagree to strongly agree. The variables and measurement scales used in the questionnaire are presented in Table 1.

Table 1. Variables and Types of Scale Used in the Questionnaire.

Section A: Demographic Background	Nominal Scale
Section B: Behavioural Intention (BI)	
Section C: Perceived Behavioural Control (PBC)	
Section D: Social Norms (SN)	Likert Scale
Section E: Attitudes (ATTI)	
Section F: Personal Norms (PN)	

Source: Developed by the authors based on the standard Likert scale structure [35].

A pilot test was conducted with thirty respondents to assess clarity and reliability. All Cronbach's alpha values exceeded 0.70, showing reliability. The main analysis was conducted using SmartPLS version 4.1.1.8. Measurement model assessment involved examining indicator reliability, internal consistency reliability, convergent validity, and discriminant validity using Fornell–Larcker and HTMT criteria. The structural model assessment examined path coefficients, significance levels, explained variance (R^2), and effect sizes (f^2). Bootstrapping with five thousand resamples was performed to test the significance of the hypothesized relationships.

4. Results

Table 2 presents the respondents' demographic background. The majority of the respondents were female (59.42%), while 40.58% were male. The respondents were aged between 18 and 30 years, with the largest age group being 21–23 years (74.78%, $n = 258$). In terms of ethnicity, the largest proportion of respondents were Chinese (24.35%, $n = 84$), followed by Bidayuh (22.32%, $n = 77$), Malay (17.39%, $n = 60$), and Iban (16.52%, $n = 57$). The highest educational qualification attained by the respondents was predominantly STPM/Matriculation (51.60%, $n = 178$), followed by a Bachelor's degree (36.81%, $n = 127$). In terms of monthly household income, the largest proportion of respondents reported household incomes of less than RM1500 (31.30%, $n = 108$), followed by RM1500–RM2500 (22.61%, $n = 78$). Most respondents belonged to households comprising four to five members (49.28%, $n = 170$), followed by households with six or more members (33.91%, $n = 117$), whereas only 4.06% ($n = 14$) belonged to single-person households.

Figure 8 presents the PLS-SEM structural model and the predictive relationships between PBC, SN, ATTI, PN, and BI.]

The structural model is represented by arrows connecting the latent constructs, with standardized path coefficients (β) indicating the strength of the predictive relationships between the exogenous constructs and BI. All four exogenous constructs demonstrated positive and statistically significant predictive relationships with BI. Among them, PN exhibited the largest standardized path coefficient ($\beta = 0.246$), closely followed by ATTI ($\beta = 0.245$), SN ($\beta = 0.224$), and PBC ($\beta = 0.166$). Furthermore, the coefficient of determination ($R^2 = 0.538$) indicates that the model explains 53.8% of the variance in BI. According to Chin [36], an R^2 value above 0.50 is considered moderate in behavioural research, suggesting that the proposed model has satisfactory explanatory power for predicting youths' behavioural intention to adopt hydrogen energy.

Table 2. Respondents' Demographic Background.

No.	Category (N = 345)	<i>n</i>	%	No.	Category (N = 345)	<i>n</i>	%
1	Age			4	Highest Academic Qualifications		
	18–20	27	7.83		STPM or Matriculation	178	51.60
	21–23	258	74.78		Diploma or Equivalent	35	10.14
	24–26	52	15.07		Bachelor’s Degree	127	36.81
	27–30	8	2.32		Master’s Degree & PhD	5	1.45
	Total	345	100.00		Total	345	100.00
2	Gender			5	Household Income		
	Male	140	40.58		Less than RM1500	108	31.30
	Female	205	59.42		RM1500–RM2500	78	22.61
	Total	345	100.00		RM2501–RM3500	49	14.20
3	Ethnic Group				RM3501–RM5000	37	10.72
	Bidayuh	77	22.32		RM5001–RM7500	32	9.28
	Iban	57	16.52		RM7500 and above	41	11.89
	Chinese	84	24.35		Total	345	100.00
	Melanau	25	7.25		Household Size		
	Malay	60	17.39		1 person	14	4.06
	Orang Ulu (Kayan/Kenyah)	8	2.32	2–3 people	44	12.75	
	Other	34	9.86	4–5 people	170	49.28	
	Total	345	100.00	6 or more people	117	33.91	
				Total	345	100.00	

Note: Bold text indicates the category headings within the table.

