Food Product Environmental Footprint Literature Summary:

Coffee

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Executive Summary:

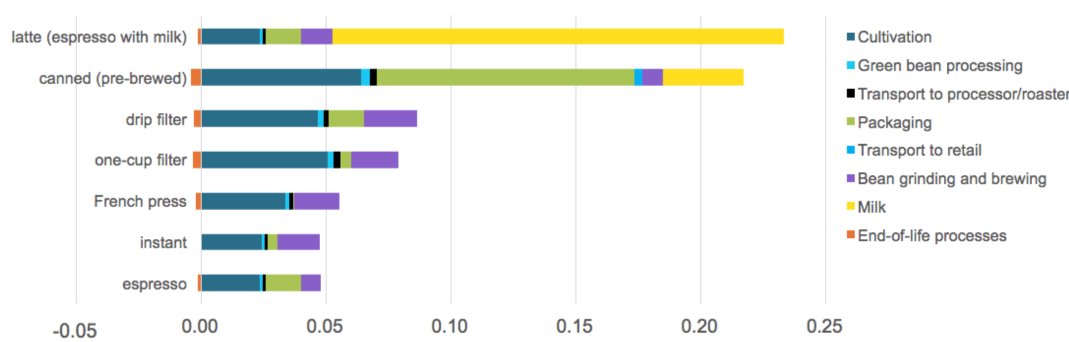
Coffee

Coffee is one of the most valuable internationally traded commodities, second only to oil. World coffee consumption in 2015 totaled 9.13 billion kilograms. Sixteen percent of this (1.46 billion kilograms) was consumed in the U.S. alone. For environmentally conscious coffee consumers in the global north, their “daily grind” may feel like an uncomfortable compromise: coffee is only grown in tropical and equatorial areas. It must be shipped long distances. To complicate things further, the coffee value chain is incredibly diverse. Companies of all types and sizes operating across the globe may all contribute to a single cup of coffee.

Life cycle assessment (LCA) is one way in which we can measure some of the environmental impacts associated with coffee consumption and its complex value chain (shown above). Beginning with farm production and processing to distribution, roasting, packaging, brewing, and disposing the coffee and packaging waste, considering the environmental impacts associated with each stage of the coffee bean life cycle can help empower coffee drinkers and coffee purveyors to make environmentally sound choices.

Key Findings

Carbon footprint comparison of coffee brewing scenarios



Coffee is consumed in a variety of forms, from concentrated espresso to rich and creamy lattes to pre-brewed, packaged drinks. This variety of consumed forms can lead to real differences in environmental impact, and makes comparisons difficult. However, two life cycle stages stand out as most important in nearly all of the studies considered: on-farm coffee production, and the final brewing or making of coffee. Packaging format may also be a significant contributor to the environmental profile, particularly for pre-brewed varieties of coffee drinks. Multiple studies demonstrate the importance of consumer-level brewing methods and behavioral choices, offering accessible improvement opportunities.

The graph above shows proportional contribution of life cycle stage or process to the carbon footprint (CF) per serving of coffee. A number of important conclusions can be drawn including that in many cases, coffee cultivation is the dominant contributor to the CF. Interestingly, impacts of international transport of coffee from the country of production to the country of consumption, shown in the black bar, is relatively minor across all examples. Energy use in brewing coffee is another significant contributor, and adding milk to the coffee can drastically increase the overall CF on a per serving basis. In one study that included washing of a coffee cup, the impact from heating water for washing is notable, yet is very dependent on how and how often the cup is washed. Perhaps most surprising, instant coffee has the lowest carbon footprint in three different studies that consider it. This is due primarily to the smaller quantity of coffee beans required and the fact that boiling water to rehydrate instant coffee typically requires less energy than a coffee maker.

Use Phase Behaviors and Habits

Personal habits about coffee consumption – from the type of brewing method, amount consumed versus wasted, boiling of water, keeping the pot on warm vs. reheating, and cleaning, etc. – can be variables that alter the overall CF of coffee. Though seemingly easy to alter, many of these behaviors can be difficult to change especially in commercial or workplace settings. One study demonstrates that the total life cycle carbon footprint of making coffee with a single-serve capsule system is essentially equal to a drip-brewed coffee maker if there is no waste or other inefficiencies in the use of the drip coffee system. When more coffee is made than is consumed, as is common with drip-brewed systems, the impacts of wasted coffee present a trade-off with the impacts of packaging in single-serve systems that may need more material resources to produce. In general, over-preparing and wasting coffee adds to its impact, and in situations where this occurs often, it may be environmentally preferable to use single-serve systems.

