The Incubation Network & PREVENT Waste Alliance & ECCA FAMILY FOUNDATION | PRESENTS THE SUP CHALLENGE

Life Cycle Assessment Report

Introduction

As the number of alternatives to SUPs continues to grow, along with the impetus to address plastic leakage found in the environment, so does the need for a more comprehensive understanding of the environmental benefits of SUPs over the status quo. The environmental impacts of alternative solutions versus SUPs can be measured holistically through life cycle assessment (LCA), which uses a “cradle to grave” boundary to determine the impact of a product at all stages, from raw material extraction and processing, manufacturing, distribution, use, end-of-life, and transportation between life cycle stages.

> **Through LCA, consumers, manufacturers, and other decision-makers can gain a better understanding of how alternative solutions compare against SUPs and other equivalent single-use items in the foodservice industry.**

An LCA methodology following the requirements of the ISO14040/44 standards[1,2] was used to measure the potential environmental impacts across all life cycle stages of four solutions that were piloted during The Single-Use Plastics (SUP) Challenge. These four solutions fell within The SUP Challenge archetypes of reuse/refill model and plastic material alternatives.

[1] International Organization for Standardization - *ISO 14040:2006: Environmental management — Life cycle assessment — Principles and framework* (2006)
[2] International Organization for Standardization - *ISO 14044:2006: Environmental management — Life cycle assessment — Requirements and guidelines* (2006)

Study Objectives and Limitations

The LCA studies were conducted for four solutions under pilot conditions in their respective countries.

The objectives of the four LCA studies were to:

- Understand the key factors that drive the negative and positive environmental impacts of SUPs and SUP alternatives;
- Determine how the use of SUP alternatives should be optimized to achieve environmental benefits; and
- Identify potential interventions that can support the use of SUP alternatives so that they provide environmental benefits.

The four LCA studies of the pilots compared the following:

- Pilot 1: Reusable takeaway container versus single-use bagasse containers and SUP containers
- Pilot 2: Refill machine for dispensing mopping and dishwashing detergents versus high density polyethylene (HDPE) bottles
- Pilot 3: Areca palm leaf takeaway container versus a single- use paper-based container with polyethylene (PE) lining and SUP container
- Pilot 4: Palm leaf beverage straw versus SUP beverage straw

Focusing the LCAs on the pilots allows for a safe assumption that the alternative solutions analyzed in the studies would be adopted by consumers in realistic foodservice operating conditions and have potential for scaling up. Furthermore, using data captured from the pilots allows the results of the LCA studies to represent the real operating conditions of the solutions. For alternative solutions under the reuse/refill model archetype, pilot data representing consumer reuse of the solution can be applied to benchmark the current environmental performance of the product and make a comparison against the minimum level of reuse required to achieve environmental benefits over the status quo.

Intended Audience and Application of Findings

The intended audience for the findings of these LCA studies include foodservice operators, manufacturers of SUP alternatives that can be used in foodservice settings, entrepreneur support organizations (ESOs), investors, and consumers.

The results of these LCAs can be used by the intended audiences to:

- Compare the life cycle environmental impacts of alternative solutions versus SUPs and other types of single-use items in foodservice; for example, evaluating different types of beverage cups or different types of takeaway containers, but not products with different functions (e.g. beverage cup vs takeaway container) and manufactured in a different country or with different alternative materials;

- Understand which processes dominate the life cycle environmental impacts of alternative solutions and should be paid the most attention to during decision-making;

- Understand which processes have a relatively small contribution to the total life cycle environmental impacts of alternative solutions and therefore can be given minimal attention during decision-making; and

- Understand the minimum level of usage the reuse/refill solutions that the existing pilots must achieve to have environmental benefits compared to their functionally equivalent single-use item(s).

The results of these LCA studies should not be used to:

- Compare products with different functions (e.g. beverage cup versus takeaway container);

- Represent the life cycle environmental impacts of the same product manufactured, used, and disposed of in a different country[3]; or

- Represent the life cycle environmental impacts of all plastic material alternatives in general; different alternative materials will have different environmental impacts based on different material production processes.

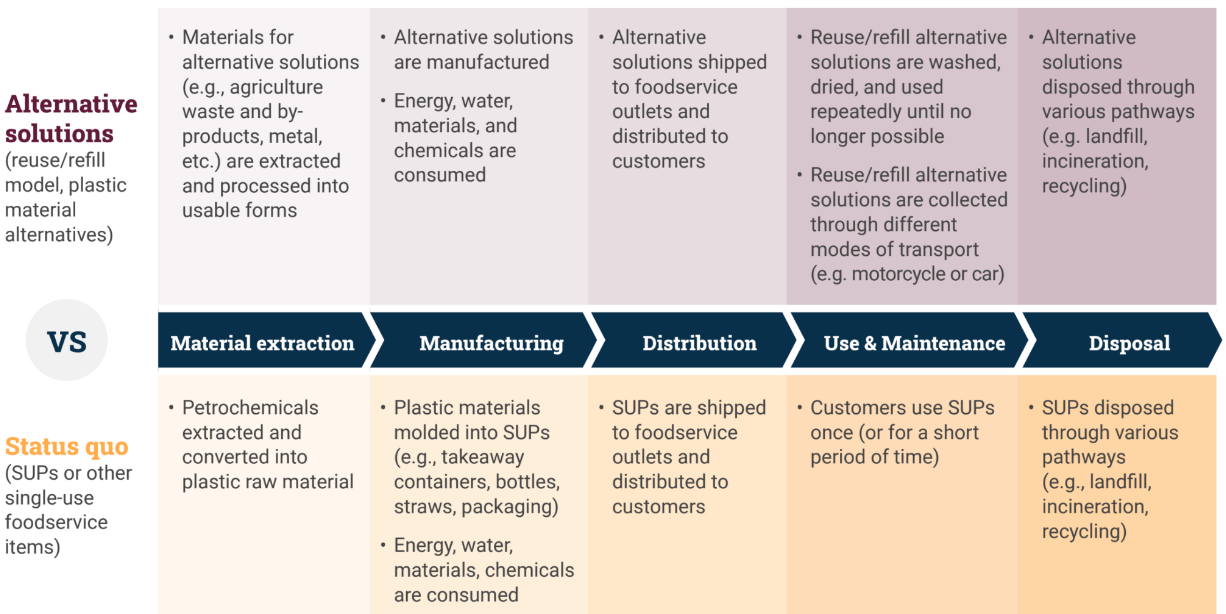
[3] Different countries have unique electricity grid mixes of renewable and non-renewable energy sources which would make the life cycle environmental impacts different from the results reported in this study focused on the specific pilots.

Methodology

System Boundary

A cradle to grave system boundary was applied for all four LCA studies. **Figure 1** illustrates the processes included in the scope of the LCA studies across all life cycle stages for both the piloted SUP alternatives, and the status quo SUPs and other single-use foodservice items.

Figure 1. System Boundary for Cradle to Grave LCA Studies of the Four Pilots



Selection of Pilots

All startups were screened, shortlisted, and selected to participate in the LCA studies. A total of four pilots were selected to participate based on the following criteria:

- Startups with alternatives to SUP takeaway containers, as these items were ranked third among the top 10 products found in global marine litter[4];
- Startups that had already collected a sufficient amount of data regarding the inputs and outputs for processes across a majority of the life cycle stages; and
- Startups that could provide the requisite data related to the operation of their solution at the pilot (e.g. frequency of use of solutions) within the necessary time frame to complete the LCA studies.

[4] Morales-Caselles et al. (2021), An inshore–offshore sorting system revealed from global classification of ocean litter, Nature Sustainability, doi: 10.1038/s41893-021-00720-8

Table 1 provides a synopsis of each pilot that went through an LCA. For Pilots 1 and 3, where the item being replaced was a single-use item but not plastic-based, comparative analysis was done between:

1. The SUP alternative provided by the startup;
2. The existing item that the foodservice operator was using prior to the pilot to reflect the pilot's operating conditions; and
3. The SUP counterpart (i.e. polypropylene takeaway container) that is commonly used by other foodservice operators and is also a significant contributor to plastic waste leakage in the respective countries[5].