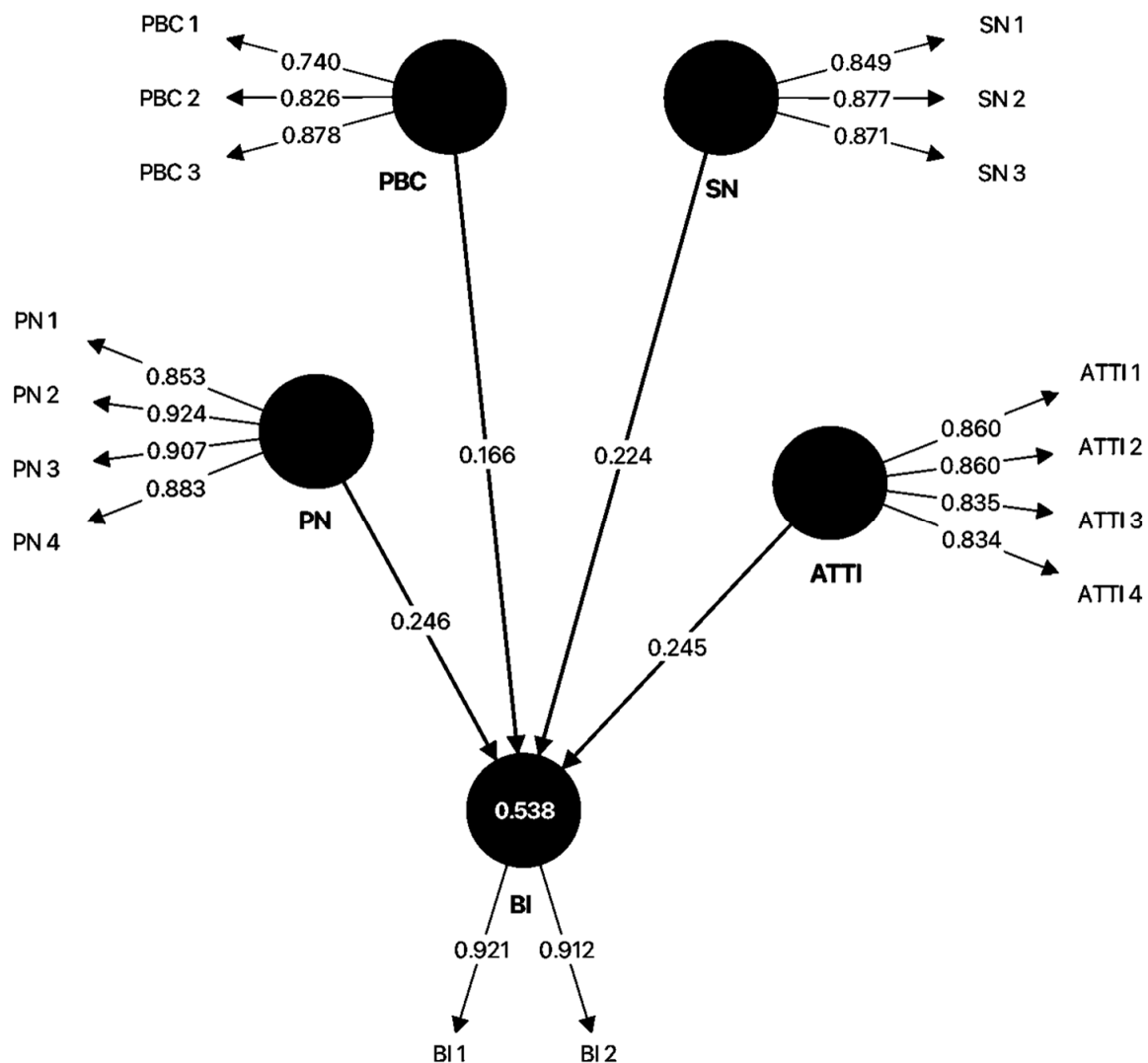


Figure 8. Measurement and Structural Model of the Proposed Research Framework. Arrows indicate the hypothesised predictive relationships between the constructs. Source: SmartPLS version 4.1.1.8.

