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# Studying Waste Separation Behaviors and Environmental Impacts toward Sustainable Solid Waste Management: A Case Study of Bang Chalong Housing, Samut Prakan, Thailand

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**Abstract:** This study aims to develop more inclusive and sustainable waste management practices to be implemented in Bang Chalong Housing, a model community with unsatisfactory waste separation and recycling rate. The extended theory of planned behavior was employed to investigate the effect of attitude, subjective norm, perceived behavioral control, knowledge, and situational factors on household waste separation intention and behavior, using structural equation modeling as a tool. Based on the questionnaire responses of 321 residents, the house owner's status exhibited a considerable impact on waste-sorting behavior. Knowledge ($\beta = 0.653$; $p < 0.001$) and subjective norm ($\beta = 0.160$; $p < 0.05$) were two significant predictors of the respondents' intention, which showed a strong influence on household waste separation behavior ($\beta = 0.804$; $p < 0.001$). Various waste management scenarios were also evaluated through material flow analysis and life cycle assessment. Installing a waste-sorting plant in addition to the current approach (recycling and landfilling) could annually reduce 26.4 tons of solid waste from being landfilled and mitigate GHG emissions by up to 47.4 tons $CO_2$ equivalent. Finally, the implications of these results on designing interventions and amending waste management schemes were discussed.

**Keywords:** municipal solid waste; source separation; waste recycling; extended TPB; structural equation modeling; material flow analysis; life cycle assessment

## 1. Introduction

Municipal solid waste has become a serious issue affecting human and environmental well-being worldwide [1]. Unlike the past, municipal solid waste these days is rapidly generated as a result of accelerated urbanization, population growth, changes in lifestyles, and novel material invention [2]. The continual increase in the amount and diversity of municipal solid waste is a major barrier to quality of life and urban development [3]. Therefore, solid waste management could serve as a key to successful sustainable development, especially in low-income and lower-middle-income states [4]. Thailand, as a developing and middle-income country, has been generating municipal solid waste ranging

from 20 to 30 tons annually [5]. The waste generation rate of Thais has been estimated as 1.1 kg/capita/day [6], higher than the average value observed in other developing countries (0.77 kg/capita/day) [7]. In 2020, only 33% of the total waste generated was sorted and recycled, 36% was landfilled and incinerated, and 31% was improperly managed by open dumping and open burning [5]. Mishandling of waste streams leads to various ecological impacts such as air pollution, greenhouse gas (GHG) emissions, and surface and subsurface contamination [2]. GHG emitted from solid waste management was estimated as 1.6 billion tons of carbon dioxide equivalent ($CO_2$ eq). This number accounted for 5% of global GHG emissions, and it is expected to rise by 62.5% by 2050 unless solid waste handling has been improved [8]. Additionally, in 2014, a huge fire crisis occurred at the unsanitary landfill located in Phraeksa district, Samut Prakan province. The incident caused severe environmental, economic, and health consequences, pushing the government to raise solid waste as an urgent national issue. Subsequently, the master plan on national solid waste management (2016–2021) has been executed based on the fundamental 3Rs principle (i.e., reduce, reuse, and recycle) [9]. The 3R elements, particularly, recycling, are a potential solution to waste management problems, aligning with the concept of circular economy [10]. The system of solid waste management involves various stages, from waste generation to waste source-handling, waste collection and transport, waste processing and utilization, and waste disposal [3]. Among these, source separation plays a key role in determining how efficient the recycling is. The Pollution Control Department (PCD) of Thailand has classified municipal solid wastes into four main types: organic, recyclable, hazardous, and general waste. The lack of waste separation at the source leads to a major obstacle to sustainable waste management, especially recyclable plastics. Thailand produces 2 million tons of plastic waste annually (12% of the entire waste generated), and only 25% of it (500,000 tons) could be recycled [11]. This trouble came up with The Roadmap on Plastic Waste Management for 2018–2030, with the target of 100% of plastic recycled by 2027 [12].

In Thailand, besides the lack of governmental support [13], changing people's behavior is another challenge to waste separation and recycling [14]. Poor separation at the source results from various factors, such as people's awareness, inadequate facilities, and difficulty of separation [2], which need to be understood through individuals' perception and behavior [15]. Bang Chalong Housing is the residential area located in Samut Prakan province, which is a peri-urban area connected to the southern part of Bangkok. We are interested in this area since it has been developed and recognized by the National Housing Authority as a model community on municipal solid waste management. Despite its good waste-related performance, the recycling program initiated in the community has been unsuccessfully implemented. This situation led to our question of why most residents were not interested in joining the program and which factors are potentially capable of changing their mindset and behaviors toward waste separation and recycling. Among various methodologies, the theory of planned behavior (TPB) has been suggested to address such environmental-related inquiries [16,17]. The TPB is a theoretical framework explaining an individual's decision-making process, in which intention and behavior are involved [18–20]. It is also used to explain an individual's pro-environmental behavior in various aspects, such as energy conservation [21–23], green hotel behavior [24,25], green-buying behavior [26], alternative transportation [27], waste-recycling behavior [28–30], and waste-sorting behavior [31–33].

To date, studies of the TPB model to predict people's behavioral intention towards waste sorting and recycling have been limited in Thailand. For instance, Apinhapath [34] applied the conventional TPB concept to study recycling behaviors in Rong-J community, Ayutthaya province. In Bangkok, source separation intention resulting from a variety of socio-economic and psychological variables was investigated by Ittiravivongs [35] and Vassanadumrongdee and Kittipongvises [13]. During the COVID-19 pandemic, Pongpunpurt et al. [36] studied factors influencing people's intention to perform plastic waste separation and recycling. In addition to the behavioral study, sustainable waste management practice requires the consideration of associated environmental performance prior to implementation. Combined

material flow analysis (MFA) and life cycle assessment (LCA) has recently emerged as a tool supporting decision-making regarding solid waste management [37–40]. Within the boundary of waste management systems, the waste flows can be systematically described by MFA [41–43], and LCA is then used to assess environmental burdens and benefits of particular materials [44,45].

Based on these explanations, this is the first study aiming to develop more sustainable and inclusive waste management schemes to be implemented in Bang Chalong Housing and other similar areas. The community status in terms of population background and waste management practice was observed. We applied the TPB model to investigate the significant predictors of household waste separation intention among residents. Environmental impacts of various waste management scenarios were evaluated using the integrated MFA and LCA, in which recyclable plastic wastes were selected as studied materials due to their high economic values [46]. We expect the findings of this work to be useful for establishing more effective infrastructure, educational campaigns, and recycling initiatives, improving household waste separation and management in local communities and beyond. More importantly, the Sustainable Development Goals (SDGs) can be promoted in terms of sustainable cities and communities (SDG 11), including sustainable consumption and production (SDG 12).

## 2. Theory of Planned Behavior and Research Hypotheses

### 2.1. Theory of Planned Behavior

The theory of planned behavior (TPB) was originally proposed by Icek Ajzen [19] as the extension of the theory of reasoned action (TRA) [47]. The TPB has been applied to evaluating an individual's intention to perform a particular behavior. According to the TPB model, the behavioral intention is predicted through a systematic investigation of various constructs, i.e., attitude, subjective norm, and perceived behavioral control [16].

- Attitude is defined as an individual's favorable or unfavorable evaluation of a specific behavior [19]. Attitude is based on people's behavioral beliefs and emotional state. Therefore, the action of a behavior tends to be performed according to what people find beneficial. On the other hand, the action of a behavior tends to be rejected if people find the behavior harmful [19,47]. Several researchers have indicated the significant effect of attitude on pro-environmental behaviors. Moreover, a positive attitude towards recycling has been discovered to be a potential predictor of an individual's recycling intention and behavior [48–52].