Table 1. Synopsis of Pilots Selected for LCA

Characteristic	Pilot 1	Pilot 2	Pilot 3	Pilot 4
Product category	Reuse/refill	Reuse/refill	Plastic material alternative	Plastic material alternative
Solution	Reusable takeaway container	Refill machine for dispensing liquid cleaning detergents	Single-use takeaway container	Single-use drinking straw
Primary raw material(s) used in the solution	Polypropylene (PP) and silicone	Stainless steel, acrylic, polyvinyl chloride, brass, HDPE	Areca palm leaves	Coconut palm leaves
Volume of solution	890 ml	100 liters (refillable tank)	750 ml	N/A
Lifetime of the solution	2 years	10 years	Single-use	Single-use
Frequency of use per item	2 times every month	16 liters dispensed every month	Single-use	Single-use
Country	Thailand	Thailand	Indonesia	India
Single-use foodservice item replaced at pilot (status quo)	Bagasse container with PET cover	HDPE bottles (1 liter) of mopping and dishwashing detergents	Paper container with PE lining	PP straws
SUP counterpart commonly used by other foodservice operators	*Compared* SUP: PP container	N/A	*Compared* SUP: PP container	N/A

[5] WWF - *Scaling up circular strategies to achieve zero plastic waste in Thailand* (2020), Vriend P, Hidayat H, van Leeuwen J, Cordova MR. (2021) Plastic Pollution Research in Indonesia: State of Science and Future Research." Front. Environ. Sci. 9:692907. doi: 10.3389/fenvs.2021.692907

Functional Unit

In order to make fair and equivalent comparisons between different products and services in a LCA, a functional unit must be defined that represents the product/service to be analyzed and is aligned with the goal and scope of the LCA study. Each alternative solution piloted has a different function in the foodservice industry and therefore requires unique functional units to compare the solutions to SUPs and other single-use foodservice items. The functional units for each pilot are:

Pilot 1: A reusable takeaway container with a volume of 890 ml used to deliver food from a restaurant twice a month, every month for two years in Thailand.

Pilot 2: 16 liters of liquid detergents dispensed at a restaurant per month, every month, for 10 years in Thailand.

Pilot 3: A single-use takeaway container with a volume of 750 ml used to deliver food from a restaurant once in Indonesia.

Pilot 4: A single-use beverage straw used to consume one beverage at a foodservice outlet in India.

Data Collection

Primary and secondary data were used to complete the LCA studies. Primary data was gathered from the startups during The SUP Challenge about their solutions and activities across the life cycle. Thus, the primary data collected from the startups about the manufacturing, distribution, use, and disposal of their alternative solutions is representative of the year 2022.

Examples of primary data collected include the material, energy, and water used in manufacturing each solution, transportation activities, and raw material production processes. When the startups were unable to provide primary data about certain processes related to their solution, secondary data from the Ecoinvent[6] database, Plastics Europe database[7], journal publications, and technical reports were used to fill the data gaps. Most of the data gaps that were filled with secondary data were the environmental impacts of extracting and producing the raw materials used in the products, freight transport, electricity generation in each pilot's respective countries, disposal of solid waste at a landfill or incinerator, and wastewater treatment.

Environmental Impact Categories

The LCA studies measured environmental impacts in the following categories, described below with their associated units of measurement:

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[6] Ecoinvent (2022), https://ecoinvent.org/
[7] Plastics Europe Eco-profiles Set (2022), https://plasticseurope.org/sustainability/circularity/life-cycle-thinking/eco-profiles-set/

Climate change: Measurement of the amount of greenhouse gasses (GHGs) released into the atmosphere due to human activities. The unit for measuring GHGs is carbon dioxide equivalent (kg CO_2-eq).

Cumulative energy demand: Measurement of the cumulative energy used, which includes energy from renewable and non-renewable sources. The unit for measuring cumulative energy demand is megajoules (MJ).

Water depletion: Measurement of the impacts to the environment as a result of consuming water that is extracted from reservoirs, lakes, rivers and groundwater. The unit for measuring water depletion is liters (l) of water equivalent.

Insights from the LCAs of the Pilots

This section describes the life cycle analysis of each product/service analyzed. For each LCA, the following information is presented:

1. Solution and pilot description;
2. Life cycle processes of each product/service analyzed as well as the key assumptions and types of data used; and
3. Findings

Interpretation of Findings

The LCAs conducted were based on data about the startups' solutions, the pilots they ran, and key assumptions dependent on the local context. This combination of local context and data allows for the safe assumption that the alternative solutions analyzed in the studies would be adopted by consumers in realistic foodservice operating conditions and have potential for scaling up. Furthermore, using data from the pilots allows the results of the LCA studies to represent the real operating conditions of the solutions. For alternative solutions under the reuse/refill model archetype, pilot data representing consumer reuse of the solution can be applied to benchmark the current environmental performance and make a comparison against the minimum level of reuse required to achieve environmental benefits over the status quo.

For results that show that the SUP alternative has larger environmental impacts than the status quo SUPs and single-use foodservice items, the solutions may not have achieved the scale required to optimize resource consumption and achieve environmental benefits. Even for results that show that the alternative solution is better for the environment than the status quo, there is still more room for reducing environmental impacts to achieve more benefits.

Pilot 1

Meal Delivery Service with Reusable Containers vs. Single-Use Bagasse Container with PET Cover and SUP PP Container

Pilot 1 was based on a meal delivery service for a restaurant in Thailand. For the pilot, the startup delivered three meals in reusable containers to customers every Monday and Thursday. The pilot introduced the business process improvement of delivering six scheduled meals in each vehicle trip rather than making single-meal deliveries. During each delivery, the startup collects the empty reusable containers from the previous delivery and brings them back to the restaurant. The startup is currently using a hybrid passenger car to deliver meals. The containers are always washed and dried after each use either by the customer or the restaurant.

The LCA of this alternative solution compares five different scenarios:

A1. Delivery of food in reusable containers using a passenger car. During each trip, six containers are delivered. This was the practice used in the pilot project.

A2. Delivery of food in reusable containers using a petrol-powered motorcycle. During each trip, six containers are delivered. This is not the current practice, but this scenario was analyzed to understand how the total environmental impacts would change if the mode of transportation was changed.

A3. This scenario is the same as A2, except a single reusable container is delivered per trip. This is not the current practice but was analyzed to understand how the environmental impacts would change if the number of units delivered per trip decreased which would result in more trips.

B. Delivery of food in a single-use bagasse container with a PET cover via motorcycle. This was the status quo before the pilot started.

C. Delivery of food in a single-use PP container via motorcycle. This is the SUP equivalent of packaging used to deliver food in similar foodservice operations.

In all five scenarios, the restaurant is located in Thailand. The functional unit used to compare the five scenarios in this LCA study of Pilot 1 is defined as the provision of a takeaway container with a volume of 890 ml to deliver food from a restaurant twice a month, every month, for two years in Thailand.

Alternative Solution: Reusable Takeaway Container

The reusable takeaway containers are made of PP and silicone with a mass of 130 grams and 10 grams respectively. The customers are located 17.5 km on average from the location of the restaurant. The startup provided primary data about the volume of the container and the mass of the materials, the amount of reuse of the containers, the delivery schedule, and the type of vehicle used to deliver the meals. Secondary data from studies by Gallego-Schemid et al. (2019)[8] and Changwichan and Gheewala (2020)[9] were used to represent the manufacturing inputs and washing requirements of the solution respectively. The Ecoinvent and Plastics Europe databases were used to calculate the environmental impacts of raw material production.

Raw material extraction: The raw materials in the reusable takeaway container are PP and silicone rubber. PP production starts with extracting crude oil and natural gas. Crude oil is refined to produce naphtha and the natural gas goes through processing. Naphtha and natural gas undergo cracking where intense heat is applied to form propylene. The propylene undergoes polymerization to produce PP resin. Silicone is produced through a series of processes that combine silicon powder with other chemical compounds. All the raw material extraction processes are assumed to take place in Thailand.

Manufacturing: At the factory in Thailand, PP goes through extrusion and thermoforming to produce the desired container shape. The silicone is also molded into the desired shape. The finished container is packaged in PE and cardboard and is ready for distribution. All processes consume electricity from the average Thailand grid mix.

Distribution: The finished reusable takeaway container is transported by truck to the restaurant which is assumed to be 70 km from the factory.

Use and maintenance: The reusable container is packed with food which is delivered to a customer using a hybrid car with a fuel economy of 25 km/liter of petrol. The customer is located 17.5 kilometers away from the restaurant. A total of six reusable containers are packed together during each delivery trip. The startup delivers the packaged food, takes back the empty reusable takeaway containers from the previous delivery, and drives back to the restaurant. The containers are washed by hand using half a liter of water and 5 grams of dish detergent, and are left out to dry on a rack. The reusable containers are assumed to be used twice every month during their two-year lifetime[10]. The containers are guaranteed to be returned each time because the startup provides the collection service. Mass allocation was used to assign the impacts of the roundtrip delivery between the container and the food. The container makes up 17% of the total mass delivered and is therefore associated with 17% of the delivery impacts, while the remaining 83% is associated with the delivery

[8] Gallego-Schmid et al. (2019), Environmental impacts of takeaway food containers, Journal of Cleaner Production, doi: 10.1016/j.jclepro.2018.11.220
[9] Changwichan and Gheewala (2020), Choice of materials for takeaway beverage cups towards a circular economy, Sustainable Production and Consumption, doi: 10.1016/j.spc.2020.02.004
[10] Based on data gathered from the pilot during The SUP Challenge, the reusable container was reused once over a period of two weeks. This study assumed that this level of reuse would be repeated every two weeks throughout the lifetime of the reusable takeaway container.

of food which is assumed to weigh 700 grams.

End-of-life: At the end of the reusable container's two-year lifetime, the container is disposed of in a waste bin. The reusable takeaway container is assumed to be sent to the Nong Khaem solid waste landfill which is approximately 30 km from the location where the takeaway container is used.