4.1. Discriminant Validity of the Measurement Constructs

Discriminant validity ensures that each latent construct in a structural model is truly distinct from others, confirming that constructs measure various conceptual dimensions [37]. In this study, discriminant validity was assessed using two complementary methods: the Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT). These techniques are widely accepted in PLS-SEM and jointly provide a thorough assessment of construct distinctiveness.

4.2. Discriminant Validity Based on the Fornell–Larcker Criterion

The Fornell–Larcker criterion compares the square root of the Average Variance Extracted (AVE) of each construct with the correlations between constructs. For discriminant validity to be established, the square root of the AVE (diagonal values) should be greater than the corresponding inter-construct correlations (off-diagonal values) [38]. As shown in Table 3, the diagonal values exceed the corresponding off-diagonal values for all constructs, indicating that each construct shares more variance with its own indicators than with other constructs. This confirms that discriminant validity has been established based on the Fornell–Larcker criterion.

Table 3. Assessment of Discriminant Validity Using the Fornell–Larcker Criterion.

	ATTI	BI	PBC	PN	SN
ATTI	0.847				
BI	0.669	0.917			
PBC	0.587	0.564	0.817		
PN	0.730	0.603	0.483	0.892	
SN	0.659	0.593	0.603	0.436	0.866

Note: Bold values represent the square roots of the Average Variance Extracted (AVE) for each construct. Source: SmartPLS version 4.1.1.8.

In Table 3, the diagonal elements (shown in bold) represent the square roots of the AVE for each construct. These values indicate the extent to which each construct explains the variance of its respective indicators. For example, the square root of the AVE for BI is 0.917, which exceeds its correlations with ATTI (0.669), PBC (0.564), PN (0.603), and SN (0.593). Similarly, the square root of the AVE for PN is 0.892, which is greater than its correlations with ATTI (0.730), BI (0.603), PBC (0.483), and SN (0.436). The same criterion is satisfied for ATTI, PBC, and SN, whereby the square root of the AVE for each construct exceeds its corresponding inter-construct correlations. These results demonstrate that each construct is empirically distinct from the other constructs in the model. Therefore, the Fornell–Larcker criterion confirms that discriminant validity has been satisfactorily established.

4.3. Discriminant Validity Based on the HTMT Criterion

The Heterotrait–Monotrait ratio (HTMT) is a rigorous criterion for assessing discriminant validity and is considered more sensitive than the Fornell–Larcker criterion in detecting a lack of discriminant validity between latent constructs [39]. According to Henseler et al. [39], HTMT values below 0.85 indicate satisfactory discriminant validity. As presented in Table 4, all HTMT values are below the recommended threshold, ranging from 0.489 to 0.818, indicating that the latent constructs are empirically distinct.

Table 4. Assessment of Discriminant Validity Using the HTMT Criterion.

	ATTI	BI	PBC	PN	SN
ATTI					
BI	0.794				
PBC	0.707	0.713			
PN	0.818	0.698	0.565		
SN	0.765	0.717	0.761	0.489	

Source: SmartPLS version 4.1.1.8.

Specifically, the highest HTMT value was observed between ATTI and PN (0.818), while the lowest value was observed between PN and SN (0.489). Since all HTMT values are below the conservative threshold of 0.85, discriminant validity is considered satisfactory for all constructs. Furthermore, the cross-loading analysis confirmed that each indicator loaded highest on its respective construct (see Appendix A), providing additional evidence of discriminant validity.

The HTMT results are consistent with those obtained using the Fornell–Larcker criterion, demonstrating that ATTI, BI, PBC, PN, and SN are empirically distinct constructs. The combined use of the Fornell–Larcker criterion and HTMT is consistent with current best

practices in PLS-SEM and provides robust evidence supporting the discriminant validity of the measurement model [37,39].

4.4. Reliability and Convergent Validity of the Study Constructs

Table 5 presents the results of the assessment of indicator reliability, internal consistency reliability, and convergent validity for the study constructs. The outer loadings of all retained indicators exceeded the recommended threshold of 0.70 [37], ranging from 0.740 to 0.924, indicating that all retained indicators reliably represented their respective latent constructs.