Packaging and Disposable Cups

A study of coffee packaging by Franklin Associates (2008) indicates that brick packs and laminate bags perform better with respect to energy use, GHGE and total solid waste generated, out-performing steel cans, plastic canisters, and fiberboard and steel canisters. The question of whether reusable or disposable cups, and which disposable cups, are better for the environment has to consider the energy efficiency of dishwashing machines and regional electricity grid mix, as impacts of a reusable cup (500+ uses) are almost completely driven by washing the cup. The reusable cup is the better option in regions corresponding to approximately 68 percent of the nation’s residential population for all dishwashers evaluated in one report, including the oldest (least efficient) options. This includes the Pacific Northwest, where the electricity grid mix has a lower carbon footprint than the national average and the reusable cup is the preferred option with respect to the carbon footprint regardless of dishwasher energy efficiency. For the remaining 32 percent of the nation’s population, with the most carbon intensive electricity mixes, the results depend on appliance efficiency.

Conclusions

Many individuals make daily coffee consumption choices. A better understanding of the environmental impacts of those choices can lead to reductions in system impacts. This review of the LCA literature has identified the following conclusions:

- On-farm coffee production and the “use” phase of brewing coffee (and cleaning up after consumption) stand out as the most important stages across the life cycle.
- Contrary to popular imagination, international transport from the country of coffee production to the country of consumption is a relatively minor contributor to the overall environmental footprint.
- Contrary to consumption trends, instant coffee appears to be an environmentally preferable way to consume coffee.
- Informed choices and behavioral shifts such as avoiding making too much coffee or boiling extra water, turning off “keep warm” features, and washing cups in cold rather than hot water can lead to significant reductions in the environmental impact of consuming a cup of coffee.
- Packaging can be an important contributor to environmental impact for pre-brewed coffee.
- Multi-material laminate packaging appears to be preferred over plastic, steel or fiberboard/steel canisters for packaging coffee beans.
- With multiple cup brewing systems, over-preparation and subsequent waste of brewed coffee can have a significant influence on overall environmental performance. Despite the increase in packaging, single-serve machines may represent a preferable option if they aid in avoiding over-preparation.
- Likewise, coffee machines with “ready-to-serve” or “keep warm” features can result in noticeable increases in energy consumption and thus environmental impact.
- While the literature doesn’t consistently identify a clear winner in choosing which type of single-use cup to drink your coffee from, reusable cups have demonstrated environmental benefits, particularly in areas where electricity (used for heating water and washing cups) is not entirely derived from coal or petroleum. Rinsing and reusing ceramic cups even once between full washes can dramatically improve environmental performance per use.

Overview

For many, coffee is a seemingly indispensable part of their daily routine. It should come as no surprise then that coffee is one of the most valuable internationally traded commodities, second only to oil. World coffee consumption in 2015 totaled 9.13 billion kilograms. Sixteen percent of this (1.46 billion kilograms) was consumed in the U.S. alone. For environmentally conscious coffee consumers in the global north, their "daily grind" may feel like an uncomfortable compromise: coffee is only grown in tropical and equatorial areas. It must be shipped long distances. To make matters worse, the coffee value chain is incredibly diverse. Companies of all types and sizes operating across the globe may all contribute to a single cup of coffee.

A life cycle assessment (LCA) is one way in which we can measure some of the environmental impacts associated with coffee consumption and its complex value chain. Beginning with farm production and processing to distribution, roasting, packaging, brewing, and disposing the coffee and packaging waste, considering the environmental impacts associated with each stage of the coffee bean life cycle can help empower coffee drinkers and coffee purveyors to make environmentally sound choices.

This literature summary is one of a series commissioned by the Oregon Department of Environmental Quality. For additional information on the background and objectives of these summaries, as well as on LCA methods and definitions of terms, please refer to the Food Product Environmental Footprint Foreword.

Available LCA Research

Coffee is truly an international commodity. The International Coffee Organization lists 44 exporting countries, with Brazil, Vietnam and Columbia representing the largest volume. Production methods can vary significantly, but data on specific regions is limited, so generalized comparisons of environmental impact between regions cannot be made. Combined, the European Union, United States and Japan represent nearly half of global coffee consumption. Coffee exporting countries only consume 30% of the global total.

