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Original Research Article

Carbon footprint analysis of Post-Consumer Recycled PET Value Chain of different plastic collection regions

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ABSTRACT

The substantial growth of PET bottle consumption has increased amount of plastic waste and caused environmental impacts. PET recycling is one of potential alternatives in solving plastic waste crisis; however, the system on collection and recycling of used PET bottles in Thailand is still mismanaged. In addition, recycled PET (rPET) plastics are mostly used in non-food applications (e.g., fiber and durable household goods) with low quality post-consumer recycled (PCR) resin. This study aims to compare the environmental impacts on post-consumer recycled PET value chain (from small plastic buyer (or Saleng) to recycling manufacturer) for the geographic differences in plastic collecting regions (Bangkok and Rayong province) by using the concept of life cycle assessment (LCA) analysis. Key challenges and opportunities on using rPET for food contact packaging in Thailand using PESTEL analysis were investigated. In-depth interviews with related stakeholders of PCR value chain were conducted. Preliminary result on LCA showed that post-consumer recycled PET value chain of 1 kg of used PET bottles in Bangkok (2.222 kgCO2e) emits higher carbon footprint than post-consumer recycled PET value chain in Rayong province (1.860 kgCO2e). The differences in using electricity in plastic baling processing and the distance from medium-sized (or large-sized) plastic collectors to recycling manufacturer play prominent indicators on carbon emission. The challenges of using rPET for food contact packaging are the impractical plastic collection system and waste management, high cost of technologies of PET recycling production, the migration potential of food contact chemicals on PET bottle, misuse of refillable PET bottles, lack of awareness on waste separation, and lack of regulations on rPET for food contact packaging. Moving toward rPET for food contact packaging requires not only collaboration among stakeholders across PET bottles lifecycle, but also public awareness on waste management to ensure food contact safety of rPET and sustainable value chain.

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INTRODUCTION

In 2020, 300 million tons of plastic waste were produced and brought to the market annually, and only 9% of total global plastic waste were recycled and reused properly. Some plastic wastes are disposed by incineration, 19% causing severe pollution, 50% going to landfills, and 22% remaining in nature, leading to global warming and imbalance ecosystems (The Organization for Economic Co-operation and Development, 2022). Plastic waste on Polyethylene terephthalate (PET) bottle category has the most significant proportion of recycled plastics compared to other types of recycled plastic. In 2018, Thailand had approximately 600,000 tons per year of bottle collection for recycling, representing 17.6% of the total amount of plastic waste 3.49 million tons per year (World Bank Group, 2021). Under this signal, Thailand has prioritized climate change impacts by developing the Climate Change Master Plan 2015-2050 for mitigation, adaptation, and cross-cutting issues. Thailand is increasingly at risk of catastrophes and is highly vulnerable to future climate change impacts as the 9th most affected country in 1999-2018, ranked by the Global Climate Risk Index (CRI). Total GHG emissions by sector (excluding land use, land-use change and forestry) in 2016 are as follows: energy (71.65%), agriculture (14.72%), industrial processes and product use (8.90%), and waste (4.73%) (Ministry of Natural Resources and Environment, 2021)

Recycled polyethylene terephthalate (rPET) can be recycled and reused by washing before being melted and molded into a new product and repeated many times. Since the 1970s, the technique of blow molding was developed, and PET bottles had rapid growth in food and beverage consumption sectors (Leblanc, 2020). Packaging waste after consumption constitutes a highly heterogeneous waste stream such as PET bottle waste by misuse of refillable, lack of awareness on waste separation could lead to the migration potential of food contact chemicals on PET bottle. Plastic recycling process, especially in plastic packaging must be reliable and safety, such as sorting, cleaning, and reprocessing to gain high quality recycled materials for food-contact packaging. Recycling is strongly influenced by legislation and involves flourishing activities and different actors in a complex value chain such as small plastic buyers, plastic collectors, plastic buyers, and recycling manufacturers (Gasde et al., 2021).

