**Findings and recommendations**

The LCA study provided a number of findings that can be useful for optimizing the use and disposal of the carrier bags available for purchase in Denmark. The results are referred to the reference flows presented in Table I.

**Which is the most preferable disposal option for each type of carrier bag?**

After reusing the carrier bag as many times as possible, reusing the carrier bag as a waste bin bag is better than simply throwing away the bag in the residual waste and it is better than recycling. Recycling can potentially offer benefits in the case of heavy plastic bags, such as PP, PET and polyester. Reuse as a waste bin bag is most beneficial for light carrier bags, such as LDPE, paper and biopolymer. When reuse as a waste bin bag is not feasible, for example when the bag can easily be punctured, torn, or wetted, as in the case of paper and biopolymer bags, incineration is the most preferable solution from an environmental point of view. Table II provides a summary of the results obtained for each carrier bag.

**Table II. Overview of the most preferable end-of-life option for each of the carrier bag types assessed.**

| Carrier bag material | Preferable end-of-life after normal reuse |
|---|---|
| Plastic, LDPE | Reuse as waste bin bag |
| Plastic, PP | Recycle, reuse as waste bin bag if possible, else incinerate |
| Plastic, recycled PET | Recycle, reuse as waste bin bag if possible, else incinerate |
| Plastic, polyester PET | Reuse as waste bin bag if possible, else incinerate |
| Biopolymer | Reuse as waste bin bag if possible, else incinerate |
| Paper | Reuse as waste bin bag if possible, else incinerate |
| Textile | Reuse as waste bin bag if possible, else incinerate |
| Composite | Reuse as waste bin bag if possible, else incinerate |

**Which is the carrier bag providing the lowest environmental impacts?**

In general with regards to production and disposal, LDPE carrier bags, which are the bags that are always available for purchase in Danish supermarkets, are the carriers providing the overall lowest environmental impacts for most environmental indicators (Table III). In particular, LDPE carrier bags with rigid handle provided in general the lowest environmental impacts in the majority of the impact categories included in this LCA study. Carrier bags alternatives that can provide a similar performance are unbleached paper and biopolymer bags, but for a lower number of environmental indicators. Heavier carrier bags, such as PP, PET, polyester, bleached paper and textile bags need to be reused multiple times in order to lower their environmental production cost. Between the same bag types, woven PP carrier bags provided lower impacts than non-woven PP bags, unbleached paper resulted more preferable than bleached paper, and conventional cotton over organic cotton.

**How many times should the carrier bags be reused?**

For all carrier bags, reuse as many times as possible before disposal is strongly encouraged. Table IV reports the number of calculated primary reuse times necessary to lower the environmental impacts associated with all carrier bag alternatives to the levels of the LDPE carrier bag. Therefore, the numbers reported in Table IV refer to minimum number of reuse times. The number of calculated reuse times varies if only one environmental indicator is observed, or if all environmental indicators are taken into account. The calculated number of reuse times might be compliant with the lifetime of PP, PET and polyester carrier bags, but might surpass the lifetime of bleached paper, composite and cotton carriers, especially considering all environmental indicators. The number of calculated reuse times was rather uniform across impact categories for LDPE carrier bags. For PP, PET, biopolymer and paper carrier bags, some

impact categories presented higher reuse times than others. Lastly, the very high number of reuse times scored by cotton and composite bags is primarily due only to the ozone depletion impact category, for which the cotton production dataset provides larger impacts than the reference LDPE carrier bag.

**Table III. Carrier bags providing the lowest environmental impacts for all the environmental indicators considered. The order in which the bags are listed corresponds to the raking of their LCA results starting from the lowest impact. Only the three lowest scoring bags are listed. The results refer to the reference flow provided in Table I.**

| Environmental indicator | Carrier bags providing lowest impacts |
|---|---|
| Climate change | Paper unbleached, biopolymer, LDPE |
| Ozone depletion | LDPE |
| Human toxicity, cancer effects | Paper unbleached, LDPE |
| Human toxicity, non-cancer effects | Composite, PP, LDPE |
| Photochemical ozone formation | LDPE |
| Ionizing radiation | LDPE |
| Particulate matter | LDPE |
| Terrestrial acidification | LDPE |
| Terrestrial eutrophication | LDPE |
| Freshwater eutrophication | LDPE |
| Marine eutrophication | PP, LDPE |
| Ecosystem toxicity | LDPE |
| Resource depletion, fossil | Paper unbleached, LDPE |
| Resource depletion, abiotic | PP, LDPE |
| Water resource depletion | LDPE, biopolymer |