Despite its global popularity, coffee has received limited attention in the life cycle assessment literature. Nine studies considering the full "cradle-to-grave" life cycle represented in Figure 1 have been identified. Of these, three report results in ways that limit comparisons with other studies. An additional four studies were identified that consider only the production of green coffee beans, and yet another study compares only coffee preparation methods. Other studies look only at packaging for coffee beans or disposable coffee cup and lid systems.

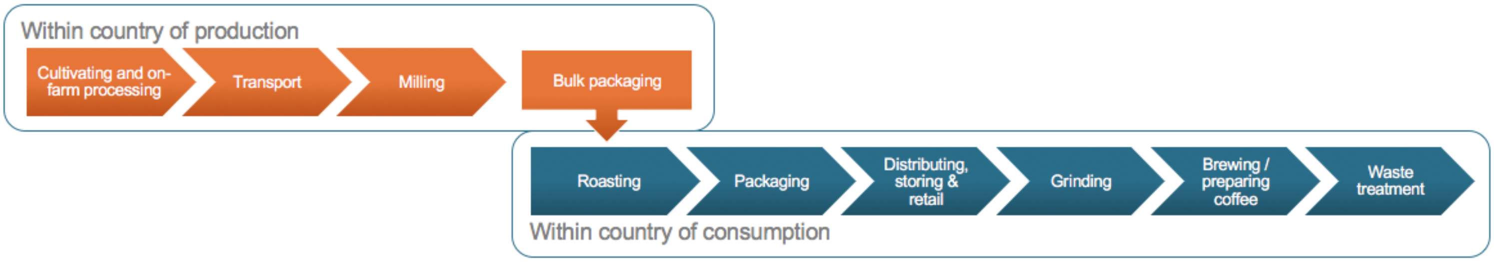


FIGURE 1. Life cycle stages for coffee.

Key Findings

Coffee is consumed in a variety of forms, from concentrated espresso to rich and creamy lattes to pre-brewed, packaged drinks. This variety of consumed forms can lead to real differences in environmental impact, but it also makes “apples-to-apples” comparisons difficult. However, two life cycle stages stand out as most important in nearly all of the studies considered: on-farm coffee production, and the final brewing or making of coffee. While cultivation practices and growing regions likely have real influences on coffee production impacts, limited data prevents conclusive comparisons. Fortunately, repeated studies demonstrate the importance of consumer-level brewing methods and behavioral choices, offering accessible improvement opportunities.

Figure 2 shows the contribution to greenhouse gas emissions (GHGE) per serving of coffee by life cycle stage or process, for a variety of coffee preparation methods and final coffee forms. Results from five cradle-to-grave studies are presented, but comparisons within a given study are more reliable.