- Subjective norm is defined as the social pressure and constraints affecting an individual to choose whether to execute a planned behavior [19,47]. It is guided by normative beliefs regarding the major referent approval or disapproval of the behavior by a person or groups such as communities, family, friends, and colleagues. Previous studies illustrated that subjective norm is perceived in the form of pressure sensing from others—for example, seeing surrounding people separate waste helps drive residents to sort their waste [13,53]. Moreover, subjective norm has been discovered to be a determinant strongly influencing engagement in waste sorting and recycling, particularly for Asian people [54].

- Perceived behavioral control refers to the self-assessment of an individual on their capability and willingness to perform behaviors [19,55,56]. It is a reflection of a person's past experiences and predicted obstacles that either encourage or prevent individuals from expressing a given behavior. The correlation between perceived behavioral control and people's intention has been observed by various researchers [51,57,58]. Interestingly, Shen et al. [53] asserted that the intention towards waste-sorting behavior of the younger generation is most affected by perceived behavioral control.

Based on the conventional TPB model, our research hypotheses are proposed as follows:

**Hypothesis 1 (H1).** *Intention has a positive impact on household waste separation behavior.*

**Hypothesis 2 (H2).** *Attitude has a significant impact on the intention to perform household waste separation.*

**Hypothesis 3 (H3).** *Subjective norm has a significant impact on the intention to perform household waste separation.*

**Hypothesis 4 (H4).** *Subjective norm is the strongest predictor of household waste separation intention.*

**Hypothesis 5 (H5).** *Perceived behavioral control has a significant impact on the intention to perform household waste separation.*

*2.2. Extended TPB*

Although the TPB model is well known for three predictors (i.e., attitude, subjective norm, and perceived behavioral control), its structure is flexible. Additional predictors are applied and combined with the original TPB model to enhance the model's explanatory power based on the specific context and background of the research problem [20,59]. The examples of added predictors are behavioral, normative, and control beliefs [60]; past behavior [61,62]; moral norm [60,63]; self-identity [61]; and awareness of consequences [64]. In this work, as demonstrated in Figure 1, we extended the TPB model by adding two relevant predictors, namely, situational factor and knowledge.
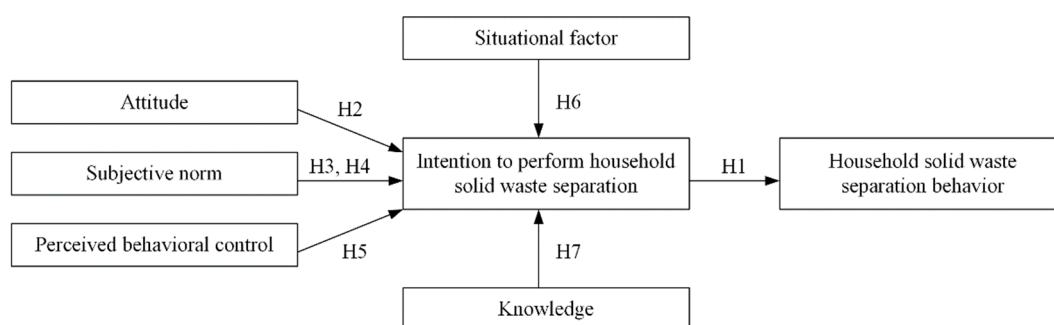


**Figure 1.** Extended TPB framework.

- A situational factor is defined as the given situation regarding the behavioral context and the individual's characteristics [65]. Situational factors can be used as a determinant in predicting the intention of individuals [66,67]. In waste management fields, Schultz et al. [68] stated that situational variables provide a significant increase in waste-recycling behavior. Moreover, the situational factor in terms of consumer perception of lacking conveniences (i.e., waste storage facilities and separation time) significantly affected recycling intention and behavior [69,70].
- Knowledge is an important additional factor correlated to people's intention toward environmentally responsible behaviors such as waste separation and recycling [31,71]. Environmental knowledge was proven to be a factor indirectly affecting pro-environmental behaviors in the form of environmental awareness, values, and attitudes [32,72]. The lack of environmental information associated with waste separation and management can pose as a hindrance to residents whose desire to correctly sort their waste [73,74]. Hence, waste-related knowledge should be taken into account when investigating waste separation and recycling behaviors.

These explanations brought us the following hypotheses:

**Hypothesis 6 (H6).** *Situational factors have a positive impact on the intention to perform household waste separation.*

**Hypothesis 7 (H7).** *Knowledge has a positive impact on the intention to perform household waste separation.*

### 3. Methodology

#### 3.1. Study Area

Bang Chalong Housing is a residential community located in Bang Chalong Subdistrict, Bang Phli District, Samut Prakan Province, Thailand (13°36′03.6″ N 100°44′54.9″ E). Our study area was the first phase (Area 1) of this community (Figure 2), in which 16 buildings with 625 households are present.
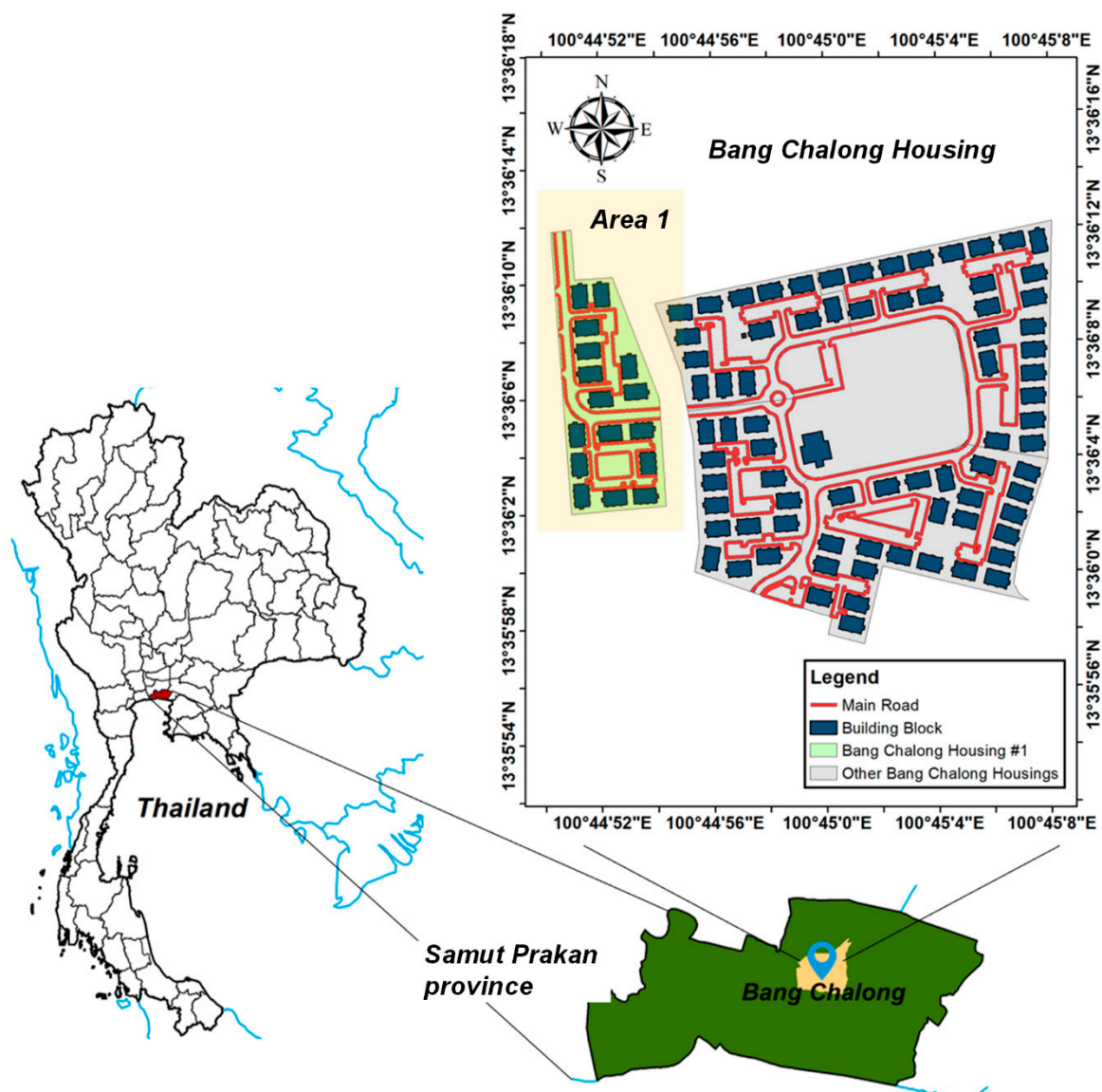


