Comprehensive cost model for sustainable post-consumer plastic packaging waste collection

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Introduction

• Post-consumer Plastic Packaging Waste Recycling
  ❏ Source-separation / Post-separation
  ❏ Curbside / Drop-off
  ❏ Tax/Municipality types
Motivation and Research Aim

Plastic waste collection design has to meet the demand of
• Handling the recycling of waste in the future
• In an efficient and sustainable way

We aim for
• developing a comprehensive calculation model which evaluates the eco-efficiency of various collection systems
• providing decision support on choosing the most suitable collection method for municipalities.
The collection costs consist of vehicle cost, labour cost, container cost and emission cost.

Vehicle cost is split into fixed and variable cost.

This calculation is based on one municipality for the period of a year and per ton of plastic waste collected.
## Model – Fixed Vehicle Cost

\[
C_{veh_{fix}} = \left(n_{veh} \times \left[ C_{veh_{cap}} + C_{veh_{insu}} + C_{veh_{tax}} \right]\right)/Q_{year}
\]

<table>
<thead>
<tr>
<th>Description</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle capital cost</td>
<td>[ C_{veh_{cap}} = \left( C_{veh_{inv}} - C_{veh_{sal}} \right)/Dep + 0.5 \left( C_{veh_{inv}} - C_{veh_{sal}} \right) \times %_{int} ]</td>
</tr>
<tr>
<td>The number of vehicles</td>
<td>[ n_{veh} = \left( 1/Eff_{%} \right) \times \frac{Time_{veh}}{Time_{tyr}} ]</td>
</tr>
<tr>
<td>Time needed to collect waste</td>
<td>[ Time_{veh} = Time_{col_{veh}} + Time_{idl_{veh}} + Time_{haul_{veh}} ]</td>
</tr>
<tr>
<td>Total collection time between stops</td>
<td>[ Time_{col_{veh}} = \frac{D_{dri_{veh}}}{V_{dri_{veh}}} ]</td>
</tr>
<tr>
<td>Total idling time</td>
<td>[ Time_{idl_{veh}} = n_{stops} \times Time_{stop} ]</td>
</tr>
<tr>
<td>Total hauling time</td>
<td>[ Time_{haul_{veh}} = \frac{D_{haul_{veh}}}{V_{haul_{veh}}} ]</td>
</tr>
<tr>
<td>The total travel distance while hauling</td>
<td>[ D_{haul_{veh}} = 2 \times n_{loads} \times D_{dri_{haul}} ]</td>
</tr>
<tr>
<td>The number of drops at the unloading location</td>
<td>[ n_{loads} = \frac{Q_{year}}{\text{truck}_{load}} ]</td>
</tr>
</tbody>
</table>
## Model – Variable Vehicle Cost

$$C_{veh\_var} = \left( C_{veh\_fuel} + C_{veh\_main} \right) / Q_{year}$$

<table>
<thead>
<tr>
<th>Term</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>The total cost of fuel</td>
<td>$C_{veh_fuel} = C_{veh_dri} + C_{veh_idle} + C_{veh_haul}$</td>
</tr>
<tr>
<td>Total fuel cost while driving during collection</td>
<td>$C_{veh_dri} = CS_{dri_fuel} \times D_{dri_veh} \times P_{fuel}$</td>
</tr>
<tr>
<td>Total fuel cost while idling</td>
<td>$C_{veh_idle} = CS_{idl_fuel} \times Time_{idl_veh} \times P_{fuel}$</td>
</tr>
<tr>
<td>Total fuel cost driving to unloading location</td>
<td>$C_{veh_haul} = CS_{haul_fuel} \times D_{haul_veh} \times P_{fuel}$</td>
</tr>
<tr>
<td>The total travel distance while collecting</td>
<td>$D_{dri_veh} = (n_{stops} - 1) \times D_{dri_stop}$</td>
</tr>
<tr>
<td>The number of stops while collecting (drop-off)</td>
<td>$n_{stops} = Q_{year} / truck_{load}$</td>
</tr>
<tr>
<td>The number of stops while collecting (curbside)</td>
<td>$n_{stops} = (n_{hh} \times freq_{col}) / hh_{con}$</td>
</tr>
</tbody>
</table>
# Model – Labour and Container Costs

## Labour Cost

$$C_{labour} = (C_{driver} + C_{loader}) \times freq_{col} \times n_{veh}$$

- **Driver’s labour cost**
  $$C_{driver} = W_{driver} \times n_{driver} \times \frac{Time_{yr}}{hr_{driver}}$$

- **Loader labour cost**
  $$C_{loader} = W_{loader} \times n_{loader} \times \frac{Time_{yr}}{hr_{loader}}$$

## Container Cost

$$C_{cont\_drop-off} = n_{cont} \times (C_{cont\_maint} + C_{cont\_inv})$$

- **The investment cost of drop-off containers**
  $$C_{cont\_inv} = \frac{Cont_{inv}}{Dep} + \left(\frac{Cont_{inv} \times \%_{int}}{2}\right)$$

- **The number of drop-off containers**
  $$n_{cont} = \left(\frac{Q_{year}}{freq_{col}}\right) / Cont_{cap}$$

