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

Authors: Jim Groot, Xiaoyun Bing, Hilke Bos-Brouwers

Jacqueline Bloemhof-Ruwaard

Food Chain Sustainability and Dynamic, Top Institute food and Nutrition, NL

Food and Biobased Research, Wageningen UR, NL

Operations Research and Logistics, Wageningen University, NL

Presented by: Xiaoyun Bing

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Introduction

- **Post-consumer Plastic Packaging Waste Recycling**
  - ❑ Source-separation / Post-separation
  - ❑ Curbside / Drop-off
  - ❑ Tax/Municipality types

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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.

Model

- 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

$$C_{veh\_fix} = \left(n_{veh} \times \left[C_{veh\_cap} + C_{veh\_insu} + C_{veh\_tax}\right]\right)/Q_{year}$$

Vehicle capital cost	$C_{veh\_cap} = \left(C_{veh\_inv} - C_{veh\_sal}\right)/Dep + 0.5\left(C_{veh\_inv} - C_{veh\_sal}\right) \times \%_{int}$
The number of vehicles	$n_{veh} = (1/Eff_{\%}) \times Time_{\_veh}/Time_{\_tyr}$
Time needed to collect waste	$Time_{\_veh} = Time_{col\_veh} + Time_{idl\_veh} + Time_{haul\_veh}$
Total collection time between stops	$Time_{col\_veh} = D_{dri\_veh}/V_{dri\_veh}$
Total idling time	$Time_{idl\_veh} = n_{stops} \times Time_{\_stop}$
Total hauling time	$Time_{haul\_veh} = D_{haul\_veh}/V_{haul\_veh}$
The total travel distance while hauling	$D_{haul\_veh} = 2 \times n_{loads} \times D_{dri\_haul}$
The number of drops at the unloading location	$n_{loads} = Q_{year}/truck_{load}$

Model – Variable Vehicle Cost

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

The total cost of fuel	$C_{veh\_fuel} = C_{veh\_dri} + C_{veh\_idle} + C_{veh\_haul}$
Total fuel cost while driving during collection	$C_{veh\_dri} = CS_{dri\_fuel} \times D_{dri\_veh} \times P_{fuel}$
Total fuel cost while idling	$C_{veh\_idle} = CS_{idl\_fuel} \times Time_{idl\_veh} \times P_{fuel}$
Total fuel cost driving to unloading location	$C_{veh\_haul} = CS_{haul\_fuel} \times D_{haul\_veh} \times P_{fuel}$
The total travel distance while collecting	$D_{dri\_veh} = (n_{stops} - 1) \times D_{dri\_stop}$
The number of stops while collecting (drop-off)	$n_{stops} = Q_{year} / truck_{load}$
The number of stops while collecting (curbside)	$n_{stops} = (n_{hh} \times freq_{col}) / hh_{con}$

Model – Labour and Container Costs

Labour Cost

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

Driver's labour cost	$C_{driver} = W_{driver} \times n_{driver} \times Time_{\_tyr} / hr_{driver}$
Loader labour cost	$C_{loader} = W_{loader} \times n_{loader} \times Time_{\_tyr} / hr_{loader}$

Container Cost

$$C_{cont,drop-off} = n_{cont} \times \left(C_{cont\_maint} + C_{cont\_inv}\right)$$

The investment cost of drop-off containers	$C_{cont\_inv} = \frac{Cont_{inv}}{Dep} + (Cont_{inv} \times \%_{int})/2$
The number of drop-off containers	$n_{cont} = (Q_{year} / freq_{col})/Cont_{cap}$
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

