Carbon Saving achieved by Recycling

Paper, Plastic, Metal & Glass

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1. Introduction

Recycle Guru' is an online platform helping citizens recycle their waste by enabling the informal recycling sector. 'Recycle Guru' wants to use resources sustainably for a healthy, clean community and to instil greater dignity in the recycling profession as well as into the perception of citizens who rely upon their services.

'Recycle Guru' initiates recycling process, by collecting Paper, Plastic, Metal & Glass wastes from households in Bangalore. Hence Paper, Plastic, Metal & Glass were defined as four major categories (with further subcategories) of waste collected for recycling.

The motive of this project was to create a tool to estimate the Energy and GHG Emissions (or Carbon Footprint) conservation benefits of recycling versus the business-as-usual option for municipal waste management in India – landfilling. Achieved Energy saving is contextualized in terms of contexts equivalent hour of usage of CFLs, Ceiling Fans, Laptop, Washing Machine, LCD TV and the equivalent carbon sequestration capacity of Trees.

2. Paper

Paper waste is categorized into following categories.

- Paper sheets & Newspaper Inserts
- Newsprint
- Cardboard & Magazines.

As per the observed pattern so far by Recycle Guru team in combined categories, percentile contribution of each waste type is as follows.

Paper sheets – 95% & Newspaper Inserts – 5%
Cardboard – 60% & Magazines – 40%

2.1 Avoided Emissions from Manufacturing

Life cycle emission (implies manufacturing from Virgin material, 0% recycled material) of each subcategory mentioned above is as follows.

Table 1: Life cycle emission of Virgin & Recycled Paper

Type	Virgin Paper : Life cycle emission (kgCO2e/kg)	Recycled Paper : Life cycle emission (kgCO2e/kg) (100% recycled)
Paper sheets	2.58	1.62
Newspaper Inserts	3.30	1.77
Newsprint	3.15	1.55
Cardboard	2.62	2.67
Magazines	2.86	1.49

2.2 Avoided Emissions from Disposal

Business-As-Usual Case: Landilling is assumed to be BAU disposal mechanism. Landfilling of degradable-organic-carbon containing materials (such as paper) leads to generation and emission of Methane (a Greenhouse Gas) which has a Global Warming Potential (GWP) of 21[1].

Alternative Case: If this paper waste is recycled instead of landfilled, it avoids the consequent methane emissions from landfilling. As per 2006 IPCC Guidelines for National Greenhouse Gas Inventories for Emissions from Solid Waste Disposal (SWD), avoided methane emissions from landfilling is estimated. For Bangalore, type of Solid Waste Disposal is considered to be 'Unmanaged - deep (>5m waste) depth'.

Using First order decay method,[2] emission is estimated to be **1.725 kg CO2e/kg of waste**.

2.3 Total Avoided Emissions from Recycling

Emission saving for each category is estimated using following equation:

Life Cycle emission of Virgin Material – Life Cycle emission of Recycled Material + Land filling Emission

[1] Global Warming Potential (GWP) defined as An index, based upon radiative properties of well-mixed greenhouse gases , measuring the radiative forcing of a unit mass of a given well-mixed greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide which is assigned a GWP of 1
[2] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5 – Waste, Chapter 3, Equation 3.1

Based on above formula resultant emission achieved for various types is as follows.

Table 2: Paper: Total avoided emission (per kg of Paper)

	Life Cycle emission: Virgin Material (kgCO2e/kg) (A)	Life Cycle emission: Recycled Material (kgCO2e/kg) (B)	Land filling emission (kgCO2e/kg) (C)	Emission Achieved (kgCO2e/kg) (A-B+C)
Paper sheets & Newspaper Inserts	2.61	1.63	1.725	2.70
Newsprint	3.15	1.55	1. 725	3.32
Cardboard & Magazines	2.72	2.20	1. 725	2.24

3. Plastic:

Plastic waste is categorized into following categories

- High Value Plastic (High Density Polyethylene)
- PET Bottles (Polyethylene Terephthalate)
- Low Value Plastic (Low Density Polyethylene)

3.1 Avoided Emissions from Manufacturing

Life cycle emission (implies manufacturing from Virgin material, 0% recycled material) of each subcategory mentioned above is as follows.

Table 3: Life cycle emission of Virgin & Recycled Plastic

Type	Virgin Plastic: Life cycle emission (kgCO2e/kg)	Recycled Plastic: Life cycle emission (kgCO2e/kg)
High Value Plastic	4.30	3.57
PET Bottles	6.94	4.21
Low Value Plastic	5.09	3.50

3.2 Avoided Emissions from Disposal

Since Degradable Organic Carbon in plastic is almost negligible, methane generation from its disposal in landfills is considered to be Zero.

3.3 Total Avoided Emissions from Recycling

Emission saving for each category is estimated using following equation:

Life Cycle emission of Virgin Material – Life Cycle emission of Recycled Material + Land filling Emission

Based on above formula resultant emission achieved for various types is as follows.

