Executive Summary

The relative environmental profiles of single-use corrugated fiberboard shipping containers and reusable plastic shipping containers have been investigated in recent years using a life cycle approach. Most of these studies evaluate the containers in the context of European markets, and further research is needed to better understand the relative environmental profiles of single-use corrugated fiberboard containers and reusable plastic containers for produce transport, storage and display in the U.S.

The Corrugated Packaging Alliance (CPA) has commissioned Quantis to perform an ISO 14044 compliant comparative LCA of corrugated containers (CC) and reusable plastic containers (RPC) used to transport and display fresh produce (e.g., apples) in the U.S. This investigation aims to identify the relative environmental performance of these two container systems. More specifically, the objectives of the study are to:

I. Establish credible and transparent profiles of the life cycle potential environmental impacts of corrugated containers and reusable plastic containers utilizing appropriate and accepted databases and LCIA characterization factors according to ISO 14040 and 14044:2006;
II. Identify the magnitude and confidence of comparative environmental advantages of either system; and
III. Ensure compliance of results with ISO 14044 (clause 6) and ISO 14040 (clause 7) to support a public comparative claim, including critical review by a panel of interested parties.

This study includes comparative statements regarding the environmental performance of the two products. It evaluates the relative environmental performance of single-use corrugated fiberboard containers and reusable plastic containers in the context of the U.S. produce market through an ISO 14044 compliant LCA.

The CC and RPC under evaluation are utilized for transporting produce from produce grower to a retail market. The reusable container studied is a standard footprint RPC that is available in the U.S. as a produce packaging solution. The CCs evaluated for comparison are the most prevalent size used for each commodity and were selected based on data from member companies who combined provide more than 70% of the boxes to the produce sector.

The functional unit for this study is to provide containment during filling, transport and display of 907,185 kg (1,000 short tons) of grocery market produce in the United States in a manner that maintains the safety of the produce for human consumption and that is consistent with commercial supply chains. The container profiles investigated are specific to eight types of produce: apples, carrots, grapes, lettuce (head), oranges, onions, tomatoes and strawberries. As the intent of this study is to capture a snapshot of average U.S. industry operations, only U.S.-grown produce are considered, and seasonal variation is not discretely evaluated.

This study assesses the life cycle of CCs and RPCs from the extraction and processing of all raw materials through the end-of-life of the containers. The models are intended to represent the RPC and CC industries and associated processes in the United States at the time the study is conducted. As there is a lack of published studies evaluating the myriad parameters applicable to this assessment (e.g., recycled content, RPC number of uses, etc.), the work herein represents CPA's understanding of each industry based on its own research. Information from pre-existing, recent life cycle studies on CCs and RPCs are used as applicable in conjunction with information offered in confidence by both CC and RPC industry members. Available life cycle data for some elements of the systems represent industry operations as early as 2002 (NREL 2014).

TRACI 2.1 is chosen as the primary impact assessment method for this study, except in the case of the non-renewable energy indicator. TRACI's fossil fuel use indicator is substituted by the non-renewable energy indicator from IMPACT2002+ v2, as it is a direct assessment of energy use and does not require projections regarding the future state of resource availability and consumption. Environmental indicators for land use and land transformation are excluded. These are not able to be adequately quantified due to the lack of inventory data. Also excluded are indicators for ecotoxicity and human health (carcinogens and non-carcinogens) because the toxicity-related data used for the RPC and CC systems are not comparable. A total of seven (7) environmental metrics are evaluated with no normalization of results or weighting of impact categories: acidification, eutrophication, global warming, non-renewable energy, ozone depletion, respiratory effects and smog formation. Two (2) inventory flows are also presented: freshwater consumption and solid waste. GaBi 8 software is employed to perform the calculations.

Several additional evaluations are performed to understand the robustness of the study conclusions. These include numerous sensitivity tests around the CC and the RPC systems, calculation of results using a second impact assessment method (ReCiPe 2016), and a data quality assessment. The latter consists of a completeness and consistency check of the data, a contribution analysis, and an uncertainty analysis. An external panel has been commissioned to conduct a review in accordance with the ISO 14040 series.

Results

Figure ES-1, ES-2 and ES-3, following below, demonstrate some of the baseline results found in this study. Figure ES-1 depicts the market-weighted average results for each container system. Figure ES-2 shows the commodity-specific results for CC and RPC systems. Figure ES-3 depicts the potential ranges of impact for each container system carrying apples. Conclusions reached by this study are based on the baseline results for all commodities in combination with results of the sensitivity tests and uncertainty and data quality analyses performed.