**Figure 2.** Bang Chalong Housing area (photo obtained from Wikipedia and Google Maps).

In this part, two groups of data were mainly investigated:

#### 3.1.1. Community's Solid Waste Composition

The municipal solid waste was subjected to random sampling and analysis using the quartering method adapted from the Pollution Control Department (PCD) of Thailand. Raw data were collected once a month from October 2020 to June 2021 (9 months), and the solid waste samples were classified into four categories as follows:

1. Organic or food waste.
2. Recyclable waste such as paper, glass, metal, rubber, clothes, leather, and plastic. Specifically, plastic wastes were sorted into seven types, including polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), expanded polystyrene (EPS), and multilayer ones.
3. Hazardous waste such as aerosol cans, fluorescent lamp, and batteries.
4. Others such as infectious wastes and thermosetting plastic.

### 3.1.2. Community's Solid Waste Management

This part aims at understanding the current solid waste management within the community. Data were collected from field observation, relevant documents obtained from Bang Chalong Subdistrict Administrative Organization (SAO), and personal communication with a juristic person in charge of the community's waste management.

### 3.2. Questionnaire Survey

A structured questionnaire was created to collect two parts of the data: (1) socio-economic factors, including age, gender, education level, monthly income, occupation, ownership status, and household size, and (2) socio-psychological factors related to the TPB model. A set of statements (Table 1) both adapted from the literature and newly designed in this work was provided to respondents. The responses were received in the form of their level of agreement to those statements using a five-point Likert scale, ranging from strongly disagree (−2) to strongly agree (2).

Before the questionnaire distribution, a pilot study was carried out using Google Forms in order to verify the factor loadings of all the items on the questionnaire. The participants received the link through convenience sampling, and 41 questionnaire responses were collected. According to Yamane's formula [75], a sample size of at least 244 of 625 households was required at a confidence level of 95%. The final version of questionnaires was administered to each household in August 2021 with the aid of community administrators. A response rate of 57.8% was achieved, and 321 valid questionnaire responses were considered adequate for further analysis.

**Table 1.** Extended TPB constructs and the questionnaire statements.

| Construct | Item | Observed Variable | Source |
|---|---|---|---|
| Attitude toward the behavior (AT) | AT1 | I think household waste separation is a good activity. | [67] |
| | AT2 | I think household waste separation is a useful activity. | [67] |
| | AT3 | I think waste separation should be promoted in Thailand. | [67] |
| Subjective norm (SN) | SN1 | My family thinks I should separate household waste. | [67] |
| | SN2 | My friends influence me to separate waste. | [67] |
| | SN3 | Residents in my community influence me to think that I should separate household waste. | [30] |
| | SN4 | Community leaders influence me to think that I should separate household waste. | This study |
| | SN5 | Actors or actresses influence me to think that I should separate household waste. | This study |
| | SN6 | Politicians influence me to think that I should separate household waste. | This study |
| | SN7 | Religious leaders (e.g., monks and priests) influence me to think that I should separate household waste. | This study |

**Table 1.** *Cont.*

| Construct | Item | Observed Variable | Source |
|---|---|---|---|
| Perceived behavioral control (PBC) | PBC1 | I think I adequately understand how to separate household waste. | [60] |
| | PBC2 | I think household waste separation is an easy task. | [67] |
| | PBC3 | I think I can separate my household waste. | [67] |
| Situational factors (SF) | SF1 | I have insufficient space for household waste separation. | [67] |
| | SF2 | I think household waste separation is a time-consuming activity. | [13] |
| | SF3 | I have insufficient facilities for waste separation (e.g., bins for separated waste and nearby drop-off points). | [71] |
| Knowledge (KN) | KN1 | I think I have knowledge of the benefits of household waste separation. | [31] |
| | KN2 | I think I have knowledge of how to correctly separate household waste. | [31] |
| | KN3 | I think I have knowledge of the negative impacts resulting from not separating household waste. | [31] |
| Intention (IN) | IN1 | I intend to start separating household waste before disposing of it. | [76] |
| | IN2 | I intend to separate household waste in the near future. | [76] |
| | IN3 | I'm pleased to participate in the upcoming project relating to household waste separation. | This study |
| Behavior (BE) | BE1 | I always separate household waste before disposing of it. | [67] |
| | BE2 | I always separate food waste from others before disposing of it. | [67] |
| | BE3 | I seldom separate my household waste. | [77] |
| | BE4 * | I separate my household waste: always (80–100%), often (60–79%), sometimes (40–59%), occasionally (20–39%), rarely (1–19%), never (0%). | This study |

* The item was only considered for the study of socio-economic factors due to its different measurement scale compared to others (i.e., the frequency was applied instead of the agreement level).

### 3.3. Data Analysis

The effect of socio-economic factors was investigated on four observed variables, including BE1 ("I always separate household waste before disposing of it"), BE2 ("I always separate food waste from others before disposing of it"), BE3 ("I seldom separate my household waste"), and BE4 ("I separate my household waste"). Based on the Shapiro–Wilk method, non-parametric statistical analysis was applied in this part, as the collected data did not normally distribute. We used the Mann–Whitney U test to analyze the effect of gender, which comprised two independent variables. The Kruskal–Wallis one-way analysis of variance test was employed for the remaining factors, namely, age, education, income, occupation, ownership status, and household size. If a significant difference ($p$-value < 0.05 at 95% confidence) was observed, the results were then be analyzed through a post-hoc test with pairwise comparison.

For the second part of the questionnaire, structural equation modeling (SEM) was applied for data analysis using IBM SPSS AMOS 22.0. The theoretical model was evaluated for its consistency with the actual data using factor analysis and path analysis. With the aid of SEM, the socio-psychological factors (AT, SN, PBC, SF, KN, and BE) could be

indirectly measured through the questionnaire statements observed by the respondents' self-assessment. The analysis was conducted with two sub-models: (1) the measurement model to study the relationship between latent variables and observed variables using confirmatory factor analysis (CFA), and (2) the structural model to determine the significant influence among latent variables using multiple regression analysis.

