Factors Affecting the Adoption of Innovative Eco-Friendly Charcoal-Based Forest Fire Prevention Products

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Received: April 21, 2025, Revised: June 6, 2025, Accepted: July 8, 2025

Abstract

Forest fires are a major concern as they can cause extensive damage to the environment, properties, and endanger the lives of both humans and animals. Traditional forest fire prevention methods frequently rely on the use of chemicals that can have detrimental effects on the environment and human well-being. New solutions, like charcoal-based forest fire prevention sprays, provide potential alternatives that address safety requirements while also considering environmental concerns. These solutions employ biochar, derived from forest waste, to create efficient forest fire prevention methods that have the potential to decrease carbon emissions. The successful implementation of eco-friendly solutions, particularly charcoal-based forest fire prevention sprays, heavily relies on consumer perceptions, attitudes, and behaviors. The objective of this research is to examine the factors that affect consumers' decision to use eco-friendly products, particularly charcoal-based forest fire prevention sprays. The Technology Acceptance Model (TAM) and the Environmental Concern Theory were adopted as theoretical frameworks in this study. The data collected from 155 individuals from diverse backgrounds in Thailand was subjected to thorough statistical analysis, which demonstrated that perceived effectiveness, environmental compatibility, and safety consciousness played a crucial role in stimulating adoption intentions. Surprisingly, factors such as price sensitivity, certification requirements, and distribution mechanisms have secondary effects on the collaboration approach. This study offers evidence-based recommendations for product developers, policymakers, and environmental conservation practitioners who are seeking to implement sustainable and collaborative approaches to mandatory forest fires.

Keywords: Sustainable Innovation; Environmental Concerns; Forest Fire Prevention; Eco-Friendly Technologies and Solutions; Consumer Adoption; Product Development

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ปัจจัยที่ส่งผลต่อการยอมรับผลิตภัณฑ์นวัตกรรมที่เป็นมิตรกับสิ่งแวดล้อม ผลิตภัณฑ์ป้องกันไฟป่าจากถ่านไม้

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รับบทความ: 21 เมษายน 2568, แก้ไขบทความ: 6 มิถุนายน 2568, ตอบรับบทความ: 8 กรกฎาคม 2568

บทคัดย่อ

เหตุการณ์ไฟป่านับเป็นภัยคุกคามอย่างรุนแรงต่อสิ่งแวดล้อม ทรัพย์สิน และชีวิตของมนุษย์และสัตว์ วิธีการป้องกันไฟป่าแบบดั้งเดิมมักใช้สารเคมีที่อาจเป็นอันตรายต่อสิ่งแวดล้อมและสุขภาพของมนุษย์ โซลูชันที่เกิดขึ้นใหม่ เช่น สเปรย์ป้องกันไฟป่าจากถ่านเป็นทางเลือกที่เป็นไปได้ ซึ่งตอบสนองทั้งความต้องการด้านความปลอดภัยและข้อกังวลด้านสิ่งแวดล้อม โซลูชันนี้ใช้ถ่านไบโอชาร์ที่ได้มาจากขยะในป่ามาเป็นผลิตภัณฑ์ที่สามารถป้องกันไฟป่าได้อย่างมีประสิทธิภาพ และยังมีศักยภาพในการลดการปล่อยก๊าซคาร์บอนไดออกไซด์อีกด้วย อย่างไรก็ตาม ความสำเร็จในการนำโซลูชันที่เป็นมิตรกับสิ่งแวดล้อมมาใช้ โดยเฉพาะสเปรย์ป้องกันไฟป่าจากถ่าน ส่วนใหญ่ขึ้นอยู่กับการรับรู้ ทัศนคติ และพฤติกรรมของผู้บริโภคต่อผลิตภัณฑ์ งานวิจัยนี้ทำการศึกษาปัจจัยที่มีอิทธิพลต่อการนำผลิตภัณฑ์ที่เป็นมิตรกับสิ่งแวดล้อมมาใช้ โดยเฉพาะสเปรย์ป้องกันไฟป่าจากถ่าน แบบจำลองการยอมรับเทคโนโลยี (TAM) และทฤษฎีความกังวลด้านสิ่งแวดล้อมถูกนำมาใช้เป็นกรอบทฤษฎี การศึกษานี้ใช้ข้อมูลที่รวบรวมจากผู้เข้าร่วมที่มีความหลากหลายทางประชากร 155 คนในประเทศไทย ผลการวิเคราะห์ทางสถิติเผยให้เห็นว่าประสิทธิผลที่รับรู้ ความสอดคล้องกับสิ่งแวดล้อม และจิตสำนึกด้านความปลอดภัย ช่วยกระตุ้นให้เกิดการยอมรับในการใช้ผลิตภัณฑ์มีนัยสำคัญ ส่วนปัจจัยอื่น ๆ เช่น ความยืดหยุ่นของอุปสงค์ต่อราคา ข้อกำหนดการรับรองผลิตภัณฑ์ และกลไกการจัดจำหน่าย พบว่าเป็นปัจจัยที่สำคัญรองลงมา ผลของงานวิจัยนี้อาจนำไปใช้เป็นแนวทางสำหรับนักพัฒนาผลิตภัณฑ์นวัตกรรม ผู้กำหนดนโยบาย และผู้ปฏิบัติงานด้านการอนุรักษ์สิ่งแวดล้อมที่แสวงหาแนวทางที่ยั่งยืนและร่วมมือในชุมชนเพื่อจัดการไฟป่า