$$C_{GHG} = Ct_{co2} \times F_{tot} \times GHG_{factor}$$

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

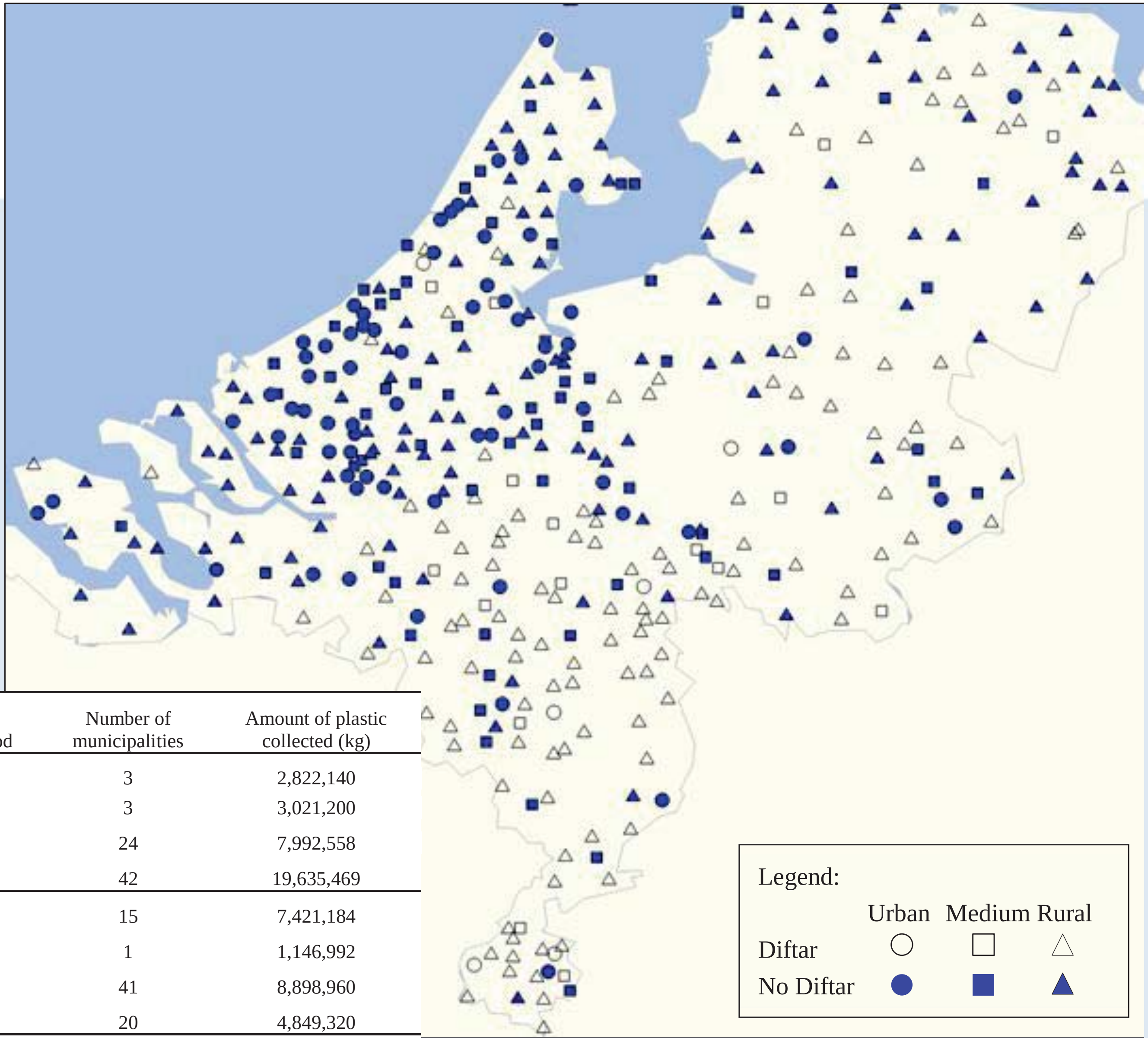
Case Description

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

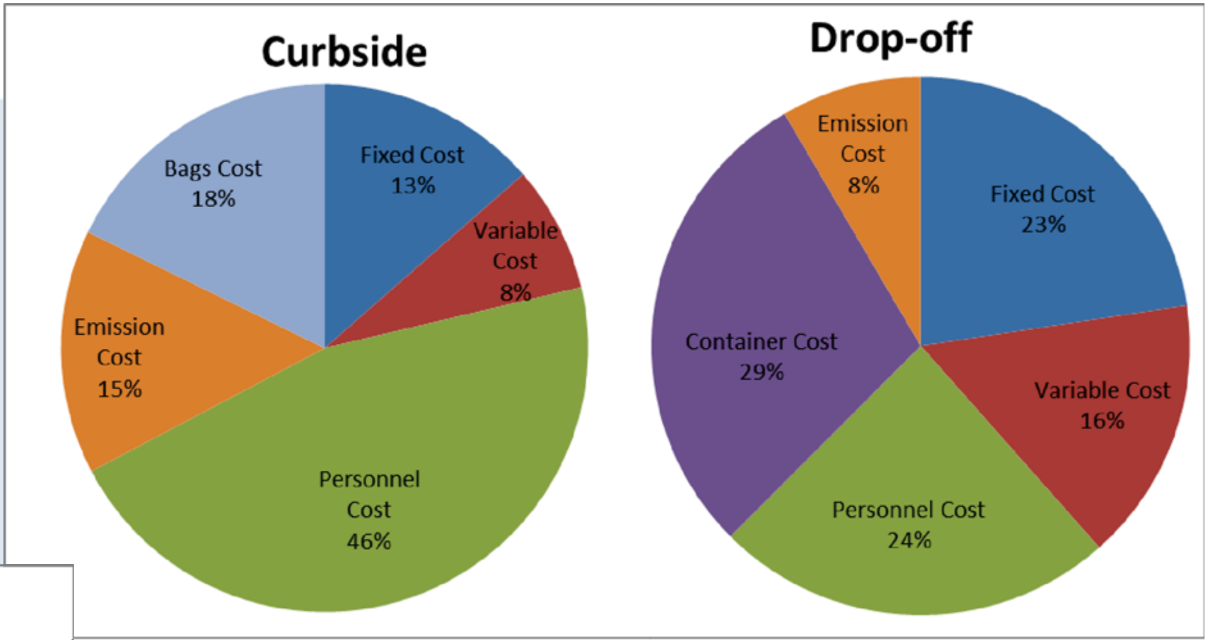
Municipalities

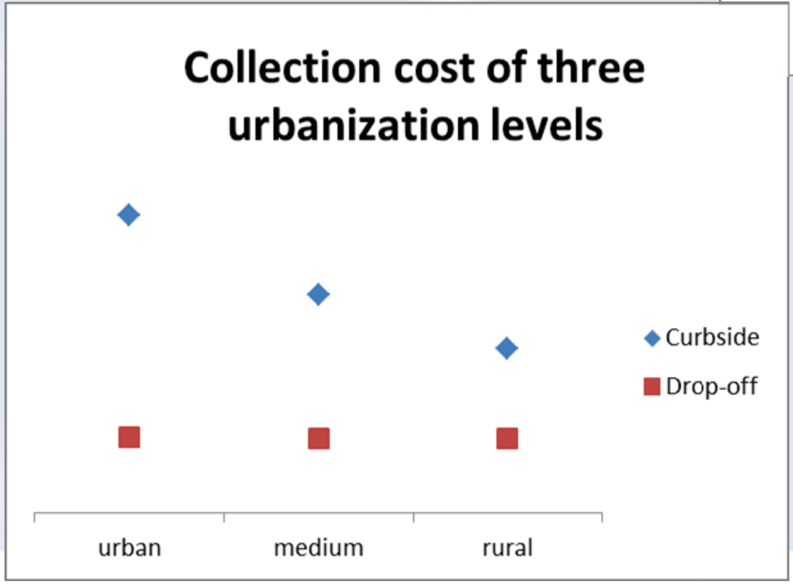


Urbanization level	Tax system	Collection method	Number of municipalities	Amount of plastic collected (kg)
Urban	Diftar	Curbside	3	2,822,140
	Diftar	Drop-off	3	3,021,200
	No Diftar	Curbside	24	7,992,558
	No Diftar	Drop-off	42	19,635,469
Medium	Diftar	Curbside	15	7,421,184
	Diftar	Drop-off	1	1,146,992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