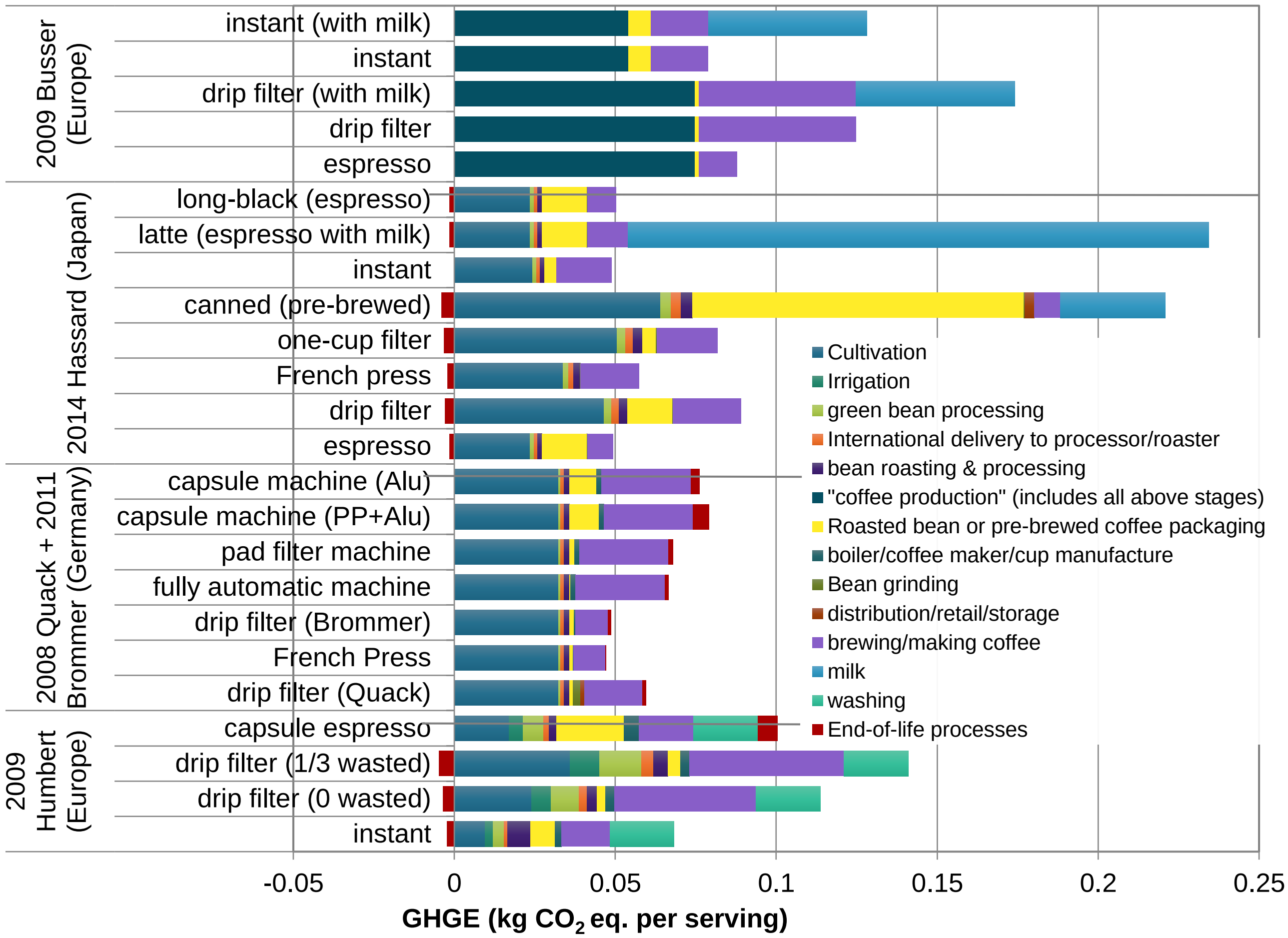


FIGURE 2. Greenhouse gas emissions across the life cycle of coffee, from a collection of studies showing different coffee forms and brewing methods.

Some stages (such as washing) are not considered in all studies. Note that Brommer (2011) only analyzed the coffee preparation stages, but refer to Quack (2008) coffee production as a reference point. (PP+Alu) means coffee capsules made of polypropylene and aluminum, whereas (Alu) refers to all aluminum capsules

Note that some of the studies in Figure 2 also present results for additional environmental impact categories (non-renewable energy use, water use, acidification, eutrophication, photochemical ozone creation), but in nearly all cases, the results of these alternative impacts mirror the same trends and conclusions as the GHGE findings.

A number of important conclusions can be drawn from Figure 2. In many cases, coffee cultivation (farming) is the dominant contributor to GHGE. Energy use in brewing coffee is also a significant contributor. Adding milk can clearly increase the carbon footprint of coffee consumption, in some cases contributing more than the coffee itself. Note that the studies included here did not consider the contribution of sweeteners. Interestingly, impact from international transport of coffee from the country of production to consumption is relatively minor across all examples. Packaging can be a notable contributor to GHGE, especially with pre-brewed, packaged coffee (in this Japanese case, in a steel can). In the study that included

washing of a coffee cup (Humbert, 2009), the impact from heating water for washing is notable, although this is very dependent on consumer behavior (how and how often you wash your cup). Perhaps most surprising, instant coffee has the lowest carbon footprint in the three different studies that consider it. This is due primarily to the smaller quantity of coffee beans required and the fact that boiling water to rehydrate instant coffee typically requires less energy than a coffee maker.

Green Coffee Production

While the agricultural production of coffee beans stands out as an important contributor to the environmental impact of a cup of coffee, very few of the identified studies offer much detail into the sources of these on-farm impacts. Quack (2008) evaluates the product carbon footprint for a German retail and consumer goods company that is the 4th largest coffee producer in the world. They consider a single source, *Arabica* coffee from North Tanzania, and find that the biggest contributors in the country of production are the manufacturing of fertilizer and pesticides (79%) and cultivation and processing on the farm (19.2%).

