Life Cycle Assessment of coffee consumption: comparison of single-serve coffee and bulk coffee brewing

Final Report

Prepared for:

PACKAGING CONSORTIUM

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June 2, 2015

PROJECT INFORMATION	
Project title	Life Cycle Assessment of coffee consumption: comparison of single-serve coffee and bulk coffee brewing
Contracting organization	PAC, Packaging Consortium
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Version	Final report
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Executive summary

Context

According to the United Nations Environment Programme (UNEP) and the World Resources Institute (WRI), one third of all food produced worldwide is wasted. In an effort to address the issue, PAC launched the PAC FOOD WASTE initiative to investigate the causes of food waste, identify innovative packaging solutions, extend product shelf life and inform and educate the broader community. One of the initiative's first projects aimed to elucidate the relationships between North American packaging and the causes of food waste along the food value chain through a life cycle assessment (LCA) of coffee systems whose key differences lie in their packaging and coffee brewing process. PAC therefore commissioned Quantis to conduct a formal ISO 14 040-44-compliant LCA study comparing the environmental performances of single-serve coffee using a capsule system and bulk coffee using a drip-brewed system for one 8-oz. serving of filtered coffee in the North American market. The aim was to answer a series of questions, including:

- What is the environmental footprint of single-serve coffee and how does it compare to the footprint of drip-brewed coffee?
- How do consumer habits influence the life cycle impacts (brewing and waste, disposal of the grounds and expired bulk coffee)?
- What is the percentage of each input (including packaging) in the overall footprint, from coffee bean growing to brewing to product and packaging disposal?

Life cycle of a coffee system

The study assessed the life cycle of brewing coffee using single-serve capsules (system 1) or bulk coffee (system 2), from the extraction and processing of all raw materials to the end-of-life management of the coffee and packaging system (see figure i).

The single-serve capsule was modeled to represent a generic capsule based on current designs that uses standard abaca filter. The drip-brewed coffee system was modeled to represent a generic no. 4 standard abaca filter based on current product and packaging designs and a generic bulk coffee packaging system based on current designs.

divided into five main life cycle stages: (1) Coffee supply, (2) Materials and production, (3) Distribution, (4) Use, and (5) End-of-life.

The method used to evaluate the environmental impact is the peer-reviewed, internationally recognized IMPACT 2002+ vQ2.21 life cycle impact assessment (LCIA) method adapted by Quantis, which considers 17 different potential impact categories (midpoint) and then aggregates them into four damage (endpoint) categories: climate change, human health, ecosystem quality and resource depletion (see Figure i). They are presented along with the inventory indicator for water withdrawal, which is not yet accounted for in any endpoint category.

A critical review of the study was carried out by a panel of external experts that included Gregory A. Norris (Harvard T.H. Chan School of Public Health), Terrie Boguski (Harmony Environmental) and Getachew Assefa (Triple Ten Consulting) to validate compliance with ISO 14 040-44 standards. The results of the critical review are available in Appendix E.

Consumer behaviours and energy efficiency: key parameters

The coffee systems considered in this study provide very different consumer experiences, and consumer behaviours are vastly different.. Consumers have virtually no control of inputs and outputs of the single-serve system. Conversely the consumer controls all aspects to the drip-brewing process including the amount of coffee brewed, the amount of water used and the amount of time the coffee is left on the hot plate. The results presented in this report indicate that consumer behaviours pertaining to coffee waste and energy use constitute key parameters when determining the environmental performance of a coffee system. Unfortunately, there are few reliable studies or surveys on consumer behaviours in the literature. As a result, this study relied on a series of scenarios tested with sensitivity analyses to pinpoint the tipping points of system comparisons.

It was anticipated that the drip-brewed system would generate two types of coffee waste: **coffee waste due to over-preparing** (i.e. when the consumer brews more coffee than necessary to avoid shortage) and **coffee waste due to inferior freshness** (i.e. when the consumer disposes of a certain amount of bulk coffee before it is consumed in its entirety due to lack of freshness since bulk grains are kept over a longer period of time). In addition, certain drip-filter brewers are equipped with a **hot plate to keep the coffee warm** for a certain period of time—a feature that impacts the energy efficiency of the coffee making process. Certain coffee makers will have an auto shut-off feature that minimizes the time of use of the hot plate, while other models will keep the coffee warm for longer periods.