The carbon footprint is the total amount of carbon dioxide emitted throughout the product life cycle by products or services from all stages and calculated in the form of carbon dioxide equivalents or CO2e (Chaiyaboot, Kosanlavit, Kongritti, and Noinumsai, 2021). Life cycle assessment (LCA) is a "Cradle-to-Cradle" approach for assessing industrial systems, enabling the estimation of the cumulative environmental impacts resulting begins with collecting raw materials from each stakeholder, including transporting raw materials and fuels, and the product life cycle ends at the stage that all materials are delivered to recycling manufacturers (Sevde and Hanife, 2016).

A comprehensive literature review and interviews were conducted to identify the challenges and opportunities on using rPET for food contact packaging. The six PESTEL aspects were adopted and reclassified into themes pertaining to the construction business environment including political, economic, social-culture, technological, environmental, and legal forces. The study by Gasde et al., (2021) indicted that current political force is guided by a circular economy and leaded to further regulations, such as increase the use of recycling rate and waste avoidance. Both political and legal forces play a significant role in the challenging implementation of new identification and screening technologies.

Bangkok is capital city of Thailand with a dense population of 10 million people, which generate plenty of solid wastes. In 2021, Bangkok's solid waste was 12,214 tons/day, and solid waste was recycled by 3,564 tons/day (Pollution Control Department, 2022). Another developing economic area, Rayong is an industrial area that belongs to the Eastern Economic Corridor (EEC), which has main import and export ports, and the recycling manufacturers and waste collectors. In 2021, Rayong's solid waste was 1,086 tons/day, and solid waste was recycled by 105 tons/day. Many small plastic buyers in Bangkok and Rayong transport plastic bales to similar location of the recycling manufacturer, thus these provinces were selected for the study.

Comparison of the environmental impacts on post-consumer recycled PET from small plastic buyers to recycling manufacturer) for the geographic differences in plastic collecting regions (Bangkok and Rayong province) were examined by using life cycle assessment (LCA) technique. Key challenges and opportunities on using rPET for food contact packaging in Thailand using PESTEL analysis were investigated.

MATERIALS AND METHODS

Methodology

Stakeholders from small plastic buyers to recycling manufacturer were chosen using purposive sampling method. Selected stakeholders were interviewed and compared the environmental impacts of the geographic differences in term of carbon emission in the unit of kgCO2e. The perspectives on using rPET for food packaging and business performance to examine key challenges and opportunities using PESTEL analysis.

Two main sources of data were collected. First, for primary data, in-depth interviews were conducted with key stakeholders who are relevant to the post-consumer recycled PET value chain in Bangkok and Rayong province. The various chain actors were interviewed (May-September 2022) including small plastic buyers (or Saleng) (n=2), medium-sized (or large-sized) plastic buyers (n=4), recycling manufacturer (n=1), and plastic experts (n =3). Interviews were divided into three parts: 1) business and production data to analyze the value chain 2) the environmental impacts in term of carbon footprint by using LCA and 3) challenges and opportunities on rPET for food packaging. Carbon footprint assessment between geographic differences in plastic collecting regions (Bangkok and Rayong province) were examined.

Stakeholders of the post-consumer recycled (PCR) value chain including households, small plastic buyers, medium (or large) plastic buyers, and recycling manufacturer were analyzed to determine margins (Purcell, 2022). This study focused on the value chain primary activity of inbound logistics, operations, and outbound logistics leading to cost and create value of conducting activities that generate a profit. Value chain support activities include technology development and procurement (Tarver, 2021). Cost analysis in the value chain of PCR were calculated including labour, transportation, and raw materials (activity base).

Transportation cost and % margin (Bloomenthal, 2021). calculations are as follows:

% margin = (selling price – cost) / selling price * 100

Transportation cost = (amount of fuel used / distance traveled) * fuel price

where the calculation is based on the function unit (kilogram PET bottle). Transportation cost (baht/km) is based on types of vehicles and captures round trip (100% loading on inbound and 0% loading on outbound).

PESTLE analysis

The PESTLE analysis is an acronym for political, economic, social, technological, legal, and environmental forces. This analysis is one of the tools for conducting environmental scans or analyze the key drivers of change that enables identifying threats and opportunities for determining growth or decline, current state, and strategic direction as external factors (Heise, Crisanb, and Theuvsen, 2015; Gasde et al., 2021).