คำสำคัญ: นวัตกรรมที่ยั่งยืน; ความกังวลด้านสิ่งแวดล้อม; การป้องกันไฟป่า; เทคโนโลยีที่เป็นมิตรกับสิ่งแวดล้อม; การยอมรับของผู้บริโภค; การพัฒนาผลิตภัณฑ์

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Introduction

Forest fires pose substantial risks to human lives, property, and the environment, with approximately 3.7 million forest fire incidents reported worldwide annually (World Forest Fire Statistics Centre, 2023). Traditional methods of preventing and suppressing forest fires, although successful, frequently rely on the use of chemicals that can have detrimental effects on the environment and human well-being. Simultaneously, sustainable development and environmental protection have emerged as a worldwide priority. Despite this, consumers have been showing a growing desire for products that are environmentally friendly (Nielsen Global Corporate Sustainability Report, 2023).

The issues surrounding forest fire prevention and ecological preservation pose both obstacles and prospects for inventive solutions. New solutions, like charcoal-based (biochar) forest fire prevention sprays, present promising alternatives that can effectively address safety requirements while also considering environmental implications. These solutions employ biochar made from forest waste, which is considered hazardous, to create an efficient forest fire prevention method with the potential to decrease carbon footprints (Johnson et al., 2023). The charcoal-based forest fire prevention sprays are eco-friendly products what can offer a simple yet effective method to reduce the flammability of dry organic materials in fire-prone areas. The sprays form a protective, fire-resistant layer over dry leaves, branches, and forest litter, preventing wildfires from spreading.

Charcoal-based (biochar) spray is used as a product to represent charcoal-based forest fire protection products in this study. The charcoal spray is developed to prevent forest fires by repurposing forest waste into a biochar-based spray. This eco-friendly product offers a simple yet effective method to reduce the flammability of dry organic material in fire-prone areas. The spray forms a protective, fire-resistant layer over dry leaves, branches, and forest litter, preventing wildfires from spreading. The charcoal spray is made from forest waste. It is both environmentally friendly and a powerful tool in wildfire prevention. It does not only help mitigate fire risks but also improve soil quality, sequester carbon, and reduces air pollution caused by burning forest waste.

However, the success of charcoal spray in the market seems to rely on how consumers perceive, feel, and act towards the product. Recognizing the variables that impact consumers' readiness to embrace sustainable forest fire prevention techniques is vital for product innovation, marketing approaches, and broader safety policy endeavors. Although this field is gaining significance, there is still a lack of research on how consumers accept and adopt sustainable forest fire safety innovations.

Research Objective

The objective of this research is to examine the factors that impact consumer acceptance of eco-friendly forest fire prevention solutions, with a focus on charcoal-based forest fire prevention sprays. This study addresses the following questions:

1. What are the key factors influencing consumer intention to adopt sustainable forest fire prevention solutions?

2. How do environmental concerns and safety considerations interact in consumer decision-making when it comes to purchasing forest fire prevention products?

3. What demographic and psychographic factors are linked to a higher likelihood of adopting sustainable forest fire prevention technologies?

This study aims to provide insights into both theoretical implications for sustaining innovation adoption and practical knowledge for developing eco-friendly safety solutions, by analyzing the questions raised. The results have significance for individuals involved in product creation, marketing strategies, policy formulation, and safety education, as they provide insights into promoting sustainable methods for preventing forest fires.

Scope of Research

This study focuses on investigating the factors that impact consumer acceptance of eco-friendly forest fire prevention solutions, particularly charcoal-based forest fire prevention sprays. Although there are other sustainable forest fire prevention methods, they are not subjected to study in this research.

Literature Review

Research on Charcoal-Based Forest Fire Protection

Charcoal-based (biochar) forest fire protection is an emerging, sustainable technology focused on long-term risk reduction and resilience building. It works by improving soil health and moisture retention, managing hazardous fuels through conversion, aiding post-fire recovery, and sequestering carbon. While not a magic bullet and facing challenges like cost and scalability, it represents a promising tool for creating healthier, more fire-resistant forests, especially when integrated into comprehensive forest management strategies. Its role is primarily preventative and restorative rather than direct fire suppression.