In **scenarios A2** and **A3**, the same activities take place across all life cycle stages except instead of a passenger car, a motorcycle with a fuel economy of 55 km/liter of petrol is used to deliver the meals to the customers.

Status Quo: Single-Use Bagasse Container with PET Cover

The reusable takeaway container replaced a single-use bagasse container with a PET cover. The single-use bagasse takeaway container is manufactured in Thailand and has a total mass of 26.5 grams. The bowl is made of 17.8 grams of bagasse and the PET cover has a mass of 8.7 grams. The life cycle inventory of the bagasse was based on a LCA study by Fangmongkol and Gheewala 2020[11] about bagasse takeaway containers made in Thailand. Secondary data from the Ecoinvent and Plastics Europe databases were used to represent the environmental impacts of producing PET and other required inputs.

Raw material extraction: Bagasse is collected from sugar mills in Thailand. The bagasse undergoes pulp cooking, pulp washing, pulp screening, and pulp bleaching. The processed bagasse is transported 23.5 km to the takeaway container production facility. PET is made through extracting crude oil and natural gas that undergo cracking to produce ethylene. The ethylene undergoes a series of chemical processes to form amorphous PET. The amorphous PET is transported by truck to the takeaway container factory at an assumed distance of 50 km.

Manufacturing: At the factory, the takeaway container is made through pulp mixing and beating, wet forming, dry forming, edge cutting, appearance checking, metal detecting, UV disinfection, sealing, and packing. The amorphous PET undergoes extrusion and thermoforming to form the shape of the cover. The final container is packaged in PE bags.

Distribution: The finished bagasse takeaway container is transported by freight truck to the restaurant, which is assumed to be 70 km from the factory.

Use and maintenance: The restaurant packs the meal in the bagasse takeaway container and delivers it to the customer by a motorcycle (one-way trip) with a fuel economy of 55 km/liter of petrol[12] and

[11] Fangmongkol and Gheewala (2020), Life cycle assessment of biodegradable food container from bagasse in Thailand, Journal of Sustainable Energy and Environment
[12] MotoMalaysia (2017), Honda Wave 125i overview, https://www.motomalaysia.com/honda-wave-125i-price-specs-malaysia/

has tailpipe CO_2 emissions of 0.051 kg CO_2/km[13]. The customer is located 17.5 km away from the restaurant. The customer consumes the food and disposes the takeaway container in a waste bin. Mass allocation was used to assign the impacts of the one-way delivery between the container and the food. The container makes up 4% of the total mass delivered and is therefore associated with 4% of the delivery impacts while the remaining 96% is associated with the delivery of food which is assumed to weigh 700 grams.

End-of-life: The disposed bagasse takeaway container is assumed to be sent to the Nong Khaem solid waste landfill which is approximately 30 km from the location where the takeaway container is used.

SUP: PP Takeaway Container

The single-use PP takeaway container is manufactured in Thailand and has a mass of 35 grams. The life cycle inventory of the container was based on a study by Gallego-Schmid et al. (2019)[14] and adapted for this LCA study. Secondary data from the Ecoinvent and Plastics Europe databases were used to represent the environmental impacts of producing PP and other required inputs.

Raw material extraction: PP production starts with extracting crude oil and natural gas. The crude oil is refined to produce naphtha and the natural gas goes through processing. Naphtha and natural gas undergo cracking where intense heat is applied to form propylene. All the raw material extraction processes are assumed to take place in Thailand.

Manufacturing: At the factory in Thailand, the PP goes through extrusion and thermoforming to produce the desired container shape. The finished container is packed in both PE and cardboard and is ready at the factory for distribution. All processes consume electricity from the average Thai grid mix.

Distribution: The finished SUP takeaway container is transported by freight truck to the restaurant which is assumed to be 70 km away from the factory.

Use and maintenance: The restaurant packs the meal in the PP takeaway container and delivers it to the customer by a one-way motorcycle trip with a fuel economy of 55 km/liter of petrol[15] and tailpipe CO_2 emissions of 0.051 kg CO_2/km[16]. The customer is located 17.5 km away from the restaurant. The

[13] Sustainable Urban Transport Project (2015), Can electricity replace Gasoline? Unlocking the potential of electric two-wheelers in Thailand, https://sutp.org/publications/can-electricity-replace-gasoline-unlocking-the-potential-of-electric-two-wheelers-in-thailand/

[14] Gallego-Schmid et al. (2019), Environmental impacts of takeaway food containers, Journal of Cleaner Production, doi: 10.1016/j.jclepro.2018.11.220

[15] MotoMalaysia (2017), Honda Wave 125i overview, https://www.motomalaysia.com/honda-wave-125i-price-specs-malaysia/

[16] Sustainable Urban Transport Project (2015), Can electricity replace Gasoline? Unlocking the potential of electric two-wheelers in Thailand, https://sutp.org/publications/can-electricity-replace-gasoline-unlocking-the-potential-of-electric-two-wheelers-in-thailand/

customer consumes the food and disposes the takeaway container in a waste bin. Mass allocation was used to assign the impacts of the one-way delivery between the container and the food. The container makes up 5% of the total mass delivered and is therefore associated with 5% of the delivery impacts while the remaining 95% is associated with the delivery of food which is assumed to weigh 700 grams.

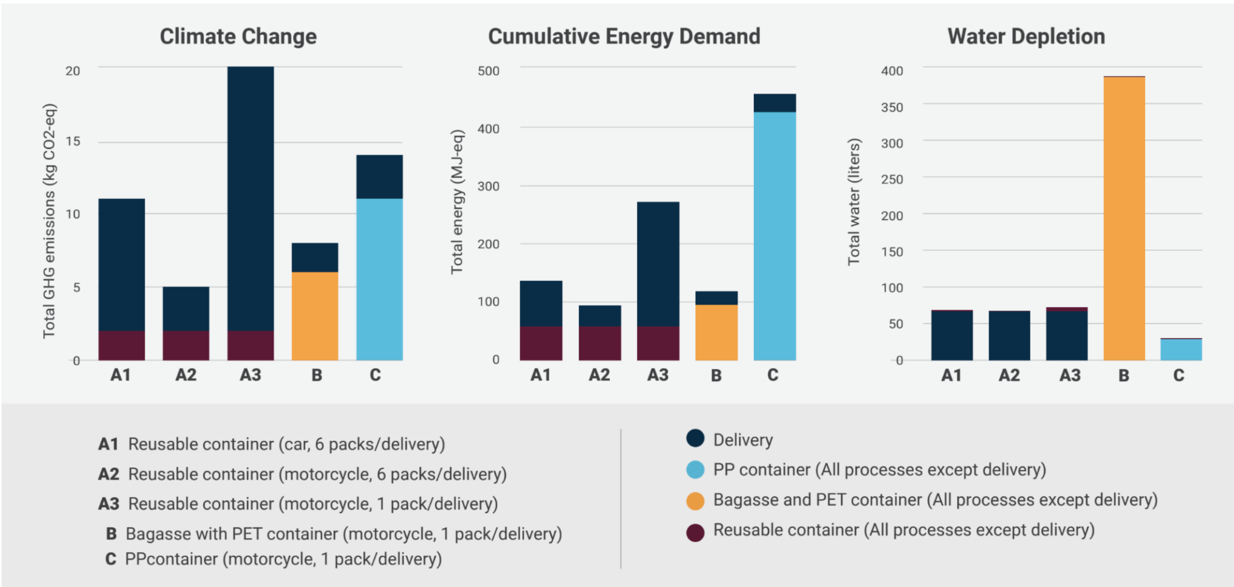
End-of-life: The disposed SUP takeaway container is assumed to be sent to the Nong Khaem solid waste landfill which is approximately 30 km from the location where the takeaway container is used.

Findings

The results of the LCA showed that the reusable containers had better environmental performance (i.e. less negative environmental impact) than single-use containers under certain conditions. **Figure 2** illustrates the total environmental impacts of each scenario at two uses per month and breaks down the impacts of delivery versus all the other processes in the life cycle. In the category of climate change, the existing pilot that uses a hybrid car has higher GHG emissions than the status quo of the bagasse and PET container, but lower GHG emissions than the PP container. However, switching deliveries to a motorcycle with lower tailpipe GHG emissions and a higher fuel economy reduces the delivery impacts by more than 50% and would make the total impacts of the reusable takeaway containers lower than the bagasse and PET containers and the PP container.

In **scenario A3**, the delivery impacts of just one reusable container per trip by motorcycle was much higher than the delivery impacts of the single-use bagasse container and PP container for a few reasons. First, the reusable container travels double the distance compared to the single-use containers because the container must be returned to the restaurant. Second, per delivery trip, the reusable container has a higher share of the impacts because the reusable container has a higher share of the total mass delivered (food and container) compared to the single-use bagasse and PP containers which were lighter. Although the current pilot uses a car to travel round-trip to deliver the takeaway containers and collect the spent ones, it can still have lower total GHG emissions and energy demand compared to the PP container because the car was able to carry six packed meals during a single round-trip, instead of just one container which is shown in **scenarios A3**, **B**, and **C**.

