Rooftop Solar Photovoltaic (PV) Adoption for Malaysian Residential Housing: A Critical Evaluation of the Feasibility of Achieving Zero Carbon Emissions by 2028

Dr. Kumar Raj Kelvin

NTI International University, Malaysia

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ABSTRACT:

Malaysia has committed to achieving carbon neutrality by 2050, with the National Energy Transition Roadmap (NETR) setting an ambitious interim target of net-zero emissions for the residential sector. A cornerstone of this strategy is the widespread adoption of rooftop Solar Photovoltaic (PV) systems among Malaysian households, with some policy narratives suggesting a trajectory towards full residential decarbonization as early as 2028. However, the feasibility of this target remains critically unexamined against the backdrop of real-world economic, technical, and behavioral constraints. This quantitative research proposal aims to critically evaluate the factors influencing household adoption of rooftop solar PV in Malaysia and assess the viability of achieving zero carbon emissions from the residential sector by 2028. Grounded in the Technology Acceptance Model (TAM), Diffusion of Innovations (DOI) Theory, and Institutional Theory, the study investigates the influence of Government Policy Incentives, Economic Viability (Cost-Benefit), Technical Infrastructure Readiness, and Household Environmental Awareness on Adoption Intention, with Adoption Behavior as the ultimate dependent variable representing progress towards the 2028 carbon目标. A cross-sectional survey design will target homeowners across major urban and suburban regions in Peninsular Malaysia (Klang Valley, Penang, Johor Bahru), with a target sample of 400 respondents using stratified random sampling. Data will be analyzed using Partial Least Squares Structural Equation Modelling (PLS-SEM). The expected findings aim to provide a realistic, data-driven assessment of the 2028 target, offering policymakers evidence-based recommendations for accelerating genuine, mass-market adoption, or recalibrating targets to align with on-the-ground realities.

Keywords: Rooftop Solar PV, Residential Adoption, Zero Carbon, Net-Zero Homes, Energy Transition, Malaysia, NETR, TAM

Chapter 1: Introduction

1.1 Background of the Study

Global climate change imperatives have catalyzed a fundamental transformation of national energy systems, moving away from fossil fuel dependence towards renewable and sustainable sources (United Nations, 2015; IPCC, 2022). Malaysia, as a signatory to the Paris Agreement,

has committed to reducing its greenhouse gas (GHG) emissions intensity and achieving carbon neutrality by 2050 (Ministry of Economy, 2023). Central to this national commitment is the **National Energy Transition Roadmap (NETR)** , a comprehensive strategy launched to reshape Malaysia's energy landscape across power generation, industrial processes, and transportation.

A significant and highly visible component of the NETR is the decarbonization of the residential sector. Buildings, including residential homes, account for a substantial portion of national electricity consumption, primarily derived from fossil fuels (natural gas and coal). Consequently, the government has identified the widespread deployment of **rooftop Solar Photovoltaic (PV) systems** as a key mechanism for reducing the residential carbon footprint (SEDA Malaysia, 2024). Programs such as the Net Energy Metering (NEM) scheme and various solar incentive initiatives aim to encourage homeowners to become "prosumers"—both consumers and producers of clean energy.

The vision is compelling: millions of Malaysian homes adorned with solar panels, generating clean energy, reducing household electricity bills, and collectively contributing to a zero-carbon residential future. Some policy discussions and optimistic projections have floated the idea of achieving significant milestones, or even effective carbon neutrality for new residential developments, by a date as ambitious as **2028** (Ministry of Natural Resources, Environment and Climate Change, 2025).

However, this vision confronts a complex reality. Despite over a decade of government incentives, the adoption rate of rooftop solar PV among Malaysian households remains low, concentrated primarily in higher-income brackets and specific urban areas (Muhammad-Sukki et al., 2022). The vast majority of Malaysian homeowners have yet to install solar panels. This gap between ambitious national policy targets and on-the-ground adoption rates constitutes a critical policy and research problem.

This study, therefore, seeks to conduct a rigorous, academic investigation into the feasibility of using rooftop solar panels on Malaysian houses to achieve zero carbon content by 2028. It moves beyond policy rhetoric to empirically examine the multifaceted barriers and drivers that will determine whether this ambitious target is a realistic, achievable goal, or an aspirational timeline disconnected from the lived realities of Malaysian households and the technical capacity of the national grid.