Figure i: Summary of the life cycle of one serving of coffee and the life cycle impact assessment method IMPACT 2002+ vQ2.21

In order to provide a practical, comprehensive overview of the product system, the LCA considered all identifiable upstream inputs in each life cycle stage. For example, truck transport emissions as well as the impacts of the additional processes and inputs required to produce the fuel were considered when determining the environmental impact of transportation. The production chain of all inputs can therefore be traced to the initial extraction of raw materials. As illustrated in Figure i, the systems are

In single-serve systems, the type of capsule and coffee machine determine the amount of coffee used and brewed, virtually eliminating any risk of coffee overconsumption. In addition, the capsules contain a single serving of coffee, which remains fresh until the capsule is inserted into the brewer, thus also considerably limiting the risk of waste due to inferior freshness. For these reasons, neither type of coffee waste was included in the single-serve system scenarios. However, the energy efficiency of single-serve coffee machines varies according to the type of heater, parts insulation and available features. **Flow-type heaters are the most efficient coffee machine water heaters** since they are only activated for brewing and switch off immediately afterwards (the automatic shut-off feature is not required). Machines may also have a ready-to-serve mode, which is a preheat function requiring that the coffee machine be equipped with a reservoir of water that is kept at 85°C to 90°C at all times for immediate brewing. **In this study, coffee machines equipped with a ready-to-serve mode were considered to be the less efficient option**.

These different behaviours were taken into account when setting out the scenarios in Table i.

Table i: Study scenarios

System 1 **Single-serve coffee**	System 2 **Drip-brewed bulk coffee**
S1a Single-serve, efficient One serving of single-serve coffee using a machine with a flow-type heater: BEST CASE	**S2a Drip-brewed, accurate** One serving of drip-brewed coffee for an accurate amount of coffee and no coffee waste, heated with a hot plate for 37 minutes: BEST CASE
S1b Single-serve, ready to serve feature One serving of single-serve coffee using a machine with a ready-to-serve feature: WORST CASE	**S2b Drip-brewed, 50% coffee waste over-preparing** One serving of drip-brewed coffee with 50% waste due to over-preparing
	S2c Drip-brewed, 30% coffee waste, loss of freshness One serving of drip-brewed coffee for an accurate amount of coffeeand30% coffee waste due to inferior freshness retention
	S2d Drip-brewed, 50% coffee waste over-preparing, 30% coffee waste loss of freshness, 2 hours of heating One serving of drip-brewed coffee with 50% waste due to overconsumption and 30% coffee waste due to inferior freshness retention, heating with a hot plate for 2 hours: WORST CASE

Results and conclusions

The adoption of a single-serve coffee system by North American consumers would realize significant environmental benefits including coffee waste reduction. Additional benefits could be achieved with the development of coffee machines with better energy-saving capabilities and extended service lives.

The single-serve coffee system's packaging generates more packaging waste. However, when considering the entire life cycles of each system, the amount of coffee required making up for consumer waste and the electricity consumed for brewing (which depend on consumer habits and coffee machine features) drive the differences in impact.

Overall, the single-serve best case scenario posts a better environmental performance than the drip-brew system from the perspective of the systems' full life cycles. This advantage is specifically attributable to:

- Typical consumer behaviours, including waste due to coffee over-preparation (S2b) and inferior packaging freshness retention (S2c), which cause the drip-brew system to generate greater impacts;
- The amount of coffee required to make up for consumer waste and the electricity consumed for drip brewing, which further increase the overall footprint of the drip system;
- Minimal coffee waste by the single-serve system, which provides an exact serving of coffee even though it creates more packaging waste.

When compared, the best case scenarios for both coffee systems (S1a and S2a) are considered equivalent from the perspective of the climate change indicator (see figure ii). Furthermore, the single-serve coffee system with a ready-to-serve feature that keeps the water hot for immediate coffee preparation (S1b) generates a more significant climate change impact than the best case scenario for the drip-brewed coffee system (S2a). But the best case scenario for the drip-brewed coffee system (S2a) is not representative of average consumer behaviours since bulk coffee brewing is not always accurate and consumers tend to make more coffee than necessary to avoid shortage. The climate change scores were sensitive to consumer behaviours, and, when assessing all of the study scenarios, the coffee waste and electricity consumption parameters were found to affect the indicator results:

- Only 2% coffee waste due to over-preparing and approximately 3% coffee waste due to inferior freshness retention push the climate change score for the drip-brewed system higher than the score for the single-serve best case scenario.