A study based on experimental plots in both Costa Rica and Nicaragua compared the influence of management practices on on-farm carbon footprint (Noponen et al, 2012). They found that increasing management inputs (more fertilizer, pesticides, etc.) increased yields per acre but also increased GHGE per kilogram of coffee produced. This was true in both organic and conventional systems, but no general conclusion could be made about the comparative carbon footprints of organic and conventional systems. Nitrous oxide emissions from the soil (due to the direct and indirect addition of nitrogen fertilizer) stood out as the biggest contributor to the carbon footprint, although it was acknowledged that these emissions are poorly understood, particularly for agroforestry systems in tropical regions, and results are highly dependent on the estimating method. Also poorly understood is the role that companion trees in shade-grown agroforestry coffee plantations play in sequestering carbon. Research suggests that coffee agroforestry plantations shaded by leguminous trees may sequester additional carbon but that this is largely counterbalanced by nitrous oxide emissions (Hergoualc'h et al, 2012).

Use Phase Behaviors and Habits (*What you do matters!)*

The Humbert study reported in Figure 2 demonstrates that use phase (coffee brewing and cup washing) results can vary by a factor of two depending on consumer behavior. These behaviors include brewing extra coffee that is not consumed, boiling extra water to make a cup of instant coffee, leaving the coffee machine on to keep coffee warm or to keep single-serve machines in ready-to-brew mode, or even washing the coffee cup in warm vs. cold water. Büsser and Jungbluth (2009) list a similar collection of behavioral shifts as the most relevant measures to reduce the environmental impact of a cup of coffee. One passage in particular hints at the challenges of the "behavioral shifts," especially in an office setting:

> *Reducing leftovers of brewed coffee avoids wastage of coffee in its drinking form and wastage of hot water. This can be achieved with a coffee machine producing single cups or with a good planning of the amount of necessary coffee. However, this might not be an appropriate option during business meetings or not feasible when a large number of coffees have to be served in a short time. Using instant coffee and hot water in thermos flasks can be a suitable option in such cases, although not all consumers consider instant coffee an acceptable substitute for coffee made from ground beans.*

Another cradle-to-grave study compared single-serve capsule brewing with drip-brewed coffee for a North American market (Quantis Canada, 2015). The study demonstrates that the total life cycle carbon footprint of making coffee with a single-serve capsule system is essentially equal to a drip-brewed coffee maker *if* there is no waste or other inefficiencies. When more coffee is made than is consumed, as is common with drip-brewed systems, the impacts of wasted coffee present a trade-off with the impacts of packaging in single-serve systems. This study was based on a single-serve brewing system that used capsules (pods) made primarily of polystyrene. Polypropylene and other materials are also commonly used for such capsules, depending on brand and system, and can require significantly greater resources to manufacture[1]. Thus, the exact amount of coffee that would need to be wasted to balance with the impacts of the increased packaging in single serve systems is dependent on the kinds of packaging materials used. In addition, some single-serve brewing systems include a "ready to serve" feature that keeps water hot and consumes additional energy. The take-home message here is that over-preparing and wasting coffee adds to its impact, and in situations where this often occurs, it may be environmentally preferable to use single-serve systems.

Packaging and Disposable Cups

A study of coffee packaging by Franklin Associates (2008) indicates that brick packs and laminate bags perform better with respect to energy use, GHGE and total solid waste generated, out-performing steel cans, plastic canisters, and fiberboard and steel canisters. An earlier study by De Monte *et al.* (2005) supports this result.

The question of whether reusable or disposable cups, and which disposable cups, are better for the environment has been investigated numerous times, and most studies are generally inconclusive or lean toward disposable options being better (Franklin Associates, 2006; Lighard and Ansems, 2007; van der Harst and Potting, 2013; van der Harst et al., 2014; Potting and van der Harst, 2015). Woods and Bakshi (2014), however, conducted a thorough comparison of polystyrene single-use cups and reusable ceramic cups in a U.S. context and based on a 16 ounce serving size, paying careful attention to uncertainty introduced by dishwashing machine energy efficiency and regional electricity grid mix. These two parameters are important since the life cycle impacts of reusable cups averaged over 500 uses are almost completely driven by washing the cup. Results of this study show that the least GHGE emitting option – reusable or

