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ORIGINAL RESEARCH ARTICLE

Risk, efficacy, and the moderating role of policy effectiveness in microplastic reduction intentions

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Abstract: Microplastics pose serious threats to both the environment and human health. Although governments have introduced various policies and promoted international cooperation to address this issue, the effectiveness of these efforts is closely linked to the importance of individuals' engagement, which is shaped by their perceptions. However, limited research has examined how such perceptions interact with perceived policy effectiveness in shaping pro-environmental behavioral intentions. To address this gap, this study aims to examine how risk perceptions (perceived severity and perceived vulnerability) and efficacy beliefs (self-efficacy and response efficacy) influence behavioral intentions to reduce microplastic emissions within the framework of protection motivation theory, and whether perceived policy effectiveness moderates these relationships. We conducted a nationwide survey of South Korean adults and analyzed the data using hierarchical regression to test the proposed hypotheses. The results revealed that both risk perception and efficacy had significant positive effects on behavioral intentions, with response efficacy emerging as the strongest predictor, followed by perceived severity, self-efficacy, and perceived vulnerability. Perceived policy effectiveness did not directly affect behavioral intentions but moderated the relationship between self-efficacy and behavioral intentions. The moderation effect indicated that higher perceived policy effectiveness attenuated the positive relationship between self-efficacy and pro-environmental behavioral intentions, suggesting a potential motivation crowding-out effect. These findings highlight the importance of integrating psychological factors and perceptions of policy effectiveness into policy design. They offer valuable insights for environmental campaigns, communication strategies, and governance efforts aimed at promoting sustainable behaviors to mitigate microplastic emissions.

Keywords: Microplastic emissions; Pro-environmental intentions; Protection motivation theory; Risk perception; Efficacy; Policy effectiveness

1. Introduction

Plastic production has increased significantly due to its ease of manufacture and low cost, with current annual global output estimated at approximately 400 million tons.[1] With a global recycling rate of less than 10%, plastic waste often flows into the ocean, thereby contributing significantly to marine plastic pollution.

Over time, this waste degrades into microplastics, which pose serious risks to both environmental and human health.[2,3] Recent studies have demonstrated that microplastics can enter the human body not only through the consumption of contaminated food and water, but also through the inhalation of airborne particles during routine activities.[4] In fact, researchers have detected microplastics in human blood and even in breast milk.[5,6]

As global attention to plastic pollution has intensified, governments and international organizations have advanced collaborative initiatives to address plastic emissions. The 2015 Sustainable Development Goals (SDGs) highlight SDG 6, SDG 14, and SDG 15 as key foundations for policies aimed at protecting marine ecosystems from microplastic threats.[7] In 2022, the United Nations Environment Assembly adopted a resolution in which member states committed to establishing a legally binding international agreement to address plastic emissions. Compared to previous resolutions that primarily focused on marine environments, this resolution emphasizes the full life-cycle management of plastics, marking a significant advancement in international governance.[8]

The World Trade Organization has also advanced discussions on plastics from a trade and environmental perspective. For example, the Informal Dialogue on Plastics Pollution and Environmentally Sustainable Plastics Trade, launched in November 2020, seeks to promote trade measures that enhance plastics circularity and reduce pollution.[9] As a key factor in global governance, the European Union requires member states to submit annual reports on plastic bag consumption and has adopted comprehensive mitigation measures, including collection targets for plastic bottles and recycling targets for plastic packaging.[9] Similarly, the G7 and G20 have initiated a range of international efforts to address plastic pollution.[9]

However, intergovernmental cooperation does not always yield successful outcomes. The fifth session of the Intergovernmental Negotiating Committee (INC-5.1) was held in Busan, South Korea, from November 25 to December 1, 2024, where participating countries expressed divergent views and failed to reach a consensus. Moreover, the current international agenda on microplastics remains primarily focused on marine issues, and no legally binding instrument has yet been established to address these concerns.

International responses to microplastics remain limited, and national policy efforts are also at an early stage. In particular, South Korea has not yet established a comprehensive legislative framework for the reduction and management of microplastics. A draft law was submitted in 2024, but it has not been enacted.[10] Some local governments have undertaken various initiatives to reduce plastic use,[11] but national-level policies have lacked coherence and continuity. For instance, the withdrawal of the plastic straw ban in 2023 created uncertainty for both businesses that had invested in compliance infrastructure and the public.[12]

The limited progress at both international and national levels underscores the necessity of collective action across multiple stakeholders. In particular, during the early stages of policy formation, strategies are needed to enhance the acceptance of policy actors to ensure that initiatives lead to effective policy development and implementation. Specifically, governments play a central role in addressing environmental problems through international cooperation and the formulation and implementation of policies. However, to enhance policy effectiveness, it is essential to secure active individual participation. As environmental issues require substantial time to resolve and exhibit long time lags between polluting behavior and mitigation outcomes,[13] relying solely on voluntary action is insufficient. Therefore, it is necessary to encourage and facilitate pro-environmental intentions as precursors to actual behavioral change. Research on the determinants of individuals' intentions from a policy perspective begins with this critical awareness.[14]

Previous research on individuals' pro-environmental behavior has primarily focused on affective and normative dimensions, aiming to reduce the gap between environmental awareness and actual behavior. In other words, much of the literature has focused on individuals' internal factors.[15-19] In contrast, only a few studies have examined how perceptions of policy performance influence behavioral change. Research on microplastics has largely concentrated on technological and scientific aspects—such as the impacts of microplastics on the human body[20-22] or environmental contamination[23-25]—while socioscientific studies on environmental behavior, including efforts to reduce microplastic emission, remain at an early stage.

Pro-environmental behaviors driven by shifts in individual perceptions can promote fundamental and long-term transformations. Moreover, individual change can contribute to transformation at societal and national levels, thereby highlighting its broader significance. To explain such changes, it is necessary to examine not only psychological factors but also how individuals perceive the effectiveness of policies. However, despite growing concern about microplastic

pollution, little research has explored this connection. This study addresses this gap by analyzing how risk perception, efficacy, and perceived policy effectiveness jointly shape pro-environmental intentions.