Table 5. Reliability and Validity of the Study Constructs.

Variable	Item	Outer Loading	Composite Reliability	AVE	Cronbach's Alpha
Behavioural Intention	BI_1	0.921	0.913	0.840	0.810
	BI_2	0.912			
Perceived Behavioural Control	PBC_1	0.740	0.857	0.667	0.751
	PBC_2	0.826			
	PBC_3	0.878			
Social Norms	SN_1	0.849	0.900	0.749	0.833
	SN_2	0.877			
	SN_3	0.871			
Attitude	ATTI_1	0.860	0.911	0.718	0.869
	ATTI_2	0.860			
	ATTI_3	0.835			
	ATTI_4	0.834			
Personal Norms	PN_1	0.853	0.940	0.796	0.914
	PN_2	0.924			
	PN_3	0.907			
	PN_4	0.883			

Source: SmartPLS version 4.1.1.8.

Convergent validity was established, as all constructs achieved average variance extracted (AVE) values above the recommended threshold of 0.50, ranging from 0.667 (PBC) to 0.840 (BI). Furthermore, Composite Reliability (CR) values ranged from 0.857 to 0.940, while Cronbach's alpha (α) values ranged from 0.751 to 0.914, exceeding the recommended threshold of 0.70. These findings demonstrate satisfactory internal consistency reliability and convergent validity for all constructs.

Overall, the measurement model demonstrated satisfactory reliability and validity, supporting its suitability for subsequent structural model assessment.

4.5. Predictive Relationships of PBC, SN, ATTI, and PN with BI

This section presents the results of the PLS-SEM structural model analysis examining the predictive relationships between PBC, SN, ATTI, PN, and BI. The hypotheses were evaluated based on the standardized path coefficients (β), significance levels (p -values), effect sizes (f^2), and the explanatory power of the model (R^2). The results are presented in Table 6, followed by a discussion of each hypothesised relationship.

Table 6. Predictive Relationships of PBC, SN, ATTI, and PN with BI.

Hypothesis	Path	Standardized Beta (β)	<i>t</i> -Value	<i>p</i> -Value	Effect Size (f^2)	Result	R^2
H ₁	PBC → BI	0.166	2.711	0.007	0.034	Supported	0.538
H ₂	SN → BI	0.224	3.898	<0.001	0.053	Supported	
H ₃	ATTI → BI	0.245	3.569	<0.001	0.041	Supported	
H ₄	PN → BI	0.246	4.522	<0.001	0.060	Supported	

Source: SmartPLS version 4.1.1.8.

All hypothesised relationships were statistically significant and supported.

Table 6 presents the results of the hypothesis testing. The Path column represents the hypothesised relationships between the latent constructs, while the standardized beta coefficient (β) indicates the strength and direction of each hypothesised relationship. The *t*-value and *p*-value were used to assess the statistical significance of each hypothesised relationship, whereas the effect size (f^2) reflects the relative contribution of each construct to the explained variance in BI. The Result column indicates whether each hypothesis was supported, while the coefficient of determination (R^2) represents the proportion of variance in BI explained by the structural model. Based on Cohen's [27] guidelines, the effect sizes (f^2) for PBC (0.034), SN (0.053), ATTI (0.041), and PN (0.060) are all classified as small, indicating that each construct contributed a small effect to the explained variance in BI. Furthermore, the structural model explained 53.8% of the variance in BI ($R^2 = 0.538$), indicating moderate explanatory power according to Chin [36].

Hypothesis 1 (H₁). *Perceived Behavioural Control has a significant positive predictive relationship with youths' Behavioural Intention towards hydrogen energy adoption.*

PBC demonstrated a significant positive predictive relationship with BI ($\beta = 0.166$, $p = 0.007$), supporting H₁. The findings suggest that greater perceived control over adopting hydrogen energy is positively associated with BI. However, the small effect size ($f^2 = 0.034$) indicates that PBC contributed a small effect to explaining BI. This finding is consistent with prior research suggesting that the adoption of new energy technologies is associated with external factors such as cost, infrastructure availability, and access to technology [14,40].