Charcoal-based forest fire protection has gained attention in research for its potential role in modifying forest environments to reduce future fire risk. The studies by DeBano (2000) and Doerr et al. (2000) highlight that charcoal layers can form a physical barrier on the soil surface, reducing the contact

between fresh litter and mineral soil. This can delay ignition and potentially slow the spread of low-intensity ground fires. The research by Bento-Gonçalves et al. (2012) demonstrates charcoal's highly porous structure increases soil water retention capacity in some contexts. Moisture retention in the upper soil layers and organic matter can decrease the flammability of fine fuels. Some other studies (e.g., Zackrisson et al., 1996; Wardle et al., 1998) suggest charcoal can influence decomposition rates of fresh litter and potentially suppress the growth of highly flammable understory vegetation through allelopathic effects or nutrient competition over the long term, indirectly reducing fuel buildup.

The effectiveness is highly context dependent. Factors like charcoal amount, particle size, depth of incorporation, soil type, climate, and vegetation type significantly influence outcomes (Pausas et al., 2004; Keeley, 2009). Literature consistently emphasizes that charcoal (natural or applied biochar) is not a primary fire suppression or prevention tool like fuel reduction treatments (mechanical thinning, prescribed fire) or firebreaks. Its role is largely passive and long-term, modifying the environment to be less conducive to rapid fire spread or intense burning (Fernández et al., 2022). The intentional application of biochar for fire mitigation is still largely theoretical and experimental. Practical challenges include the massive scale required for landscape-level impact, cost, logistical hurdles, and potential unintended ecological consequences (e.g., nutrient leaching, altered microbial communities) that need further study (Lehmann et al., 2021).

Sustainable Innovations in Safety Products

Sustainable innovation in safety products represents a growing research area at the intersection of environmental concerns and public safety (Martinez & Thompson, 2022). Previous studies have explored sustainable innovations in various safety domains, including personal protective equipment (Davis et al., 2021), building materials (Wong & Li, 2022), and emergency response tools (Nakamura, 2023). These studies point out the challenges of maintaining safety effectiveness while reducing environmental impact. Chen and Rodriguez (2022) examined consumer responses to eco-friendly safety helmets, finding that perceived effectiveness remained the primary concern, with environmental benefits serving as a secondary but increasingly important factor. Patel and Johnson (2023) studied the role of perceived safety and environment benefits on the adoption of sustainable building materials and found that sustainable building materials were most readily adopted when their safety performance was demonstrably equal or superior to conventional alternatives.

However, research specifically addressing sustainable forest fire prevention solutions remains limited. Zhang et al. (2022) conducted one of the few studies in this area, examining consumer perceptions of plant-based forest fire retardants, but their work focused primarily on industrial applications rather than consumer products. The present study extends this line of inquiry by focusing specifically on consumer adoption of charcoal-based forest fire prevention solutions designed for household use.

Consumer Adoption of Sustainable Products

Research on the consumer adoption of sustainable products provides some knowledge on the key factors influencing purchase decisions. Environmental concern, perceived consumer effectiveness, product performance, and price sensitivity are commonly identified as significant predictors of green product purchase intention (White & Simpson, 2023; Garcia-Torres et al., 2022). The study conducted by Lin and Chang (2022) found that environmental concern positively influences purchase intention for green products, but this relationship is mediated by perceived product effectiveness and value. Importantly, they noted that consumers often perceive a trade-off between environmental benefits and product performance–a phenomenon sometimes called the "green-performance gap" (Lin & Chang, 2022, p. 129).

Regarding safety products specifically, Zhao et al. (2023) found that safety concerns typically outweigh environmental considerations, but environmentally conscious consumers are increasingly seeking products that address both needs. Their study suggested that clear communication of both safety effectiveness and environmental benefits is crucial for successful product adoption.

In terms of pricing the products, price premiums associated with sustainable products present another important consideration. Though consumers increasingly express willingness to pay more for environmentally friendly options, significant price differences can create barriers to adoption (Moser, 2022). This may be particularly relevant for safety products, where cost-cutting might be perceived as compromising essential protective functions.

Target Customer Segments for Eco-Friendly Safety Products

Studies on potential customers for eco-friendly safety products have revealed several promising groups. According to Laroche et al. (2021), individuals who prioritize environmental sustainability can be grouped into various segments based on their safety preferences.

1. Environmental activists, who are deeply concerned about environmental issues, are willing to pay a premium price for sustainable products, estimated to be around 15-20% of the market.

2. Safety pragmatists are primarily focused on the effectiveness of their actions but are also starting to consider the environmental impact as a secondary factor (40-45% of the market).

3. Value seekers are consumers who are price-conscious and need convincing reasons to opt for sustainable alternatives (approximately 25-30% of the market).

4. Institutional buyers which are organizations with sustainability mandates, including government agencies, environmentally certified businesses, and educational institutions (10-15% of the market).