### 3.4. MFA and LCA

This part aims to compare the environmental impacts caused by different management options for two plastic waste materials: (1) polyethylene terephthalate (PET), plastic waste with high economic value, and (2) polyethylene (PE), plastic waste with a bulk volume (results obtained from Section 3.1.1) but with a low recycling rate of only 19% in 2019 [11]. Six scenarios (S0–S5), as displayed in Table 2, were investigated. We gathered both primary (field observation and personal communication) and secondary (relevant statistical reports from the community) data to establish the MFA of PET and PE wastes using the STAN 2.6 software [78], in which three stages were incorporated: (1) waste generated from consumption, (2) waste separation and transferring, and (3) waste recycling/disposal.

**Table 2.** Waste management scenarios used for environmental impact assessment.

| Scenario | Description | Note |
|---|---|---|
| S0 | Recycling + landfilling | Current waste management in Bang Chalong Housing community |
| S1 | 100% recycling | A sustainable waste management option [79] |
| S2 | 100% landfilling [a] | The most common waste disposal method in Thailand [11] |
| S3 | 100% incineration | Plastic waste burned by a municipal incinerator [b] without energy recovery |
| S4 | 100% waste-to-energy (WtE) | Plastic waste burned by a municipal incinerator [b] with energy recovery |
| S5 | Waste-sorting plant + recycling + landfilling | Waste-sorting plant installed to improve the current approach to plastic waste management |

[a] No waste loss during transportation to landfill. [b] Incinerator was equipped with air pollution control equipment.

The environmental impacts of an individual scenario were evaluated by life cycle assessment (LCA). We assumed that the environmental impacts from post-consumer plastics (sorting, collection, and transportation) were equal for all scenarios. Therefore, the system boundary included only the end-of-life of plastic wastes (i.e., landfilling, incineration, and recycling). The functional unit was set as the annual amount of PET and PE plastic waste to be managed. The life cycle inventory was obtained from the MFA results as well as the ecoinvent database v3.6 provided in SimaPro 9.1.1.7 (more details in Table S9, Supplementary Material). We applied the CML-IA baseline V3.06 with midpoint assessment for the impact assessment of each scenario. A variety of impact categories was assessed as follows: abiotic depletion; abiotic depletion of fossil fuels; global warming potential GWP100a; ozone layer depletion; human toxicity; freshwater aquatic, marine aquatic, and terrestrial ecotoxicity; photochemical oxidation; acidification; and eutrophication.

## 4. Results and Discussion

### 4.1. Solid Waste Composition and Current Management

The composition of municipal solid waste generated from Bang Chalong Housing is displayed in Figures S1–S3 (Supplementary Material). In this community, organic (64.4%) and recyclable (33.4%) wastes were two major waste compositions. This result was similar to those found in several communities, such as the capital and most populous city, Bangkok [13]; the peri-urban area in Nonthaburi [80]; and the tourist area in Chiang Rai province [81], indicating that organic waste or food waste is an urgent issue among various

waste management problems in Thailand [5]. For recyclable wastes (Figure S2), we mainly observed plastic (67.1%), paper (15.5%), and glass (14.6%). Due to its high proportion and value, plastic waste was then sorted and classified into seven materials, as displayed in Figure S3. As a result of household appliances and food packaging, PE (48.3%), PP (26%), multilayer (12.7%), and PET (10.8%) were found as the major plastic materials.

As presented in Figure 3, the community currently handles generated solid waste through four major approaches, as follows:

- Installation of six garbage bins (6 $m^3$ in volume each) around the area, each of which can carry approximately 2.7 tons of solid waste. Each household needs to pay for a waste management cost of THB 25 per month. Once these bins are full, the legal entity is responsible for the additional steps. The waste transporter of Bang Chalong subdistrict municipality collects this waste to dispose of in Phraeksa subdistrict, Samut Prakan. Currently, the community generates solid waste of around eight to nine bins per month, each of which costs THB 1200 for collection, transportation, and disposal.
- Establishment of a recycling program through which residents can sell their recyclable wastes and used cooking oil. Then, these items are resold by the community's leader to the external market (e.g., junk shops and waste collectors). This activity leads to a smaller waste volume, which minimizes the overall waste management cost and provides additional income to the community's residents. In addition, people joining this recycling program can get a lucky-draw coupon as a New Year's prize.
- Installation of a green cone using existing soil organisms to turn organic/food wastes into fertilizer via aerobic degradation. This method is still under development to be best suited to the community, and 20% of organic waste is expected to be minimized by 2022.
- Installation of hazardous and infectious waste-collecting points to avoid contamination and hazard to people and the environment. Bang Chalong Subdistrict Administrative Organization (SAO) is responsible for managing these wastes, from collection to final disposal, at no expense.
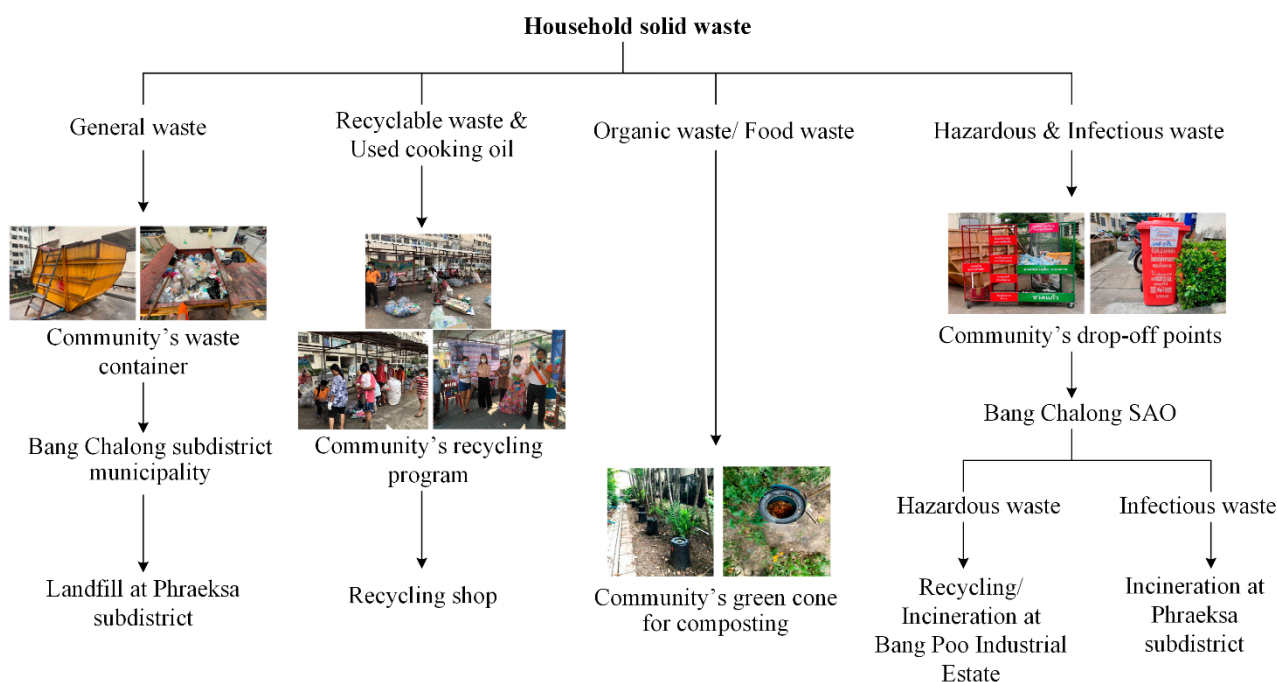


**Figure 3.** Current waste management routes in Bang Chalong Housing community.

Bang Chalong Housing has been promoted as a model community of solid waste management practice. Based on the questionnaire response to item BE4, 53% of the respondents frequently separate household waste, whereas 47% occasionally or do not separate waste. Although most respondents exhibited waste separation behavior, only 11% of the total residents had participated in the community's recycling program. Therefore, it is vital to understand the residents' perception on waste separation and recycling. In addition, factors influencing their waste separation behavior should be investigated in order to improve the community's waste management system to be more collaborative and sustainable.