Therefore, drawing upon Rogers'[26] protection motivation theory (PMT), this study aims to address the following research question: What personal and policy factors shape individuals' pro-environmental intentions to engage in behaviors that reduce microplastic emissions? To this end, we examine the roles of risk perception and efficacy in influencing behavioral intentions. Moreover, the study explores whether perceived effectiveness moderates the influence of these psychological factors. The findings aim to provide policy-relevant insights for strengthening individual intentions toward microplastic reduction.

2. Literature review and theoretical background

2.1. Pro-environmental behavior and PMT

Pro-environmental behavior encompasses various individual actions aimed at preserving the environment and conserving resources.[27] Both internal (e.g., environmental awareness) and external (e.g., sociodemographic conditions) factors influence such behavior. However, recent studies have increasingly emphasized the importance of internal factors, including individuals' perceptions and attitudes.[28-30]

Legal regulations, as a direct approach to addressing environmental issues, can shift market dynamics and prompt immediate behavioral change among individuals. However, the effectiveness of such policies ultimately depends on the compliance of citizens—the primary targets of regulation—and governments cannot regulate all behaviors that impact the environment.[31] Therefore, policymakers need to promote internal transformations fundamentally to resolve environmental crises that arise from the accumulation of individual actions.[32] Pro-environmental behaviors driven by individual perceptions represent fundamental and long-term solutions to environmental problems.[32-34] Furthermore, such behaviors can reduce regulatory costs and enhance policy effectiveness.

Theories explaining the influence of individual perceptions on environmental behavior have evolved through diverse ways. One of the most widely applied frameworks is the theory of planned behavior (TPB), introduced by Ajzen and Madden[35] in 1986. TPB extends the theory of reasoned action by incorporating factors that lie beyond an individual's control.[30] Researchers have extensively applied TPB to explain pro-environmental behavior, as it provides strong explanatory and predictive power for understanding human actions.[36-38] However, TPB has faced criticism for its limited explanatory capacity in situations involving ambiguous personal interests, particularly when addressing altruistically motivated environmental behaviors.[39] In response, many studies have adopted the extended TPB by incorporating additional variables or integrating it with other theoretical frameworks that emphasize the moral and normative dimensions of behavior.[40,41]

Schwartz[42] proposed the norm activation model (NAM) to explain altruistically motivated individual behavior. According to NAM, such behavior is triggered by three key components: personal norms, awareness of consequences, and ascription of responsibility.[39] Subsequently, Stern[27] integrated Schwartz's NAM with the value-based view of environmental behavior and the new environmental paradigm to develop the value–belief–norm theory (VBN). According to the VBN theory, broad and stable values shape beliefs about the human–environment relationship (as conceptualized in the new environmental paradigm), which in turn influence awareness of consequences and ascription of responsibility. These constructs activate personal norms, ultimately motivating pro-environmental behavior.[43]

VBN theory remains widely employed to explain pro-environmental behavior; however, it has limitations in accounting for emotional factors such as feelings of risk or fear. The fear associated with microplastics may exceed that related to other environmental issues, as microplastics are now pervasive across ecosystems and within the human body. Their potential impacts on the environment and human health remain largely uncertain.[44] The uncertainty surrounding microplastics can increase public risk perception,[45] and media coverage and recent reports may further intensify it.[46] Moreover, recent discussions highlight the gap between environmentally friendly attitudes and actual behaviors, underscoring the role of efficacy as a key explanatory factor.[32] Therefore, this study also considers the role of efficacy in shaping pro-environmental behavior.

Given this context, Rogers'[26] PMT provides a suitable framework for explaining pro-environmental behaviors such as reducing microplastic use. PMT was originally developed to explain how fear appeals influence individual behavior by addressing both risk perception and efficacy. The original theory proposed that perceived severity, vulnerability, and response efficacy jointly contribute to protection motivation.[47] The revised PMT differentiates between two distinct cognitive processes:

threat appraisal and coping appraisal.[26] Although researchers have primarily applied PMT to health-related behaviors, it has also been widely used to examine behavioral change and its determinants, particularly those related to safety and preventive actions.[48] Given that microplastics threaten both human health and the environment, PMT offers a strong theoretical basis for predicting pro-environmental behaviors aimed at microplastic reduction.[46] Furthermore, by considering individuals' risk perception and efficacy simultaneously in addressing environmental problems, PMT serves as a comprehensive and balanced model.

2.2. Application of PMT to microplastic reduction intentions

2.2.1. Risk perception and pro-environmental intentions

Risk perception refers to individuals' subjective assessment of threats and is widely recognized as a key factor in shaping behavioral responses.[19,49-51] In the revised PMT, threat appraisal comprises two cognitive elements: perceived severity and perceived vulnerability.[26] Rogers[26] argued that when a threat is perceived as severe, or when individuals believe they are vulnerable to it, they are more likely to reduce behaviors that could exacerbate the threat.[52]

Research on the effects of individuals' risk perception on pro-environmental behavior has been conducted across multiple contexts, particularly in relation to climate change.[51,53] However, few studies have examined individuals' perceptions of specific environmental pollutants. In the case of microplastics, most research focuses on their sources and distribution,[54,55] or on their environmental and human health impacts from scientific and technological perspectives.[56,57] Studies analyzing individuals' pro-environmental responses to microplastics from a social scientific perspective remain limited and underdeveloped.

Most studies measure and analyze perceived severity and perceived vulnerability as distinct constructs,[58,59] and given the potential differences between these perceptions, it is important to examine them separately. For example, the 2023 National Environmental Awareness Survey conducted by the Korea Environment Institute revealed that individuals clearly distinguish between the perceived severity of environmental problems and vulnerability.[60] According to the results, 88.4% of respondents viewed climate change as a serious issue, whereas only 58% believed it had a serious impact on themselves. Based on the above discussion, this study distinguishes between these two concepts and proposes the following hypotheses:

(i) Hypothesis(v)1.1:(v)The perceived severity of~~~ of microplastic threats is positively related to individuals' intentions to reduce microplastic emissions.
(ii) Hypothesis 1.2: The perceived vulnerability to microplastic threats is positively related to individuals' intentions to reduce microplastic emissions.

