**Designing Cost-Effective Supply Chains for Plastics at the End-of-Life: Supplementary material**

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This document presents supplementary data for the paper Designing Cost-Effective Supply Chains for Plastics at the End-of-Life. Table S1 lists information regarding the global context of end-of-life (EoL) plastics recycling and the challenges and solutions proposed in various territories. Moreover, the data used for cost estimation in the main contribution’s case study are also presented. Specifically, Tables S2 and S3 show the data on distances between sources, collection points, and facilities. In contrast, Tables S4 to S7 summarize the values utilized for estimating capital and operating cost of the operating units.

**Table S1.** Challenges and opportunities identified in various countries based on recycling and the supply chain of plastics.

| **Country** | **Identified Challenges** | **Proposed Solutions** | **Reference** |
| --- | --- | --- | --- |
| Australia | * Poor-quality mixed polymer used by recyclers.
* No data management of Bioplastic consumption.
* Adoption of the latest recycling technologies.
 | * One potential approach to micro recycling is developing the MICRO factories created by SMaRT@UNSW Centre, which focuses on the micro-level investigation and extracting complex material characteristics, transformations, and interactions.
* Technological innovation to recycle and transform the problematic EoL plastic into resources, either products or sustainable feedstocks.
 | (Hossain, Islam, Ghose, et al., 2022) |
| India | * Over-import of EoL plastic from overseas.
* Ambiguity on Legal aspects concerning stakeholders of the plastic supply chain.
* Source separation of polyolefin waste and capacity building to reuse plastics.
 | * Recycling-oriented product design adoption by manufacturers.
* Integration of informal recyclers into formal collection and recycling channels.
* Upscaling and commercializing bio-based plastic.
 | (Hossain, Islam, Shanker, et al., 2022) |
| Netherlands | * Costs of recycling are 36.7% higher than those of energy recovery
 | * Financial incentives are recommended to promote recycling over incineration.
 | (Çevikarslan et al., 2022) |
| United States of America | * Grade-specific data, such as HDPE, LDPE, PET, etc., are not routinely collected.
* Plastic management pattern is linear rather than circular.
* Unprofitable recycling routes.
* Cheap landfilling costs.
* Missing federal regulations for enforcing and incentivizing plastic recycling.
 | * Grade-specific understanding of current efficiencies.
* Plastic recycling incentives.
* Identification of stakeholders for informed decision-making.
* Enforcing sustainable materials management practices for plastics.
 | (Di et al., 2021) |
| Turkey | * Heavy import of 756,000 tons of plastic EoL from the UK and EU27 in 2020.
* Turkey contributes the highest share (16.8%) of European marine plastic pollution.
 | * Improving its domestic recycling infrastructure.
* Restrictions on excessive import of plastic EoL.
* Conducting ecological and human health risk assessment studies.
 | (Gündoğdu & Walker, 2021) |
| China | * Increased use of virgin materials and imported recycled pellets since the 2017 import restriction.
 | * To boost the amount of recovered household EoL plastics, the government implemented laws on MSW separation.
 | (Yoshida, 2021) |
| Taiwan  | * Following the China ban, Taiwan saw a two- to three-fold rise in EoL paper and plastic imports compared to the quantity imported the year before.
 | * There are new regulations on the importation of recyclable EoL with strict border inspection.
 | (Yoshida, 2021) |
| Italy | * The variety in the chemical components of plastic polymers makes recycling and disposal of them equally challenging.
 | * There is an urgent need to follow an integrated and transversal view of the global value chains of plastics.
* A holistic and integrated viewpoint must be adopted regarding the worldwide supply and demand chains of plastics, emphasizing the recycling and reuse of plastics to prevent the generation of landfills.
 | (Paletta et al., 2019) |
| Greece | * The problem of excessive plastic consumption in recreational activities appears to be partially caused by individual behavior.
 | * Mitigation solutions should be based on combining economic and non-economic measures for maximum efficiency.
* For the most prominent effectiveness, mitigation techniques should include economic and non-economic approaches. Strategies that promote a sense of responsibility via economic activity may also be effective.
 | (Mentis et al., 2022) |
| France  | * A case study revealed that 83% of the 3147 anthropogenic materials classified in waste collected by a recovery system in an urban river were made of plastic.
* The source of the plastic manufacture must be regulated to stop this residual leaking.
 | * Immediate implementation of a 5R circular plastic economy (i.e., Reduce, Reuse, Repair, Replace, Recycle)
* Putting monitoring into practice using common baselines like the OSPAR/TSG-ML classification and its updates in various environmental compartments, from sources (e.g., urban areas) to receiving environments (e.g., rivers and oceans).
 | (Tramoy et al., 2022) |
| Hungary  | * Low public awareness and behavior change.
* Inadequate circular economy implementation: Despite the legislative framework, a circular economy for plastics remains elusive.
* Disparities in infrastructure and cost-effectiveness: Hungary faces disparities in infrastructure for different types of plastics. While certain plastics like polyethylene and polypropylene have adequate infrastructure, others, such as PET bottles, require significant improvement.
 | * Behavioral change and education.
* Enhanced circular economy strategies: Develop and implement strategies that encourage a circular economy for plastics, addressing economic and environmental concerns.
* Infrastructure enhancement: Invest in and expand infrastructure for collecting and recycling specific types of plastics, particularly PET bottles. Align infrastructure development with recycling goals and explore partnerships with stakeholders to facilitate improvement.
* Cost analysis of the supply chain for better recycling.
 | (Náhlik et al., 2022) |