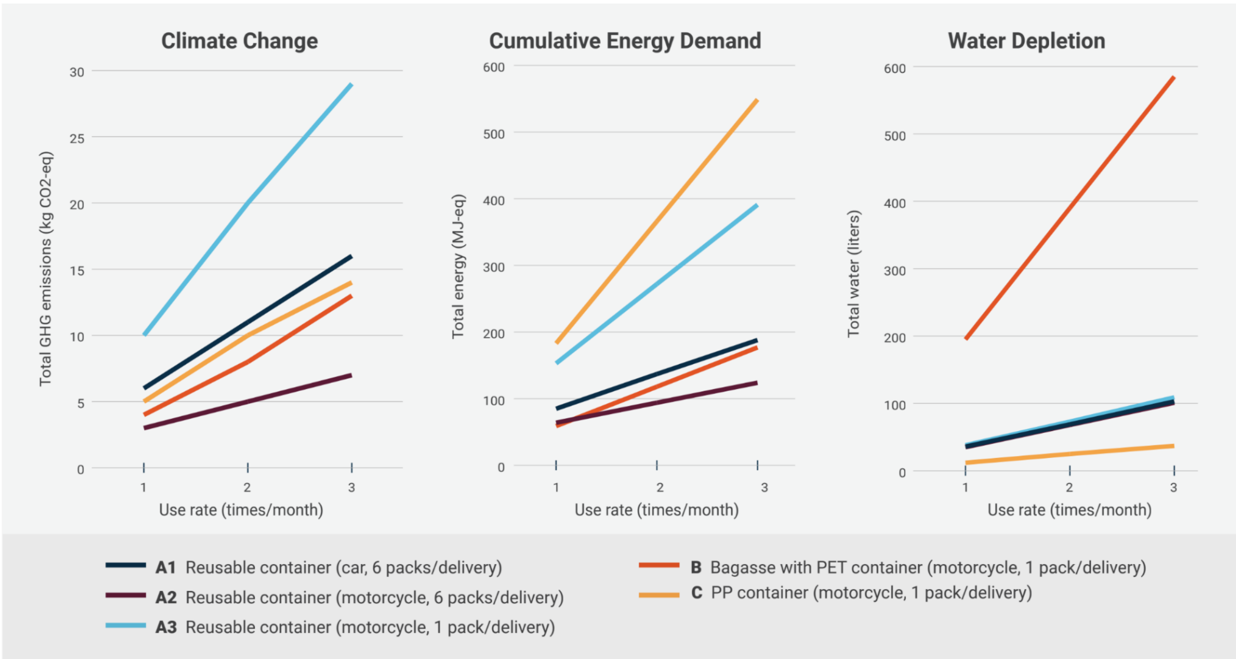
Figure 2. Life Cycle Environmental Impacts of Reusable Container Versus Single-Use Takeaway Containers When Used Twice per Month



Without considering the impacts from delivery, the reusable containers had lower impacts in climate change and cumulative energy demand compared to the single-use takeaway containers because fewer containers needed to be manufactured and disposed of in the reuse/refill solution. The reusable containers delivered both by car and motorcycle had higher total impacts than the PP containers, only in the category of water depletion. This was because the reusable containers consumed more water during the use and maintenance stage. The single-use bagasse and PET container had very high impacts in water depletion because of the large amount of water that is required in the process of raw sugar production where bagasse is the by-product of interest.

The environmental performance of reusable containers compared to single-use containers can vary depending on how frequently they are reused. **Figure 3** shows the total impacts of each takeaway container at use rates of between one and three times per month. The line graphs show that using a reusable container to deliver six containers of food per trip would have lower impacts than the single-use containers regardless of the frequency of use, in terms of climate change and cumulative energy demand. However, the single-use PP container would have the lowest impact on water depletion regardless of the frequency of use due to higher water demands during the washing stage of the reusable container.

Figure 3. Life Cycle Environmental Impacts of Reusable Container Versus Single-Use Takeaway Containers When Used Between One to Three Times per Month



Overall, for this specific pilot, the business model of delivering a set of scheduled meals allowed for a higher number of containers to be delivered per trip and reduced the amount of single-use containers. This led to the lower total environmental impacts compared to single-use containers in two out of the three categories analyzed.

Companies should try to deliver more than one container per trip to reduce the environmental impacts of delivery.

At a scaled up version of the pilot, it would be preferable to use a two-wheeler vehicle to deliver the meals instead of a passenger car in order to reduce energy demand and prevent tailpipe GHG emissions.

Pilot 2

Refill Machine vs. HDPE Bottles

The pilot is set up at a restaurant in Thailand. The restaurant uses a refill machine to dispense mopping and dishwashing detergent for cleaning the restaurant. Before the pilot, the restaurant was purchasing the liquid detergents from bottles made of HDPE. The restaurant currently uses 16 liters of liquid detergents each month. The functional unit used to compare the machine versus the HDPE bottles in this LCA study was defined as the provision of 16 liters of liquid detergents at a restaurant per month, every month, for 10 years in Thailand. The startup provided primary data on the materials and components of the machine, electricity and water consumption at the factory, solid waste and wastewater generated at the factory, and distances between the factory and the restaurant, and the restaurant and the refill hub. All other data required for the LCA were gathered from secondary sources.

Alternative Solution: Refill Machine

The machine is made of both electrical and non-electrical parts and has a total mass of 23 kg. It contains two HDPE storage tanks of 50 liters each, one for storing mopping detergent and one for storing dishwashing detergent. Additional parts include the pumps; screen; bill and coin acceptor devices; wires; plastic buttons and pipes; and stainless steel sheets for the overall structure.

Raw material extraction: All the machine components are manufactured in Thailand except for the coin and bill acceptors which are imported by a container ship that travels approximately 4,270 km.

Manufacturing: The mechanical and electrical components arrive at the factory where they are fabricated into the machine. The coin and bill acceptors are imported from abroad while the remaining parts are manufactured domestically in Thailand. It is assumed that the domestic parts are made in the Samut Prakarn industrial area which is approximately 100 km from the machine factory. The factory consumes electricity from the Thailand average grid mix. Water is consumed in the process of painting and washing the machine. Wastewater is disposed of in the sewerage system and solid waste generated is sent to a landfill.

Distribution: The machine is transported by freight truck to the restaurant and is later filled with the liquid detergents. The distance traveled is approximately 20 km.

Use and maintenance: Use stage activities include electricity use when operating the machine, and transportation of the liquid detergents for refilling. The machine consumes electricity when on standby 24 hours/day and consumes more electricity during the time when liquid detergents are dispensed. The restaurant currently dispenses 16 liters of liquid detergents per month from the machine[17]. When the storage tank is empty, the company brings more liquid detergents from its refill

[17] Based on data collected from the pilot during The SUP Challenge, 16 liters of liquid was dispensed over a period of one month. This amount of liquid dispensed was assumed to be repeated every month throughout the 10-year lifetime of the refill machine.

hub located 7 km from the restaurant. The liquid detergents are brought on a truck that carries the liquids in large reusable HDPE containers that are provided by the company supplying liquid detergents. The impacts of the refillable HDPE storage tanks have been excluded from the LCA because they are shared amongst many other customers besides the machine company and have a lifetime of more than 10 years and are therefore expected to have a negligible contribution to the total life cycle environmental impacts of the machine.

End-of-life: At the end of its 10 year lifetime, the machine is brought back to the manufacturer where its parts are stripped out and sent to a waste management facility. The stainless steel casing and structure (72% of the total mass) that remains is reused for another machine, and is expected to last for an additional five years before it must be disposed of. When disposed of, the stainless steel is sent to the waste management facility to be recycled where a total of 80% of the scrap steel is used to displace virgin steel production. The copper from the wires is stripped out and it is also assumed that 80% of the copper is used to displace virgin copper production. All the remaining parts are disposed of at a landfill that is assumed to be 40 km away.

Status Quo: HDPE Bottles

Before the pilot, HDPE bottles were used to carry the liquid detergents that the restaurant required each month. In this study, a 1 liter HDPE bottle with a mass of 80 grams was used to represent the SUP. This bottle size is used to represent the amount of HDPE displaced for every liter of liquid detergent dispensed through the machine. In the LCA, production of HDPE bottles was represented with secondary data from the Ecoinvent and Plastics Europe databases.

Raw material extraction: HDPE production starts with extracting crude oil and natural gas. The crude oil is refined to produce naphtha and the natural gas goes through processing. Naphtha and natural gas undergo cracking where intense heat is applied to form ethylene. The ethylene undergoes polymerization to produce HDPE resin. All the raw material extraction processes are assumed to take place at petrochemical refineries in Thailand.

Manufacturing: The HDPE resin is transported by truck to the factory where the bottles of liquid detergents are made, which is assumed to be 70 km away. At the factory, the HDPE resin goes through blow molding to create the desired bottle shape. The bottles are filled with liquid cleaning detergent. The environmental impacts associated with producing the liquid detergent and filling up the bottles have been excluded from this analysis because the scope of the study is only focused on the packaging.