2.2.2. Efficacy and pro-environmental intentions

Efficacy is a key construct in Bandura's[61] social learning theory and is widely regarded as an important predictor of pro-environmental behavior.[62,63] It is a central factor in conceptualizing individuals as proactive agents capable of influencing environmental outcomes.[31] Many studies have confirmed the positive relationship between efficacy and pro-environmental behavior,[46,62,64-66] although most of these studies focus primarily on self-efficacy.

In PMT, efficacy comprises two components: Self-efficacy and response efficacy. Self-efficacy refers to an individual's belief in their ability to perform a protective behavior, whereas response efficacy denotes the belief that the recommended action is effective in mitigating the threat.[67] Self-efficacy is one of the strongest predictors of pro-environmental behavior, and higher levels of self-efficacy positively influence individuals' participation in government policies and institutions.[30] Some studies have also found that its impact on policy support surpasses that of other forms of efficacy.[68] Meanwhile, some studies have examined collective efficacy, derived from Bandura's concept of self-efficacy, which is defined as the shared belief among members of a group in their collective capability to achieve goals or resolve problems.[69] However, research on the effects of collective efficacy on pro-environmental behavior has produced relatively inconsistent findings.

Empirical evidence indicates that response efficacy directly and indirectly exerts a significant positive influence on pro-environmental behavior as well.[70] For instance, Van Valkengoed *et al*.[66] examined a similar construct, "outcome efficacy," and demonstrated its predictive power in individuals' climate change adaptation behaviors. Research on microplastics has also shown that both self-efficacy and response efficacy positively influence environmental behaviors.[46]

Based on the above discussion, this study distinguishes between self-efficacy and response efficacy. The hypotheses regarding the relationship between efficacy and pro-environmental behavior are as follows:

(i) Hypothesis 2.1: Self-efficacy is positively related to individuals' intentions to reduce microplastic emissions.

(ii) Hypothesis 2.2: Response efficacy is positively related to individuals' intentions to reduce microplastic emissions.

2.3. The moderating role of perceived policy effectiveness

Although individual efforts to protect the environment continue, the accelerating nature of environmental problems can lead to feelings of helplessness and fatigue. Under such circumstances, individuals often expect responsible action from those with greater power and influence.[71] These expectations were also evident in the 2023 Public Attitudes toward the Environment Survey conducted by the Korea Environment Institute. According to the survey, 42.7% of respondents identified the central government as the primary actor responsible for environmental protection.

In addition, over 60% indicated that they would be more willing to engage in pro-environmental behaviors if the government or corporations made greater efforts. These findings suggest that individuals recognize the importance of governmental efforts in addressing environmental issues,[60] and that the performance of powerful actors may influence individual behavioral intentions.

Perceptions of policy outcomes—specifically, the perceived effectiveness of policies—constitute a major factor influencing individuals' behavioral intentions. In the environmental policy domain, where tangible improvements are often difficult to observe in the short term, perceived policy effectiveness may play a particularly important role. Empirical research demonstrates that perceptions of policy effectiveness strengthen individuals' pro-environmental behaviors.[72] Similarly, a study involving 40,000 participants across 20 countries identified perceived policy effectiveness as a key determinant of support for climate policies.[73] These findings suggest that perceived policy effectiveness may enhance the relationship between individuals' environmental perceptions and their behaviors. In other words, perceptions of governmental policy effectiveness may not only directly shape individuals' pro-environmental behaviors but also amplify the influence of their environmental perceptions.

Research examining the relationship between individuals' perceptions and their behavioral intentions, particularly with respect to the moderating role of perceived policy effectiveness, remains limited. Moreover, findings from previous studies are not fully consistent. Nevertheless, empirical evidence suggests that perceived policy effectiveness can positively shape the relationship between perception and pro-environmental intentions. For instance, environmental knowledge enhances concern and fosters more favorable environmental attitudes, thereby strengthening pro-environmental intentions.[74] In addition, Liao *et al.*[75] found that perceived policy effectiveness positively moderates the relationship between individuals' attitudes toward pro-environmental behavior and their intentions.

Building on these findings, this study hypothesizes that perceived policy effectiveness will positively moderate the influence of individuals' risk perception and efficacy on their intentions to reduce microplastic consumption. The hypotheses are as follows:

(i) Hypothesis 3: Perceived policy effectiveness positively moderates the relationship between risk perception and individuals' intentions to reduce microplastic emissions.

(ii) Hypothesis 4: Perceived policy effectiveness positively moderates the relationship between efficacy and individuals' intentions to reduce microplastic emissions.

3. Methods

3.1. Research framework

In this study, we investigated the effects of risk perception, comprising perceived severity and perceived vulnerability, and efficacy—comprising self-efficacy and response efficacy—on individuals' intentions to reduce microplastic emissions. In addition, we examined whether perceived policy effectiveness moderates the relationships among risk perception, efficacy, and pro-environmental behavioral intentions. Although intentions are not identical to actual behavior, previous studies have commonly employed pro-environmental intentions as a valid proxy for predicting environmental actions.[30] Figure 1 presents the research framework developed based on this approach.

3.2. Data collection and sampling

To test the proposed hypotheses, we conducted a nationwide online survey through a professional research firm. The survey employed stratified quota sampling based on gender and age, targeting adults aged 19 and older from the firm's national online panel. A total of 1,000 responses were collected. The survey was administered between November 24 and 30, 2023. To enhance participants' understanding, the survey included a description of microplastics and examples of substances that generate them.