Results

Composition of costs →

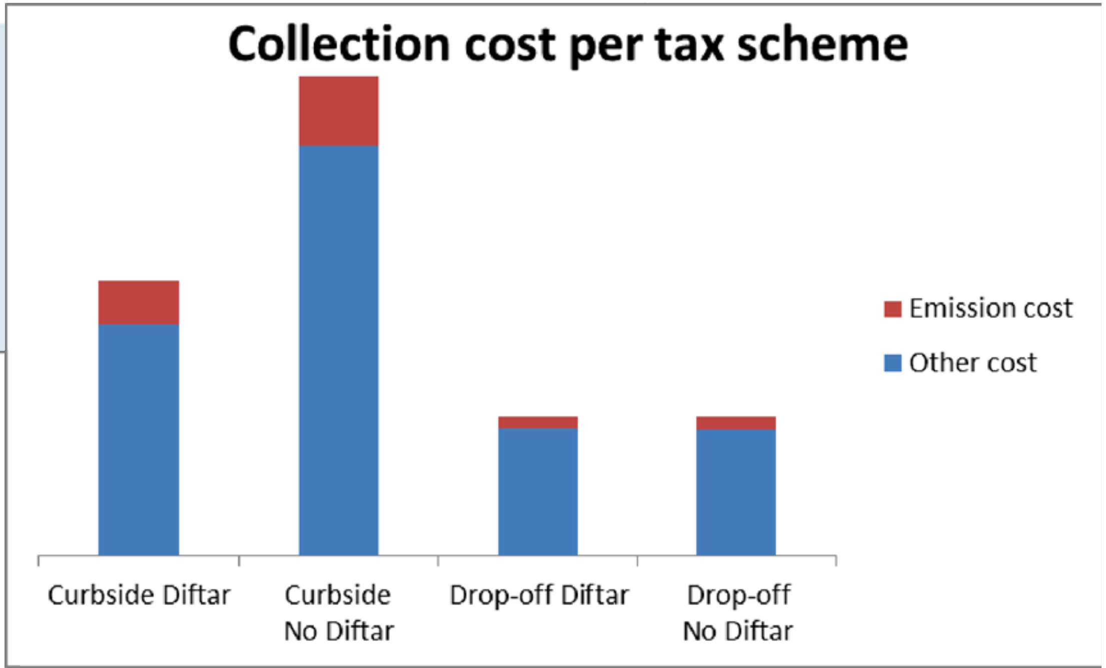


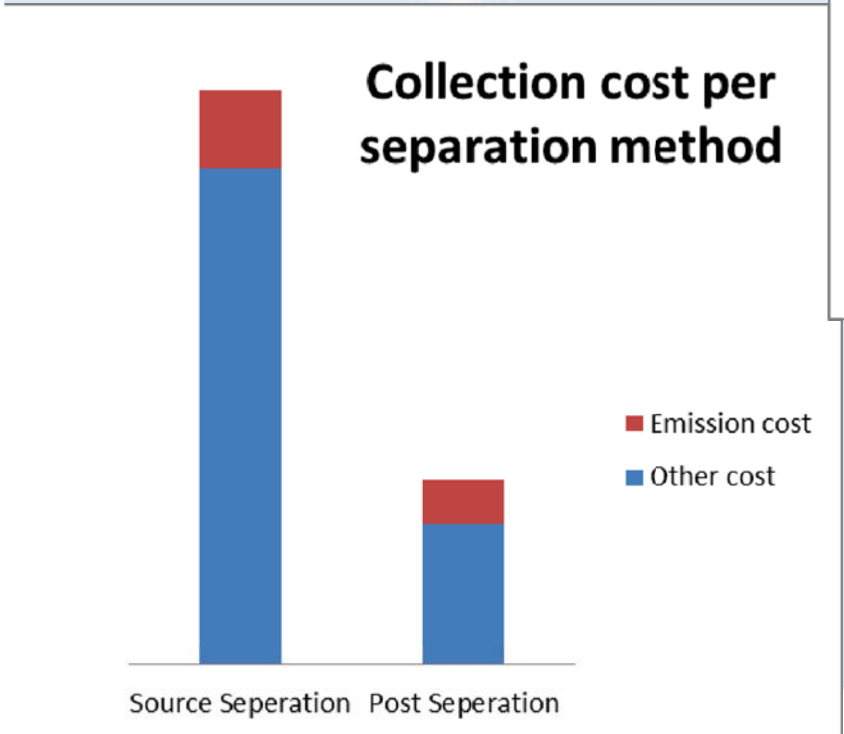


← Urbanity

Results

Tax charges →

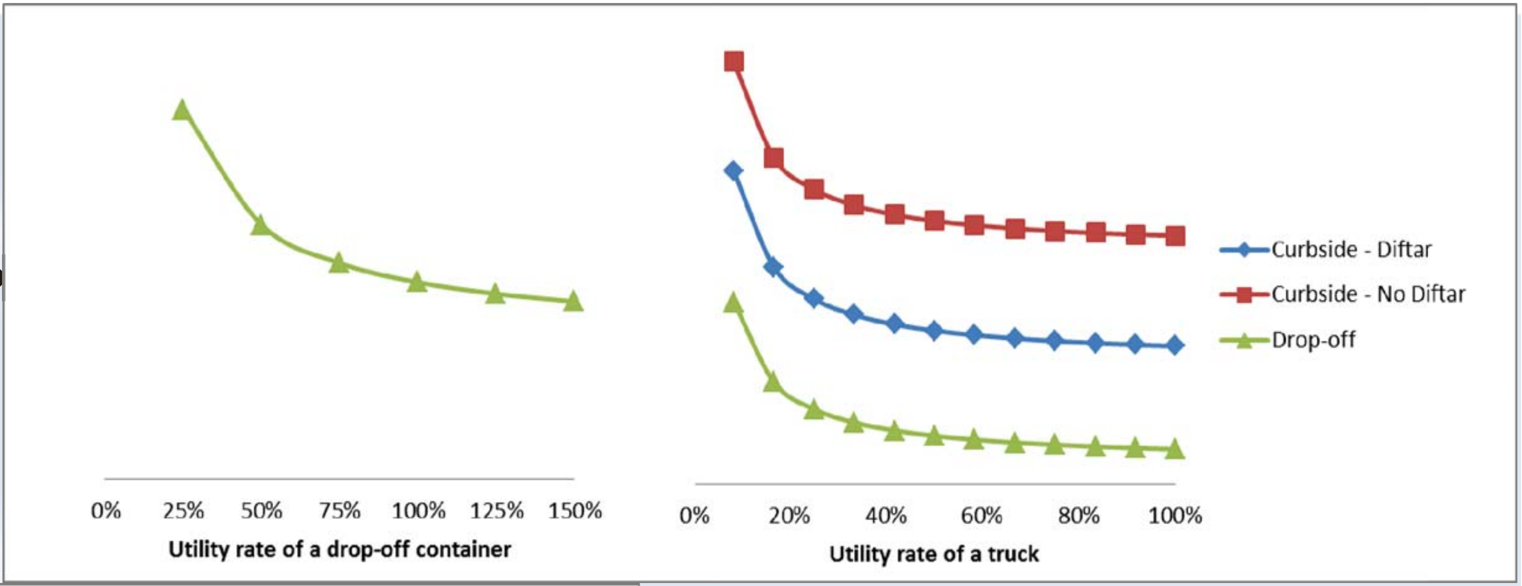