Distribution: The HDPE bottles with liquid detergent are shipped to a local store near the site of the restaurant. The distance from the liquid detergent factory to the local store is assumed to be 50 km.

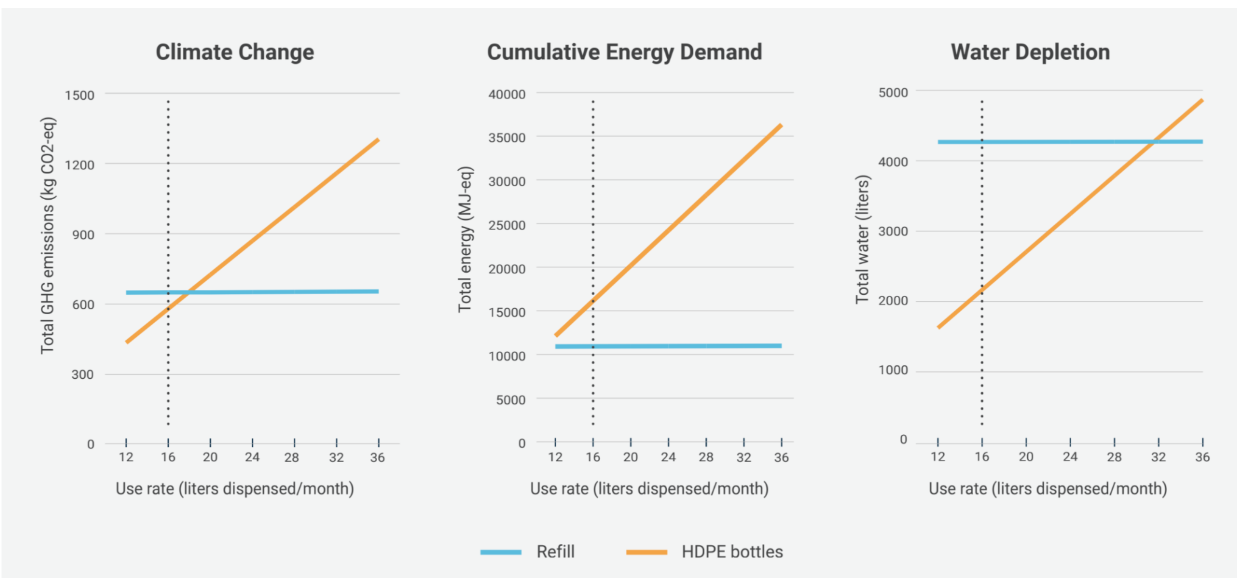
Use and maintenance: The restaurant purchases bottles of liquid cleaning detergent at their local store. Once the bottle is depleted, the restaurant disposes of the bottle in a waste bin.

End-of-life: The disposed bottles are assumed to be sent to the landfill in Nakhon Pathom province that is 16 km from the restaurant. Although HDPE can be recycled, this study assumes that the bottle is not recycled because at the site of the pilot there is a lack of access to plastic recycling services and informal waste pickers inconsistently pick up recyclable materials.

Findings

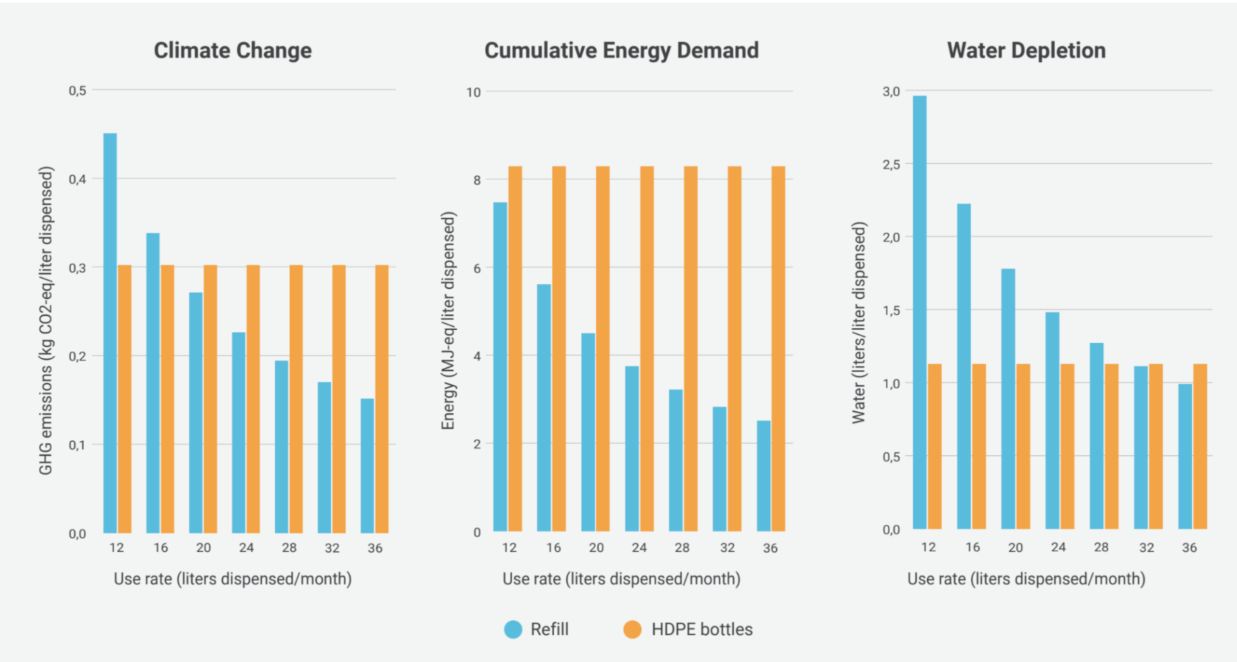
The results of the LCA showed that the refill machine must dispense 32 liters of liquid detergents per month during the 10 year lifetime to have lower total environmental impacts compared to the HDPE bottles. **Figure 4** compares the life cycle environmental impacts of the machine versus the equivalent amount of HDPE bottles at increasing monthly rates of dispensing liquid. The pilot currently dispenses at a rate of 16 liters per month which is indicated by the black dotted vertical line in the graphs in **Figure 4**. The machine has a total capacity of 100 liters. Thus, almost one third of the machine's liquid detergent storage capacity must be dispensed each month to achieve environmental benefits over SUPs in the three impact categories analyzed.

Figure 4. Life Cycle Environmental Impacts of Refill Machine Versus SUP (HDPE) Bottles for Cleaning Liquids Over 10 Years



Each impact category has a different monthly liquid dispense rate that the machine must achieve in order for it to have a lower total impact than the equivalent HDPE bottles used. This is due to the total environmental impacts of manufacturing the machine and how the impacts are distributed across the number of uses during a given lifetime. **Figure 5** compares the life cycle environmental impacts of the machine versus the HDPE bottles per liter of liquid detergent dispensed. The life cycle environmental impacts of producing one liter HDPE bottle stays constant regardless of the monthly use rate, while the life cycle environmental impacts per liter of liquid dispensed decrease as the use rate increases because the machine's impacts are distributed over a higher number of uses during the 10-year lifetime.

Figure 5. Life Cycle Environmental Impacts of Refill Machine Versus SUP (HDPE Bottles) per Liter of Liquid Detergent Consumed



In the category of climate change, the machine must dispense 17 liters or more per month to have a better environmental performance, whereas in the category of cumulative energy demand, a dispense rate of 12 liters per month is already sufficient to have a better environmental performance over HDPE bottles. In the category of water depletion, the machine needs to achieve a much higher monthly use rate of at least 32 liters per month to have a better environmental performance over HDPE bottles. This is because the machine's manufacturing process uses a large amount of water; nearly a quarter (24%) of the total water depletion of the machine was from water consumption during the manufacturing stage.

In all impact categories, the machine showed a small increase in impacts when the monthly use rate increased. The only activities that had an increase in impacts as a result of an increase in use rate is the electricity used when dispensing the cleaning detergents and the amount of transportation required to refill the machine. The machine's standby electricity use comprised more than half of the total impacts across all three categories. The production of the metal structure had the second highest contribution to the total impacts followed by the coin and bill acceptor components. Transport of the liquid detergents to refill the machine made up a little over 1% of the total impacts in the categories of climate change and cumulative energy demand and less than 1% in water depletion.

For the HDPE bottles, the production of HDPE and blow molding it into the bottles made up more than 90% of the total impacts in all three categories. In this study, the total GHG emissions was 0.302 kg

CO_2-eq/HDPE bottle, which translates to 3.8 kg CO_2-eq/kg HDPE bottle. Other studies have reported higher and lower values. An LCA study by the Waste & Resources Action Programme (2010)[18] showed that milk HDPE bottles had GHG emissions of 4.7 kg CO_2-eq/kg bottle with disposal by incineration, whereas an LCA study conducted by Treenate et al. (2017)[19] showed that HDPE bottles had GHG emissions of 5.5 kg CO_2-eq/kg bottle. Based on these differences in GHG emissions per HDPE bottle, the minimum level of use of the machine to have environmental benefits over HDPE bottles may be slightly lower than what is reported in this study.