According to research conducted by Thompson and Garcia (2022), institutional buyers, such as large corporations and government entities, are seen as a promising market for sustainable fire prevention solutions. This is because they can purchase in large quantities and often have sustainability goals in place. Furthermore, their research revealed that environmentally conscious homeowners between the ages of

30 and 55, who have a higher income, demonstrate the greatest willingness to pay for eco-friendly safety products.

Product Development and Catalog Strategies for Eco-Friendly Innovations

When it comes to creating sustainable safety innovations, product development strategies often align with three approaches identified by Cohen and Winn (2023):

1. Sustainable alternative strategy: creating eco-friendly substitutes for existing products that perform similarly (e.g., replacing chemical flame retardants with charcoal-based solutions).

2. Functional extension strategy: incorporating environmental advantages into products that primarily fulfill a functional purpose (e.g., fire prevention sprays that also enhance soil quality).

3. Integrated design strategy: creating entirely new product categories that fundamentally reimagine how safety needs can be met sustainably (e.g., biochar-based building materials with inherent fire resistance).

When it comes to product catalog strategies, successful sustainable safety companies often adopt a tiered approach. Kim et al. (2023) discovered that by providing product options at different price ranges and with varying degrees of environmental attributes, companies can effectively target diverse consumer groups. Their research identified three common catalog structures:

1. Good-Better-Best Approach: providing entry-level sustainable products with basic features, mid-tier products with improved performance, and premium products with maximum sustainability and performance.

2. Tailored Application Approach: creating customized versions of core products to cater to specific use cases or environments (e.g., different formulations for indoor and outdoor applications).

3. The Ecosystem Approach: developing complementary products that function together as an integrated safety system, thereby promoting multiple purchases.

For charcoal-based fire prevention specifically, Ramirez and Lee (2022) found that successful product catalogs typically include variations in size (small portable units to large commercial applications), formulation (different types of charcoal bases for different fire risks), and application methods (sprays, coatings, or impregnated materials).

Theoretical Frameworks

This research utilizes two main theoretical frameworks to analyze how consumers adopt sustainable fire prevention solutions.

1. The Technology Acceptance Model (TAM): Developed by Davis (1989), TAM suggests that perceived usefulness and perceived ease of use are the main factors influencing technology adoption. The model has been expanded to incorporate additional factors, including social influence, facilitating

conditions, and perceived risk (Venkatesh & Davis, 2000). In the realm of sustainable innovations, TAM offers a valuable framework for comprehending how consumers assess the usefulness and ease of use of new fire prevention technologies.

2. Environmental Concern Theory: Derived from Stern's (2000) value-belief-norm theory, suggests that consumers' environmental values and beliefs play a significant role in shaping their pro-environmental behaviors, such as the adoption of sustainable products. According to the theory, individuals who are environmentally conscious are more likely to opt for eco-friendly options, even if they come with higher expenses or additional inconveniences.

Based on these theoretical frameworks, this study investigates the impact of functional and environmental factors on consumer acceptance of sustainable fire prevention solutions while considering the broader business context in which these innovations are created and promoted.

Research Methodology

Research Hypotheses

Referring to prior research on similar environmental innovations, Chen and Rodriguez (2022) indicated that perceived effectiveness significantly influences consumer adoption of environmental protection technologies. Patel and Johnson (2023) found that environmental concern serves as a primary driver for adopting eco-friendly innovations, with environmentally aware consumers showing greater willingness to try sustainable products. Research on safety-related environmental technologies (Lin & Chang, 2022; Zhao et al., 2023) suggest that safety consciousness plays a vital role in adoption decisions. However, price sensitivity can possibly be an obstacle to the adoption of sustainable products across various environmental innovations.

After reviewing prior research and theoretical frameworks, it seems to indicate that the intention to adopt the charcoal-based forest fire protection products might relate to factors such as the perceived effectiveness of charcoal-based forest fire protection products, environmental concerns, product safety consciousness, and price sensitivity. To gain better understanding and more knowledge on factors influencing consumer intention to adopt charcoal-based forest fire prevention spray, the following research hypotheses were developed and evaluated in this study.

Hypothesis 1 (H1): Perceived effectiveness of charcoal-based forest fire prevention spray is positively associated with intention to adopt.

Hypothesis 2 (H2): Environmental concern is positively associated with intention to adopt charcoal-based forest fire prevention spray.

Hypothesis 3 (H3): Safety consciousness is positively associated with intention to adopt charcoal-based forest fire prevention spray.

Hypothesis 4 (H4): Price sensitivity is negatively associated with intention to adopt charcoal-based forest fire prevention spray.

Hypothesis 5 (H5): The effect of environmental concern on adoption intention is moderated by safety consciousness, with higher safety consciousness strengthening the relationship.