**Table S2.** Distances in km for a single trip between source location and collection points (CP) and their proportional operational expenditure (OPEX) of transportation (Approximate values based on Google map) (All OPEX parameters are calculated for a round trip, e.g., single trip x 2).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CP\Source** | **School**  | **Industry** | **Shops**  | **Household**  |
| CP1 | 6.8 | 11 | 5.962 | 4 |
| CP2 | 8.8 | 3.5 | 12.4 | 5.962 |
| CP3 | 9.6 | 5.3 | 1.3 | 1 |

|  |
| --- |
| **Proportional OPEX parameter (EUR/t)** |
| 2.366 | 3.828 | 2.075 | 1.392 |
| 3.062 | 1.218 | 4.315 | 2.075 |
| 3.341 | 1.844 | 0.452 | 0.348 |

**Table S3.** Distances in km for a single trip from CP to the recycling facility and their concomitant operational expenditure (OPEX) of transportation (Approximate values based on Google map distances).

|  |  |  |
| --- | --- | --- |
| **Collection Points** | **Distances (km)** | **Proportional OPEX parameter (EUR/t)**  |
| CP1 | 12 | 4.176 |
| CP2 | 14 | 4.872 |
| CP3 | 9 | 3.132 |

**Table S4.** Capital expenditures (CAPEX) and operational expenditures (OPEX) associated with the recycling facility's general expenses.

| **Item** | **Parameters** | **Consideration Values** | **Parameter value** |
| --- | --- | --- | --- |
| **Operational Capacity** | Plant capacity  | 11,782 tons/year |  |
| Shift position operators  | One every two process steps |  |
| Regular schedule operators | 2 |  |
| **Considerations** | Evaluation period | Ten years [Assumption] |  |
| **Considerations****CAPEX**  | Depreciation rate  | 10% for ten years |  |
| Conveyor cost annualized | 5000 EUR | 5,000 |
| Infrastructure  | 60% of Equipment | 3,000 |
| **CAPEX**  | Project management costs  | 10% of Equipment | 500 |
| Contingency charges  | 15% of Equipment | 750 |
|  | Total Fixed Investment Annualized fixed CAPEX | 9,250 |
| Operators annual wage  | 10,416 EUR/year/person  | 20,832 |
| **OPEX**  | Premium for shift operators  | 23% over annual wage | 4,791 |
| Cost of labor (including supervision and engineering)  | 125% of operator wages  | 26,040 |
| Yearly insurance  | 1.5% of equipment cost | 75 |
| General plant overhead  | 30% of labor and maintenance | 8,112 |
| Maintenance | 20% of Equipment | 1,000 |
| Electricity price in Hungary | 0.30 EUR/kWh |  |
| General Electricity running cost with 5.6 kwh with conveyor running 4160 hrs/year |  | 2,329 |
|  | Total Fixed operational cost OPEX (EUR/year) | 42,347 |