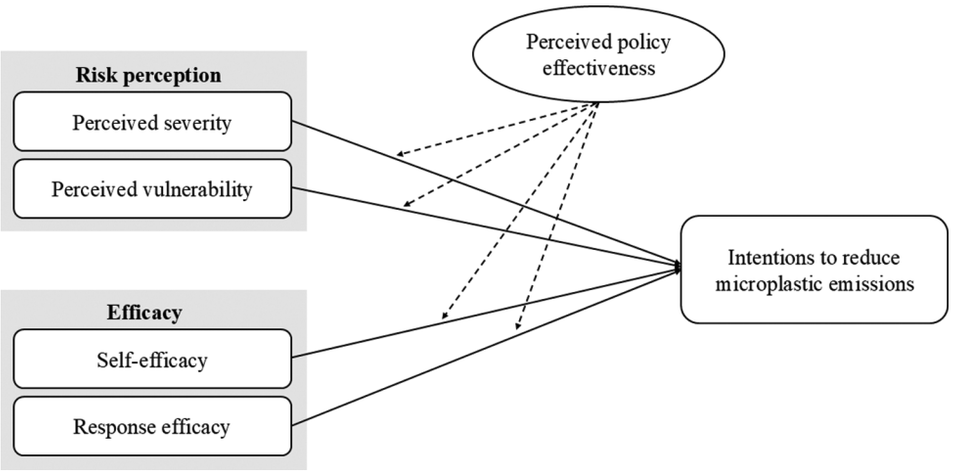

Figure 1. Research framework

Before data collection, all prospective participants were provided with a clear explanation of the survey's purpose and the categories of demographic information to be collected. No personally identifiable information was collected that could directly reveal participants' identities. All personal data were handled with strict confidentiality and used solely for statistical analyses relevant to the study. Participation in the survey was voluntary, and only individuals who provided informed consent took part. Participants were informed that they could withdraw from or terminate the survey at any time without penalty. The English translation of the informed consent form is presented in Table A1.

Among the respondents, 51% were male (n = 510) and 49% were female (n = 490). In terms of age, 16.9% were in their 20s (n = 169), 17.4% in their 30s (n = 174), 21.4% in their 40s (n = 214), 23.6% in their 50s (n = 236), and 20.7% were 60 years or older (n = 207). Regarding education level, 66% held a bachelor's degree (n = 660), followed by high school graduates (16.4%, n = 164), graduated degree holders (10.9%, n = 109), university students (5.7%, n = 57), and those with a middle school education or below (1%, n = 10). In terms of monthly income, the largest group (20.4%, n = 202) earned approximately KRW 3–4 million, while the smallest group (4.2%, n = 42) earned less than KRW 1 million. Regarding political ideology, 56.7% identified as moderate (n = 567), 23% as progressive (n = 230), and 20.3% as conservative (n = 203).

3.3. Variables and measurement

The dependent variable in this study refers to individuals' voluntary intention to reduce microplastic emissions. This study aimed to examine the influence of risk perception and efficacy on individuals' pro-environmental intentions to reduce microplastic emissions and to determine whether these relationships are moderated by the perceived policy effectiveness of governmental regulations. Intentions to reduce microplastic emissions were assessed using four items that evaluated voluntary effort in daily life, such as "I'm willing to use a reusable shopping bag instead of disposable plastic bags to reduce microplastic emissions" and "I'm willing to use a tumbler or reusable bottle instead of disposable paper cups to reduce microplastic emissions."

The independent variables in this study consist of perceived risk and efficacy, grounded in PMT. Risk perception comprises perceived severity and perceived vulnerability, each measured using three items. Perceived severity refers to individuals' perceptions of the seriousness of microplastic impacts on themselves and their families, local communities, and Korean society. In contrast, perceived vulnerability refers to individuals' perceptions of the likelihood of experiencing health-related harm from microplastics affecting themselves, their families, local communities, and Korean society.

Efficacy was conceptualized as comprising two factors: Self-efficacy and response efficacy.[46,58] Self-efficacy denotes individuals' confidence in planning and implementing actions to address microplastic emissions and was evaluated using five items.[76] Response efficacy refers to the perceived effectiveness of the recommended actions in mitigating microplastic emissions and was assessed using two items that evaluated the perceived effectiveness of reducing single-use product consumption and recycling.

Finally, perceived policy effectiveness refers to individuals' judgment regarding how effective government policies are in addressing microplastic issues. In this study, it was assessed using a single item: "What is your opinion on the effectiveness of the current government policies addressing microplastic issues? (e.g., regulations on single-use cups, straws, and plastic bags)." This study also examined whether perceived policy effectiveness moderates the effects of individuals' risk perception and efficacy on their intentions to reduce microplastic emissions.

The analytical model incorporating all the variables discussed above is specified in Equation I:

$$Intentions = \beta_0 + \beta_1 Severity + \beta_2 Vulnerability + \beta_3 Self + \beta_4 Response + \beta_5 Policy + \beta_6 (Severity \times Policy) + \beta_7 (Vulnerability \times Policy) + \beta_8 (Self \times Policy) + \beta_9 (Response \times Policy) + \gamma Controls + \varepsilon \quad (I)$$

where:

(i) "Intentions" denotes individuals' pro-environmental behavioral intentions to reduce microplastic emissions.
(ii) "Severity" and "Vulnerability" represent the two dimensions of perceived risk.
(iii) "Self" and "Response" indicate self-efficacy and response efficacy, respectively.
(iv) "Policy" refers to perceived policy effectiveness.

The interaction terms capture the moderating effects of "Policy" on the relationships between risk perception, efficacy, and pro-environmental intentions. "Controls" include gender, age, income, education, and political ideology (e.g., moderate, conservative), with the error term ε representing unexplained variance.

All variables were assessed using five-point Likert scales, and the mean scores were used for analysis. Descriptive statistics were calculated to summarize the characteristics of the survey responses (Table 1). The mean score of the dependent variable—intentions to reduce microplastic emissions—was 4.067, ranking second among all measured variables. The mean scores of the independent variables were as follows: perceived severity (3.829), perceived vulnerability (3.859), self-efficacy (3.205), and response efficacy (3.980). Among these variables, response efficacy recorded the highest mean score. The mean score of the moderating variable (perceived policy effectiveness) was 3.336.

As shown in Table 1, given the sufficient sample size (n = 1,000) and the observation that skewness values were below 2 and kurtosis values were below 7—thresholds commonly accepted in the literature as suggested by West *et al*.[77]—the dataset can be regarded as adequately meeting the assumption of normality.

Regarding the reliability and validity of the measurements, all constructs demonstrated strong internal consistency, with Cronbach's α and composite reliability values exceeding 0.7. All factor loadings (λ) were above 0.5, and the average variance extracted values were greater than 0.5, indicating adequate convergent validity. Discriminant validity was confirmed, as the square root of each construct's average variance extracted values exceeded its inter-construct correlations in most cases. All survey items, along with the detailed results of the reliability, validity, and model fit analyses, are presented in Table A2.