- **The cost of plastic bags for curbside collection**
  $$C_{bag\_curbside} = n_{hh} \times freq_{col} \times C_{bag}$$

- **The cost of post-separation containers**
  $$C_{cont\_post} = n_{hh} \times C_{240\_inv}/Dep$$
Modal – Emission Cost

\[
C_{GHG} = C_{t co2} \times F_{tot} \times GHG_{factor}
\]

Total fuel use

\[
F_{tot} = CS_{dri\_fuel} \times D_{dri\_veh} + CS_{idl\_fuel} \times Time_{idl\_veh} + CS_{haul\_fuel} \times D_{haul\_veh}
\]

- Data used:
  - Average carbon pricing according the European Union Emission Trading Scheme
  - GHG factor derived from UK-DEFRA report
Case Description

- 418 municipalities in NL
- Five urban classes
- Combination of post-separation and source-separation
- Combination of curbside and drop-off collection in source-separation
- Combination of Diftar and non Diftar

- Total amount of source separated plastic: 100.343 tons
- Total amount of post-separated plastic: 39.754 tons
# Municipalities

## Urbanization level

<table>
<thead>
<tr>
<th>Urbanization level</th>
<th>Tax system</th>
<th>Collection method</th>
<th>Number of municipalities</th>
<th>Amount of plastic collected (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>Diftar</td>
<td>Curbside</td>
<td>3</td>
<td>2,822,140</td>
</tr>
<tr>
<td></td>
<td>Diftar</td>
<td>Drop-off</td>
<td>3</td>
<td>3,021,200</td>
</tr>
<tr>
<td></td>
<td>No Diftar</td>
<td>Curbside</td>
<td>24</td>
<td>7,992,558</td>
</tr>
<tr>
<td></td>
<td>No Diftar</td>
<td>Drop-off</td>
<td>42</td>
<td>19,635,469</td>
</tr>
<tr>
<td>Medium</td>
<td>Diftar</td>
<td>Curbside</td>
<td>15</td>
<td>7,421,184</td>
</tr>
<tr>
<td></td>
<td>Diftar</td>
<td>Drop-off</td>
<td>1</td>
<td>1,146,992</td>
</tr>
<tr>
<td></td>
<td>No Diftar</td>
<td>Curbside</td>
<td>41</td>
<td>8,898,960</td>
</tr>
<tr>
<td></td>
<td>No Diftar</td>
<td>Drop-off</td>
<td>20</td>
<td>4,849,320</td>
</tr>
<tr>
<td>Rural</td>
<td>Diftar</td>
<td>Curbside</td>
<td>93</td>
<td>23,998,526</td>
</tr>
<tr>
<td></td>
<td>Diftar</td>
<td>Drop-off</td>
<td>23</td>
<td>4,452,553</td>
</tr>
<tr>
<td></td>
<td>No Diftar</td>
<td>Curbside</td>
<td>73</td>
<td>12,679,202</td>
</tr>
<tr>
<td></td>
<td>No Diftar</td>
<td>Drop-off</td>
<td>35</td>
<td>3,424,486</td>
</tr>
<tr>
<td>Post-separation</td>
<td>-</td>
<td>-</td>
<td>124</td>
<td>39,754,334</td>
</tr>
</tbody>
</table>

## Legend:

- Urban
- Medium
- Rural

- Diftar
- No Diftar

Total plastic collected:
- Post-separation: 39,754,334 kg
Results

Composition of costs

Collection cost of three urbanization levels

Curbside

- Bags Cost 18%
- Fixed Cost 13%
- Variable Cost 8%
- Emission Cost 15%
- Container Cost 29%
- Personnel Cost 46%
- Personnel Cost 24%

Drop-off

- Emission Cost 8%
- Fixed Cost 23%
- Container Cost 29%
- Variable Cost 16%

← Urbanity
Results

Tax charges

Collection cost per separation method

Collection cost per tax scheme

- Curbside Diftar
- Curbside No Diftar
- Drop-off Diftar
- Drop-off No Diftar

- Emission cost
- Other cost

Separation Methods
Sensitivity Analysis

Utility rates

Collection cost by a varying amount of source separated plastic

Plastic waste input
Sensitivity Analysis

Fuel cost and Carbon price

- Doubling the fuel price would lead to an increase of total cost by 9% in source-separation and 12% in post-separation.

- Doubling the carbon cost would lead to a larger increase of total cost by 13% in source-separation and 24% in post-separation.
Conclusion

Source-separation has a higher total cost than post-separation.

Curbside collection generates more emission than drop-off collection.

Waste tax charges influence the cost of curbside collection more than the cost of drop-off collection.

Collection trucks and containers should be at least about half full, so that the collection can be eco-efficient.

The impact on doubling the current used carbon price has even greater impact on the total cost change than doubling the fuel price.
Further Research

- Include the possibility of potential treatment facilities in the network together with the options of multi-modality.

- Conduct a separate study on collection logistics inside municipalities to be integrated with this research for a more comprehensive and detailed network logistics and emission cost analysis.
Thank you for your attention!