Table 4: Plastic: Total avoided emission (per kg of Plastic)

	Life Cycle emission: Virgin Material (kgCO2e/kg) (A)	Life Cycle emission: Recycled Material (kgCO2e/kg) (B)	Land filling emission (kgCO2e/kg) (C)	Emission Achieved (kgCO2e/kg) (A-B+C)
High Value Plastic	4.30	3.57	0	0.73
PET Bottles	6.94	4.21	0	2.73
Low Value Plastic	5.09	3.50	0	1.59

4. Metal

Metal waste is categorized into one category; however it comprises Aluminum & Steel.

- Metal (Aluminum & Steel)

As per the pattern observed so far, percentile contribution of Aluminum & steel in metal waste is found to be 75% & 25% respectively.

4.1 Avoided Emissions from Manufacturing

Life cycle emission (implies manufacturing from Virgin material, 0% recycled material) of each subcategory mentioned above is as follows.

Table 5: Life cycle emission of Virgin & Recycled Metal

Type	Virgin Metal: Life cycle emission (kgCO2e/kg)	Recycled Metal : Life cycle emission (kgCO2e/kg)
Aluminum	25.3	2.92
Steel	2.1	0.60

4.2 Avoided Emissions from Disposal

Since Degradable Organic Carbon in plastic is almost negligible, methane generation from its disposal in landfills is considered to be Zero.

4.3 Total Avoided Emissions from Recycling

Emission saving for each category is estimated using following equation:

Life Cycle emission of Virgin Material – Life Cycle emission of Recycled Material + Land filling Emission

Based on above formula resultant emission achieved for various types is as follows.

Table 6: Metal: Total avoided emission (per kg of Metal)

	Life Cycle emission: Virgin Material (kgCO2e/kg) (A)	Life Cycle emission Recycled Material (kgCO2e/kg) (B)	Land filling emission (kgCO2e/kg) (C)	Emission Achieved (kgCO2e/kg) (A-B+C)
Metal	19.5	2.34	0	17.2

5. Glass

Glass waste is categorized into following categories

- Beer Bottles (Brand: Kingfisher)
- Container Glass
- Generic Glass

As per the pattern observed so far by Recycle Guru team, there were many instances when Beer Bottles were counted in pieces instead of kilogram. Hence, carbon saving from beer bottle is estimated based on number of pieces taken for recycling.

Kingfisher beer bottles (made up of glass) mostly come in 650ml and 330ml[3]. These two major categories are considered in modeling the carbon saving from piece of each type.

5.1 Avoided Emissions from Manufacturing

Life cycle emission (implies manufacturing from Virgin material, 0% recycled material) of each subcategory mentioned above is as follows.

Table 7: Life cycle emission of Virgin Glass

Type	Virgin glass: Life cycle emission (kgCO2e/kg)	Recycled Glass: Life cycle emission (kgCO2e/kg)
Container Glass	0.87	0.47 (70% Recycled)
Generic Glass	1.54	1.49 (15% Recycled)

Table 8: Life cycle emission of Virgin Beer Bottle Glass

Type	Virgin glass: Life cycle emission (kgCO2e/piece)	Recycled glass: Life cycle emission (kgCO2e/piece) (70% Recycled)
Beer Bottle (Kingfisher), 650 ml	0.43	0.23
Beer Bottle (Kingfisher), 330 ml	0.26	0.14

5.2 Avoided Emissions from Disposal

Since Degradable Organic Carbon in plastic is almost negligible, methane generation from its disposal in landfills is considered to be Zero.

5.3 Total Avoided Emissions from Recycling

Emission saving for each category is estimated using following equation:

Life Cycle emission of Virgin Material – Life Cycle emission of Recycled Material + Land filling Emission

Based on above formula resultant emission achieved for various types is as follows.

[3] http://www.kingfisherworld.com/

Table 9: Glass: Total avoided emission (per kg of Glass)

	Life Cycle emission from Virgin Material (kgCO2e/kg) (A)	Life Cycle emission from Recycled Material (kgCO2e/kg) (B)	Land filling emission (kgCO2e/kg) (C)	Emission Achieved (kgCO2e/kg) (A-B+C)
Container Glass	0.87	0.47	0	0.4
Generic Glass	1.54	1.49	0	1.5

Table 10: Beer Bottle: Total avoided emission (per piece of beer bottle)

Type	Life Cycle emission: Virgin Material (kgCO2e/piece)(A)	Life Cycle emission: Recycled Material (kgCO2e/piece)(B)	Land filling emission (kgCO2e/piece)(C)	Emission Achieved (kgCO2e/piece) (A-B+C)
Beer Bottle (Kingfisher), 650 ml	0.43	0.23	0	0.19
Beer Bottle (Kingfisher), 330 ml	0.26	0.14	0	0.11

6. Contexts calculations

Energy saving achieved is expressed in terms of following contexts.