Data collection approaches including discussions, interviews, and surveys can be used to evaluate the environment (Buye, 2021). Secondary data sources included scientific studies, reports, media information, and corporate reports (Gasde, et al., 2021). Thus, this study applied the interviews and reviews on secondary data sources in the areas of recycling process, packaging, and the circular economy to evaluate challenges and opportunities on rPET for food-contact packaging in Thailand.

Carbon footprint analysis

Carbon footprint analysis in the concept of LCA focuses on assess the environmental impacts of post-consumer PET bottles. LCA (5 stages: raw material, production, transportation, consumption, waste management) The functional unit is defined as a "one kilogram PET bottle" commonly used. The scope of this study is Cradle-to-Cradle (raw material, production stages). Analysis of the product (PCR bottle) of each stakeholder started from transporting raw materials and using fuels at small plastic buyers to delivering to the recycling manufacturer.

The data used to analyze carbon footprint is provided from interviews and previous literature by calculating the carbon footprint, developed with ISO 14040:2006 Environmental management - life cycle assessment - principles framework (Thai Industrial Standards, 2009). Transportations were set by the different types of vehicles based on each stakeholder, and the distance on round trips. The outgoing trip is fully loaded (100% loaded), and the incoming trip has no load (or 0% loaded). Emission Factor (EF) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere, provided by Thailand greenhouse gas management organization (TGO, 2022). The amount of the carbon footprint (kg CO_2e) is formulated (TGO, 2022) as follows:

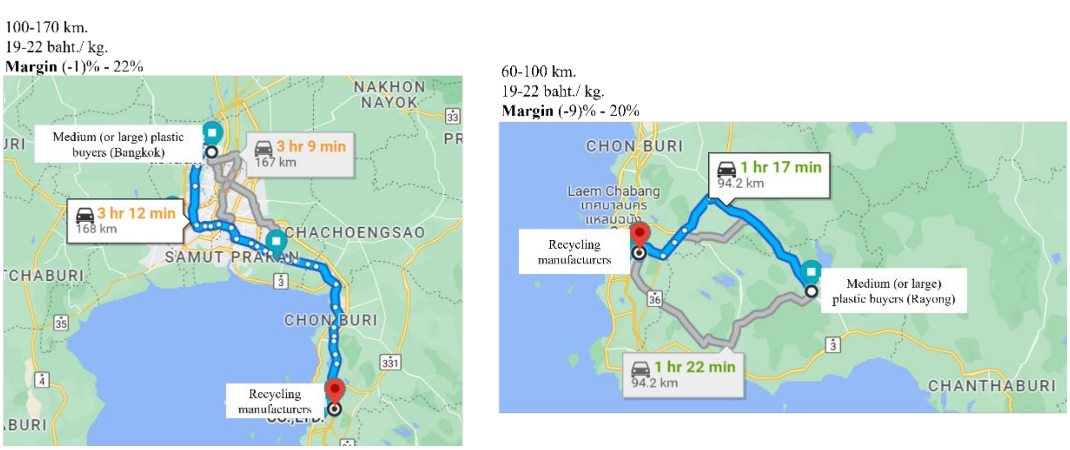
Carbon footprint = A × EF

where A represents activity data (e.g. liters of fuel burnt, kg of resin manufactured) and EF represents emission factor (e.g. kg CO_2 /liter of fuel burnt, kgCO_2 /kg resin manufactured)

RESULTS AND DISCUSSION

Post-consumer recycled (PCR) value chain

The location and the distance between stakeholders in the different regions are shown in Figure 1 (a) and (b). The primary activity of inbound logistics (receiving of raw materials and transportation), operations (converting PCR bottles to plastic bale), and outbound logistics (selling and distributing). Bangkok is the most densely populated in Thailand and higher number of small plastic buyers and medium (or large) plastic buyers than Rayong province. Raw material (PCR bottles) transportation from households to small plastic buyers was in an area of 10-20 kilometer (km) and was transported to the medium (or large) plastic buyers (distance 20-60 km) for pre-processing (grading, cleaning, and baling) before distributing to the recycling manufacturer (distance 100-170 km). Rayong has shorter distance between stakeholders to the recycling manufacturer than Bangkok. PCR bottle transportation from households to small plastic buyers was in the range of 20-30 km and transported to the medium (or large) plastic buyers (distance 30-60 km) for pre-processing (grading, cleaning, and baling) and delivered to the recycling manufacturer (distance 60-100 km). Location of recycling manufacturer and different activities to distribute from PCR bottles to plastic bale influence the cost and value added to the rPET.