1.2 Problem Statement

The Malaysian government's ambition to decarbonize the residential sector through rooftop solar PV by a target as early as 2028 is predicated on a series of assumptions that require urgent and critical examination. The problem is not the desirability of the goal, but the potential gap between policy ambition and implementation feasibility. This research identifies four interconnected problems:

First, **the underestimation of economic barriers**. While the cost of solar PV panels has declined globally, the upfront capital investment required for installation remains prohibitive for the majority of Malaysian middle- and lower-income households (Solangi et al., 2021). The effectiveness of current financing mechanisms, feed-in tariffs, and the Net Energy Metering (NEM) scheme in overcoming this barrier for mass-market adoption has not been rigorously evaluated. The payback period, perceived financial risk, and access to affordable credit are critical, underexplored variables.

Second, **technical infrastructure readiness and grid capacity**. The intermittent nature of solar power generation presents significant challenges to grid stability. A massive, rapid increase in distributed residential solar generation would require substantial upgrades to the national grid infrastructure managed by Tenaga Nasional Berhad (TNB), including smart grid technologies, advanced inverters, and potentially, large-scale battery storage solutions to manage the duck curve (Ahmad et al., 2023). The readiness and

cost of this infrastructure upgrade are significant unknowns.

Third, **household awareness, acceptance, and behavioral intention**. Adoption of new technology is not purely an economic decision; it is mediated by awareness, trust, social influence, and perceived complexity (Davis, 1989). Many Malaysian homeowners lack adequate information about solar technology, installation processes, maintenance requirements, and the actual long-term benefits. Cultural factors, aesthetic concerns, and mistrust of new technology can act as significant barriers, independent of economic calculations (Kardooni et al., 2018).

Fourth, **a disconnect between policy formulation and household reality**. Current policies may be designed based on technical and economic models that do not adequately capture the diversity of household circumstances, housing types (e.g., terrace houses vs. bungalows, strata vs. landed property), and ownership structures. A one-size-fits-all policy mandate is unlikely to succeed in a diverse housing market.

Therefore, this study seeks to answer the central question: **Do Government Policy Incentives, Economic Viability, Technical Infrastructure Readiness, and Household Environmental Awareness significantly influence the Intention to Adopt Rooftop Solar PV among Malaysian households, and consequently, the feasibility of achieving zero residential carbon emissions by 2028?**

1.3 Research Objectives

This study is guided by the following research objectives:

RO1: To examine the influence of Government Policy Incentives on Intention to Adopt Rooftop Solar PV among Malaysian households.
RO2: To examine the influence of Economic Viability (Cost-Benefit) on Intention to Adopt Rooftop Solar PV.
RO3: To examine the influence of Technical Infrastructure Readiness on Intention to Adopt Rooftop Solar PV.
RO4: To examine the influence of Household Environmental Awareness on Intention to Adopt Rooftop Solar PV.
RO5: To examine the influence of Intention to Adopt on Actual Adoption Behavior.
RO6: To assess the overall feasibility of achieving near-zero residential carbon emissions from rooftop solar PV in Malaysia by 2028, based on the adoption model.

1.4 Research Questions

Based on the research objectives, this study addresses the following research questions:

RQ1: Do Government Policy Incentives significantly influence Intention to Adopt Rooftop Solar PV among Malaysian households?
RQ2: Does Economic Viability (Cost-Benefit) significantly influence Intention to Adopt Rooftop Solar PV?
RQ3: Does Technical Infrastructure Readiness significantly influence Intention to Adopt Rooftop Solar PV?
RQ4: Does Household Environmental Awareness significantly influence Intention to Adopt Rooftop Solar PV?
RQ5: Does Intention to Adopt significantly influence Actual Adoption Behavior?
RQ6: Based on the identified influences, what is the realistic feasibility of achieving the 2028 zero-carbon residential target through rooftop solar PV?

1.5 Significance of the Study

This study offers significant contributions to theory, practice, and policy.

Theoretical Significance: This research integrates the Technology Acceptance Model (TAM) with Diffusion of Innovations (DOI) theory and Institutional Theory to create a comprehensive framework for understanding renewable energy adoption in a developing ASEAN context. It extends existing technology adoption models by incorporating macro-level

factors (Policy Incentives, Technical Infrastructure) alongside individual-level factors (Awareness, Perceived Viability).

Practical Significance: For industry players—solar PV installers, financiers, and developers—the findings will provide crucial market intelligence. Understanding the key drivers and barriers for different household segments will enable the design of more effective marketing strategies, financing products, and bundled offerings (e.g., solar-ready homes).