3.4. Analytical strategy

To test the hypotheses proposed in this study, hierarchical regression analyses were performed. First, zero-order correlations were examined to identify the relationships among the main variables and the intention to reduce microplastic use, as well as to assess the potential multicollinearity.

Subsequently, three models were specified. Model 1 included demographic control variables—such as gender, age, education level, income, and political ideology—together with the four independent variables—perceived severity, perceived vulnerability, self-efficacy, and response efficacy. This model assessed

Table 1. Descriptive statistics for main variables

Variable	Mean	Standard deviation	Minimum	Maximum	Skewness	Kurtosis
Intentions	4.067	0.736	1	5	−0.879	4.115
Severity	3.829	0.746	1	5	−0.659	3.785
Vulnerability	3.859	0.720	1	5	−0.662	3.764
Self	3.205	0.746	1	5	−0.320	3.087
Response	3.980	0.853	1	5	−0.869	3.726
Policy	3.336	1.052	1	5	−0.480	2.609

Note: n = 1,000.

the additional explanatory power of independent variables and determined their influence on the intention to reduce microplastic use.

Model 2 added the moderating variable—perceived policy effectiveness—to the structure of Model 1. This model examined whether individuals' perceptions of the effectiveness of government regulations independently influenced their intention to reduce microplastic emissions.

The moderating effect of perceived policy effectiveness was tested in Model 3 by including interaction terms between each of the four independent variables and the moderator.[78] Interaction terms were created by multiplying the independent variables with the moderator. Given the high correlations among predictors, moderators, and interaction terms, all variables involved in the interaction terms were mean-centered to minimize multicollinearity.

All analyses were conducted using STATA BE version 19 (StataCorp LLC, USA).

4. Hierarchical analysis and hypothesis testing results

4.1. Effects of risk perception and efficacy on microplastic reduction intentions

We conducted a hierarchical regression analysis to examine the effects of the independent variables on pro-environmental intentions to reduce microplastic use, as well as the moderating effects. All three models demonstrated an explanatory power exceeding 53%, with the significance of most variables remaining consistent across models, except for a few control variables.

Table 2 presents the results of the zero-order regression and the regression analyses for Models 1 and 2. A zero-order regression analysis was conducted to examine the bivariate relationships among the main variables. All independent and moderating variables were positively and significantly correlated with the intention to reduce microplastic use. To address

Table 2. Results of regression analysis on intentions to reduce microplastic emissions

Variables	Zero-order correlation	Model 1			Model 2		
		***B* (SE)**	**β**	**t**	***B* (SE)**	**β**	**t**
Constant	-	0.779*** (0.135)	-	5.776	0.770*** (0.135)	-	5.703
Risk perception							
Severity	0.545***	0.170*** (0.040)	0.172	4.205	0.167*** (0.040)	0.170	4.138
Vulnerability	0.524***	0.119** (0.041)	0.117	2.905	0.119** (0.041)	0.117	2.903
Efficacy							
Self	0.491***	0.162*** (0.025)	0.165	6.475	0.159*** (0.025)	0.161	6.290
Response	0.636***	0.325*** (0.023)	0.377	14.088	0.320*** (0.023)	0.371	13.645
Perceived policy effectiveness							
Policy	0.335***	-		-	0.017 (0.017)	0.025	1.040
Control							
Gender (female)	-	0.174*** (0.033)	0.118	5.277	0.169*** (0.033)	0.115	5.109
Age	-	0.042** (0.012)	0.078	3.409	0.041** (0.012)	0.076	3.324
Income	-	0.017* (0.008)	0.046	2.069	0.016* (0.008)	0.045	2.009
Education	-	0.012 (0.018)	0.015	0.658	0.011 (0.018)	0.014	0.634
Political ideology (moderate)	-	−0.049 (0.040)	−0.033	−1.236	−0.050 (0.040)	−0.034	−1.264
Political ideology (conservative)	-	−0.009 (0.049)	−0.005	−0.175	−0.010 (0.049)	−0.005	−0.205
n		1,000					
R^2 (ΔR^2)	-	0.541 (0.358)			0.541 (0.000)		
adjusted R^2	-	0.536			0.536		
F	-	116.42***			105.94***		

Note: *, **, and ***Indicate statistical significance at $p<0.05$, $p<0.01$, and $p<0.001$, respectively.
Abbreviation: SE: Standard error.

potential multicollinearity, where high correlations among predictors may distort regression estimates, the variance inflation factor values were examined. All variance inflation factor values were below the commonly accepted threshold of 10 (ranging from 1.21 to 3.56), indicating that multicollinearity was not a concern.

First, we assessed the effects of the independent variables on the dependent variable after controlling for demographic characteristics such as gender and age (Model 1). All independent variables had statistically significant effects on the dependent variable, and the model explained 53.6% of the variance in pro-environmental intentions. This level of explanatory power is consistent with previous studies.[46,58] Perceived severity (β = 0.172, t = 4.205, p<0.001) and perceived vulnerability (β = 0.117, t = 2.905, p<0.01) both exhibited significant positive effects on the intention to reduce microplastic emissions. Among the two, perceived severity showed a slightly stronger effect. Therefore, Hypotheses 1.1 and 1.2 (Section 2.2.1) were supported. These findings are consistent with those of previous studies by O'Connor *et al.*,[49] Semenza *et al.*,[53] Wachinger *et al.*,[50] and Zhu *et al.*,[51] which emphasize that individuals' risk perception is a key factor in motivating pro-environmental behaviors.

In terms of efficacy variables, both self-efficacy (β = 0.165, t = 6.475, p<0.001) and response efficacy (β = 0.377, t = 14.088, p<0.001) exhibited significant positive effects on the intention to reduce microplastic emissions, supporting Hypotheses 2.1 and 2.2 (Section 2.2.2). The effect of response efficacy was more than twice that of self-efficacy, making response efficacy the strongest predictor among the independent variables. Among the control variables, gender (β = 0.118, t = 5.277, p<0.001), age (β = 0.078, t = 3.409, p<0.01), and income (β = 0.046, t = 2.069, p<0.05) were positively and significantly associated with the intention to reduce microplastic emissions. These findings, which show that self-efficacy and response efficacy significantly influence pro-environmental intentions, are consistent with those of previous studies by Ku *et al.*,[30] Kim and Kim,[68] Bradley *et al.*,[70] and Van Valkengoed *et al.*,[66] all of which demonstrated the significant role of efficacy. Specifically, women, older individuals, and those with higher income levels were more likely to express intentions to reduce microplastic emissions.