Overall, for the piloted machine to achieve environmental benefits over SUPs, the monthly use rate on average will need to double when scaling up. This scaling up can be achieved by using the machine not only at the restaurant, but also providing access to other businesses located nearby who require mopping and dishwashing detergents.

Discussions with the startup revealed that since the implementation of the machine, nearby businesses and other consumers have shown interest in using the machine instead of purchasing individual bottles of liquid detergents.

Thus, it is expected that the use rate will scale up in the future and help displace more HDPE bottles.

[18] Waste & Resources Action Programme (2010), Life cycle assessment of example packaging systems for milk, Netherlands Institute for Sustainable Packaging, https://kidv.nl/life-cycle-assessment-of-example-packaging-systems-for-milk-1
[19] Treenate et al. (2017), A complete life cycle assessment of high density polyethylene plastic bottle, IOP Conference Series: Materials Science and Engineering, doi: 10.1088/1757-899X/222/1/012010

Pilot 3

Areca Palm Leaf Single-Use Takeaway Container vs. Paper-based Takeaway Container with PE Lining and PP Takeaway Container

Each container compared in this study is provided by the restaurant in Indonesia where the pilot took place. The functional unit used to compare the three types of single-use takeaway containers in this LCA study is defined as a single takeaway container with a volume of 750 ml to deliver food from a restaurant once in Indonesia.

Alternative Solution: Areca Container

The areca containers are made from fallen leaves from areca palm trees. Each container has a mass of 50 grams. The startup provided primary data about the plantation (e.g. number of trees per hectare, fertilizers used), power ratings and operating capacities of all the machines used at the factory, water consumption at the factory, and distances between the different locations in the supply chain. All other data required for the LCA were gathered from secondary sources.

Raw material extraction: The areca palm leaf takeaway containers are manufactured from collecting fallen areca palm leaves from a plantation in Indonesia. The plantation uses a small amount of fertilizer and does not require external water for irrigation because the soil has high moisture content. The leaves are brought to the factory which is 980 km away from the plantation.

Manufacturing: The leaves are brought to the factory where they are sorted, washed, pressed into the shape of the containers, and go through post-production processes to ensure quality control. They are then wrapped in PE film at an assumed amount of 0.5 grams/container. The finished products are transported to the warehouse in Jakarta which is approximately 40 km from the factory. For this product, the total impacts are calculated at two different power ratings during the leaf pressing stage, which are 7.5 kW (the current power rating) and 5.5 kW. The purpose of this comparison is to understand by how much the impacts will decrease when a lower power rating is used to press the leaves, which was reported in a related LCA study by Gautam et al. (2020)[20].

Distribution: The finished areca takeaway containers are transported in a commercial van from the warehouse to the restaurant which is 34 km away.

Use and maintenance: The restaurant packs food in the areca takeaway container, which is then delivered to the customer by motorcycle. A delivery distance of 2 km was assumed. The motorcycle has a fuel economy of 55 km/liter of petrol[21] and has tailpipe CO_2 emissions of 0.051 kg CO_2/km[22].

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[20] Gautam et al. (2020), Evaluation of Areca palm renewable options to replace disposable plastic containers using life cycle assessment methodology, Energy Reports. https://doi.org/10.1016/j.egyr.2019.08.023

[21] MotoMalaysia (2017), Honda Wave 125i overview, https://www.motomalaysia.com/honda-wave-125i-price-specs-malaysia/

[22] Sustainable Urban Transport Project (2015), Can electricity replace Gasoline? Unlocking the potential of electric two-wheelers in Thailand, https://sutp.org/publications/can-electricity-replace-gasoline-unlocking-the-potential-of-electric-two-wheelers-in-thailand/

The customer consumes the food and disposes the takeaway container in a waste bin. Mass allocation was used to assign the impacts of the one-way delivery between the container and the food. The container makes up 7% of the total mass delivered and is therefore associated with 7% of the delivery impacts while the remaining 93% is associated with the delivery of food, which is assumed to weigh 700 grams.

End-of-life: The disposed areca takeaway container is assumed to be sent to the landfill at Bantar Gebang which is 40 km from the location where the takeaway container is used. Although the areca container can be composted, landfilling of the waste was assumed because the customer is assumed to not have access to home composting.

Status Quo: Paper-based Takeaway Container with PE Lining

Before the pilot, the restaurant delivered food in a takeaway container made of PE-lined paper. This container is manufactured in China and has a mass of 24 grams. The life cycle inventory of the container was based on an LCA study by Buccino et al. (2017)[23] that analyzed ice cream cups made of PE-coated paper. As the material in their study and this study are very similar, the life cycle inventory was modified to fit the paper-based takeaway container in this LCA study. Secondary data from the Ecoinvent and Plastics Europe databases were used to represent the environmental impacts of producing PE and other required inputs.

Raw material extraction: PE-lined paper is the core material used in making the container, which is made of kraft paper and polyethylene. The polyethylene-lined paper is assumed to be manufactured in China.

Manufacturing: The factory in China uses electricity from the average China grid mix to make the PE-lined paper container. The final product is packaged in PE at an assumed amount of 0.5 grams per container.

Distribution: The finished takeaway container is transported from the factory in China to the port (an assumed distance of 200 km), where it is transported to Indonesia on a freight container ship (a distance of 3,847 km), and arrives at the port in Jakarta. The takeaway container is transported to the restaurant which is assumed to be 25 km away from the shipping port.

Use and maintenance: The restaurant packs food in the paper-based takeaway container which is then delivered to the customer by motorcycle. A delivery distance of 2 km was assumed. The

[23] Buccino et al. (2017), LCA of an ice cream cup of polyethylene coated paper: how does the choice of the end-of-life affect the results?, Environmental Technology, doi: 10.1080/09593330.2017.1397771

motorcycle has a fuel economy of 55 km/liter of petrol[24] and has tailpipe CO_2 emissions of 0.051 kg CO_2/km[25]. The customer consumes the food and disposes the takeaway container in a waste bin. Mass allocation was used to assign the impacts of the one-way delivery between the container and the food. The container makes up 3% of the total mass delivered and is therefore associated with 3% of the delivery impacts while the remaining 97% is associated with the delivery of food which is assumed to weigh 700 grams.

End-of-life: The disposed takeaway container is assumed to be sent to the landfill at Bantar Gebang which is approximately 40 km from the location where the takeaway container is used.

SUP: PP Takeaway Container

The single-use PP takeaway container is manufactured in Indonesia and has a mass of 30 grams. The life cycle inventory of the container was based on a study by Gallego-Schmid et al. (2019)[26] and was adapted for this LCA study. Secondary data from the Ecoinvent and Plastics Europe databases were used to represent the environmental impacts of producing PP and other required inputs.

Raw material extraction: PP production starts with extracting crude oil and natural gas. The crude oil is refined to produce naphtha and the natural gas goes through processing. Naphtha and natural gas undergo cracking where intense heat is applied to form propylene. All the raw material extraction processes are assumed to take place in Indonesia.

Manufacturing: At the factory in Indonesia, PP goes through extrusion and thermoforming to produce the desired container shape. The finished container is packed in cardboard and PE and is ready at the factory for distribution. All processes consume electricity from the average Indonesia grid mix.

Distribution: The finished PP takeaway container is transported by truck to the restaurant which is assumed to be 1,000 km away from the factory.

Use and maintenance: The restaurant packs food in the PP takeaway container which is delivered to the customer by motorcycle. A delivery distance of 2 km was assumed. The motorcycle has a fuel economy of 55 km/liter of petrol[23] and has tailpipe CO_2 emissions of 0.051 kg CO_2/ km[24]. The customer consumes the food and disposes the takeaway container in a waste bin. Mass allocation was used to assign the impacts of the one-way delivery between the container and the food. The container makes up 4% of the total mass delivered and is therefore associated with 4% of the delivery impacts while the remaining 96% is associated with the delivery of food which is assumed to weigh

[24] MotoMalaysia (2017), Honda Wave 125i overview, https://www.motomalaysia.com/honda-wave-125i-price-specs-malaysia/
[25] Sustainable Urban Transport Project (2015), Can electricity replace Gasoline? Unlocking the potential of electric two-wheelers in Thailand, https://sutp.org/publications/can-electricity-replace-gasoline-unlocking-the-potential-of-electric-two-wheelers-in-thailand/
[26] Gallego-Schmid et al. (2019), Environmental impacts of takeaway food containers, Journal of Cleaner Production, doi: 10.1016/j.jclepro.2018.11.220

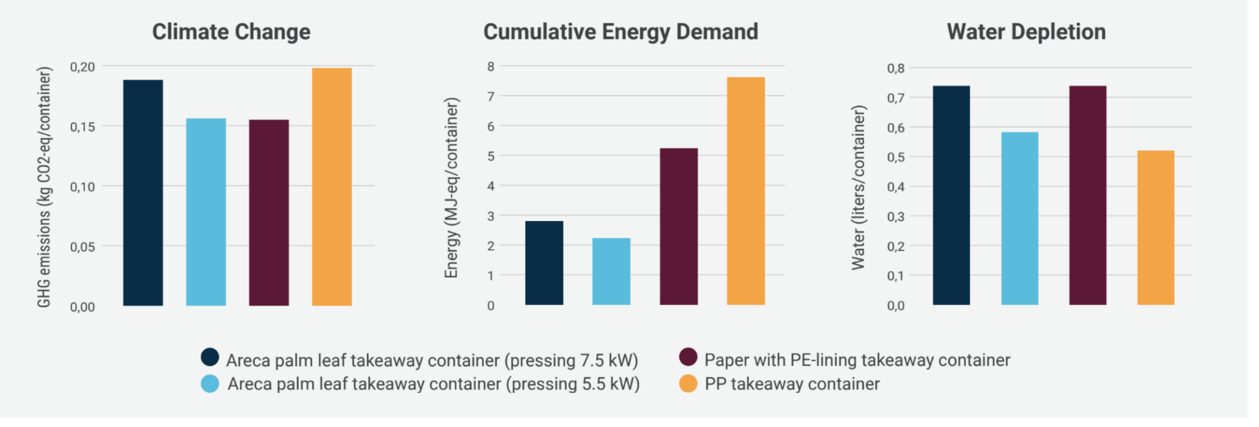
700 grams.