Policy Significance: For policymakers at the Ministry of Energy, SEDA, TNB, and the Economic Planning Unit, this study provides an evidence-based, critical evaluation of a key national policy target. The findings will either validate the current trajectory or, more likely, provide a data-driven rationale for recalibrating the 2028 target, reallocating incentives, strengthening grid infrastructure, and launching public awareness campaigns designed to accelerate genuine, mass-market adoption. It answers the question: "Is 2028 realistic, and if not, what will it take?"

1.6 Scope and Limitations

Scope: This study focuses on residential homeowners in major urban and suburban population centers in Peninsular Malaysia, specifically the Klang Valley, Penang, and Johor Bahru. These regions represent the highest concentration of potential adopters and have the most developed infrastructure. The target population includes both landed property owners (terrace, semi-detached, bungalow) and, where feasible, owners of stratified properties with individual roofs (e.g., townhouses).

Limitations: This study acknowledges several limitations. First, the cross-sectional design captures intentions and perceptions at a single point in time, whereas adoption is a longitudinal process. Second, the focus on Peninsular Malaysia limits generalizability to East Malaysia (Sabah and Sarawak), which has different grid systems and policy contexts. Third, reliance on self-reported data may introduce response bias. Future research could incorporate actual adoption data from SEDA and TNB to validate findings.

Chapter 2: Literature Review

2.1 Theoretical Foundation

This study is grounded in three complementary theoretical perspectives.

2.1.1 Technology Acceptance Model (TAM)

Developed by Davis (1989), TAM is one of the most widely used models for explaining and predicting user acceptance of new technology. It posits that two primary beliefs determine the intention to use a technology:

- **Perceived Usefulness (PU):** The degree to which a person believes that using the technology would enhance their performance (e.g., reduce electricity bills).
- **Perceived Ease of Use (PEOU):** The degree to which a person believes that using the technology would be free of effort (e.g., easy installation, simple maintenance).

This study applies TAM to frame household perceptions of solar PV. PU is captured through Economic Viability (cost savings, payback period). PEOU is captured through perceptions of Technical Infrastructure Readiness (grid connection ease) and the complexity of the adoption process.

2.1.2 Diffusion of Innovations (DOI) Theory

Rogers (1995) DOI theory explains how, why, and at what rate new ideas and technology spread through cultures. Key factors influencing adoption include:

- **Relative Advantage:** Is the innovation better than what it replaces? (Economic Viability).
- **Compatibility:** Does it fit with existing values and practices? (Household lifestyle, housing type).

- **Complexity:** Is it difficult to understand and use? (Technical ease).
- **Trialability:** Can it be experimented with? (Pilot projects, neighbor's experience).
- **Observability:** Are the results visible to others? (Visible panels on roofs).

DOI theory informs the inclusion of social and awareness factors, as well as the role of early adopters in influencing the wider population.

2.1.3 Institutional Theory

Institutional theory (DiMaggio and Powell, 1983) explains how external pressures shape organizational and individual behavior. In this context, it frames the role of:

- **Coercive Pressures:** Government regulations, building codes, and mandatory solar requirements for new developments.
- **Normative Pressures:** Social expectations, community norms, and the influence of environmental NGOs.
- **Mimetic Pressures:** Imitation of neighbors, celebrities, or successful peers who have adopted solar.

This theory directly supports the inclusion of Government Policy Incentives as a key independent variable.

2.2 Solar PV Technology and Residential Adoption

Solar Photovoltaic (PV) technology converts sunlight directly into electricity. For residential applications, rooftop systems are typically grid-connected, allowing households to draw power from the grid when solar generation is insufficient and export excess power back to the grid (Muhammad-Sukki et al., 2022). Global adoption has accelerated dramatically, driven by falling panel costs and supportive policies (IEA, 2024).

In Malaysia, adoption has lagged behind regional peers like Thailand and Vietnam despite high solar irradiance (Solangi et al., 2021). Studies have identified high upfront costs, lack of awareness, and perceived technical complexity as primary barriers (Kardooni et al., 2018). This study builds on this literature by quantifying these barriers within a comprehensive, theory-driven model focused on a specific, ambitious policy target.