Next, the moderating variable—perceived policy effectiveness—was incorporated to determine whether individuals' perceptions of the effectiveness of governmental regulations independently influenced their intention to reduce microplastic emissions (Model 2). The findings revealed no statistically significant direct effect of perceived policy effectiveness on individuals' reduction intentions. The explanatory power of Model 2 was the same as that of Model 1 (adjusted R^2 = 0.536). This finding suggests that although individuals may comply with existing government regulations, such compliance does not necessarily translate into voluntary pro-environmental intentions. Although perceived policy effectiveness was above moderate level (Table 1), its influence on intentions was non-significant, indicating a

Table 3. Moderating effects of perceived policy effectiveness

Variables	Model 3		
	***B* (SE)**	**β**	***t***
Constant	3.731*** (0.109)	-	34.100
Risk perception			
Severity	0.162*** (0.040)	0.164	4.000
Vulnerability	0.114** (0.041)	0.112	2.787
Efficacy			
Self	0.154*** (0.025)	0.156	6.093
Response	0.317*** (0.024)	0.367	13.147
Perceived policy effectiveness			
Policy	0.022 (0.017)	0.032	1.326
Interaction			
Severity–policy	−0.023 (0.038)	−0.029	−0.622
Vulnerability–policy	−0.025 (0.037)	−0.030	−0.669
Self–policy	−0.045* (0.022)	−0.054	−2.018
Response–policy	0.024 (0.020)	0.035	1.193
Control			
Gender (female)	0.166*** (0.033)	0.113	5.005
Age	0.040** (0.012)	0.075	3.245
Income	0.014 (0.008)	0.040	1.801
Education	0.013 (0.018)	0.017	0.755
Political ideology (moderate)	−0.054 (0.040)	−0.036	−1.354
Political ideology (conservative)	−0.002 (0.049)	−0.001	−0.040
n	1,000		
R^2 (ΔR^2)	0.547 (0.006)		
Adjusted R^2	0.540		
F	79.18***		

Note: *, **, and ***Indicate statistical significance at p<0.05, p<0.01, and p<0.001, respectively.
Abbreviation: SE: Standard error.

potential mismatch between individuals' understanding of policy objectives and their perceptions of risk and efficacy regarding microplastics.

A *post hoc* power analysis based on the sample size (n = 1,000), the observed R^2 (0.541), and the significance level (α = 0.05) indicated a statistical power of 1.000, which substantially exceeds the recommended threshold of 0.80.[79] This result confirms that the present study had sufficient power to detect the observed effects, as the 0.80 benchmark proposed by Cohen[79] is widely recognized as a conventional standard in social science research.

Models 1 and 2 confirmed that all explanatory variables proposed by PMT had significant effects. These findings suggest that PMT provides a robust framework for explaining individuals' pro-environmental intentions.

4.2. Moderating effects of perceived policy effectiveness

Table 3 presents the moderating effect of perceived policy effectiveness through the interaction terms (Model 3). The explanatory power of Model 3 slightly increased to 54.7% compared with Models 1 and 2. For Model 3, a *post hoc* power analysis was also conducted using the sample size (n = 1,000), the observed R^2 (0.547), and the significance level (α = 0.05). The analysis yielded an estimated statistical power of 1.000, well above the conventional threshold of 0.80 proposed by Cohen.[79] This result provides strong evidence that the study design ensured sufficient statistical power, thereby enhancing the robustness and credibility of the observed findings.

While previous studies have reported both positive and negative moderating effects of perceived policy effectiveness on the relationship between individual perceptions and pro-environmental intentions, the present findings revealed a negative moderating effect on the intention to reduce microplastic emissions (β = −0.054, t = −2.018, p<0.05), contrary to the expectation outlined in Hypothesis 4 (Section 2.3). This suggests that when individuals perceive government microplastic regulation policies as effective, the influence of their self-efficacy on pro-environmental intentions diminishes. In particular, Wan *et al.*[80] suggested that this phenomenon occurs because positive perceptions of regulatory effectiveness may activate other internal motivations, thereby diminishing the relative impact of self-efficacy on pro-environmental intentions. Although the study by Wan *et al.*[80] did not yield statistically significant results; it demonstrated a similar directional pattern to that of the present study, in which perceived policy effectiveness weakened the relationship between self-efficacy and recycling intentions. Liao *et al.*[75] found that the direction of the moderating effect varied depending on the type of policy—empowerment-oriented policies strengthened the relationship, whereas incentive-based policies weakened it. Meanwhile, Shen *et al.*[41] and Fu *et al.*[81] reported a positive moderating effect on the relationship between self-efficacy and behavioral intentions.

In the relationships among perceived severity, perceived vulnerability, response efficacy, and the intention to reduce microplastic emissions, there were no significant moderating effects of perceived policy effectiveness. However, although this relationship was statistically non-significant, the interaction between response efficacy and reduction intention exhibited a uniquely positive moderating effect among all independent variables. This finding may suggest the potential for a synergistic effect when policy interventions are aligned with citizens' response efficacy.

Among the control variables, consistent with Model 1, gender and age remained significant predictors of reduction intentions. Specifically, female and older respondents were more likely to express stronger intentions to reduce microplastic consumption. The analytical results indicate that females, compared with males, and older individuals tend to demonstrate stronger pro-environmental intentions, consistent with previous studies by Minton and Rose[28] and Kim *et al.*[46]

Figure 2 illustrates the moderating effect of perceived policy effectiveness in Model 3. As shown in the figure, all lines display an upward trend, indicating

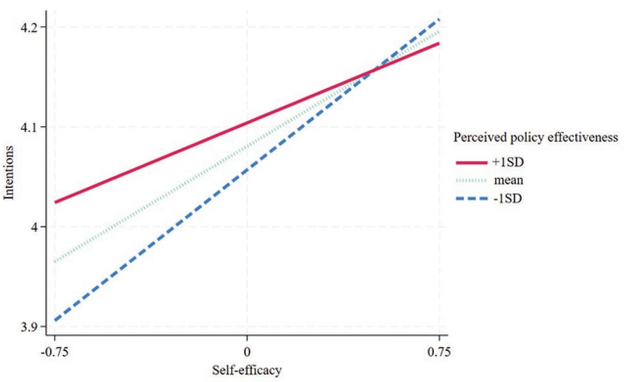

Figure 2. Moderating effect of perceived policy effectiveness

Note: Both self-efficacy and intention values were mean-centered.