Hypothesis 2 (H₂). *Social Norms have a significant positive predictive relationship with youths' Behavioural Intention towards hydrogen energy adoption.*

Supporting H₂, SN demonstrated a significant positive predictive relationship with BI ($\beta = 0.224$, $p < 0.001$). The effect size was small ($f^2 = 0.053$). The findings suggest that perceived social norms from family, friends, and society are positively associated with individuals' BI towards hydrogen energy adoption. This finding is consistent with previous studies highlighting the role of perceived social acceptance in behavioural intention, particularly in the context of emerging technologies [16].

Hypothesis 3 (H₃). *Attitudes have a significant positive predictive relationship with youths' Behavioural Intention towards hydrogen energy adoption.*

ATTI demonstrated a significant positive predictive relationship with BI ($\beta = 0.245$, $p < 0.001$), supporting H₃. The findings suggest that favourable perceptions of hydrogen energy, including its environmental benefits and sustainability potential, are positively associated with BI towards hydrogen energy adoption. However, the small effect size

($f^2 = 0.041$) indicates that ATTI contributed a small effect to explaining BI. This finding is consistent with prior research showing that favourable attitudes are associated with BI towards the adoption of environmentally sustainable technologies [16,40].

Hypothesis 4 (H₄). *Personal Norms have a significant positive predictive relationship with youths' Behavioural Intention towards hydrogen energy adoption.*

Among the constructs examined, PN exhibited the largest standardized path coefficient with BI ($\beta = 0.246$, $p < 0.001$, $f^2 = 0.060$), supporting H₄. This suggests that an individual's moral obligation and sense of responsibility towards environmental protection are positively associated with BI towards hydrogen energy adoption. Although the effect size ($f^2 = 0.060$) is considered small based on Cohen's [27] guidelines, it was the largest among the constructs examined, indicating that PN made the greatest relative contribution to the explained variance in BI. This finding is consistent with prior research highlighting ethical and moral considerations as key factors associated with pro-environmental behaviour [22].

Overall, all hypothesised relationships were statistically significant, with PN exhibiting the largest standardized path coefficient, followed by ATTI, SN, and PBC.

5. Discussion

The findings of this study indicate that all four hypothesised constructs (PBC, SN, ATTI, and PN) exhibited significant predictive relationships with BI towards hydrogen energy adoption among the sampled youths in Kuching, Sarawak. Among the constructs examined, PN exhibited the largest standardized path coefficient, suggesting the potential value of incorporating a moral construct beyond the original TPB variables. This finding may reflect the context of hydrogen energy adoption in Kuching, Sarawak, where hydrogen technology is still at an early stage of development and public awareness remains relatively limited. Under these circumstances, the respondents may have relied more on their moral responsibility towards environmental sustainability than on direct experience or practical considerations when forming their BI. This finding is consistent with the critical review by Scovell [41], which highlighted that PN has received relatively limited attention in hydrogen technology acceptance research but may play an important role in public acceptance of hydrogen technologies. Similar findings were reported by Al Mamun et al. [42], who concluded that Malaysian youths' values and PN are positively associated with pro-environmental behaviour and energy conservation practices in addressing climate-related challenges. These findings further support the importance of moral responsibility in relation to environmentally responsible BI. Likewise, Si et al. [43] found that PN was positively associated with energy-saving intentions among young people in China. Their findings further support the potential importance of PN in promoting environmentally responsible behaviour among youths, which is consistent with the findings of the present study.

In addition to PN, the TPB constructs (ATTI, SN, and PBC) also exhibited significant positive predictive relationships with BI, indicating that behavioural intention towards hydrogen energy adoption is associated with both moral and rational considerations. The relatively strong predictive relationship of SN suggests that youths' behavioural intention towards hydrogen energy adoption is associated not only with their personal evaluations but also with the perceived expectations and support of important social groups, such as family members, peers, and educators. This finding highlights the importance of social influence in relation to youths' behavioural intention towards hydrogen energy adoption, particularly during the early stages of technology adoption when direct experience with hydrogen energy remains limited. The positive predictive relationships observed for ATTI, SN, and PBC are consistent with TPB, which proposes that favourable evaluations of a

behaviour, perceived social expectations, and individuals' perceived capability to perform the behaviour are associated with BI. Scovell [41] further suggested that integrating TPB with complementary theoretical perspectives, including moral and affective constructs, may provide a more comprehensive explanation of public acceptance of hydrogen technologies.