- Compact Fluorescent Lamp
- Ceiling Fan
- Laptop
- Washing Machine
- LCD TV
- Trees

Electricity emission factor (including AT&T Loss) for Bengaluru city is **1.27 kgCO2e/kwh generated[4].**

6.1 Saving in terms of contexts.

Table 11: Energy consumption of contexts (appliances)

Appliance	Power Consumption (W)	Daily Use (Hrs)	Annual Use (Days)	Energy Consumption (kwh) / Year
CFL	15	4	365	21.9
Ceiling Fan	50	8	240	96
Laptop	60	8	260	124.8
Washing Machine	573	1	365	209.2
LCD TV, 20 Inch, 5 Star	Not applicable	3	365	51.7

Emission factor (EF) used in equations given below, should be obtained from following tables.

- Paper – Table 3
- Plastic – Table 6
- Metal – Table 9
- General Glass - Table 13
- Glass (Beer Bottles)- Table 14

Equation 1: Carbon saved (kgCO2e) for combined categories (Type 1 & Type 2[5])

$$Carbon\ saved\ (kgCO2e) = \big((Prportion - 1\,\% * EF\ of\ Type\ 1) + (Proportion - 2\,\% * EF\ of\ Type\ 2)\big) * Recycled\ Quantity$$

Example 1: If 2 kg of 'Paper Sheets & Newspaper Inserts' are collected for recycling.

$$Carbon\ saved\ (kgCO2e) = ((95\% * 2.24) + (5\% * 2.82)) * 2 = 4.6\ \text{kgCO2e}$$

[4] cBalance Research, CEA Statistics

[5] Type 1 & Type 2 are waste types in combined categories, like 'Paper Sheets' (Type 1) & 'Newspaper Inserts' (Type 2)

Equation 2: Carbon saved (kgCO2e) for uncombined categories

$$Carbon\ saved\ (kgCO2e) = Recycled\ Quantity\ (kg) * EF$$

Example 2: If 2 kg of 'Low value plastic' are collected for recycling.

$$Carbon\ saved\ (kgCO2e) = 2 * 1.59 = 3.18\ kgCO2e$$

Equation 3: Energy saving (kwh) based on Carbon saving

$$Energy\ saved\ (kwh) = \frac{Carbon\ saved\ (kgCO2e)}{Electricity\ emission\ factor\ (kgCO2e/kwh)}$$

Example 3: If 2 kg of 'Low value plastic' are collected for recycling, this is eventually saving 3.18 kgCO2e

$Energy\ saved\ (kwh) = \frac{3.18}{1.27}$ = 2.50 kwh

Equation 4: Estimating operations of number of contexts saved.

$$Operations\ of\ Number\ of\ context\ saved = \frac{Energy\ saved\ (kwh)}{Context's\ energy\ consumption\ per\ year}$$

Example 4: If 20 kg of metal is collected for recycling this eventually would save 269 kwh of energy.

$$\text{CFL (numbers)} = \frac{269}{21.9} = 12$$

$$\text{Ceiling Fans (numbers)} = \frac{269}{96} = 3$$

$$\text{Laptops (numbers)} = \frac{269}{124.8} = 2$$

$$\text{Washing Machine(numbers)} = \frac{269}{209.2} = 1$$

$$\text{LCD TV(numbers)} = \frac{269}{51.7} = 5$$

Equation 5: Estimating equivalent number of Tree's sinking

$$\text{Annual Sinking work of Trees (numbers)} = \frac{\text{Carbon saved (kgCO2e)}}{\text{Generic Tree's sinking / year}[6]}$$

Example 2: If 20 kg of metal is collected for recycling this eventually would save 343.2 kgCO2e.

$$\text{Annual Sinking work of Trees (numbers)} = \frac{343.2}{12} = 29 \text{ Trees work}$$

[6] A Generic tree sinks 12 kgCO2/year, with lifetime of 20years (accounting for tree-planting mortality rate)

7. Assumptions:

Following assumptions were taken in order to estimate energy saving.

- Compact Fluorescent Lamp (CFL) used in contexts calculation is assumed to be of 15 W and operates for 4 hours/day throughout a year.
- Ceiling Fan used in contexts calculation is assumed to be of 50 W, with 'NO Star' and operates for 8 hours/day, for 8 months a year.
- LCD TV used in contexts calculation is assumed to be of 20 inch, with '5 Star' rating and operates for 3 hours/day throughout a year.
- A Generic Laptop used in contexts calculation is assumed to be of 60 W and operates for 8 hours/day, 260 days a year (Only weekdays in a year are considered)
- A Generic Washing Machine used in contexts calculation is assumed to be of 573 W and operates for an hour throughout a year.
- After consulting with local scrap vendor, Beer bottle (Kingfisher) of 650ml has weight of 500gram & 330ml has weight of 300gram.