Abbreviation: SD: Standard deviation.

that self-efficacy positively influences the intention to reduce microplastic emissions. When perceived policy effectiveness is low (dashed line), the positive relationship between self-efficacy and reduction intentions is stronger, as reflected by the steeper slope. In contrast, when perceived policy effectiveness is high (solid line), the slope becomes flatter, suggesting a diminished effect of self-efficacy on reduction intentions. This pattern implies that individuals who perceive government regulations as more effective may rely less on self-efficacy when forming intentions to reduce microplastic use. This result contradicts the initial hypothesis that perceived policy effectiveness would positively moderate the relationship between self-efficacy and individuals' pro-environmental behavioral intentions.

5. Discussion and policy implications

Based on the findings, several policy implications can be drawn. First, the results supporting Hypotheses 1.1 and 1.2 suggest that individuals with higher levels of perceived severity and vulnerability regarding microplastics are more likely to intend to reduce microplastic use. Across all models, perceived severity exhibited a stronger effect than perceived vulnerability. This indicates that while people recognize the seriousness of environmental problems, they may not perceive them as immediate or personal threats.

In South Korea, microplastic-related policies have been repeatedly postponed, modified, or withdrawn by the government,[12] resulting in the absence of a coherent institutional framework for microplastic reduction. Moreover, microplastics represent a typical example of an environmental issue that falls into the so-called "environmental blind spot".[7] Although microplastics are pervasive in everyday life, appearing in clothing and drinking water, they are difficult to directly perceive. Furthermore, while people may be aware of the problems associated with plastic packaging and single-use products that generate microplastics, the convenience of disposables makes voluntary behavioral change difficult to achieve. In other words, individuals either fail to recognize the problem or, even when aware, tend to prioritize convenience over environmental protection.[7]

Therefore, it is necessary to establish a stable institutional framework with a consistent direction to address the problem of microplastics. Consistent policies can convey clear messages to policy targets, thereby facilitating their participation in pro-environmental behaviors. In addition, public campaigns can be implemented to actively raise public awareness of the risks posed by microplastics, especially their persistent yet invisible presence in daily life. It is also important to identify and communicate everyday sources of microplastic emission that are often overlooked. A good example is the European Union's MicroDrink project, which aims to improve drinking water quality by mitigating microplastic contamination and enhancing public awareness of the issue.[82]

Second, the results supporting Hypotheses 2.1 and 2.2 indicate that both self-efficacy and response efficacy positively influence individuals' intentions to reduce microplastic use. Among all predictors, response efficacy—the belief that one's efforts will be effective—exhibited the strongest effect. This suggests the importance of clearly communicating the impact of individual actions. As environmental issues often involve a long lag between personal efforts and visible outcomes, efficacy may diminish over time. Previous research has shown that providing immediate feedback can strongly encourage pro-environmental behavior.[83] Therefore, it is important to communicate specific information about how individual efforts, such as reducing plastic use, can lead to long-term reductions in microplastic emissions. Reducing this time lag can help strengthen response efficacy and contribute to microplastic reduction. As individuals experience tangible outcomes from their daily actions, they may feel more connected to environmental issues, which in turn can enhance their pro-environmental intentions at the psychological level.[84] This underscores the importance of designing policy mechanisms that provide timely and visible feedback to sustain individuals' efficacy beliefs and encourage long-term engagement in pro-environmental behaviors.

An illustrative policy example is Seoul City's "personal cup point system," which provides discounts and reward points to consumers who use personal cups.[85] By utilizing accumulated data, individuals can monitor their annual contributions to reducing single-use product consumption. By linking visible contributions with tangible rewards, the system functions as an effective policy instrument that reinforces motivation for pro-environmental behavior.

Third, rather than applying uniform regulations, it is important to design policies that account for individuals' internal motivations. The moderation test for Hypothesis 4 revealed that when people perceive government regulations as effective, the influence of self-efficacy on the intentions to reduce microplastic emissions decreases. Consistent with Wan *et al*.,[80] this

suggests that belief in regulatory effectiveness may activate other internal motivations, such as a sense of obligation to comply with rules, thereby reducing the relative impact of self-efficacy on intentions.

Similar patterns have been observed in studies examining the relationship between government regulation and corporate motivation, where external environmental regulations can undermine internal motivations such as autonomy and moral responsibility—a phenomenon known as the "motivation crowding-out effect." This effect is particularly pronounced among groups with high levels of internal motivation.[86] These findings imply that strict government mandates may reduce individuals' self-efficacy. Therefore, in addition to penalty-based or restrictive policies, governments should also promote lifestyle changes through incentive-based approaches that stimulate people's internal motivations.

For example, creating living environments that support voluntary daily actions may be an effective strategy. In response to microplastic emissions from washing synthetic fabrics, several washing machine manufacturers have introduced microplastic-reducing features. If the government expands technical and financial support for such initiatives, it may help mitigate the crowding-out of companies' internal motivation caused by regulation. At the same time, enabling people to reduce microplastic emissions through everyday actions could also enhance their sense of efficacy. In January 2020, France enacted legislation mandating the installation of filters in washing machines to mitigate microplastic emissions from textiles.[87] In South Korea, however, while there have been attempts to introduce legislation aimed at reducing microplastics, these measures have yet to be enacted, and policy support remains limited.

6. Conclusion

This study examined the effects of individuals' risk perception and efficacy on their intentions to reduce microplastic emissions, as well as whether this relationship is moderated by perceived policy effectiveness. In particular, this study applied the PMT framework, which provides distinct policy-relevant insights compared with previous research.