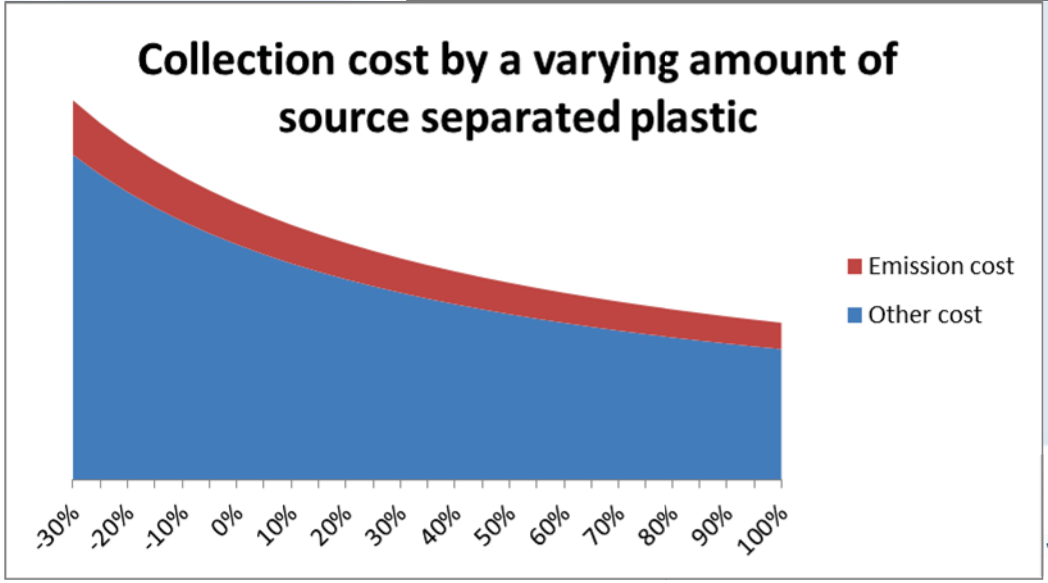


← Separation Methods

Sensitivity Analysis

Utility rates→





← 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!

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