End-of-Life: The disposed SUP takeaway container is assumed to be sent to the landfill at Bantar Gebang which is 40 km from the location where the takeaway container is used.

Findings

The results of the LCA study show that the areca palm leaf container had lower total impacts than single-use PP containers in the categories of climate change and cumulative energy demand (**Figure 6**). However, in the category of water depletion, the areca container had higher impacts than the PP container because of the large amount of water used at the areca container factory to wash the leaves.

Figure 6. Life Cycle Environmental Impacts of Areca Leaf Versus Paper-Based and SUP Takeaway Containers



Most of the areca container's impacts during raw material extraction and processing came from the electricity used in the heat pressing process at around 7.5 kW, even if the leaves are just pressed for less than two minutes. Bringing down the heating power rating to 5.5 kW as reported in a similar LCA study by Gautam et al. (2020)[27] in India results in a noticeable reduction in all three impact categories. At a lower heating rate of 5.5 kW, the areca container has lower water depletion than the paper-based container with PE lining.

Compared to the PE-lined paper container that existed before the pilot, the total impacts of the areca palm leaf container were nearly equal to or lower in the categories of climate change and water depletion at a heat pressing power rating of 5.5 kilowatts. In cumulative energy demand, the areca palm leave container had lower total impacts compared to both single-use containers.

[27] Gautam et al. (2020), Evaluation of Areca palm renewable options to replace disposable plastic containers using life cycle assessment methodology, Energy Reports. https://doi.org/10.1016/j.egyr.2019.08.023

For the PP container analyzed in this study, the total GHG emissions without transportation for delivery by motorcycle was 0.171 kg CO_2-eq/container. A LCA study by Gallego-Schmid et al. (2019)[28] calculated the life cycle GHG emissions of the same container to be 0.151 kg CO_2-eq/container. Thus, this study's estimate of the GHG emissions of a single-use PP container is within the same order of magnitude as another LCA study and can be used to benchmark against the areca container.

Overall, the areca palm leaf containers have lower impacts to the environment than single-use PP containers in climate change and cumulative energy demand, but higher impacts in water depletion. By using less water and a lower heating power rating for pressing the leaves at the factory, the total water depletion of the areca containers could be reduced to be lower than the PP container.

> **However, using a lower heating power rating will be difficult to achieve as a high amount of heat is required to evaporate the water content within the leaves and press the containers into the desired shape.**

[28] Gallego-Schmid et al. (2019), Environmental impacts of takeaway food containers, Journal of Cleaner Production, doi: 10.1016/j.jclepro.2018.11.220

Pilot 4

Coconut Palm Leaf Single-Use Straw vs. PP Straw

Pilot 4 tested a single-use drinking straw made from coconut palm leaves. The functional unit of comparison was a single-use beverage straw used to consume one beverage at a foodservice outlet in India. Each beverage straw compared in this LCA study is provided by the foodservice operator in the pilot in India.

Alternative Solution: Straw Made of Waste Coconut Palm Leaves

The palm leaf-based straws are made from waste leaves from coconut palm tree plantations. Each straw has a mass of 2 grams. The startup provided primary data on the distances between the leaf processing centers, straw processing centers, and post-production facility; factory machine capacities; power ratings of each machine; water consumption rate; and mass of packaging for the straws. All other data required for the LCA were gathered from secondary sources.

Raw material extraction: The waste leaves from the various coconut palm tree plantations are collected in small amounts and the collection process does not harm the forest area. The leaves are brought to different leaf processing centers by truck. In this study, the shortest distance between the plantation and leaf processing center was selected, which was 57 km. The maximum possible distance was 597 km. At the leaf processing center, the leaves undergo washing, cutting, knurling, and scraping, all of which consume electricity and water. The processed leaves are sent to a straw processing center. In this study, the shortest distance between the leaf processing center and straw processing center was selected, which was 19 km. The maximum possible distance was 630 km.

Manufacturing: At the straw processing center, the processed leaves are rolled into straws. Next, the straws are sent to the post-production facility where they go through manual inspection, buffing, wax bursting, polishing, sterilization, and packaging. Each straw is packaged individually in paper and 150 straws are packed together in a biodegradable plastic pouch. In this study the shortest distance between the straw processing center and the post-production facility was selected, which was 119 km. The maximum possible distance was 660 km.

Distribution: The palm leaf straws are transported to the foodservice outlet by freight truck, at an assumed distance of 100 km.

Use and maintenance: The customer uses the palm leaf straw at the restaurant, which is disposed of in a waste bin after the meal is finished.

End-of-life: The disposed palm leaf straw is assumed to be sent to an incinerator which is assumed to be 100 km from the foodservice outlet where the straw is used.

SUP: PP Straw

The PP straw is manufactured in India and has a mass of 0.7 grams including the low density polyethylene (LDPE) packaging. The life cycle inventory of the straw was based on a study by Chang and Tan (2021)[29]. Secondary data from the Ecoinvent and Plastics Europe databases were used to represent the environmental impacts of producing polypropylene and other required inputs.

Raw material extraction: PP production starts with extracting crude oil and natural gas. The crude oil is refined to produce naphtha and the natural gas goes through processing. Naphtha and natural gas undergo cracking where intense heat is applied to form propylene. The propylene undergoes polymerization to produce PP resin. LDPE goes through a similar process starting with cracking to form ethylene and polymerization to form LDPE resin.

Manufacturing: At the factory, PP goes through extrusion to form the straw. Similarly, the LDPE resin goes through extrusion to form LDPE film for the packaging. The straw is packaged in LDPE and is ready for distribution. All processes at the factory consume electricity from the average India grid mix.

Distribution: The finished SUP straws are transported by truck to the F&B outlet which is assumed to be 100 km away from the factory.

Use and maintenance: The customer uses the SUP straw at the restaurant, which is disposed of in a waste bin after the meal is finished.

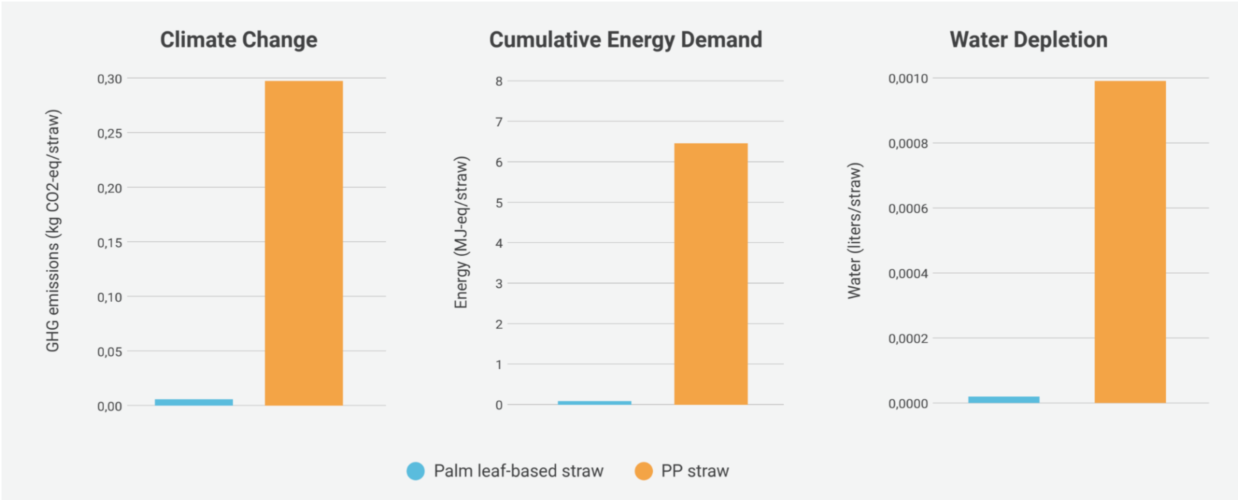
End-of-life: The disposed SUP straw is assumed to be sent to an incinerator which is assumed to be 100 km from the F&B outlet where the straw is used.