- When compared to the less efficient single-serve coffee machine (ready-to-serve mode, S1b), the tipping points for coffee waste due to overconsumption and inferior freshness retention are 23% and 30%, respectively.
- When both types of coffee waste (50% due to over-preparing and 30% due to inferior freshness) are considered in the same scenario (S2d) along with the longer use of the hot plate (2 hours versus 37 minutes), the gap between the impact scores of the two studied coffee systems widens further.

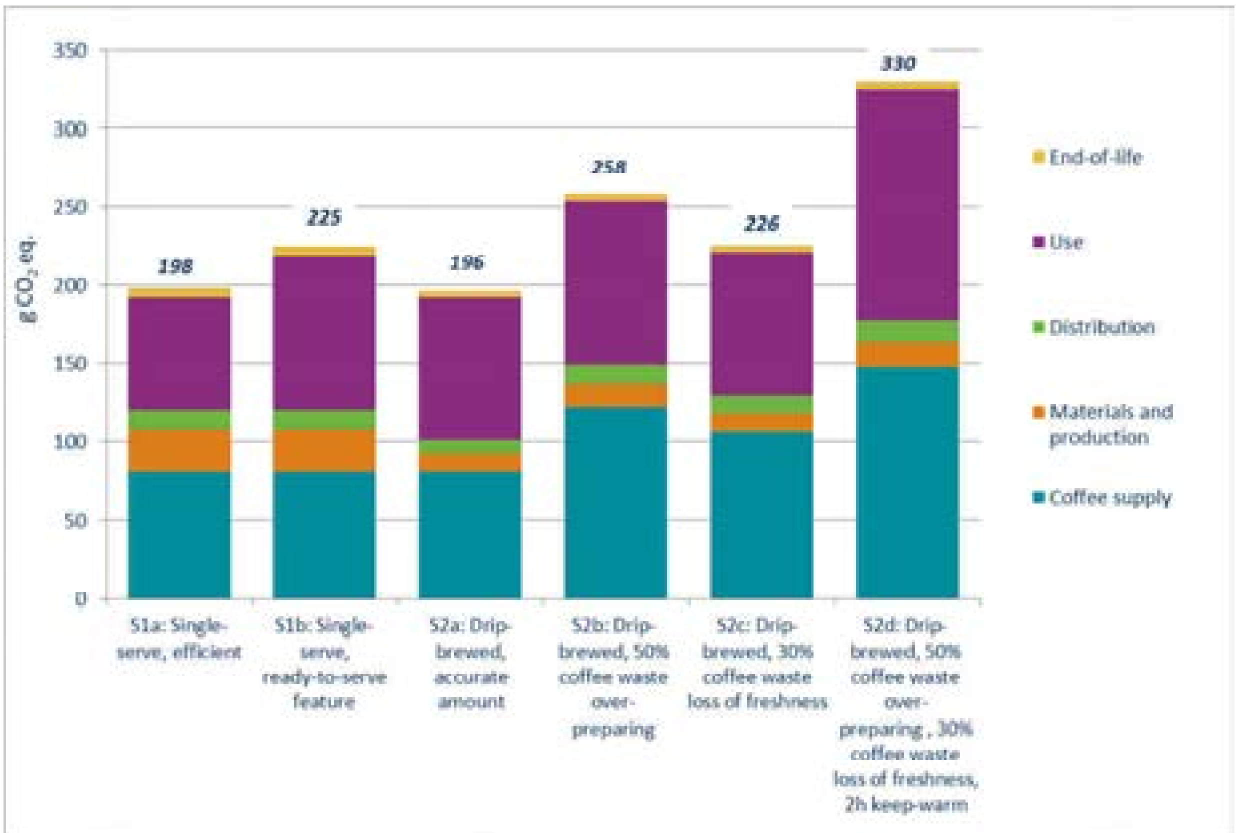

Figure ii: Comparative results for the climate change indicator