### 4.2. Effects of Socio-Economic Factors on Household Waste Separation Behavior

The respondents' socio-economic data in terms of gender, age, education, monthly income, occupation, ownership status, and household size are presented in Table 3. The responses indicated that most of residents are female (58.6%) and aged 31 to 45 years old (44.2%). Most of them have graduated from high school or equivalent (44.2%) and work as a company's employee (51.7%). Moreover, they mainly possess homeowner status (48.6%), with a household size of one to two people (62.9%) and a monthly income ranging from THB 15,001 to 20,000 (31.1%). The effect of these factors on household waste separation behavior was investigated through four variables (BE1, BE2, BE3, and BE4), as described in Table 1. The statistical results are illustrated in Tables S1–S7 (Supplementary Material).

**Table 3.** Socio-economic data of the 321 respondents in Bang Chalong Housing community.

| Parameter | Categories | Frequency | Percentage |
|---|---|---|---|
| Gender | Male | 133 | 41.4% |
| | Female | 188 | 58.6% |
| Age | 18–30 | 58 | 18.1% |
| | 31–45 | 142 | 44.2% |
| | 46–60 | 96 | 29.9% |
| | Above 60 | 25 | 7.8% |
| Education level | Below high school | 85 | 26.5% |
| | High school | 142 | 44.2% |
| | Bachelor's degree | 64 | 19.9% |
| | Master's degree or above | 30 | 9.4% |
| Household monthly income (THB) | Below 5000 | 21 | 6.5% |
| | 5000–10,000 | 56 | 17.5% |
| | 10,001–15,000 | 82 | 25.6% |
| | 15,001–20,000 | 100 | 31.1% |
| | Above 20,000 | 62 | 19.3% |
| Occupation | Public-sector employee | 16 | 5.0% |
| | Private-sector employee | 166 | 51.7% |
| | Own business | 24 | 7.5% |
| | Self-employed | 78 | 24.3% |
| | Student | 9 | 2.8% |
| | Unemployed | 21 | 6.5% |
| | Others | 7 | 2.2% |
| Ownership status | Owner | 156 | 48.6% |
| | Renter | 96 | 29.9% |
| | Tenant (no rental fee) | 69 | 21.5% |
| Household size (people) | 1–2 | 202 | 62.9% |
| | 3–4 | 99 | 30.8% |
| | 5–6 | 20 | 6.3% |

Waste separation at the source is considered a recycling behavioral pattern for which the effect of gender is still unconcluded [82]. In this work, the four observed variables (BE1–BE4) between males and females did not significantly differ (*p*-value > 0.05 at 95% confidence), implying that waste separation behavior was not affected by gender. This finding corresponds well with the studies of De Feo and De Gisi [83] and Hage and Soder [84]. According to previous researchers [85,86], females tend to have more participation in pro-environmental behaviors and waste-related activities than males, particularly in communities in which recycling is not a conventional behavior [87]. This explanation supports our results, since Bang Chalong Housing is a model community in which most residents, both male and female, have been acquainted with recycling activities.

Age is the sociodemographic factor most studied in regard to recycling behavior [36]. The previous studies by Saphores et al. [85] and Meneses and Palacio [88] reported that adults aged 36–65 years old are most willing to act on recycling behaviors. However, age was not a significant parameter affecting the waste separation behavior of Bang Chalong Housing's residents. As the community's recycling program has been operational for several years, household waste separation has become the norm and most adults always bring their children to join in the recycling activity. Moreover, the community's recycling point can serve as a common place for all generations to keep in touch and spend their time together.

The impacts of educational level on recycling behaviors vary from study to study [89]. Researchers found that people with a higher educational level have a higher tendency to separate and recycle solid waste [83,85]. On the other hand, Ma et al. [3] showed that the respondents with less education play a greater role in separating waste at the source. In contrast, we observed no significant effect of educational level on waste separation behavior, consistent with the findings from Ekere et al. [86] and Lee and Paik [90]. As shown in Table 3, the majority of residents had graduated from Thailand's high school or below, in which environmental education is not emphasized. Therefore, we concluded that there is no significant difference in environmental knowledge among the residents.

In this work, we found a significant impact of monthly income on two observed variables (BE1 and BE2). The difference was observed between people with a monthly household income of THB < 5000 and THB 5001–10,000. However, we did not notice any difference between the sampling groups with a monthly income greater than THB 10,001. Therefore, it could not be concluded that higher monthly income led to a higher household waste separation rate. Our finding showed diverse relationships between monthly income and household waste separation, unlike the study of Lee and Paik [90,91], which reported that the recycling behavior of Korean households was significantly impacted by income. Specifically, household income is a flexible determinant in which opportunity cost can be involved. Separating solid waste may be a time-consuming activity that causes higher opportunity cost, particularly for high-income households [84].

For ownership status, a significant difference was detected in the observed variable BE4 (i.e., "I separate my household waste") between homeowners (mean rank = 169.59) and tenants (mean rank = 136.09). The results agreed well with the study of Wang et al. [92], which suggested that people with homeowner status have more positive attitude towards waste separation intention. To clarify, homeowners seem to separate household waste more often than others since they have planned to stay in their homes for a long period. Therefore, they are willing to improve the environmental living conditions through their own behaviors.

In terms of occupation and household size, we did not observe a significant impact on waste separation behavior. This could be due to the similar characteristics among Bang Chalong Housing's residents. The majority of them work as a private-sector employees (>50%) and have a household size of 1–2 people (>60%). Thus, household waste separation behavior could not be explained by occupation or household size, consistent with the findings of Keramitsoglou and Tsagarakis [93].

Overall, our findings correspond well with the study conducted in Bangkok [13], except for that of gender, age, and monthly income. These results suggest that it is necessary to understand the characteristics of each area prior to design and implementation of waste management guidelines and practices. Additionally, the context of each area such as waste management system and infrastructure, people lifestyles, politics, economics, as well as social interaction should be considered [33,94].

### 4.3. Effects of Socio-Psychological Factors on Household Waste Separation Behavior

4.3.1. Measurement Model and Structural Model

Table 4 illustrates the measurement model after some variables were eliminated to achieve satisfactory results and a good explanation of the latent variables. The original measurement model is also given in Table S8 (Supplementary Material). We tested the construct reliability using Cronbach's alpha coefficient and composite reliability (CR). All constructs had a Cronbach's alpha ranging from 0.752 to 0.919 and agreed well with the threshold value of 0.7 [95]. The CR values were all greater than 0.7, exceeding the acceptable level recommended by Kline [96]. In addition, the convergent validity and the suitability of items making up the construct were assessed, employing factor loading and the average variance extracted (AVE). It is clear that the loadings of all items were above the recommended value of 0.7 [97]. The AVE values ranging from 0.605 to 0.792 also agreed with the threshold of 0.5 [98]. Therefore, the measurement model exhibited adequate reliability and validity.