**Table IV. Calculated number of primary reuse times for the carrier bags in the rows, for their most preferable disposal option, necessary to provide the same environmental performance of the average LDPE carrier bag, reused as a waste bin bag before incineration. The results refer to the reference flow provided in Table I.**

| | LDPE average, reused as waste bin bag | |
|---|---|---|
| | Climate Change | All indicators |
| LDPE simple, reused as waste bag | 0 | 1 |
| LDPE rigid handle, reused as waste bag | 0 | 0 |
| Recycled LDPE, reused as waste bag | 1 | 2 |
| PP, non-woven, recycled | 6 | 52 |
| PP, woven, recycled | 5 | 45 |
| Recycled PET, recycled | 8 | 84 |
| Polyester PET, recycled | 2 | 35 |
| Biopolymer, reused as waste bag or incinerated | 0 | 42 |
| Unbleached paper, reused as waste bag or incinerated | 0 | 43 |
| Bleached paper, reused as waste bag or incinerated | 1 | 43[4] |
| Organic cotton, reused as waste bag or incinerated | 149 | 20000 |

[4] The highest value for bleached paper is set to as minimum be equal to the value for unbleached paper.

| | | |
|---|---|---|
| Conventional cotton, reused as waste bag or incinerated | 52 | 7100 |
| Composite, reused as waste bag or incinerated | 23 | 870 |

The sensitivity analysis on data and assumptions highlighted the importance of the choice of reference flow, which was determining for the calculated number of reuse times for organic cotton. The reference flow choice depends on the fulfilment of the function expressed by the functional unit. In particular, the results showed the importance of the carrier bags design, which should be focused on maximizing volume and weight holding capacity, while minimizing the amount of material needed and the final weight of the carrier bag.
Our final recommendations are the following[5]:

- **Simple LDPE bags**: Can be directly reused as waste bin bags for climate change, should be reused at least 1 time for grocery shopping considering all other indicators; finally reuse as waste bin bag.
- **LDPE bags with rigid handle**: Can be directly reused as waste bin bags considering all indicators; finally reuse as waste bin bag.
- **Recycled LDPE bags**: Reuse for grocery shopping at least 1 time for climate change, at least 2 times considering all indicators; finally reuse as waste bin bag.
- **PP bags, non-woven**: Reuse for grocery shopping at least 6 times for climate change, at least 52 times considering all indicators; finally dispose with recyclables, otherwise reuse as waste bin bag if possible, lastly incinerate.
- **PP bags, woven**: Reuse for grocery shopping at least 5 times for climate change, at least 45 times considering all indicators; finally dispose with recyclables, otherwise reuse as waste bin bag if possible, lastly incinerate.
- **PET bags**: Reuse for grocery shopping at least 8 times for climate change, at least 84 times considering all indicators; finally dispose with recyclables, otherwise reuse as waste bin bag if possible, lastly incinerate.
- **Polyester bags**: Reuse for grocery shopping at least 2 times for climate change, at least 35 times considering all indicators; finally dispose with recyclables, otherwise reuse as waste bin bag if possible, lastly incinerate.
- **Biopolymer bags**: Can be directly reused as waste bin bags for climate change, should be reused at least 42 times for grocery shopping considering all other indicators. Finally, reuse as waste bin bag if possible, otherwise incinerate.
- **Unbleached paper bags**: Can be directly reused as waste bin bags for climate change, should be reused at least 43 times considering all other indicators. Finally, reuse as waste bin bag if possible, otherwise incinerate.
- **Bleached paper bags**: Reuse for grocery shopping at least 1 time for climate change, at least 43 times considering all indicators; reuse as waste bin bag if possible, otherwise incinerate.
- **Organic cotton bags**: Reuse for grocery shopping at least 149 times for climate change, at least 20000 times considering all indicators; reuse as waste bin bag if possible, otherwise incinerate.
- **Conventional cotton bags**: Reuse for grocery shopping at least 52 times for climate change, at least 7100 times considering all indicators; reuse as waste bin bag if possible, otherwise incinerate.