The empirical analysis demonstrated that perceived severity, perceived vulnerability, self-efficacy, and response efficacy were all positively associated with individuals' intentions to reduce microplastic emissions. Among these variables, response efficacy exerted the greatest influence. In addition, a moderating effect of perceived policy effectiveness was identified: higher perceptions of policy effectiveness attenuated the positive effect of self-efficacy on reduction intentions.

This study provides several valuable insights. First, the findings underscore the need to incorporate individuals' perceptions and psychological factors into policy design. Second, this study applied PMT as the theoretical framework for understanding microplastic reduction intentions, thereby demonstrating its applicability within this emerging research domain. In particular, the finding that response efficacy exhibited the strongest explanatory power suggests that policy design should ensure individuals clearly understand the potential impact of their actions on environmental improvement. Finally, by empirically verifying the moderating effect of perceived policy effectiveness, this study highlights that achieving environmental policy goals requires not uniform regulations but the development of diverse policy instruments that reflect the psychological characteristics of the target population.

While these contributions are meaningful, several limitations should be acknowledged. As the analysis was based on survey data, there may be a gap between behavioral intentions and actual behaviors. Further research should measure actual microplastic reduction behaviors and compare them with stated intentions to provide deeper behavioral insights. Furthermore, differentiating perceptions of policy effectiveness, including how individuals evaluate the impact of incentives, could provide more specific and actionable policy implications.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: All authors

Data curation: All authors
Formal analysis: Mihyeon Yu
Funding acquisition: Yoomi Kim
Investigation: Mihyeon Yu
Methodology: Yoomi Kim, Mihyeon Yu
Project administration: Yoomi Kim
Resources: Yoomi Kim, Yungwook Kim, Hyemi Lee
Software: Mihyeon Yu
Supervision: Yoomi Kim
Validation: Mihyeon Yu, Yoomi Kim
Visualization: Mihyeon Yu
Writing–original draft: Mihyeon Yu
Writing–review & editing: Yoomi Kim, Mihyeon Yu

Ethics approval and consent to participate

This study was conducted in compliance with the ethical standards of Ewha Womans University, Seoul, South Korea. Before data collection, all prospective participants were informed about the study's objectives, given a definition of microplastics along with examples of substances that produce them, and informed of the categories of demographic data to be collected. Details regarding the informed consent form are provided in Table A1. No personally identifiable information that could directly reveal participants' identities was collected. All data were handled with strict confidentiality and used exclusively for statistical analyses relevant to the study's objectives. Participation was voluntary, and informed consent was obtained from all participants. Participants were also informed of their right to withdraw from or terminate the survey at any time without penalty.

Consent for publication

Not applicable. This study does not contain any individual person's identifiable data in any form, including individual details, images, or videos.

Availability of data

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. All shared data will be anonymized to protect participant confidentiality.

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Appendices

Table A1. Consent procedure

Korean original (translated into English)[a]
Research information and consent form
Dear participant,
This study aims to investigate public perceptions, policy acceptance, consumer attitudes, and behaviors related to microplastics through a survey. The personal information collected will include basin demographic details such as gender, age, and marital status; however, no information that could identify you individually will be collected. All personal data will be kept strictly confidential and will be used solely for statistical analyses required the research.
Please note that there are no "right" or "wrong" answers. We kindly ask you to respond honestly and thoughtfully. By selecting the "I Agree" checkbox below, you indicated your consent to participate in this study. Even if you consent, you may withdraw from the survey at any time without any penalty or disadvantage. If you wish to withdraw, please click the "End Survey" button at the bottom of the online survey page.
Would you like to participate in this survey?
□ I Agree (Proceed to the next page) □ I Do Not Agree (End the survey)

Note: [a]The original Korean version of the consent form provided to participants is available from the corresponding author on request.

Table A2. Reliability and validity of measurement

Variables	Items	α
Intentions to reduce microplastic emissions	I'm willing to accept immediate inconvenience or personal costs to reduce microplastic emissions	0.874
	I'm willing to use a reusable shopping bag instead of disposable plastic bags to reduce microplastic emissions	
	I'm willing to use a tumbler or reusable bottle instead of disposable paper cups to reduce microplastic emissions	
	I'm willing to use products that are effective in reducing microplastic emissions, such as washing machines equipped with microplastic filters, even if they are more expensive	
Perceived severity	How serious do you think the impact of microplastics on you and your family?	0.921
	How serious do you think the impact of microplastics will be on your local community?	
	How serious do you think the impact of microplastics will be on Korean society?	
Perceived vulnerability	To what extent do you think you and your family are likely to experience health problems caused by microplastics?	0.895
	To what extent do you think your local society is likely to experience health problems caused by microplastics?	
	To what extent do you think Korean society is likely to experience health problems caused by microplastics?	
Self-efficacy	I'm capable of coming up with specific plans to solve the problem of microplastics	0.851
	I have enough financial resources to carry out plans to solve the problem of microplastics (e.g. purchasing a tumbler)	
	I have a lot of people who support me when I try to solve microplastic problems (e.g. family or friends)	
	I believe I can manage financial difficulties associated with microplastic problems	
	I believe I can carry out the actions required to address the microplastic problem without difficulty	
Response efficacy	I believe that reducing the use of disposable products (e.g., paper cups, straws, plastic bags) is an effective way to address the microplastic problem	0.776
	I believe that separating and recycling plastic waste is an effective way to address the microplastic problem	

(Cont'd...)

Table A2. ***(Continued)***

Variables	Items	α
Perceived policy effectiveness	What is your opinion on the effectiveness of the current government policies addressing microplastic issues (e.g., regulations on single-use cups, straws, plastic bags)?	-
Control	Gender, age, income, education, and political ideology	-

Note: Model fit indices indicated an acceptable model fit (χ^2=741.196; p=0.000; root mean square error of approximation=0.076; comparative fit index=0.946; standardized root mean square residual=0.051). All factor loadings (λ) were statistically significant (p<0.001) and exceeded 0.5. Composite reliability (>0.7) and average variance extracted (>0.5) demonstrated adequate construct reliability and convergent validity, and discriminant validity was also supported.