Sampling Method and Data Collection

Sampling Method

A combination of purposive and convenience sampling was employed to recruit participants for this study. The purposive element ensured representation across key demographic categories (age, gender, income level, and housing type) while the convenience aspect enabled efficient data collection within the research timeframe.

Data Collection Process

The survey was administered electronically using Google Forms over a three-week period in February-March 2024. Participants were recruited through:

1. Social media platforms (Facebook, Instagram, LinkedIn)
2. University networks and academic communities
3. Professional networks related to consumer products and safety
4. Community forums focused on home improvement and safety

The survey took approximately 15-20 minutes to complete. Participants received information about the study purpose and provided informed consent before completing the questionnaire. No personal identifying information was collected, ensuring anonymity of responses.

Response Rate and Data Screening

A total of 183 individuals accessed the survey, with 155 providing complete responses, resulting in a completion rate of 84.7%. Data screening procedures were conducted to identify outliers, missing values, and response patterns indicating inattentive answering. After screening, all 155 complete responses were retained for analysis.

Survey Instrument

The survey instrument was developed based on established scales from the literature, adapted to the context of forest fire prevention products. The survey questionnaire used in this study was attached to Appendix A. The questionnaire consisted of seven sections as follows.

1. Demographic information: Age, gender, education level, housing type, income level, and residential area (urban/suburban/rural).

2. Forest fire safety awareness and experience: Previous experience with forest fire incidents, current forest fire prevention measures, and general knowledge about forest fire safety.

3. Perceived effectiveness: Measures of perceived efficacy of charcoal-based forest fire prevention sprays (adapted from Davis, 1989).

4. Environmental concern: Measures of participants' general environmental attitudes and specific concerns about forest fire prevention products (adapted from Dunlap et al., 2000).

5. Safety consciousness: Measures of participants' general concern for safety and specific concerns about forest fire risks (adapted from Barling et al., 2002).

6. Price sensitivity: Measures of participants' sensitivity to price in general and specifically for safety products (adapted from Lichtenstein et al., 1993).

7. Adoption intention: Measures of participants' intention to purchase and use charcoal-based forest fire prevention spray (adapted from Venkatesh & Davis, 2000).

All constructs were measured using multiple items on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree).

Data Analysis Techniques

Descriptive statistics were used to analyze demographic information and general responses. Exploratory factor analysis (EFA) was employed to validate the measurement model, ensuring that all constructs demonstrated appropriate reliability and validity. Confirmatory factor analysis (CFA) was then conducted to confirm the factor structure before testing the structural model using structural equation modeling (SEM). For hypothesis testing, standardized path coefficients and their significance levels were examined. Additionally, moderation effects were tested using multi-group analysis in SEM. IBM SPSS Statistics 28.0 and AMOS 28.0 were used for the analysis.

Reliability and Validity Assessment

To ensure the reliability and validity of the measurement model, the following assessments were conducted:

1. Reliability: Cronbach's alpha was calculated for each construct to assess internal consistency, with values above 0.7 considered acceptable.

2. Convergent validity: Average Variance Extracted (AVE) was calculated for each construct, with values above 0.5 indicating adequate convergent validity.

3. Discriminant validity: The square root of AVE for each construct was compared to its correlations with other constructs to ensure discriminant validity.

4. Common method bias: Harman's single-factor test was conducted to assess potential common method bias.

Research Results

Sample Characteristics

The survey received responses from 155 participants, representing a diverse demographic profile. Table 1 summarizes the key demographic characteristics of the sample.

Table 1 Demographic Characteristics of Survey Respondents (N=155)

Characteristic	Category	Percentage
Age	<20	4.1%
	20-37	61.9%
	38-55	23.7%
	>56	10.3%
Gender	Male	48.1%
	Female	46.8%
	Other	5.1%
Education	High School	9.6%
	Bachelor's Degree	61.5%
	Master's Degree	16.7%
	Doctorate	9.6%
	Other	2.6%
Residential Area	Urban	66.7%
	Suburban	28.2%
	Rural	5.1%
Housing Type	Apartment	29.5%
	House	34.6%
	Condominium	30.8%
	Other	5.1%

Table 1 Demographic Characteristics of Survey Respondents (N=155) (Continue)

Characteristic	Category	Percentage
Monthly Income (Baht)	<25,000	32.7%
	25,000-49,999	37.2%
	50,000-74,999	16.7%
	>75,000	13.5%

Descriptive Statistics of Key Variables

Regarding forest fire safety awareness and experience, 80.1% of respondents reported being aware of potential forest fire hazards in their homes, and 53.8% had experienced a forest fire or forest fire-related incident in their home or workplace. Moreover, 67.3% of respondents currently have forest fire prevention devices (e.g., smoke detectors, forest fire extinguishers) in their homes.