Despite the positive predictive relationships of ATTI, SN, and PBC, practical barriers such as limited hydrogen infrastructure, affordability concerns, and restricted public exposure may continue to constrain BI towards hydrogen energy adoption. This observation is consistent with the systematic review by Steller et al. [44], which identified factors such as infrastructure availability, financial considerations, public trust, and public knowledge as important factors associated with hydrogen technology acceptance. Although Sarawak has made substantial progress through initiatives such as the PCDS 2030 and the SHER, hydrogen technology is still at an early stage of implementation. Consequently, improving accessibility, expanding hydrogen infrastructure, and strengthening public engagement remain essential to translate favourable BI into actual hydrogen energy adoption.

From a practical perspective, efforts to promote hydrogen energy adoption should extend beyond investments in infrastructure and financial incentives by strengthening environmental responsibility, moral responsibility, and personal commitment among youths. Educational programmes, university outreach initiatives, community engagement activities, and sustainability campaigns that emphasise the environmental benefits of hydrogen energy could complement technological and policy initiatives, thereby contributing to greater public acceptance and supporting Sarawak's long-term hydrogen energy transition.

5.1. Policy Recommendations

The findings of this study provide several practical implications for policymakers, industry stakeholders, and educational institutions seeking to promote hydrogen energy adoption among youths in Kuching, Sarawak. Policy initiatives may extend beyond investments in hydrogen infrastructure and financial incentives by fostering a stronger sense of environmental responsibility and moral commitment among young people. Educational institutions can integrate hydrogen energy, climate change, and sustainable energy topics into academic curricula, while public awareness campaigns and community engagement programmes should emphasise the environmental and societal benefits of hydrogen energy. Such initiatives may strengthen environmental responsibility and encourage greater public acceptance of hydrogen technologies, consistent with previous studies highlighting the importance of PN and environmental values in promoting sustainable behaviour [42,43].

The significant association between SN and BI suggests that collaborative efforts involving government agencies, educational institutions, industry partners, local communities, and social media platforms could further encourage hydrogen energy adoption. Youth ambassadors, community leaders, educators, and social influencers may play an important role in promoting positive perceptions of hydrogen energy by increasing public engagement and normalising sustainable energy practices among younger generations. These collaborative efforts may strengthen social support for hydrogen energy adoption and contribute to wider public acceptance.

The significant association between ATTI and BI indicates that increasing public knowledge regarding the environmental, economic, and long-term benefits of hydrogen energy remains important. Public education programmes, exhibitions, demonstration projects, and university–industry collaborations could improve public understanding of hydrogen technologies while addressing misconceptions regarding their safety, practicality, and environmental impact. Improving public awareness may contribute to more favourable attitudes towards hydrogen energy adoption.

Although PBC demonstrated the smallest effect size among the constructs examined, it remained significantly associated with BI. This suggests that efforts to improve accessibility and reduce practical barriers remain essential. Continued investments in hydrogen infrastructure, refuelling facilities, financial incentives, and supportive government policies may help address perceived barriers to hydrogen technology adoption and support the transition from positive intention towards actual adoption. Addressing these structural barriers may also help reduce the well-documented value–action gap, where favourable intentions do not always translate into sustainable behaviour because of contextual and external constraints [45].

While the findings provide useful insights into the behavioural intention to adopt hydrogen energy among the sampled youths in Kuching, these policy recommendations should be interpreted in light of the study’s sampling characteristics. As the respondents primarily comprised urban and university-educated youths recruited through convenience sampling, caution should be exercised when extending these recommendations to the broader youth population in Sarawak. Future studies employing probability sampling and involving more diverse demographic groups, particularly rural and non-student youths, are needed to provide stronger empirical evidence for statewide policy formulation.