(a) Bangkok (b) Rayong province

Figure 1. The distance between medium (or large) plastic buyers and recycling manufacturers.

Stakeholders in value chain of PCR bottles showed as Figure 2. Both stakeholders of Bangkok and Rayong are starting from households, small plastic buyers (or Saleng), medium (or large) plastic buyers, and recycling manufacturer or rPET manufacturer. Primary activities included inbound logistics (receiving of PCR bottles form households and distributing to plastic buyers), operations (converting PCR bottles into plastic bale), and outbound logistics (distributing plastic bale to recycling manufacturer). Support activities included technology development (using different techniques for recycling process) and procurement (quality of PCR bottles). Analysis of PCR value chain is presented in Table 1. Both primary and support activities create value and cost of conducting these activities, which influenced profit margin (i.e. procurement requires high-quality raw materials that increase cost of raw materials, technology development use different chemicals for rPET recycling processing for food-contact packages compared with non-food products).

Findings revealed advantages and disadvantages on difference geographic regions. The distance between households and small plastic buyers in Bangkok is shorter than Rayong province resulting in lower cost of transportation. The loading (15kg) of Bangkok resulted in higher margin (15-37%) than Rayong (5-13%), even though the selling price on Bangkok (9-12 baht/kg) was lower than that in Rayong (16-17.5 baht/kg). Because of the dense population of the small plastic buyers and shorter distance, Bangkok has more benefits to households and small plastic buyers than Rayong. Households in Bangkok should load PCR bottles at a minimum of 13 kg load/time to obtain break-even while those in Rayong should load larger amount of PCR bottles (15 kg load/ time).

Profit margin of small plastic buyers (16-44%) in Bangkok is high due to the low cost of raw materials from household's PCR because of the dense population and high demand on PCR from plastic buyers. Transportation cost from medium (or large) plastic buyers to recycling manufacturer in Bangkok was higher than Rayong province result showed in a % margin ((-1) - 22%). Even though Rayong province has higher cost of raw materials and lower number of small plastic buyers in Rayong have lower costs of transportation due to the shorter distance to the recycling manufacturer. The results showed lower % margin ((-9) - 20%) than Bangkok because of high costs of raw material.

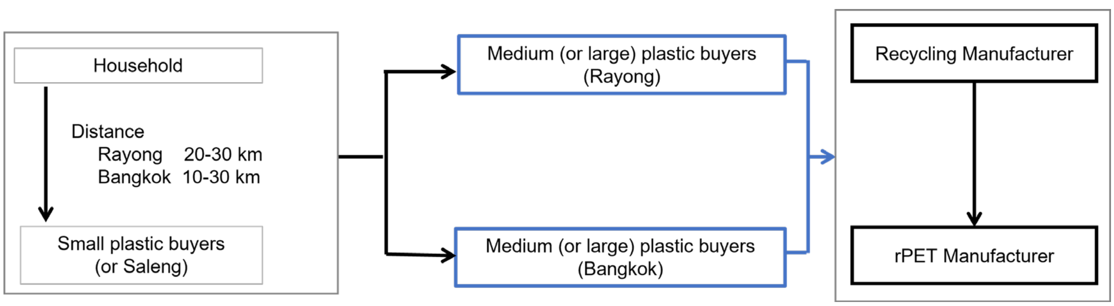


Figure 2. Value chain of post-consumer recycled (PCR)