Market-Weighted Results

The market-weighted average results in Figure ES-1 show that four of seven (4/7) impact categories are favorable for the RPC system, and three of seven (3/7) impact categories are favorable for the CC system. Specifically, acidification, ozone depletion, respiratory effects and smog formation show lesser environmental impact for RPCs. Eutrophication, global warming and non-renewable energy use demonstrate better environmental performance for CCs.

These observations of the market-weighted average results do not consider uncertainty. While the uncertainty analysis was carried out only for the commodity-specific results, it is reasonable to apply those outcomes here in a broad way. In doing so, the list of indicators that favor RPCs is narrowed to acidification, ozone depletion and respiratory effects, and the list of indicators that show an advantage for CCs reduces to global warming and non-renewable energy use. **From a market-weighted average perspective, tradeoffs exist in the environmental profiles of CCs and RPCs.**

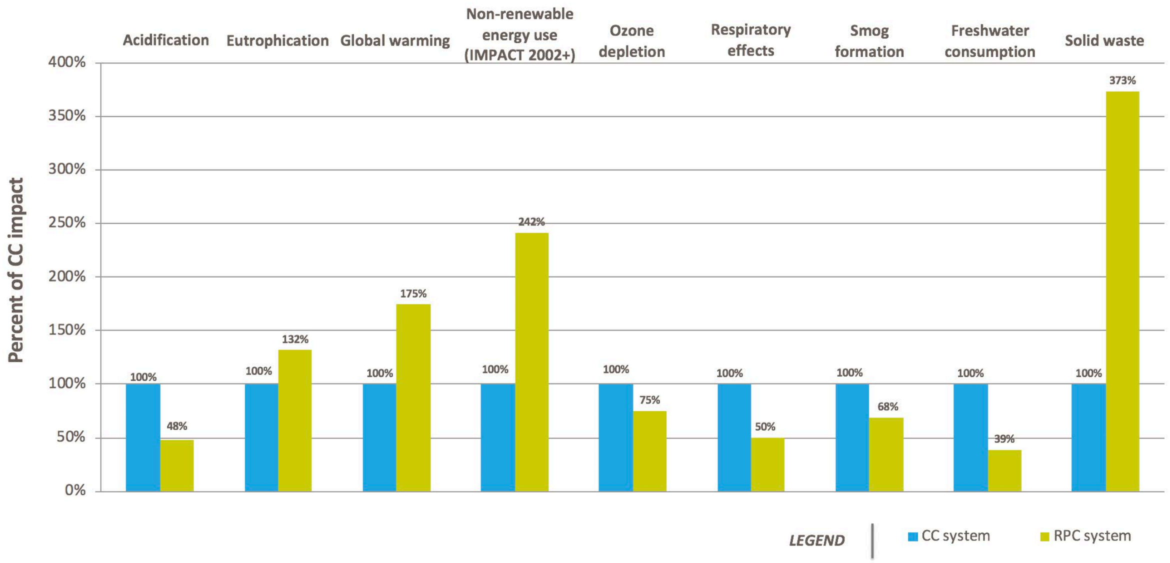

Figure ES-1. Market-weighted average results for the baseline analysis.

Commodity-Specific Results

Commodity-specific results show similar trade-offs between the container systems. Digging deeper, across the commodity-specific results shown in Figure ES-2, four of seven (4/7) impact categories are favorable for the RPC system, and two of seven (2/7) impact categories are favorable for the CC system. For the remaining indicator (eutrophication), the direction of the advantage is not consistent across commodities, as no discernible difference can be made for grapes and onions. Thus, a conclusion for eutrophication regarding the directional results cannot not be made with confidence.

The RPC system has an advantage in acidification, respiratory effects, ozone depletion and smog formation while global warming and non-renewable energy use shows an advantage for CCs. However, **after considering the uncertainty assessment of the results, (see section 5.5.2) three (3) impact categories show an advantage for RPCs (acidification, respiratory effects, and ozone depletion), and two (2) impact categories show an advantage for CCs (global warming and non-renewable energy use).** No difference between the systems can be concluded for