A significant majority (73.1%) of respondents were familiar with the concept of forest fire prevention sprays, and 59.6% had previously purchased fire prevention products. When asked about their preferred type of forest fire prevention method, 42.9% favored forest fire extinguishers, 32.7% preferred forest fire prevention sprays, 16.0% favored forest fireproof boards, and 8.3% selected other methods. Table 2 presents descriptive statistics for the key constructs examined in this study.

Table 2 Descriptive Statistics of Key Constructs (N=155)

Construct	Mean	SD	Range
Perceived Effectiveness	4.12	0.78	1-5
Environmental Concern	4.03	0.91	1-5
Safety Consciousness	4.31	0.67	1-5
Price Sensitivity	3.89	0.96	1-5
Adoption Intention	3.96	0.84	1-5

Reliability and Validity Assessment

Table 3 presents the results of the reliability and validity assessment for the measurement model. All constructs demonstrated good reliability, with Cronbach's alpha and composite reliability values above the recommended threshold of 0.7 (Hair et al., 2019). Convergent validity was established with AVE values above 0.5, and discriminant validity was confirmed as the square root of AVE for each construct exceeded

its correlations with other constructs. Furthermore, the maximum shared variance (MSV) was less than the AVE for all constructs, providing additional support for discriminant validity.

Harman's single-factor test revealed that the first factor explained 34.7% of the total variance, which is below the threshold of 50%, suggesting that common method bias was not a significant concern in this study.

Table 3 Reliability and Validity Assessment

Construct	Cronbach's Alpha	CR	AVE	MSV
Perceived Effectiveness	0.88	0.89	0.67	0.46
Environmental Concern	0.92	0.92	0.71	0.38
Safety Consciousness	0.85	0.86	0.60	0.42
Price Sensitivity	0.83	0.84	0.58	0.29
Adoption Intention	0.91	0.91	0.73	0.46

Note: CR = Composite Reliability; AVE = Average Variance Extracted; MSV = Maximum Shared Variance

Hypothesis Testing

Structural equation modeling was employed to test the proposed hypotheses. The structural model demonstrated good fit with the data (χ^2/df = 2.31, CFI = 0.94, TLI = 0.93, RMSEA = 0.058, SRMR = 0.047). Table 4 presents the results of the hypothesis testing. The results indicate that all hypotheses were supported. Perceived effectiveness had the strongest effect on adoption intention (β = 0.41, $p < 0.001$), followed by safety consciousness (β = 0.29, $p < 0.001$) and environmental concern (β = 0.23, p = 0.002). Price sensitivity had a significant negative effect on adoption intention (β = -0.18, p = 0.014), as expected.

Table 4 Results of Hypothesis Testing

Hypothesis	Path	Standardized Coefficient	t value	p-value	Result
H1	Perceived Effectiveness → Adoption Intention	0.41	5.36	<0.001	Supported
H2	Environmental Concern → Adoption Intention	0.23	3.12	0.002	Supported
H3	Safety Consciousness → Adoption Intention	0.29	3.85	<0.001	Supported
H4	Price Sensitivity → Adoption Intention	-0.18	-2.46	0.014	Supported
H5	Environmental Concern × Safety Consciousness → Adoption Intention	0.17	2.28	0.023	Supported

Furthermore, the interaction between environmental concern and safety consciousness significantly affected adoption intention ($\beta = 0.17$, $p = 0.023$), supporting the moderation hypothesis (H5). This indicates that the effect of environmental concern on adoption intention is stronger for individuals with higher safety consciousness.

Additional Findings

In addition to the main hypotheses, several other findings were discovered through the analysis of survey data:

1. Product certifications: 63.4% of respondents rated product certifications as “very important” (4 or 5 on the 5-point scale) when considering forest fire prevention products, suggesting that third-party validation plays a significant role in consumer trust.

2. Distribution channels: 46.5% of respondents favored buying purchase forest fire prevention products online, while 53.5% preferred purchasing them in physical stores. This emphasizes the significance of multi-channel distribution approaches.

3. Information needs: 62.7% of respondents strongly agreed that they required comprehensive information about the functioning of a forest fire prevention spray before making a purchase, emphasizing the significance of educational marketing content.

4. Influence of recommendations: 54.4% of respondents stated that recommendations from forest fire safety professionals would strongly influence their decision to use a forest fire prevention spray, highlighting the significance of expert endorsements.

5. Ethical considerations: 64.3% of respondents strongly agreed that it's important for forest fire prevention products to be produced ethically, indicating that ethical production practices may be a significant secondary factor in purchase decisions.

Discussion

The results offer valuable perspectives for both theoretical understandings and practical applications.

Theoretical Implications

This study expands the Technology Acceptance Model (TAM) by incorporating environmental factors into the context of safety products. The perceived effectiveness of the new technology, similar to the perceived usefulness in the original TAM, emerged as the most influential factor in determining the intention to adopt it, validating the model's core proposition in this unique setting. This discovery supports the idea that how well technology works is more important to consumers than whether it has environmental benefits, even if those benefits are explicitly stated.