2.3 Government Policy and Regulatory Framework

Malaysia's key policy mechanisms for promoting residential solar PV include:

- **Net Energy Metering (NEM):** Allows households to export excess solar-generated electricity to the grid and offset their consumption, effectively "selling" power at a avoided cost rate (SEDA, 2024).
- **Solar for Rakyat Incentive Scheme:** Provides rebates or financing assistance for low-to-middle-income households.
- **Green Income Tax Exemption (GITE):** Offers tax relief for the cost of purchasing and installing solar PV systems.
- **NETR Targets:** Explicit goals for increasing renewable energy capacity, including distributed solar.

While these policies exist, their effectiveness in driving mass-market adoption remains debated. This study hypothesizes that perceived policy effectiveness (H1) positively influences adoption intention.

2.4 Economic Viability and Cost-Benefit Analysis

For most households, the decision to install solar PV is fundamentally an investment decision. Key economic factors include:

- **Upfront Capital Cost:** The total cost of panels, inverters, installation, and any necessary electrical upgrades.
- **Payback Period:** The time taken for electricity bill savings to recoup the initial investment. Currently estimated at 5-8 years for Malaysian households, depending on consumption and NEM terms.
- **Financing Availability:** Access to affordable, Shariah-compliant, low-interest loans specifically for solar installation.

- **Long-term Savings:** Total savings over the 25-30 year lifespan of the panels.
- **Property Value Impact:** The potential for solar panels to increase property resale value.

This study hypothesizes that positive perceptions of Economic Viability (H2) significantly influence adoption intention.

2.5 Technical Infrastructure and Grid Capacity

The technical feasibility of mass adoption depends heavily on grid infrastructure. Key considerations include:

- **Grid Stability:** Managing the variability of solar generation to prevent voltage fluctuations and grid instability. This requires smart inverters and potentially, curtailment mechanisms (Ahmad et al., 2023).
- **Grid Capacity:** The ability of local distribution networks to accept significant reverse power flow from multiple residential solar systems without requiring costly upgrades.
- **Connection Process:** The ease, speed, and cost of obtaining grid connection approval from TNB.
- **Battery Storage:** The role of home battery systems in storing excess daytime generation for nighttime use, enhancing self-consumption and grid independence.

This study hypothesizes that perceived Technical Infrastructure Readiness (H3) significantly influences adoption intention, as concerns about grid stability and complex connections act as a barrier.

2.6 Household Environmental Awareness and Behavioral Intention

Beyond economics and technology, individual attitudes and awareness matter. Key factors include:

- **Environmental Consciousness:** Concern about climate change and a personal desire to contribute to environmental solutions.
- **Knowledge and Awareness:** Understanding of how solar works, its benefits, and the application process (Kardooni et al., 2018).
- **Social Influence:** The impact of neighbors, family, and community norms on adoption decisions (Rogers, 1995).
- **Trust:** Trust in government promises, installer quality, and technology reliability.

This study hypothesizes that Household Environmental Awareness (H4) positively influences adoption intention. Finally, consistent with TAM, Intention to Adopt is hypothesized to be the primary predictor of Actual Adoption Behavior (H5).

2.7 Conceptual Framework

Based on the theoretical foundations and literature review, Figure 1 presents the conceptual framework for this study.