[1] http://www.keuriggreenmountain.com/Sustainability/SustainableProducts/ProductImpact.aspx

polystyrene cup – is dependent on the regional electricity grid and may also depend on appliance (dishwasher) efficiency. The reusable cup is the better option in regions corresponding to approximately 68 percent of the nation's residential population for all dishwashers evaluated in this report, including the oldest (least efficient) options. This includes the Pacific Northwest, where the electricity grid mix has a lower carbon footprint than the national average, and the reusable cup is the preferred option with respect to GHGE regardless of dishwasher energy efficiency. For the remaining 32 percent of the nation's population, with the most carbon intensive electricity mixes, the results depend on appliance efficiency. Efficient appliances (using less electricity) make reusable cups the preferred option, while inefficient dishwashers (that require more electricity to heat water) lead to disposables having a lower carbon footprint. For other environmental impact categories (particulate matter formation; photochemical oxidant formation; ionizing radiation; terrestrial acidification; freshwater and marine eutrophication; human, terrestrial and freshwater ecotoxicity; and fossil depletion) results are either not statistically different or else favor reusable cups. Polyethylene coated paper cups are shown to have greater GHGE emissions than polystyrene cups, but the outcome is mixed across other impact categories. The authors conclude that their results indicate a strong life cycle environmental benefit of using reusable cups.

Research Gaps

Our assessment of the LCA literature of coffee suggests that there is a significant gap in understanding on-farm production. Additional research is needed to make conclusive decisions on a number of the environmentally-oriented choices offered to consumers such as organic and shade-grown beans. In a review of LCA of perennial crops, Bessou *et al.* (2013) point out the need for improvement both in methodological approaches to assessing perennial crops like coffee but also in data sets and field measurements at each stage (nursery to senescence). Like other researchers, they call for an emphasis on agroforestry systems and the multiple services they may provide, as well as a focus on tropical cropping systems where high diversity contrasts with a low rate of data availability. In particular, data and mechanistic models are needed to better simulate highly relevant nitrous oxide emissions in tropical perennial crops.

While the impacts on the consumption stage of the coffee life cycle may be better understood, additional research could focus on the social science of behavioral choices and how consumers could be persuaded to make environmentally preferable choices.

Conclusions

Many individuals make daily coffee consumption choices. A better understanding of the environmental impacts of those choices can lead to reductions in system impacts. This review of the LCA literature has identified the following conclusions:

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- Packaging can be an important contributor to environmental impact for pre-brewed coffee. Multi-material laminate packaging appears to be preferred over plastic, steel or fiberboard/steel canisters for packaging coffee beans.
- With multiple cup brewing systems, over-preparation and subsequent waste of brewed coffee can have a significant influence on overall environmental performance. Despite the increase in packaging, single-serve machines may represent a preferable option if they aid in avoiding over-preparation.
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References

Alliance for Environmental Innovation. 2000. Report of the Starbucks Coffee Company/ Alliance for Environmental Innovation Joint Task Force. Available from http://business.edf.org/files/2014/03/starbucks-report-april2000.pdf.

Bessou, C., C. Basset-Mens, T. Tran and A. Benoist. 2013. LCA applied to perennial cropping systems: a review focused on the farm stage. The International Journal of Life Cycle Assessment 18(2): 340-361.

Brommer, E., B. Stratmann and D. Quack. 2011. Environmental impacts of different methods of coffee preparation. International Journal of Consumer Studies 35(2): 212-220.

Büsser, S. and N. Jungbluth. 2009. The role of flexible packaging in the life cycle of coffee and butter. The International Journal of Life Cycle Assessment 14(1): 80-91.

Coltro, L., A. Mourad, P. Oliveira, J. Baddini and R. Kletecke. 2006. Environmental Profile of Brazilian Green Coffee. The International Journal of Life Cycle Assessment 11(1): 16-21.

Coltro, L., A. Mourad, P. d. Oliveira and J. Andrade. 2012. Regional differences of coffee cultivation in Brazil. Coffee Science 7(1): 31-41.

De Monte, M., E. Padoano and D. Pozzetto. 2005. Alternative coffee packaging: an analysis from a life cycle point of view. Journal of food engineering 66(4): 405-411.

Franklin Associates. 2006. LIFE CYCLE INVENTORY OF POLYSTYRENE FOAM, BLEACHED PAPERBOARD, AND CORRUGATED PAPERBOARD FOODSERVICE PRODUCTS. Available from https://plastics.americanchemistry.com/LifeCycle-Inventory-of-Polystyrene-Foam-Bleached-and-Corrugated-Paperboard-Foodservice-Products/.