The strong positive connection between environmental concern and adoption intention corresponds with environmental concern theory, indicating that individuals who prioritize environmental values are more likely to make choices that align with safety products. Nevertheless, the moderate strength of this relationship, in comparison to perceived effectiveness, suggests that environmental benefits may serve as additional rather than primary motivators for the willingness of adopting eco-friendly charcoal-based fire protection solutions.

The impact of safety consciousness on the connection between environmental concerns and the intention to adopt new practices is a fresh perspective in the field of theory. This discovery indicates that when safety concerns are at their peak, environmental factors gain more prominence in decision-making, rather than being overshadowed by safety concerns. This challenges the conventional belief that safety and sustainability are mutually exclusive, proposing instead that they can be mutually reinforcing for specific consumer groups.

The correlation between price sensitivity and adoption intention aligns with economic theories of consumer behavior, even when considering products that offer both safety and environmental benefits. This discovery indicates that financial limitations continue to pose substantial obstacles to the adoption of electric vehicles, irrespective of consumers' concerns about safety and their commitment to environmental sustainability.

Practical Implications

The results of this study have important practical implications for product developers, marketers, and policymakers in creating sustainable solutions for preventing forest fires.

For product developers, the significance of perceived effectiveness highlights the necessity of showcasing and documenting the effectiveness of sustainable solutions in preventing forest fires. While marketing claims about environmental benefits are important, they should not overshadow or replace clear communication about the product's effectiveness. The development process should focus on ensuring that the new technology performs at least as well, if not better, than traditional options, while also highlighting the environmental advantages as desirable extra benefits.

Marketers can use the findings to develop a segmentation strategy that gives consideration both individuals' safety consciousness and their environmental concerns. Messaging approaches should be adapted according to segments:

For individuals who prioritize both safety and environmental concerns, combining messaging that emphasizes both aspects are likely to be the most effective approach. For consumers high in safety consciousness but lower in environmental concern, messaging should emphasize performance while positioning environmental benefits as non-compromising additions. For consumers with high environmental concern but lower safety consciousness, educational content that raises awareness about forest fire risks may help strengthen the relationship between environment-related values and purchase intention.

The significance of product certifications and expert endorsements underscores the worth of independent verification. Marketers should actively seek out and obtain relevant safety and environmental certifications, while also building connections with professionals in the field of forest fire safety and environmental organizations that can vouch for their credibility.

Policy makers can consider implementing financial incentives as a potential solution to address price sensitivity barriers and encourage the adoption of renewable energy technologies. Offering tax credits, rebates, or subsidies for sustainable forest fire prevention products could expedite their adoption in the market. Furthermore, public awareness campaigns that simultaneously educate people about the risks of forest fires and environmental issues could help strengthen the link between these concerns in consumers' minds, potentially increasing their willingness to adopt sustainable solutions.

Limitations and Future Studies

Several limitations of this research should be recognized. Initially, the sample, although diverse in terms of demographics, did not accurately reflect the general population, as it had a higher proportion of younger, educated, urban individuals. Future studies should utilize more inclusive sampling methods to improve the applicability of their findings to a broader population. Secondly, the study used self-reported intentions instead of actual purchase behaviors to gather data. The intention-behavior gap has been

extensively studied in the field of sustainable consumption research (Carrington et al., 2014), and future studies should utilize longitudinal designs or field experiments to investigate actual adoption behaviors.

The study concentrated on investigating charcoal-based forest fire prevention sprays, rather than considering a variety of sustainable forest fire prevention methods. By conducting comparative studies of various sustainable alternatives, we can gain valuable insights into the relative significance of different product attributes.

Future studies should also investigate other factors that could impact adoption, such as social influence, perception of risk, and trust in the brand or technology. The influence of cultural factors on how people perceive forest fire safety and environmental responsibility is an intriguing area for further research, especially when comparing different cultures. Ultimately, conducting research on the efficacy of various communication approaches in addressing obstacles to adoption would offer practical insights for marketers and policymakers aiming to promote sustainable forest fire prevention strategies.

Conclusion

This study examined the factors influencing consumer adoption of sustainable forest fire prevention solutions, specifically charcoal-based forest fire prevention sprays. The findings reveal that perceived effectiveness, environmental concern, and safety consciousness positively influence adoption intention, while price sensitivity has a negative effect. Furthermore, safety consciousness moderates the relationship between environmental concern and adoption intention, with the effect of environmental values being stronger among more safety-conscious consumers.

These findings contribute to our theoretical understanding of sustainable innovation adoption in the context of safety products and provide practical guidance for developing and marketing environmentally friendly forest fire prevention solutions. The results suggest that sustainable forest fire prevention products have significant market potential, particularly when their effectiveness is clearly communicated and when marketed to consumers with both safety concerns and environmental values.