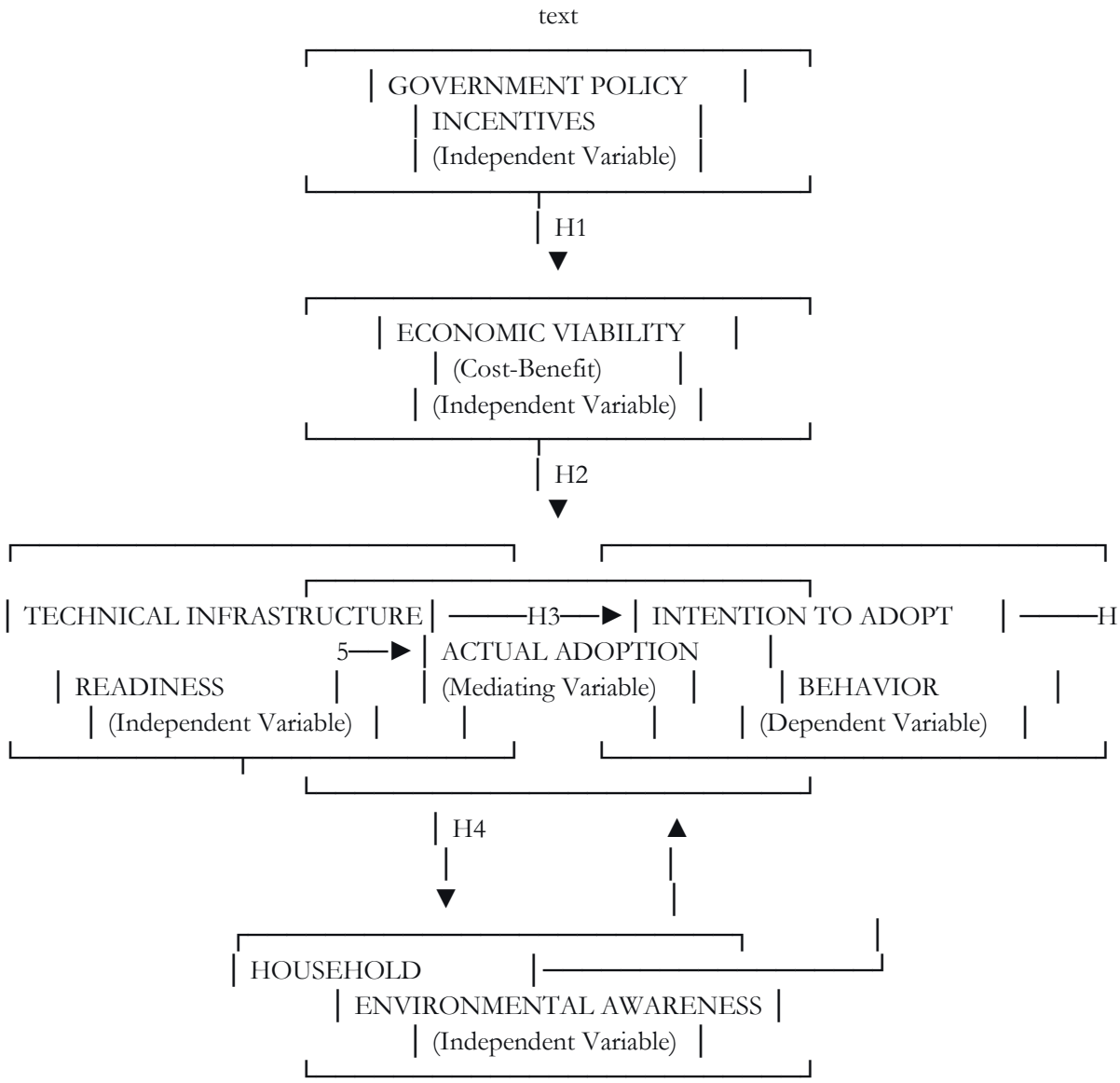

Figure 1: Conceptual Framework

2.8 Hypotheses Development

Based on the research objectives and conceptual framework, the following hypotheses are formulated:

H1: Government Policy Incentives have a significant positive influence on Intention to Adopt Rooftop Solar PV among Malaysian households.
H2: Perceived Economic Viability (Cost-Benefit) has a significant positive influence on Intention to Adopt Rooftop Solar PV.
H3: Perceived Technical Infrastructure Readiness has a significant positive influence on Intention to Adopt Rooftop Solar PV.
H4: Household Environmental Awareness has a significant positive influence on Intention to Adopt Rooftop Solar PV.
H5: Intention to Adopt has a significant positive influence on Actual Adoption Behavior.

Chapter 3: Research Methodology

3.1 Research Design

This study adopts a quantitative, cross-sectional survey design. A quantitative approach is necessary to statistically test the hypothesized relationships and provide the empirical rigor

required to influence high-level policy debate (Hair et al., 2019). The cross-sectional design is appropriate for capturing household perceptions and intentions at a single point in time.

3.2 Population and Sample

The target population consists of residential homeowners in major urban centers of Peninsular Malaysia: **Klang Valley (Kuala Lumpur/Selangor), Penang, and Johor Bahru.** These regions represent the highest concentration of potential solar adopters.

The sampling frame includes households that:

- Own landed property (terrace, semi-detached, bungalow) or stratified property with individual roof access.
- Are connected to the TNB national grid.

Following Hair et al. (2019) guidelines for PLS-SEM, a minimum sample of 200 is required for the proposed model complexity. To account for non-response and enhance generalizability, this study targets a sample of **400 respondents**.

3.3 Sampling Technique

Stratified Random Sampling will be employed. The population will be stratified by:

- **Region:** Klang Valley, Penang, Johor Bahru.
- **Household Income:** B40 (low), M40 (middle), T20 (high).
- **Housing Type:** Terrace, Semi-D, Bungalow.