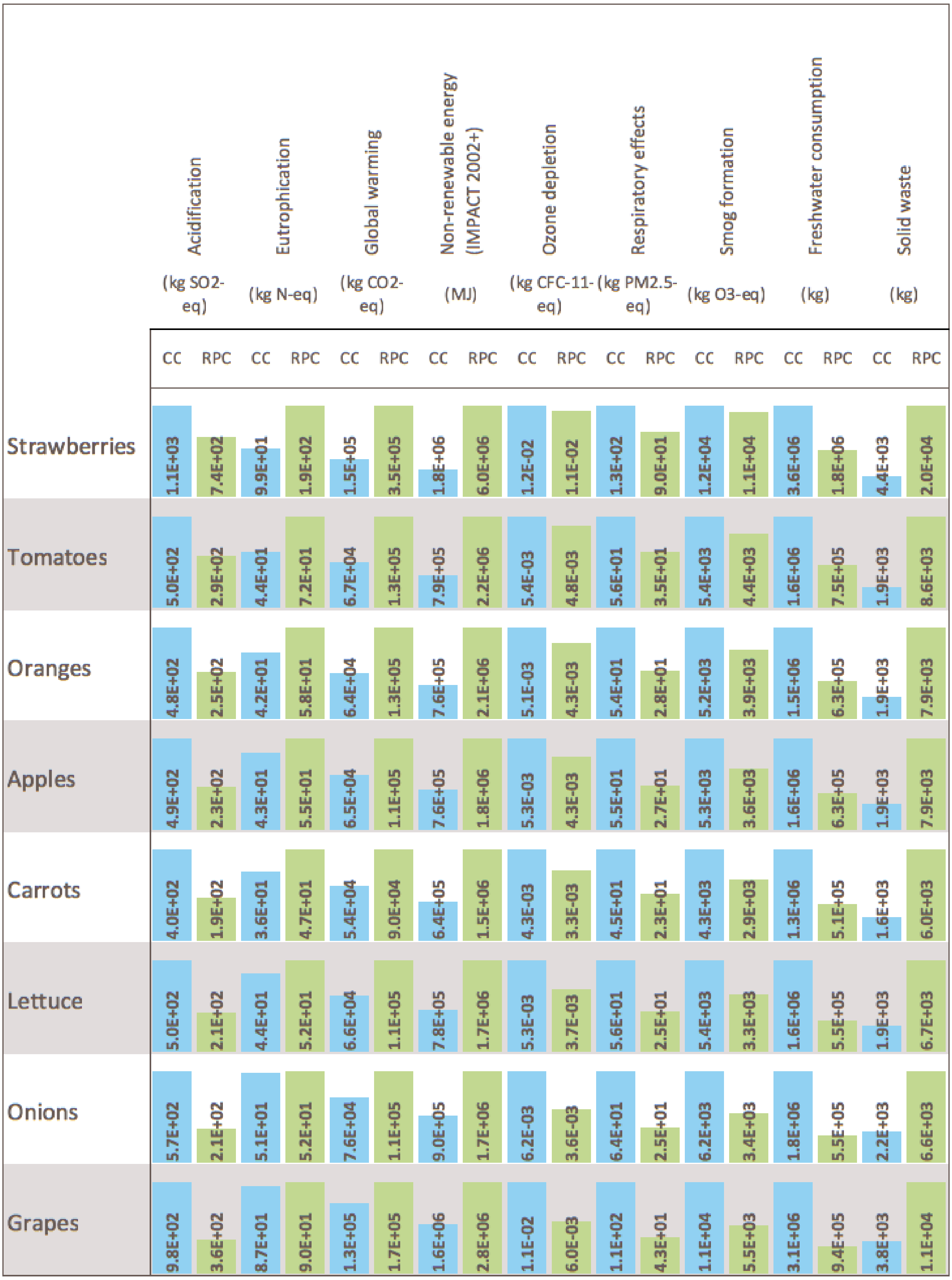

Figure ES-2. Baseline results (impact per functional unit) for the 8 commodities evaluated in this study. Commodities are ordered from greatest to least functional unit mass ratio. Each bar is shown relative to the system of greatest impact for that impact category and commodity.

smog formation and eutrophication given the level of uncertainty in those results. Further, the data quality assessment reveals that the CC inventory data used to calculate eutrophication is characterized by high uncertainty, and due to its important influence on the results, it is not possible to conclude whether one container system is more than or equally impacting as the other. This observation reinforces the conclusion made earlier regarding the inability to judge the relative performance of the container systems in terms of eutrophication. **Thus, without prioritizing types of impact, it is not possible to say from the present assessment that one of these systems is an overall better environmental performer than the other on the US market,**

and it does not appear that further refinements in data or methodology would be likely to find a fully consistent directional finding.