**Table 4.** Measurement model.

| Construct | Item Number | Item | Loading Factor | Cronbach's Alpha | Composite Reliability | Average Variance Extracted |
|---|---|---|---|---|---|---|
| AT | 3 | AT1<br>AT2<br>AT3 | 0.886<br>0.896<br>0.737 | 0.876 | 0.879 | 0.711 |
| SN | 3 | SN5<br>SN6<br>SN7 | 0.884<br>0.903<br>0.883 | 0.919 | 0.919 | 0.792 |
| PBC | 2 | PBC2<br>PBC3 | 0.855<br>0.905 | 0.872 | 0.873 | 0.775 |
| SF | 1 | SF3 | - | - * | - | - |
| KN | 3 | KN1<br>KN2<br>KN3 | 0.898<br>0.909<br>0.829 | 0.910 | 0.911 | 0.774 |
| IN | 2 | IN1<br>IN3 | 0.799<br>0.740 | 0.752 | 0.754 | 0.605 |
| BE | 2 | BE1<br>BE2 | 0.904<br>0.864 | 0.877 | 0.877 | 0.782 |

* The Cronbach's alpha of SF could not be calculated, as it was considered an observed variable.

The result of the structured TPB model and the standardized regression weight of the path analysis are shown in Figure 4 and Table 5, respectively. Both the measurement model and the structural model were evaluated for their goodness-of-fit. The overall model fit was assessed through several indices, namely, $\chi^2$/df (Chi-square divided by degree of freedom), GFI (goodness-of-fit index), AGFI (adjusted goodness-of-fit index), CFI (comparative fit index), and RMSEA (root mean square error of approximation), as displayed in Table 6. It is obvious that all model fit indices agreed well with the criteria proposed by Bortoleto et al. [99]. Thus, it can be concluded that our proposed models were acceptable and adequately fitted the data.
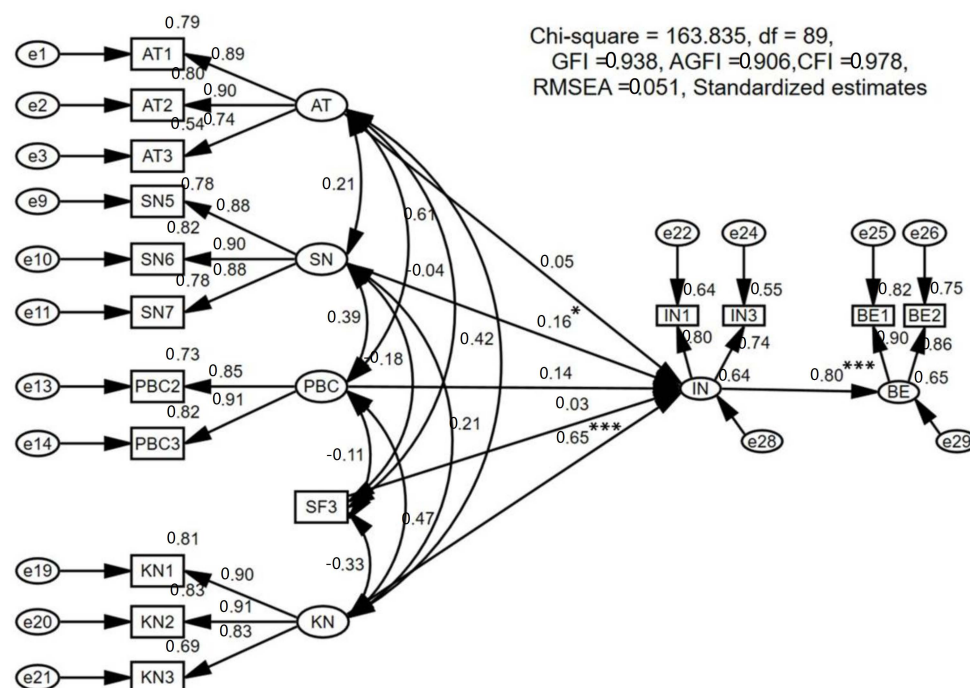
**Figure 4.** Structural model of the extended TPB framework.

**Table 5.** Path coefficients of the extended TPB framework.

| Path | Standardized Regression Weights (*β*) | *p* | Hypothesis |
|---|---|---|---|
| IN → BE | 0.804 *** | <0.001 | H1 |
| AT → IN | 0.046 | 0.477 | H2 |
| SN → IN | 0.160 * | 0.002 | H3 & H4 |
| PBC → IN | 0.139 | 0.055 | H5 |
| SF3 → IN | 0.028 | 0.566 | H6 |
| KN → IN | 0.653 *** | <0.001 | H7 |

* Significant at $p < 0.05$; *** significant at $p < 0.001$.

**Table 6.** Goodness-of-fit of the model.

| Model | Fit Index | | | | |
|---|---|---|---|---|---|
| | $\chi^2/df$ | GFI | AGFI | CFI | RMSEA |
| Criteria | <3.0 | >0.9 | >0.9 | >0.9 | <0.07 |
| Measurement model | 1.853 | 0.941 | 0.905 | 0.978 | 0.052 |
| Structural model | 1.841 | 0.938 | 0.906 | 0.978 | 0.051 |

### 4.3.2. Interpretation of the SEM Results

As displayed in Table 5, only subjective norm and knowledge showed a positive and significant impact on people's intention to perform household waste separation. This finding supported hypotheses H3 and H7. The path coefficients revealed that a unit increase in subjective norm and knowledge would raise the residents' intention to separate waste by 0.16 and 0.65 units, respectively. It is obvious that knowledge played the greatest role in predicting the intention of respondents to separate household waste. Thus, hypothesis H4 was rejected. This result agrees well with the study of Ittivivongs [35], which found that knowledge is a factor highly affecting the waste-recycling intention of people living in Bangkok. Having sufficient knowledge could increase the willingness of people to separate and recycle waste [76,100], enhance public participation and environmental awareness [1], and change people's attitude toward waste separation behavior [93]. Subjective norm was another factor influencing people's intention to separate household waste.

Matthies et al. [101] indicated the positive influence of parental behaviors on children's personal norm regarding recycling, and this norm could be enhanced by gaining more knowledge from others [102]. In Bang Chalong Housing community, people tend to collaborate in household waste separation as a result of social pressure. The recycling campaign has been transferred from generation to generation and, more importantly, the community's administrators always present their outstanding leadership and intimate relationships with residents in endorsing household waste separation and recycling. Furthermore, we observed the strong impact of intention on waste separation behavior. The path coefficient of 0.80 indicated that waste separation behavior expanded 0.80 units for a single unit added to intention. Hence, hypothesis H1 was accepted.

In this work, attitude did not significantly impact the intention to separate household waste. This result implies that the respondents did not recognize waste separation as an activity that is beneficial to their lives, which might be due to lack of time, knowledge, rewards, or social pressure [103]. Thus, hypothesis H2 was rejected. Our result differs from several previous studies [60,82], but agrees with that observed in Bangkok [13]. Most people in Bangkok and Bang Chalong Community work as employees. This might cause difficulty in carrying out waste separation due to limited time as well as the lack of waste separation knowledge [104]. Likewise, the remaining constructs, i.e., PBC and situational factors, were not significant predictors of household waste separation intention. Hypotheses H5 and H6 were thus rejected. The result implies that the intention to perform waste separation behavior was not influenced by individuals' past experiences, which is inconsistent with the study of Pakpour et al. [15] and Shi et al. [33]. Additionally, convenient facilities such as bins and drop-off points were not a significant factor determining waste separation behavior of Bang Chalong Housing's residents.