Franklin Associates. 2008. LCI Summary for Eight Coffee Packaging Systems. prepared for The Plastics Division of The American Chemistry Council. Available from https://plastics.americanchemistry.com/LCI-Summary-for-8-Coffee-Packaging-Systems/.

Hassard, H., M. Couch, T. Techa-Erawan and B. McLellan. 2014. Product carbon footprint and energy analysis of alternative coffee products in Japan. Journal of Cleaner Production 73: 310-321.

Hergoualc'h, K., E. Blanchart, U. Skiba, C. Hénault and J.-M. Harmand. 2012. Changes in carbon stock and greenhouse gas balance in a coffee (Coffea arabica) monoculture versus an agroforestry system with Inga densiflora, in Costa Rica. Agriculture, Ecosystems & Environment 148: 102-110.

Humbert, S., Y. Loerincik, V. Rossi, M. Margni and O. Jolliet. 2009. Life cycle assessment of spray dried soluble coffee and comparison with alternatives (drip filter and capsule espresso). Journal of Cleaner Production 17(15): 1351-1358.

Lighart, T. N. and A. M. M. Ansems. 2007. Single use Cups or Reusable (coffee) Drinking Systems: An Environmental Comparison. TNO, 2006-AS-R0246(E)/B. Available from https://www.tno.nl/media/2915/summary-research-drinking-systems.pdf.

Noponen, M. R., G. Edwards-Jones, J. P. Haggar, G. Soto, N. Attarzadeh and J. R. Healey. 2012. Greenhouse gas emissions in coffee grown with differing input levels under conventional and organic management. Agriculture, ecosystems & environment 151: 6-15.

PE Americas. 2009. Comparative Life Cycle Assessment Ingeo™ biopolymer, PET, and PP Drinking Cups. prepared for Starbucks Coffee Company. Available from http://www.natureworksllc.com/~/media/The_Ingeo_Journey/EcoProfile_LCA/LCA/PEA_Cup_Lid_LCA_FullReport_ReviewStatement_121209_pdf.pdf.

Potting, J. and E. van der Harst. 2015. Facility arrangements and the environmental performance of disposable and reusable cups. The International Journal of Life Cycle Assessment 20(8): 1143-1154.

Quack, D., U. Eberle, R. Liu and B. Stratmann. 2008. Case Study Tchibo Privat Kaffee Rarity Machare by Tchibo GmbH: Documentation. Available from http://www.pcf-projekt.de/files/1232962944/pcf_tchibo_coffee.pdf.

Quantis. 2011. Comparative full life cycle assessment of B2C cup of espresso made using a packaging and distribution system from Nespresso Espresso and three generic products: Final Report. prepared for Nespresso. Available from https://www.nestle-nespresso.com/asset-library/documents/quantis - comparative lca on four capsules systems 2011.pdf.

Quantis Canada. 2015. Life Cycle Assessment of coffee consumption: comparison of single-serve coffee and bulk coffee brewing: Final Report. prepared for PAC. Available from http://www.pac.ca/assets/pac0680-full-lca.pdf.

Salinas, B. 2008. Life Cycle Assessment of Coffee Production. Luminaire Coffee Equipment. Available from http://luminairecoffee.com/img/lca_paper.pdf.

Salomone, R. 2003. Life cycle assessment applied to coffee production: investigating environmental impacts to aid decision making for improvements at company level. Food, Agriculture and Environment 1(2): 295-300.

van der Harst, E. and J. Potting. 2013. A critical comparison of ten disposable cup LCAs. Environmental impact assessment review 43: 86-96.

van der Harst, E., J. Potting and C. Kroeze. 2014. Multiple data sets and modelling choices in a comparative LCA of disposable beverage cups. Science of The Total Environment 494: 129-143.

von Geibler, J., F. Cordaro, K. Kennedy, M. Lettenmeier and B. Roche. 2016. Integrating resource efficiency in business strategies: a mixed-method approach for environmental life cycle assessment in the single-serve coffee value chain. Journal of Cleaner Production 115: 62-74.

Woods, L. and B. R. Bakshi. 2014. Reusable vs. disposable cups revisited: guidance in life cycle comparisons addressing scenario, model, and parameter uncertainties for the US consumer. The International Journal of Life Cycle Assessment 19(4): 931-940.