<u>Best and Worst Case Results</u>

The best and worst case scenarios support these conclusions. Taking the apple system as an example (Figure ES-3), the RPC system range of results for non-renewable energy use sits completely above the CC system range of results for the same indicator. This lack of overlap confirms the deduction made from the baseline and uncertainty analyses: the CC system uses less non-renewable energy than the RPC system across all market

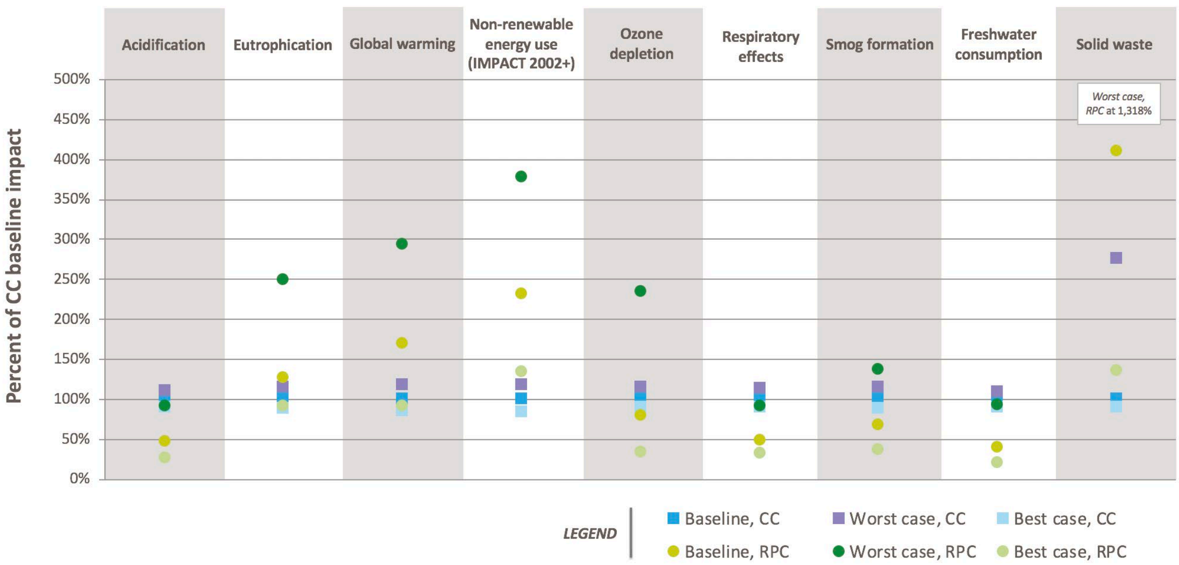

Figure ES-3. Baseline, best and worst case scenarios for RPCs and CCs containing apples. For each indicator, a score higher than 100% indicates greater impact than the CC baseline results.

conditions. A similar and opposite conclusion can be drawn when comparing the best and worst case results for apples in acidification and respiratory effects. The ranges of RPC results are almost entirely below the range of the CC results, meaning that in most market conditions, RPCs are less impacting for these two indicators. For all other indicators, there is notable overlap between the span of best and worst case results for the two systems. This means that neither container system has a clear advantage for these metrics.

The strawberry and grape systems show similar outcomes. However, the overlap between the best and worst case results occurs in somewhat different indicators. This means that **within the range of industry variability captured by the sensitivity analyses, the directional conclusions can change for all but a small number of indicators, specific to each commodity.**

<u>Conclusions</u>

While tempting, it is not appropriate to determine the comparative advantage between container types by counting the number of indicators in which a container system shows less impact. Counting the number of categories supporting a container system requires the assumption that each category of impact is equally important. While it is possible to have views or values that define the importance of each category, it is not possible for the authors to defend these values as more correct than the values that might lead another party to a different decision. It is therefore not possible here to draw a definitive conclusion of environmental superiority in cases where there are conflicting indicators that require a trade-off that is primarily value-based. In such cases, including the current one, the only overall conclusion that can be drawn is that trade-offs exist between the systems. Users of this study may apply values systems to arrive at conclusions that may assist in making selections between the container systems under different market conditions.

The inventory flows, freshwater consumption and solid waste, are not considered when comparing the environmental performance of the CC and RPC systems because they are inventory flows only and not impact indicators. They are included to provide a sense for the amounts of these flows required/generated by the system, which allows for some reflection on how results of this study may differ from those of comparable past and future assessments.