Table 1: Post-consumer recycled (PCR) value chain analysis

Geographic area	Variables	Household to small plastic buyer (or Saleng)	Small plastic buyer to Medium-sized (or large-sized) plastic buyer	Medium-sized (or large-sized) plastic buyer to recycling manufacturer
Bangkok	Distance (km)	10-30	20-60	100-170
	Selling Price (baht/kg)	9-12	15-17	19-22
	% margin	15-37%	16-44%	(-1) – 22%
	Weight (kg)	15	500	1,000
Rayong	Distance (km)	20-30	30-60	60-100
	Selling Price (baht/kg)	16-17.5	17-18.5	19-22
	% margin	5-13 %	(-8)- 9%	(-9) – 20%
	Weight (kg)	15	500	1,000

Note: Calculation is based on 100% loading on inbound and 0% loading on outbound. % margin was calculated including labor, transportation, and raw materials. Transportation for each stakeholder is based on the type of vehicle and truck. Household (car: fuel consumption 14.76 km/Lt.), Small plastic buyer (small truck with 4 wheels: fuel consumption 10 km/Lt.), and Plastic buyer (truck with 6 wheels: fuel consumption 6 km/Lt.)

Figure 4. GHG of Post-Consumer PET bottle raw materials and production (Factor unit: 1 kg used PET bottles) of Bangkok and Rayong province

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Carbon footprint on PCR value chain

The comparison between two differences in plastic collecting regions (Bangkok and Rayong province) on the environmental impact is based on LCA approach as showed in Figure 4. Preliminary results on carbon emission on PCR value chain of 1 kg of used PET bottles. From Cradle-to-Cradle, total carbon footprint of 1 kg of used PET bottles in Bangkok (2.222 kgCO2e) is larger than that in Rayong (1.860 kgCO2e). Carbon emission in Bangkok contributed from raw materials (0.036 kgCO2e) and production (2.187 kgCO2e). Rayong emitted carbon from raw materials (0.032 kgCO2e) and production (1.828 kgCO2e).

Calculate carbon footprint of 1 kg used PET bottle by set the outgoing trip is fully loaded (100% loaded), and the incoming trip has no load (or 0% loaded), and activity data with EF (TGO (2022). The differences in using electricity in plastic baling processing of plastic buyers and the distances from medium-sized (or large-sized) plastic buyer to recycling manufacturers play prominent indicators on carbon emissions. A study by Gileno and Ramos (2021) found that the transportation characteristics, such as average distance and load, resulting in impacts on carbon emissions.

Key challenges and opportunities

Summary results from interviewing key stakeholders in PCR bottle value chain showed in Table 2. Both challenges and opportunities were remarked and combined with previous studies. PESTEL analysis on usage of rPET for food contact packaging in Thailand is presented in Table 3. National agenda on Thailand 4.0 economic model and 2021-2026 BCG strategic plan are drivers to modernize rPET for food sector and adjust to climate change crisis and sustainability of resources. Unstable politics could be a threat to rPET value chain because of the high frequency of irregular issues and change on leaders. For economic force, increasing recycling rates by businesses create new business (e.g.,upcycled products, waste collection platforms), but threats from covid-19 resulted in currency volatility and rising of material prices affecting plastic import and export industry (James, 2019; World Bank Group, 2021; Gasde et al., 2021). With social and cultural forces, nowadays, some consumers tended to reduce plastic waste and support sustainable products, but still lack of awareness on waste separation, misuse of refillable PET bottles (Pollution control department, 2020) and slowly adopt new technology. For technological force on driving rPET for food packages, technology on recycling process is limited to large business and high investment. Increase in sortation efficiency and quality of rPET are required (James, 2019). Environmental forces on environmentally friendly labels (i.e., carbon footprint label) and demand on green products can reduce environmental pollution and plastic wastes, but plastic collection systems and waste management are impractical. Legal force on the regulations on rPET in food packages is in early stage and stringent. The law of using rPET in food contact packaging in Thailand had permission in June 2022. According to interview with the stakeholders (especially manufacturer), the regulation on rPET for food packages is too strict and various laboratory tests on food contact contaminations are very high. Thus, there are potential on application of rPET in food packages in Thailand, but proper waste management in closed-loop recycling highly need to be developed with safety assessment system.