[5] The number of times for “all indicators” refers to the highest number of reuse times among those calculated for each impact category. For light carrier bags (LDPE, PP, PET...) the high numbers of reuse times are given by a group of impact categories with similar high values. Conversely, for composite and cotton the very high number of reuse times is given by the ozone depletion impact alone. Without considering ozone depletion, the number of reuse times ranges from 50 to1400 for conventional cotton, from 150 to 3800 for organic cotton, and from 0 to 740 for the composite material bag. The highest number is due to the use of water resource, but also to freshwater and terrestrial eutrophication. Results for the number of reuse times for each impact category, minimum-maximum ranges and average number of reuse times are provided in Appendix C.

- **Composite bags**: Reuse for grocery shopping at least 23 times for climate change, at least 870 times considering all indicators; reuse as waste bin bag if possible, otherwise incinerate.

It should be considered that if the reference LDPE bag is reused for shopping, this will increase the needed number of reuse times for the other bags proportionally. The results obtained on the minimum number of reuse times are intended to raise the discussion among the stakeholders on the effective expected lifetime of each carrier bag. While the calculated number of reuse times might be compliant with the functional lifetime of PP, PET and polyester carrier bags, it might surpass the lifetime of bleached paper, composite and cotton carriers, especially considering all environmental indicators.

**Summary of the critical review**

**Reviewers**
A critical review according to ISO 14040/14044 was performed by Line Geest Jakobsen and Trine Lund Neidel from COWI A/S in January 2018.

**Review process**
The review process involved the following phases:
- COWI conducted the first review in January 2018.
- DTU answered to the questions raised by COWI and corrected the report according to the outcomes of the review in January 2018.
- COWI evaluated the corrections and compiled a final review statement.

The critical review from COWI can be found in full in Appendix D. The main points highlighted in the critical review are provided below.

The LCA report has been reviewed with respect to compliance with the ISO 14040 and 14044 International Standards. The report was found to comply with the standards to a large extent. The authors state that the report does not comply with the standard because an exchange with a panel of experts was not made during the project phases.

The method chosen for selecting the functional unit and reference flow was verified with a sensitivity analysis. The results of the sensitivity analysis showed that the choice of reference flow influenced heavily the carrier bags with high impacts connected to production and with a lower volume than the one expressed in the functional unit (mainly organic cotton). The authors added a dedicated section on carrier bag design where they provide comments on the influence of the carrier bag design on the results.

The critical review highlighted that specific attention should have been dedicated to data quality assessment and to the clear statement of critical assumptions. The authors added dedicated sections on data quality assessment, critical assumption and on the influence on data and assumptions on the results. The influence of selected critical assumptions on the results was assessed with a sensitivity analysis.

After the review, the authors added further specifications on the carrier bag types (e.g. polyester polymer type), adjusted language and typos, and added further details for improving the overall understanding of the report.

# 8. Conclusions

This study identified the best disposal option for each of the carrier bags available in Danish supermarkets in 2017. In general, reusing the carrier bag as a waste bin bag is better than simply throwing away the bag in the residual waste and it is better than recycling. Recycling can potentially offer more benefits in the case of heavy plastic bags, such as PP, and PET. Reuse as a waste bin bag is most beneficial for light carrier bags, such as LDPE, paper and biopolymer. When reuse as a waste bin bag is not feasible, for example when the bag can easily be punctured, torn, or wetted, incineration is the most preferable solution from an environmental point of view.

In general, LDPE carrier bags, which are the bags that are always available for purchase in Danish supermarkets, are the carriers providing the overall lowest environmental impacts when not considering reuse. In particular, between the types of available carrier bags, LDPE carrier bags with rigid handle are the most preferable. Effects of littering for this type of bag were considered negligible for Denmark. Carrier bags alternatives that can provide a similar performance are unbleached paper and biopolymer bags, but for a lower number of environmental indicators. Heavier carrier bags, such as PP, PET, polyester, bleached paper and textile bags need to be reused multiple times in order to lower their environmental production cost. Between the same bag types, woven PP carrier bags provided lower impacts than non-woven PP bags, unbleached paper resulted more preferable than bleached paper, and conventional cotton over organic cotton.