The environmental performance of each system is influenced by variation within their life cycles, and the combination of assumptions made for a single system causes the total impact to vary. The ranges observed for this study's context demonstrate that **the assumptions about the RPC life cycle coupled with the assumptions for the CC life cycle can affect the directional**

findings of the study in certain indicators. This is true for all indicators.

CC weight and RPC transportation distances are the most influential factors in determining the relative results between the two container systems. However, it appears that even in those conditions within the market variability that would seem to favor one system more so than the other, a clear environmental advantage for either system is not likely to exist for most commodity systems.

The results, on balance, show that variation exists in the comparative findings among the categories of impact assessed, and**, for a given commodity, the environmental trade-offs between container systems can be predicted based on the ratio of the masses of containers required to achieve the functional unit for each container system.** The difference in container mass needed to ship a specified quantity of produce determines which indicators show an advantage for each container system.

Both systems have opportunities to improve and lessen their impact on the environment. For the CC system, this includes minimizing container weight and maximizing container recovery. The RPC system can achieve environmental performance improvement through increasing reuse and recycled content along with reducing breakage/loss as well as transport distances.

For most of the environmental indicators considered, the impacts associated with produce production far outweigh most or all of the processes in the life cycle of a container, and differences of even a few percent in produce loss between the two container types would likely dictate the relative environmental performance for those indicators. Data describing product protection of the containers (i.e., perishability differences) are not available but could potentially push the advantage in one direction or the other if a significant difference exists.

While this study considers a steady-state market in which the containers evaluated are not changing in the middle of providing the functional unit, it is important to note that container weights and/or dimensions can change over time. Additionally, custom container designs for specific retailers, though not evaluated here, can result in inventories of containers with useful service life remaining when the designs are no longer needed. When a system stops operating before the containers meet their useful service life, a larger portion of the production and disposal impacts of the containers are allocated to that system. In other words, the impact per container is higher because there are fewer lives over which those impacts are distributed.

An important knowledge gap is around the number of RPCs in float[1]. This study takes a conservative approach, assuming float makes up a very small portion (<1%) of the total mass of crates in the system. The effect of this approach is that environmental impact associated with float is negligible. If float is a much larger portion of total mass, its contribution to impact can be important and therefore should be included in a study such as this one.

Considering the conclusions of this study with those of other LCAs comparing CCs and RPCs, the overall deduction is that **environmental trade-offs indeed exist between the RPC and CC systems, and the market characteristics, which vary by geography, have an important influence on these trade-offs**. Given the closeness of results between the two systems in certain impact categories and the sensitivity of the results to certain factors, it is clearly important to model in detail the specific market in question.

[1] Float refers to the quantity of excess RPCs that exist in the total system. These excess RPCs are required to assure the flexibility to respond to surges in system demand or extended time in the return loop.

4.3.1 Completeness and consistency check

The completeness check ensures that data used are applicable and sufficiently comprehensive to meet the objectives of the goal and scope. The consistency check ensures that assumptions, methods and data are consistent with the goal and scope of the report.

All data used are (1) checked regarding their temporal, geographical and technological representativeness, (2) collected at the highest level of detail possible, and (3) documented according to the best practices available. In particular, differences in the quality of data for each system are noted.

4.3.2 Contribution analysis

The contribution analysis illustrates the extent to which each process modeled contributes to the overall impact of the systems. Probing into the systems in this manner allows for a better understanding of the sources of environmental impacts as well as where the greatest opportunities for improvement exist. Further, identification of the most important aspects of the life cycle indicates where it is important to focus on data quality. Processes with a substantial influence on results should be characterized by high-quality information. Similarly, lower quality data may be suitable in the case of a process whose contribution is minimal. In this study, the contribution analysis identifies the processes with highest impact for each system and environmental indicator. Datasets which represent greater than three percent (3%) of impact in any indicator for either system are reported in the contribution analysis.

4.3.3 Uncertainty analysis

Several uncertainties are introduced during the preparation of an LCA, including parameter uncertainty, model uncertainty, uncertainty due to choices in modeling, spatial variability, temporal variability, and variability between sources/objects (Huijbregts 2001). The uncertainty analysis for this study focuses on the total propagated uncertainty (total uncertainty based on the relationships between parameters) resulting from individual parameter uncertainty (empirical inaccuracy, poor representativeness and lack of data). Parameter and propagated uncertainty exist in both the inventory and impact characterization phases of LCA.