Overall, the results supported hypotheses H1, H3, and H7 while rejecting hypotheses H2, H4, H5, and H6. The intention of Bang Chalong Housing's residents to perform household waste separation was significantly affected by knowledge and subjective norm. Moreover, the intention exhibited a positive impact on waste separation behavior following the TPB principle. Based on these findings, the community's leader should produce effective educational campaigns through community-based activities to enhance public environmental knowledge and their engagement in waste separation and recycling. In addition, governmental organizations as well as local authorities should integrate formal environmental education into various communication channels such as television, schools, books, posters, the internet, or even signs on dustbins [103]. Once people are more involved in source separation and recycling programs, community leaders should frequently inform the residents of waste management status and progress, allowing them to realize the consequences of their actions. Finally, the community may offer monetary, psychological, or social rewards (e.g., scholarships, praise, or certificates, respectively) to those with satisfactory waste-related behaviors. This measure not only increases people's incentives for waste separation but also creates a community role model, enhancing the significant function of the subjective norm.

*4.4. Environmental Impacts of Various Waste Management Scenarios*

In this part, we analyzed the environmental impacts generated from various waste management scenarios (Table 2) using MFA and LCA. Two types of plastic wastes, including PET and PE, were selected as representative of all waste due to their high economic opportunity and circular economy potential.

According to the MFA results (Figure 5), the studied community annually generates 289.62 tons of solid waste, and this number was further applied for all scenarios. The Bang Chalong Housing community currently manages the two types of plastic waste through recycling and landfilling (S0). With this approach, the annual amount of PET and PE of 1.14 tons (15.81%) and 0.70 tons (2.54%), respectively, is separated and undergoes the community's recycling program (Figure 5a). On the other hand, the plastic waste disposed in the community's garbage bin is ultimately managed by landfilling, resulting in

6.07 tons of PET (84.19%) and 26.88 tons of PE (97.46%). For scenarios S1, S2, S3, and S4 (Figure 5b), the amount of PET and PE waste to be managed was 7.21 tons and 27.58 tons, respectively. For scenario S5 (Figure 5c), the current approach was provided with a waste-sorting plant from which 80% material recovery was achieved, representing the minimum separation efficiency of plastic packaging wastes by manual sorting [105]. Thus, the plastic waste managed by recycling was 5.99 tons of PET (83.08%) and 22.20 tons of PE (80.49%). Meanwhile, the plastic waste disposed of by landfilling was 1.22 tons (16.92%) of PET and 5.38 tons (19.51%) of PE.
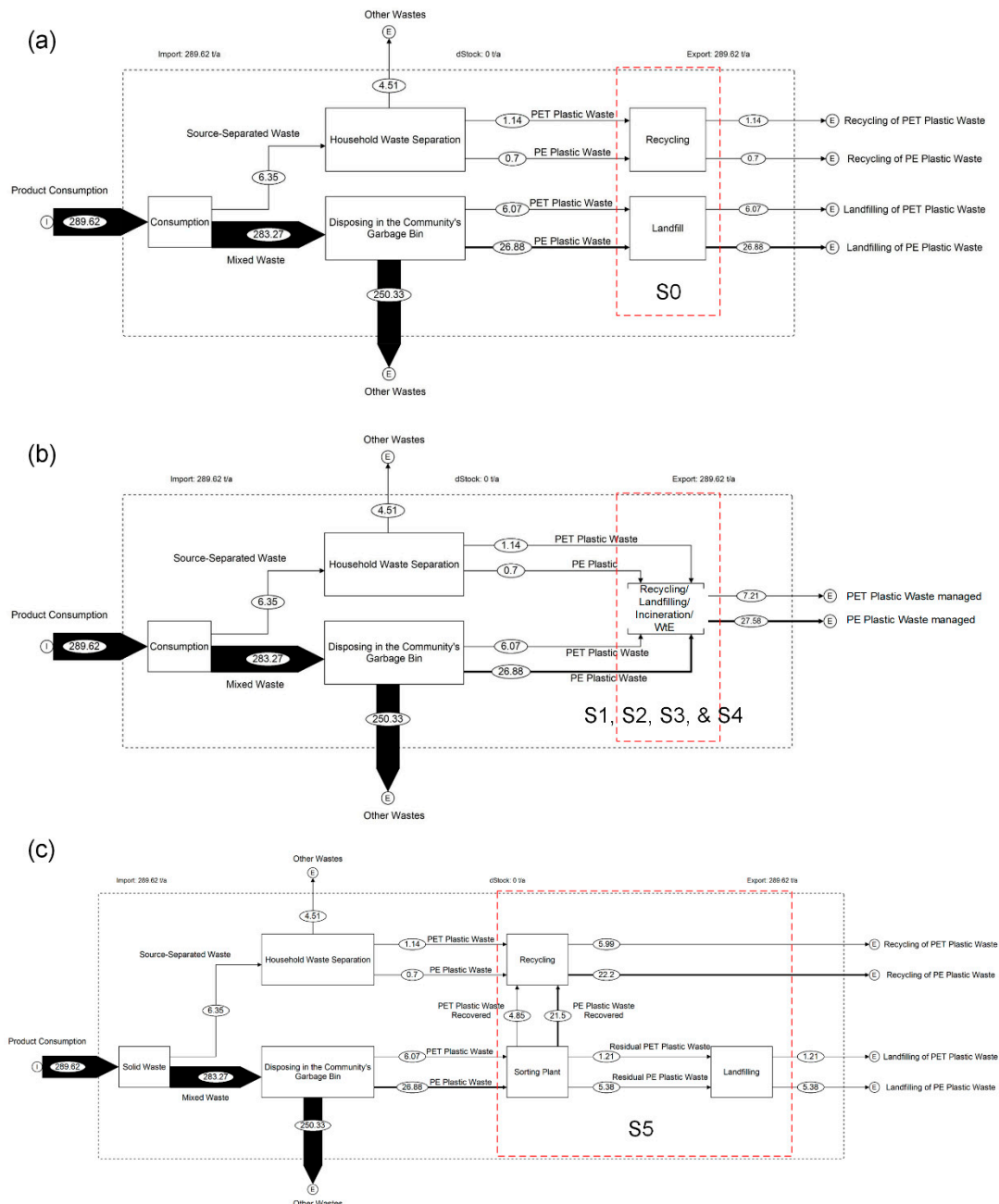


**Figure 5.** The MFA results of different waste management scenarios: (**a**) S0 (recycling and landfilling), (**b**) S1 (100% recycling); S2 (100% landfilling); S3 (100% incineration); S4 (100% WtE), and (**c**) S5 (sorting plant, recycling, and landfilling).