5.2. Limitations and Future Research

Despite its strengths, this study has several limitations. First, convenience sampling was employed, resulting in a sample that primarily comprised urban and university-educated youths. Consequently, the findings may not fully represent the broader youth population in Sarawak, particularly rural youths, non-students, and individuals from different socioeconomic, educational, and ethnic backgrounds. Although convenience sampling is practical and cost-effective, it may introduce sampling bias and reduce the representativeness of the study population [24]. Therefore, the findings should be interpreted within the context of the sampled population, and caution should be exercised when generalising the results to all youths in Sarawak.

Second, the study employed a cross-sectional research design in which data were collected at a single point in time. Accordingly, the findings should be interpreted as reflecting statistical associations rather than causal relationships. Furthermore, the temporal ordering of the study variables cannot be established, and reverse causality remains a plausible alternative explanation. In addition, the possibility of endogeneity arising from omitted variables or reciprocal relationships cannot be completely ruled out. For example, although the proposed theoretical framework assumes that PN precedes BI, the cross-sectional design does not allow the temporal ordering of these constructs to be established. Consequently, it is also plausible that stronger BI may reinforce individuals’ personal moral obligations towards hydrogen energy adoption. Moreover, hydrogen development projects and public awareness in Sarawak are continuously evolving, and youths’ perceptions and BI may therefore change over time. This observation is consistent with Scovell [41], who suggested that public beliefs, attitudes, and acceptance of hydrogen technologies are likely to evolve as familiarity with hydrogen technologies increases over time. Therefore, longitudinal research would provide valuable insights into how BI changes as hydrogen technologies become more widely implemented.

Third, this study focused primarily on the psychological constructs included in the proposed research framework and did not examine broader external factors such as government trust, media portrayal, economic incentives, and policy support. These factors may also play an important role in shaping hydrogen energy adoption.

Future studies are encouraged to employ probability sampling methods to improve sample representativeness and recruit a more diverse range of respondents, including

rural youths and non-students. Furthermore, future studies are encouraged to extend the proposed research framework by incorporating additional variables such as perceived risk, environmental knowledge, institutional trust, and media exposure to provide a more comprehensive understanding of hydrogen energy adoption behaviour. Qualitative approaches, including interviews and focus group discussions, may also provide deeper insights into the experiences and contextual factors that cannot be fully captured using quantitative methods. Finally, comparative studies involving different Malaysian states or comparisons between Malaysia and countries with more established hydrogen economies would further enrich the literature and provide valuable policy benchmarks for future hydrogen energy development initiatives.

6. Conclusions

This study examined the relationships between PBC, SN, ATTI, PN, and youths' BI towards hydrogen energy adoption in Kuching, Sarawak by extending the TPB to incorporate PN as an additional moral construct. The findings provide empirical evidence that all four hypothesised constructs were significantly associated with youths' BI, with PN exhibiting the largest standardized path coefficient, followed by ATTI, SN, and PBC. Accordingly, all four research hypotheses (H_1 – H_4) were supported.

The results indicate that both rational considerations, represented by the TPB constructs, and moral considerations, represented by PN, are positively associated with youths' BI towards hydrogen energy adoption. These findings suggest that incorporating PN into the TPB may provide additional insights into youths' BI towards hydrogen energy adoption and contribute to the growing body of literature on sustainable energy adoption, particularly in developing regions.

The findings also have important practical implications. Promoting hydrogen energy adoption should extend beyond investments in infrastructure, financial incentives, and technological advancement to include initiatives that strengthen environmental responsibility, moral responsibility, and public engagement among youths. At the same time, improving hydrogen infrastructure, increasing public awareness, and fostering supportive social environments remain important for encouraging wider public acceptance of hydrogen energy in Kuching, Sarawak.

Overall, this study contributes to a better understanding of the psychological factors associated with hydrogen energy adoption among youths in Kuching, Sarawak, and provides a foundation for future research and policy development. As hydrogen technologies continue to evolve, understanding public acceptance will remain essential for supporting a socially inclusive, sustainable, and successful hydrogen energy transition.