In this study, the uncertainty analysis focuses on the key processes of each container life cycle as identified through the contribution analysis. Processes must be important contributors to total life cycle impact and be represented by data of poor or unknown quality to be included in the uncertainty assessment. For these processes, the quantity (flow) of each process is assessed for uncertainty based on an updated pedigree matrix based on Weidema (1996). A description and characterization of the pedigree matrix is available in Appendix D. A sampling approach is taken for each system using the Monte Carlo function in the GaBi software. Results of the uncertainty assessment are presented in section 5.5.

4.4 Interpretation and requirements for comparative assertion

Conclusions from this study will be made in consideration of the baseline analysis, sensitivity tests, study limitations, data quality and uncertainty assessment results. ISO 14044 (clause 5.3) requires for comparative assertions that the scope is equivalent and data are of comparable quality and resolution for the two systems. Additionally, conclusions, limitations and recommendations are required to be consistent with the scope of the report. These requirements are met here through the implementation of the consistency check, completeness check, contribution analysis and uncertainty analysis. A critical review, also mandated by ISO 14044 for comparative assertions, is conducted as described in the following section.

4.5 Critical review

A critical review is conducted by a panel of experts who are independent of this LCA. This process ensures that the report follows the stipulations set forth in the ISO 14040 and 14044 standards (ISO 2006a, b).

For this study, the panel consists of three qualified individuals considered experts in their fields. Mr. François Charron-Doucet, Scientific Director of the Groupe AGECO, has over a decade experience in LCA and is the chair of the critical review committee. Richard Venditti, Ph.D. is an Elis and Signe Olsson Professor in the Department of Forest Biomaterials at North Carolina State University and is an expert in the pulp and paper industry. Adam Gendell is the Associate Director of the Sustainable Packaging Coalition. He brings knowledge of the packaging industry, including both RPCs and corrugated packaging.

The critical review process is carried out in several steps.

1. Report review by all panelists;
2. Clarification of and response to points raised by the reviewers; and
3. Review of responses and final comments by all panelists.

The external critical review reports, practitioner comments and practitioner responses to the review comments are available in Appendix E.

5. Results

This section provides results for the baseline analysis, sensitivity analyses and data quality assessments as described in the previous sections of this document.

5.1 Baseline results

The following are the results of the baseline analysis. The first two sections provide an overview of all eight produce types in all indicators evaluated. Outcomes are shown in two ways—as a market-weighted average across all commodities and by individual commodity—to offer an interpretation of results that are useful for different audiences. The market-weighted average perspective combines results for all commodities by using the share each commodity holds of the produce market, based on USDA data. This view of the results is intended to meet the needs of container purchasers that use only one container type, such as produce retailers. The commodity-specific view of the study outcomes is helpful to parties who purchase containers for a specific commodity, or those who could purchase different containers for different commodities, such as produce growers.

Section 5.1.3 dives one level deeper to better understand the importance of each life cycle stage for each container type.

Appendix A1 summarizes the major reference flows in the modeling, and Appendix C offers an example of the method used for carrying out impact assessment (i.e., translating the life cycle inventories to environmental impacts). Specifically, the demonstration uses the global warming baseline results for each commodity system.

5.1.1 Market-weighted average results

Figure 5-1 presents the market-weighted average results. The produce-market weights are shown in Table 5-1 and are based on the top eight commodities (by production) transported and displayed commonly in both RPCs and CCs. The apple and onion systems have the greatest influence on the average results as they comprise the largest individual portions (approximately 20% each) of fresh market production. The remaining commodities hold a share between 7-15% each.

The market-weighted average results reflect the directional trends observed at the commodity level (see section 5.1.2). Similar to the commodity-specific results, the four (4) indicators that favor RPC in every commodity—acidification, respiratory effects, ozone depletion and smog formation—show a 25-52% advantage over the CC system in the market-average results (relative to the CC system results). Global warming, non-renewable energy use, and eutrophication which show an advantage for the CC system in each commodity, show an advantage of 24%-59% over the RPC system when applying the market weights.

When applying commodity specific uncertainty results, eutrophication and smog formation are the only indicators where the results for the container systems overlap within their range of uncertainty. Thus, no conclusion can be drawn about the relative performance in eutrophication or smog formation. See sections 5.5.2 and 5.5.1, respectively, for more information.

The results of the market-weighted average depend on the market shares of each commodity at a given time. If apples and/or onions comprise a substantially smaller portion of the market, the outcomes of the market-weighted average could shift both in terms of the magnitude of difference between the container systems' environmental performance and the directional results. However, where an indicator shows an advantage for one system across all commodities, the directional results cannot change for that indicator if the market share across commodities changes.