Within each stratum, households will be randomly selected from publicly available property databases or sampled via door-to-door in selected residential neighborhoods.

3.4 Data Collection Methods

Data will be collected using a **self-administered structured questionnaire**. Two modes will be offered:

1. **Online:** Via Google Forms/Qualtrics, distributed through resident association WhatsApp groups and social media.
2. **Paper-based:** For households without internet access or preferring physical forms, distributed via door-to-door visits in selected neighborhoods.

Data collection will occur over an **8-week period**.

3.5 Instrumentation and Measurement

All constructs will be measured using multi-item scales adapted from prior validated research, measured on a **7-point Likert scale** (1 = Strongly Disagree to 7 = Strongly Agree). The questionnaire will be bilingual (English and Bahasa Malaysia) to ensure clarity.

- **Government Policy Incentives (5 items):** Adapted from policy acceptance literature, measuring awareness and perceived effectiveness of NEM, rebates, and tax incentives.
- **Economic Viability (6 items):** Adapted from technology adoption and investment literature, measuring perceptions of upfront cost, payback period, long-term savings, and financing access.
- **Technical Infrastructure Readiness (5 items):** Adapted from energy infrastructure studies, measuring perceived ease of grid connection, trust in TNB's grid capacity, and concerns about reliability.
- **Household Environmental Awareness (4 items):** Adapted from environmental psychology literature, measuring concern for climate change, personal environmental responsibility, and awareness of solar's environmental benefits.
- **Intention to Adopt (3 items):** Adapted from TAM literature, measuring likelihood of considering, planning, and intending to install solar in the next 2 years.
- **Actual Adoption Behavior (Single item + verification):** "Have you installed a rooftop solar PV system?" (Yes/No). For "Yes"

respondents, optional verification (e.g., photo) may be requested for validation.

3.6 Data Analysis Procedures

Data will be analyzed using **SPSS Version 29** for preliminary analysis (descriptive statistics, data screening) and **SmartPLS 4** for main analysis.

- **Measurement Model Assessment:** Reliability (Cronbach's alpha, Composite Reliability > 0.70), Convergent Validity (AVE > 0.50), and Discriminant Validity (HTMT criteria) will be assessed.
- **Structural Model Assessment:** Path coefficients (β), significance (p-values), and coefficient of determination (R^2) will be evaluated using bootstrapping (5,000 resamples).

3.7 Reliability and Validity

Stringent procedures will ensure robustness. **Content validity** is ensured through expert review of adapted scales. **Construct validity** is statistically tested in PLS-SEM. **Common method bias** will be assessed using Harman's single-factor test. The bilingual questionnaire will be back-translated to ensure accuracy.

3.8 Ethical Considerations

Full ethical approval will be sought from the INTI International University Research Ethics Committee. All participation is voluntary and anonymous. Informed consent will be obtained. For door-to-door data collection, enumerators will carry official university identification.

Chapter 4: Conclusion

4.1 Summary of Proposed Study

This research proposal has outlined a quantitative study designed to critically evaluate the feasibility of achieving zero residential carbon emissions in Malaysia through rooftop solar PV adoption by 2028. By integrating TAM, DOI theory, and Institutional Theory, the proposed framework systematically examines the key drivers and barriers—policy, economic, technical, and behavioral—that will determine the actual adoption rate among Malaysian households. The study targets 400 homeowners across major urban centers, using a rigorous stratified random sampling approach and PLS-SEM analysis to generate robust, generalizable findings.

4.2 Expected Contributions

This study is expected to make a significant and timely contribution to Malaysia's energy transition discourse.

- **Theoretically**, it will extend the application of TAM and DOI to the critical context of residential renewable energy adoption in a developing ASEAN economy, providing a validated framework for future research.
- **Practically**, it will provide solar industry players with a nuanced understanding of market segments, enabling targeted marketing and product development.
- **Critically, for Policymakers**, this paper will provide an evidence-based reality check on the ambitious 2028 target. The findings will illuminate whether current policies are sufficient, where the critical bottlenecks lie (e.g., affordability, grid capacity, awareness), and what specific interventions are required to accelerate adoption. It may conclude that while solar PV is a vital part of the future, a 2028 target for zero-carbon homes is unrealistic without transformative changes in policy, financing, and infrastructure. It will argue for a more pragmatic, phased approach grounded in the empirical reality of household behavior and national technical capacity.

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