Findings

The results of the LCA study showed that across all three impact categories, the palm leaf straws had lower total impacts than the SUP straws, as shown in **Figure 7**.

[29] Chang and Tan (2021), An integrated sustainability assessment of drinking straws, Journal of Environmental Chemical Engineering, doi: 10.1016/j.jece.2021.105527

Figure 7. Life Cycle Environmental Impacts of Palm Leaf-Based Straw Versus SUP Straw



The palm leaf-based straw had significantly lower impacts in all three categories because the impacts from raw material extraction and processing were very low compared to the PP straw. For the palm leaf-based straw, electricity use at the factory made up over 60% of the total impacts in all three categories. The paper packaging for the palm leaf-based straw had the second highest contribution to the total impacts to climate change and cumulative energy demand. Ground transportation activities by truck made up 3% of the total impacts to climate change and cumulative energy demand and 1% for water depletion.

For the PP straw, the process of extrusion made up more than 85% of the total impacts in the categories of climate change and water depletion followed by natural gas extraction. In the category of cumulative energy demand, natural gas extraction made up the largest share of the total impacts followed by electricity use during extrusion. The results of this study showed that the life cycle GHG emissions of the PP straw was 0.297 kg CO_2-eq/straw. GHG emissions reported in other studies were 0.140 kg CO_2-eq/straw in an LCA study by Chang and Tan (2021)[30] and 0.969 kg CO_2-eq/straw in an LCA study conducted by Thinkstep (now Sphera) that was commissioned by Tetra Pak[31]. In this study, the amount of electricity used in extrusion of a single PP straw was 0.2 kWh, based on the inventory data provided in the LCA study conducted by Chang and Tan (2021)[32]. The GHG emissions from electricity use during extrusion of the straw in India was much higher because the GHG emissions of India's grid mix was double the GHG emissions of electricity generated in Malaysia. If Malaysia's electricity was used to manufacture the straw, the GHG emissions of the straw in this study would have been 0.156 kg CO_2-eq/straw, which is close to the value reported in the study conducted at Chang and Tan (2021)[33].

Overall, the LCA results show that use of a palm-leaf based straw not only displaces SUP straws, but also offers environmental benefits in climate change, energy, and water over the status quo.

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[30] Chang and Tan (2021), An integrated sustainability assessment of drinking straws, Journal of Environmental Chemical Engineering, doi: 10.1016/j.jece.2021.105527
[31] Tetra Pak (2019), LCA of plastic & paper straws for portion-sized carton packages, https://www.tetrapak.com/content/dam/tetrapak/publicweb/gb/en/sustainability/documents/LCA-paper-plastic-straws.pdf
[32] Chang and Tan (2021), An integrated sustainability assessment of drinking straws, Journal of Environmental Chemical Engineering, doi: 10.1016/j.jece.2021.105527

Lessons Learned

The results of the LCA studies focused on the four pilots showed that SUP alternatives generally offer environmental benefits under certain conditions and for certain impact categories, depending on the type of product and how the business model operates. Further, and perhaps more important at this phase of market development, the LCAs and the pilots themselves surfaced a number of broad considerations that suggest greater opportunities and areas of exploration for startups in the SUP alternative space, as well as challenges that must be overcome if a broad-based transition to SUPs is to occur.

Given that the SUP alternative market is still nascent, existing and new startups in the space have the chance to continue to develop and refine their products to provide the greatest environmental benefit as compared to the status quo SUPs. There are also opportunities to refine business and operating models to address some of the risks and barriers to widespread adoption. Startups developing SUP alternatives should consider these points in developing their solutions, discussed briefly here and in more detail in The SUP Challenge Insights Report:

- **Sizing Demand for Reuse/Refill Solutions–And Recognizing Trade-offs:** Reuse/refill solutions that rely on capital-intensive equipment for dispensing or distributing their products will need to reach a specific scale of utilization before they can achieve environmental benefits over SUPs. These solutions may require more water over the entire life cycle due to their use and maintenance, which can result in an environmental trade-off.

- **Evaluate the Raw Materials Used:** Solutions made of bio-based materials that require minimal energy, water, and other resource inputs during the material extraction stage are likely to achieve environmental benefits over SUPs. The nature of the raw material also affects the amount of energy and water needed for the manufacturing stage during material processing and product fabrication.

- **Test Products in Market Conditions:** Most material alternatives are not built to last like SUPs, and may undergo deformation in natural conditions, which can happen during transportation and storage. Startups offering solutions need to run as many stress tests on their products to build confidence in foodservice operators.

- **Optimize Transportation of Finished Products:** Transportation of products to the customers can have a large contribution to environmental impact. This can be addressed with business process improvements which bundle multiple deliveries per trip, instead of the usual delivery process of carrying a single item per trip.

The Way Forward

The SUP Challenge was designed to help accelerate the transition to plastic alternatives and minimize the environmental impact of the alternatives. There is a clear need for ongoing innovation, testing and feedback loops between producers and users of SUPs in order to ensure that alternatives are viable. There are also several ways to move emerging solutions forward.

Harnessing the collective energy and concern of the many companies already working to advance solutions can help accelerate the transition away from single-use plastics. With refill/reuse solutions, the additional logistical requirements of washing, labeling and transporting reusable packaging bring about business opportunities for shared infrastructure that can help individual businesses better manage the costs and logistics of these aspects of product distribution.

Similarly, there is an opportunity for the many small players developing SUP alternatives to band together to offer multiple solutions to foodservice operators as well as the suppliers that are supply-chain middlemen. Foodservice operators can also use their bargaining power, as major customers, to exert influence on suppliers to encourage them to provide SUP alternatives that work across the industry.

Finally, as the LCAs detailed in this report revealed, there are real environmental costs and benefits to SUP alternatives, which policy makers, foodservice operators and solution providers should all take into consideration. Existing LCA tools such as UP Scorecard and WWF Alternative Materials Tool are useful resources for foodservice operators and solution providers to identify the environmental impacts of different packaging materials. Expanding these tools to include a greater range of packaging materials from South and Southeast Asia, such as those featured in The SUP Challenge can help operators and startups make more informed decisions on the alternative solutions to deploy, and have easier access to LCAs at lower costs.

It is our hope that the learnings in this report as well as in The SUP Challenge Insights Report and the Technical Playbook, Accelerating Circular Solutions to Single-Use Plastics, can serve as a useful starting point for additional efforts so that growth and refinement of SUP alternative solutions can occur at the pace and scale that the plastic pollution crisis demands.

About

The Incubation Network

The Incubation Network is an impact-driven initiative that sources, supports and scales holistic innovative solutions to combat plastic pollution through strengthening entrepreneurial ecosystems with a diverse network of key partners.

Part of a highly collaborative community of startups and entrepreneurs, investors, partners and programs, The Incubation Network works together with industry players to tackle key barriers to address plastic leakage and advance a circular economy. This includes sourcing and supporting, to scaling early stage or pre-investment solutions and connecting compatible ecosystem players to reinforce the value chain in waste management and recycling.

Established in 2019, The Incubation Network is a partnership between non-profit organization, The Circulate Initiative and impact innovation company, SecondMuse. The Incubation Network is open to interested collaborators, corporations, and mentors, looking to address plastic leakage and advance a circular economy in South and Southeast Asia.

For more information, visit: incubationnetwork.com

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Funders

PREVENT Waste Alliance

The PREVENT Waste Alliance serves as a platform for exchange and international cooperation for organizations from the private sector, academia, civil society and public institutions who jointly engage to advance a circular economy. The PREVENT members contribute to minimizing waste, eliminating pollutants and maximizing the re-utilisation of resources in the economy worldwide. They strive to reduce waste pollution in low- and middle-income countries and work together for the prevention, collection, and recycling of waste, as well as the increased uptake of secondary resources. The PREVENT Waste Alliance was launched in 2019 by the German Federal Ministry for Economic Cooperation and Development.

For more information, visit: **prevent-waste.net**

ECCA Family Foundation

ECCA Family Foundation was established in 2020 to support and inspire transformative change with a strong focus on preserving our global ecosystems, especially the oceans and forests, and on protecting biodiversity for our future generations.

For more information, visit: **eccafamily.foundation**

Insights Contributors

PXP Sustainability

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PXP Sustainability is a consultancy that assists businesses, non-profit organizations, and development agencies measure sustainability, identify the root causes of the challenges, and build strategies that lead to positive outcomes. PXP is driven by systems thinking, evidence-based methods, and stakeholder engagement and specializes in life cycle assessment, circular economy, and the energy transition with a focus on Southeast Asia.

The Circulate Initiative

thecirculateinitiative.org

The Circulate Initiative is a non-profit organization committed to solving the ocean plastic pollution challenge and advancing the circular economy in South and Southeast Asia. In partnership with key industry stakeholders, we work to build more circular, inclusive and investible waste management and recycling systems. The Circulate Initiative pursues two key strategies to achieve its goals: incubating new solutions and developing research and insights.

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