For all carrier bags, reuse as many times as possible before disposal is strongly encouraged. This study also calculated how many times each bag would need to be reused in order to lower its associated environmental impacts to the levels of the LDPE carrier bag. The number of calculated reuse times varies if only one environmental indicator is observed, or if all environmental indicators are taken into account.

The results are the following[9]:

- **Simple LDPE bags**: Can be directly reused as waste bin bags for climate change, should be reused at least 1 time for grocery shopping considering all other indicators; finally reuse as waste bin bag.
- **LDPE bags with rigid handle**: Can be directly reused as waste bin bags considering all indicators; finally reuse as waste bin bag.
- **Recycled LDPE bags**: Reuse for grocery shopping at least 1 time for climate change, at least 2 times considering all indicators; finally reuse as waste bin bag.
- **PP bags, non-woven**: Reuse for grocery shopping at least 6 times for climate change, and up to 52 times considering all indicators; finally dispose with recyclables, otherwise reuse as waste bin bag if possible, lastly incinerate.

[9] The number of times for “all indicators” refers to the highest number of reuse times among those calculated for each impact category. For light carrier bags (LDPE, PP, PET...) the high numbers of reuse times are given by a group of impact categories with similar high values. Conversely, for composite and cotton the very high number of reuse times is given by the ozone depletion impact alone. Without considering ozone depletion, the number of reuse times ranges from 50 to1400 for conventional cotton, from 150 to 3800 for organic cotton, and from 0 to 740 for the composite material bag. The highest number is due to the use of water resource, but also to freshwater and terrestrial eutrophication. Results for the number of reuse times for each impact category, minimum-maximum ranges and average number of reuse times are provided in Appendix C.

- **PP bags, woven**: Reuse for grocery shopping at least 5 times for climate change, at least 45 times considering all indicators; finally dispose with recyclables, otherwise reuse as waste bin bag if possible, lastly incinerate.
- **PET bags**: Reuse for grocery shopping at least 8 times for climate change, and up to 84 times considering all indicators; finally dispose with recyclables, otherwise reuse as waste bin bag if possible, lastly incinerate.
- **Polyester bags**: Reuse for grocery shopping at least 2 times for climate change, and up to 35 times considering all indicators; finally dispose with recyclables, otherwise reuse as waste bin bag if possible, lastly incinerate.
- **Biopolymer bags**: Can be directly reused as waste bin bags for climate change, should be reused and up to 42 times for grocery shopping considering all other indicators. Finally, re-use as waste bin bag if possible, otherwise incinerate.
- **Unbleached paper bags**: Can be directly reused as waste bin bags for climate change, should be reused and up to 43 times considering all other indicators. Finally, reuse as waste bin bag if possible, otherwise incinerate.
- **Bleached paper bags**: Reuse for grocery shopping at least 1 time for climate change, and up to 43 times considering all indicators; reuse as waste bin bag if possible, otherwise incinerate.
- **Organic cotton bags**: Reuse for grocery shopping at least 149 times for climate change, and up to 20000 times considering all indicators; reuse as waste bin bag if possible, otherwise incinerate.
- **Conventional cotton bags**: Reuse for grocery shopping at least 52 times for climate change, and up to 7100 times considering all indicators; reuse as waste bin bag if possible, otherwise incinerate.
- **Composite bags**: Reuse for grocery shopping at least 23 times for climate change, and up to 870 times considering all indicators; reuse as waste bin bag if possible, otherwise incinerate.

This study focused on identifying the number of reuse times based on the environmental performance of the carrier bags. The results obtained on the minimum number of reuse times are intended to raise the discussion among the stakeholders on the effective expected lifetime of each carrier bag. While the calculated number of reuse times might be compliant with the functional lifetime of PP, PET and polyester carrier bags, but might surpass the lifetime of bleached paper, composite and cotton carriers, especially considering all environmental indicators. In addition it should be kept in mind that the reuse times calculated are held up against a use of a reference bag a single time. If the reference bag is reused, it would mean that the reuse time of the other bags would increase proportionally.

In particular, the results of the present assessment have highlighted the importance of the design of the carrier bag and its functionality, especially for cotton carriers. In order to lower the number of reuse times, designs with light fabric and large volumes should be preferred. These design differences can largely lower the impacts. However, the required number of reuse times for all impact categories may still be unfeasible and more than the lifetime of the bag.