The functional unit used for LCA was 34.79 tons, indicating the total amount of PET and PE plastic waste to be handled. The environmental impacts resulting from various plastic waste management scenarios are illustrated in Figure 6 and Table S10

(Supplementary Material). The positive and negative values represent environmental burdens and environmental benefits, respectively. Among the six scenarios, S1, S5, and S4 contributed to the highest environmental advantages. Total recycling of plastic wastes (S1) or installing a waste-sorting plant (S5) could minimize the overall environmental impact generated with the current approach (S0). Incineration of PET and PE waste for energy recovery (S4) also exhibited remarkable environmental benefits, particularly for fossil fuel depletion, terrestrial ecotoxicity, acidification, and eutrophication. This can be explained by the reduced utilization of fossil fuel as well as the significant reduction of sulfur dioxide released from coal combustion [106]. In terms of environmental burdens, the current management of plastic wastes (S0) caused notable adverse impacts in terms of human toxicity, aquatic ecotoxicity, and eutrophication. These impacts mainly occurred from a major part of plastic wastes being landfilled, especially for those with unsanitary properties. Landfilling of PET and PE wastes resulted in leachate containing toxic substances, microplastics, and nutrient compounds that could contaminate the subsurface environment and eventually enter our food chain [107]. As expected, the worst environmental impacts were obtained from total landfilling (S2) and incineration without energy recovery (S3). Compared with S0, scenario S2 did not improve any environmental issue, whereas S3 showed the only benefit on the impact of eutrophication.
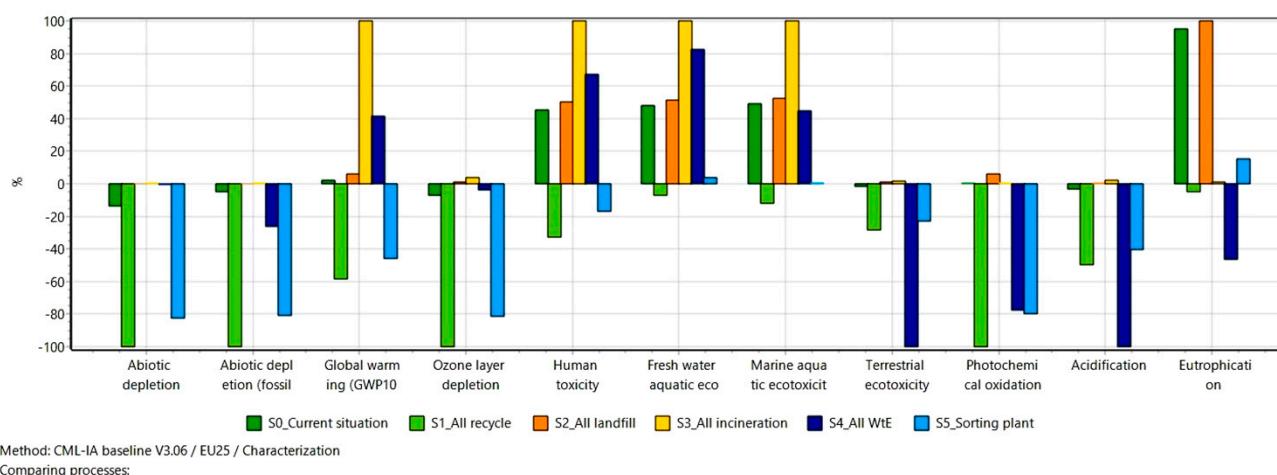


**Figure 6.** Environmental impacts of PET and PE plastic waste management by different scenarios.

Considering the effect on climate change specifically, the maximum global warming impact was observed from S3 (98,231 kg $CO_2$ eq), S4 (40,541 kg $CO_2$ eq), and S2 (5972 kg $CO_2$ eq) due to their high GHG emissions (e.g., fossil fuel combustion and anaerobic digestion). On the other hand, S1 and S5 demonstrated a mitigation of climate change impacts. Compared with the current management (S0), S1 (100% recycling) had the lowest global warming impact since the use of fossil fuel as the feedstock for plastic production could be reduced. Moreover, none of the plastic waste was disposed of at a landfill, which is the major source of methane gas. Total recycling of PET and PE waste could abate the annual GHG emissions of 59.27 tons $CO_2$ eq, resulting in THB 2035.33 of carbon credit as a community asset (the average price per ton $CO_2$ eq was THB 34.34 in 2021 [108]). The installation of a waste-sorting plant (S5) was also preferred over the current situation. A higher rate of separation of plastic wastes led to more plastic being recycled, lessening the GHG emissions by up to 47.4 tons $CO_2$ eq (THB 1627.72 of carbon credit).

In summary, S1 (total recycling) and S5 (waste-sorting plant) were the two scenarios showing advantages over the current approach in terms of environmental benefits. Based on the context of Bang Chalong Housing, S1 seemed unpractical since some PET and PE plastic wastes obtained from the community's garbage bin could be unacceptable for recycling, causing a certain number of discarded plastics. As a result, we highly recommend scenario S5 as a potential plastic waste management approach for this community. Besides GHG

emissions mitigation, a waste-sorting plant could minimize at least 26.35 tons of solid waste from being collected and transported to landfills, saving THB 12,000 annually of the overall waste management cost. Additionally, the community could make a profit from selling the separated PET and PE plastic to waste collectors, which can yield up to THB 130,000 per year (given the purchase price of THB 5 for 1 kg PET and PE plastic waste). This option, however, may need a lot of capital and a high operational cost at the beginning. Thus, the provincial or local administrative organizations should accommodate the community in terms of equipment and technical training so that the community can operate a plant itself in the long run. Furthermore, based on this option, the community could be acknowledged as a model residential area associated with the concepts of sustainable waste management and circular economy.

### 5. Conclusions and Recommendation

The purpose of this research is to develop more sustainable municipal solid waste management in Bang Chalong Housing, Samut Prakan, Thailand. The effects of socio-demographic and socio-psychological variables on household waste separation behavior were studied. The TPB framework (attitude, subjective norm, and perceived behavioral control) extended with knowledge and situational factor was employed together with SEM to determine the substantial predictor of people's behavioral intention towards household waste separation. Furthermore, we applied MFA and LCA to observe the environmental impacts of different waste management scenarios, in which PET and PE plastic wastes were chosen as the material representative. According to our findings, ownership status exhibited a significant impact on household waste separation behavior. It was found that a homeowner had a stronger attitude towards waste separation intention compared to that of tenants. Knowledge ($\beta = 0.653$) and subjective norm ($\beta = 0.160$) were two major catalysts stimulating people's intention toward household waste separation, which in turn showed a positive and strong correlation with their behavior ($\beta = 0.804$). In terms of the community's waste management, we recommend using the current approach (S0, recycling and landfilling) along with the installation of a waste-sorting plant (S5) in order to achieve the greatest environmental and economic benefits (e.g., mitigating GHG emissions, reducing overall waste volume and management expenditures, and increasing the community income through recycling programs).

This work suggests practical implications regarding the integrated waste management framework governed mainly by a public–private–people partnership (4P). The relevant government agencies should pay serious attention to household waste sorting by providing functional environmental knowledge. Well-designed educational channels must be developed for a variety of people to enhance their waste-related awareness and knowledge (e.g., waste problems and their impacts on our lives, easy procedures for household waste separation, and advantages of waste recycling). Local and community committees may create social rewards, role models, or joint activities promoting the recycling campaign, as well as encourage people to separate their wastes as a result of subjective norms or social pressure. Public and private sectors may collaborate to provide sufficient facilities and technologies to accommodate household waste separation and recycling, which in turn promotes the community's revenue in the long run. Besides the community itself, these findings are beneficial to policymakers as well as local and provincial administrative organizations in planning and implementing more effective waste management schemes in accordance with the concept of circular economy.

The present study, however, was conducted during the COVID-19 outbreak, which might have affected regular people's behaviors and solid waste composition. Moreover, our findings could not represent the whole community of Bang Chalong Housing, as the study area was confined to Area 1. To obtain more complete and practical results, further studies should be performed in new-normal situations, taking into consideration the additional TPB constructs and extended areas. The environmental impacts should be comprehensively assessed for more extensive materials and waste management choices starting from cradle

to grave. Finally, theory-driven interventions and policies should be carefully designed and implemented in real practice.

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