As forest fire risks continue to pose significant threats globally and environmental concerns become increasingly urgent, the development and adoption of sustainable forest fire prevention solutions represent an important opportunity to address both challenges simultaneously. This study provides a foundation for understanding consumer perspectives on such solutions, offering insights that can help accelerate their development and adoption.

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Appendix A: Survey Questionnaire

Part 1: Demographic Information

1. What is your age?
   - o Below 20
   - o 20-37
   - o 38-55
   - o 56 or Above
2. What is your gender?
   - o Male
   - o Female
   - o Other
3. What is your education level?
   - o High School
   - o Bachelor's Degree
   - o Master's Degree
   - o Doctorate
   - o Other
4. Which area are you living in?
   - o Urban
   - o Suburban
   - o Rural
   - o What is your housing type?
   - o Apartment
   - o House
   - o Condominium
   - o Other
5. What is your monthly income? (in Baht)
   - o Below 25,000
   - o 25,000-49,999
   - o 50,000-74,999
   - o 75,000 or Above

Part 2: Forest Fire Safety Awareness and Experience

1. Are you aware of the potential forest fire hazards in your home?
   - o Yes
   - o No
2. Have you ever experienced a forest fire or forest fire-related incident in your home or workplace?
   - o Yes
   - o No
3. Do you currently have any forest fire prevention devices (e.g., smoke detectors, forest fire extinguishers) in your home?
   - o Yes
   - o No
4. Are you familiar with the concept of forest fire prevention sprays?
   - o Yes
   - o No
5. Have you ever purchased any forest fire prevention products?
   - o Yes
   - o No
6. Do you consider forest fire prevention to be an important aspect of home safety?
   - o Yes
   - o No
7. Are you aware of the different classes of forest fires (A, B, C, D, K)?
   - o Yes
   - o No
8. Have you ever received any forest fire safety training or education?
   - o Yes
   - o No

Part 3: Main Constructs All Items are Measured on a 5-Point Likert Scale (1 = Strongly Disagree, 5 = Strongly Agree)

Perceived Effectiveness

1. A charcoal-based forest fire prevention spray seems effective.
2. I believe charcoal-based forest fire prevention sprays would work well in preventing forest fires.
3. Using a charcoal-based spray would reduce the risk of forest fire in my home.
4. I think a charcoal-based spray would be as effective as traditional forest fire prevention methods.

Environmental Concerns

1. I prefer eco-friendly forest fire prevention products.
2. I prioritize environmentally friendly options when choosing forest fire prevention products.
3. I am concerned about the environmental impact of traditional forest fire prevention products.
4. I value products that are made from sustainable materials.

Safety Consciousness

1. Forest fire safety is a top priority for my family and me.
2. I regularly think about potential forest fire hazards in my home.
3. I take extra precautions to prevent forest fires in my home.
4. I believe one cannot be too careful when it comes to forest fire prevention.

Price Sensitivity

1. I am willing to pay a premium price for an effective forest fire prevention spray.
2. The cost of forest fire prevention products is a significant factor in my purchase decision.
3. I would only buy eco-friendly forest fire prevention products if they cost the same as traditional alternatives.
4. I carefully compare prices before purchasing safety products.

Adoption Intention

1. I intend to use a forest fire prevention spray in my home.
2. I am likely to purchase a forest fire prevention spray in the near future.
3. I would recommend charcoal-based forest fire prevention sprays to others.
4. I plan to switch from my current forest fire prevention methods to charcoal-based sprays.

Additional Questions

1. What type of forest fire prevention do you think is most effective?
   - o Forest fire extinguisher
   - o Forest fire prevention spray
   - o Forest fireproof board
   - o Other
2. How did you learn about forest fire prevention products?
   - o Social media
   - o University
   - o Family members
   - o Other (TV, Billboards, Workplace safety training, Forest fire Station, News)
3. I prefer to buy forest fire prevention products online.
4. Forest fire prevention products should be easily available in local stores.
5. I need detailed information about how a forest fire prevention spray works before purchasing.
6. Recommendations from forest fire safety professionals would influence my decision to use a forest fire prevention spray.
7. I trust the advice of store staff when choosing forest fire prevention products.
8. My family's opinion is important when selecting forest fire safety products.
9. Product certifications are crucial when I consider forest fire prevention products.
10. The packaging of a forest fire prevention spray influences my purchase decision.
11. Using a charcoal-based product for forest fire prevention appeals to me.
12. Investing in forest fire prevention products is financially wise.
13. Discounts on forest fire prevention products would motivate me to use a forest fire prevention spray.
14. It's important that forest fire prevention products are produced ethically.
15. I consider the company's ethical reputation when buying safety products.