Table 2: Summary of interviews

Key stakeholders	Remarks
Small plastic buyers (n=2)	- Misuse of refillable PET bottles after consumption, leading to higher risk on contamination. - Lack of awareness on waste separation, which caused low yields of high quality of PCR bottles. - Quality control on plastic wastes is based on experience and personal relationships.
Medium-sized (or large-sized) plastic buyers (n=4)	- Cost materials of sorting PET bottles for foods are higher than non-foods. - High demand for PCR plastics is high for recycled plastics in non-food applications. - Machine and operation for pre-processing production varies among plastic buyers.
Recycling manufacturer (n=1)	- Unstable prices of rPET in the market is unstable and mainly depends on international markets. - Lack of knowledge to recycling rPET for food contact packaging under the regulations.
Plastic experts (n=3)	- Different sources of plastic flakes are highly contaminated, so cost of recycling process (collecting, sorting, and treating plastic waste) is high. - Inefficient waste management and sorting system leaded to reduce properties of plastics and quality of PCR bottles. - Consumers may unwilling to adopt rPET bottles because of appearances (i.e color, transparency, hardness) and lack of trust in recycling process.

Table 3: Key challenges and opportunities on using rPET for food contact packaging in Thailand

PESTEL analysis	Opportunity	Threats	Sources
Political force	National strategy plan moving toward sustainability and BCG	Unstable of politics and short-term policy	Interviews; James (2019)
Economic force	Additional economic benefits to businesses that apply recycled products	The costs of recycling process involved in collecting, sorting, and treating plastic waste are high.	James (2019); Interviews; World Bank Group (2021); Gasde et al., (2021)
Social and culture force	Growth of number of consumers who are willing to reduce plastic waste and adopt sustainable products and concepts.	- Lack of awareness on waste separation - Misuse of refillable PET bottles - Technology acceptance	Interviews; Pollution control department (2020); World Bank Group (2021); Gasde et al., (2021)
Technological force	-Increase in sortation efficiency and quality of rPET -New platform on waste separation	-High cost of technologies of rPET recycling production -Limit to a few large companies	James (2019); Interviews; World Bank Group (2021); Leblanc (2020)
Environmental force	-Awareness on reducing environmental pollution and plastic waste -Carbon footprint label or greener process are requested by exporters	-Impractical plastic collection system and waste management - The migration potential of food contact contamination on PET bottles	James (2019); Interviews; Pollution control department (2020); Leblanc (2020); The Organization for Economic Co-operation and Development (2022)
Legal force	Early stage on regulations on rPET for food contact packaging	- Long process on applying regulations on rPET for food contact packaging for rPET manufacturers -Lack of standard on recycling process	Interviews; Ministry of Public Health (2022)

CONCLUSIONS

The study aims to compare the environmental impacts on post-consumer recycled PET value chain (from small plastic buyer (or Saleng) to recycling manufacturer), differences in plastic collecting regions (Bangkok and Rayong province), and key challenges and opportunities on using rPET for food contact packaging in Thailand.

The Bangkok region's carbon footprint on the post-consumer recycled PET value chain (from small plastic buyers to recycling manufacturers) has a higher carbon footprint and environmental impacts than Rayong province. The difference in using electricity in plastic baling processing and the type of transport and distance results in a carbon footprint rate. Bangkok's post-consumer recycled PET value chain has a higher margin than Rayong province. Rayong province has higher cost of raw material than Bangkok. The challenges of using rPET for food contact packaging are the impractical plastic collection system and waste management, high cost of technologies of PET recycling production, the migration potential of food contact chemicals on PET bottle, misuse of refillable PET bottles, lack of awareness on waste separation, and lack of regulations on rPET for food contact packaging. Moving toward rPET for food contact packaging requires collaboration among stakeholders across PET bottle lifecycle and public awareness on waste management to ensure food contact safety of rPET and a sustainable value chain. On the other hand, the opportunities on rPET packaging in Thailand will increase with improving sortation efficiency and quality of rPET, increasing of recycling rates, reducing environmental pollution and plastic waste, and implementing the regulatory framework on safety. At the same time, the manufacturer can follow.

Further study, after the law of using rPET for food contact packaging in Thailand had permission, the economic impact of using rPET needed to analyze for the benefit of planning guidelines and prepare to deal with the impact of using rPET resins for food contact packaging.

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