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Abbreviations

The following abbreviations are used in this manuscript:

AC	Awareness of Consequences
AR	Ascription of Responsibility
ATTI	Attitudes
AVE	Average Variance Extracted
BI	Behavioural Intention
ETPB	Extended Theory of Planned Behaviour
HETR	Hydrogen Economy and Technology Roadmap
NAM	Norm Activation Model
NETR	National Energy Transition Roadmap
PBC	Perceived Behavioural Control
PCDS	Post COVID-19 Development Strategy
PLS—SEM	Partial Least Squares Structural Equation Modeling
PN	Personal Norms
SDG	Sustainable Development Goal
SHER	Sarawak Hydrogen Economy Roadmap
SN	Social Norms
TPB	Theory of Planned Behaviour
UNIMAS	Universiti Malaysia Sarawak
α	Cronbach's Alpha

Appendix A. Cross Loading

Indicator	ATTI	BI	PBC	PN	SN
ATTI 1	0.860	0.636	0.576	0.595	0.635
ATTI 2	0.860	0.550	0.506	0.656	0.529
ATTI 3	0.835	0.530	0.425	0.543	0.495
ATTI 4	0.834	0.542	0.468	0.683	0.563
BI 1	0.621	0.921	0.544	0.551	0.569
BI 2	0.606	0.912	0.488	0.554	0.517
PBC 1	0.358	0.380	0.740	0.211	0.481
PBC 2	0.479	0.446	0.826	0.453	0.435
PBC 3	0.574	0.538	0.878	0.484	0.557
PN 1	0.597	0.465	0.417	0.853	0.283
PN 2	0.673	0.554	0.437	0.924	0.358
PN 3	0.663	0.566	0.417	0.907	0.465
PN 4	0.665	0.556	0.454	0.883	0.433
SN 1	0.497	0.477	0.504	0.303	0.849

Indicator	ATTI	BI	PBC	PN	SN
SN 2	0.558	0.496	0.543	0.377	0.877
SN 3	0.646	0.559	0.519	0.442	0.871

Source: SmartPLS version 4.1.1.8. Note: The highest loading for each indicator is shown in bold, indicating that each indicator loads most strongly on its intended construct.

Appendix B. Questionnaire

Constructs/Factors	Items	Description	Measurement Items	Sources
Demographic Background	A 1–6	Collects respondents' demographic and background information	Age, Gender, Ethnic Group, Highest Academic Qualification, Household Income, Household Size.	
Behavioural Intention (BI)	BI 1 BI 2	Measures youths' intention to adopt or support hydrogen energy	I plan to use hydrogen energy resources rather than conventional energy for my car in the future. I intend to switch the source of my electricity supply from conventional energy to hydrogen energy.	[23,46]
Perceived Behavioural Control (PBC)	PBC 1 PBC 2 PBC 3	Measures perceived capability and control over adopting hydrogen energy	I have a sufficient level of understanding to make use of hydrogen energy. It is within my power to decide whether or not to use hydrogen as a source of energy. I am confident enough in myself to make the decision to adopt hydrogen energy.	[23,47,48]
Social Norms (SN)	SN 1 SN 2 SN 3	Measures perceived social influence regarding hydrogen energy adoption	Most of the people I care about would like to use hydrogen energy for their home's power. I believe that my neighbours in my neighbourhood would support using hydrogen energy to power their vehicles. Individuals whose opinions I value would prefer and support the usage of hydrogen energy to power their vehicles.	[23,46,47]

Constructs/Factors	Items	Description	Measurement Items	Sources
Attitudes (ATTI)	ATTI 1	Measures positive or negative evaluation of hydrogen energy adoption	I believe making use of hydrogen energy technology is beneficial.	[13,46,48]
	ATTI 2		Hydrogen energy technology is worth taking advantage of if it becomes available.	
	ATTI 3		I think hydrogen energy products are as good as conventional products in terms of quality.	
	ATTI 4		Hydrogen energy technology should be widely used.	
Personal Norms (PN)	PN 1	Measures moral obligation and personal responsibility towards environmentally responsible hydrogen energy adoption	It is important to me that the hydrogen-based products I use do not harm the environment.	[23,49,50]
	PN 2		I feel obligated to protect the local environment by adopting hydrogen energy solutions.	
	PN 3		I feel responsible for addressing local environmental concerns by advocating the usage of hydrogen energy.	
	PN 4		I believe that hydrogen energy should be utilised in a way that actively contributes to the environmental protection movement.	

Note: All measurement items were adapted from the cited studies and modified to suit the hydrogen energy context.

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