**Table S5.** Capital expenditure (CAPEX) and operational expenditure (OPEX)of the sorting process.

|  |
| --- |
| **Manual Sorting** |
| **Considerations** | Evaluation period | 10 years |  |
| Number of staff | 10 |  |
| Operator annual wage  | 10,416 EUR/year/person | 104,160 |
| **OPEX**  | Premium for shift operators  | 23% over annual wage | 23,957 |
| Cost of labour (including supervision and engineering)  | 125% of operator wages  | 130,200 |
| General plant overhead  | 30% of labour  | 39,060 |
|  | Fixed OPEX (EUR/year) | 193,217 |
| **Automatic Sorting** |
| **CAPEX**  | Sorting Equipment cost annualized | 3000 | Annualized Fixed CAPEX (EUR/y) |
| **OPEX**  | Operator annual wage  | 10416 EUR/y/person | 20,832 |
| Premium for shift operators  | 23% over annual wage | 4,791 |
| Cost of labour (including supervision and engineering)  | 125% of operator wages  | 26,040 |
| Yearly insurance  | 1.5% of equipment cost | 45 |
| General plant overhead  | 30% of labour  | 7,812 |
| Maintenance | 20% of Equipment | 600 |
|  | Fixed OPEX (EUR/y) | 39,288 |
|  | Proportional OPEX for automatic sorting  | 19.99 EUR/t |  |

**Table S6.** Capital expenditure (CAPEX) and operational expenditure (OPEX) costs of landfilling.

|  |  |  |  |
| --- | --- | --- | --- |
| **Operational Capacity** | Landfill site maximum capacity  | 4712 t/y [Assumption] |  |
| Shift position operators  | 1 every 2 process steps  |  |
| Regular schedule operators | 2 |  |
| **Considerations** | Evaluation period | 10 years  |  |
| Depreciation rate  | 10% for 10 years  |  |
| **Total Equipment cost EUR** | Compactor equipment cost annualized | 4,600 | 32,450 |
| Grader equipment cost annualized | 8,900 |
| Bulldozer equipment cost annualized | 18,950 |
| **CAPEX**  | Infrastructure  | 60% of Equipment | 19,470 |
| Project management costs  | 10% of Equipment | 3,245 |
| Contingency charges  | 15% of Equipment | 4,867 |
| Total infrastructure and management |  | 27,582 |
|  | Annualized Fixed CAPEX (EUR/y) | 60,032 |
| **OPEX**  | Operator annual wage  | 10,046 EUR/y | 20,832 |
| Premium for shift operators  | 23% over annual wage | 4,791 |
| Cost of labour (including supervision and engineering)  | 125% of operator wages  | 26,040 |
| Yearly insurance  | 1.5% of equipment cost | 487 |
| General plant overhead  | 30% of labour  | 7,812 |
| Maintenance | 20% of Equipment | 6,490 |
| Compactor running cost annualized (55 EUR/hr and 100 Hrs runtime) |  | 5,500 |
| Grader running cost annualized (50 EUR/hr and 100 Hrs runtime) |  | 5,000 |
| Bulldozer running cost annualized (50 EUR/hr and 100 Hrs runtime) |  | 5,000 |
| Annualized Fixed capital cost | Fixed OPEX (EUR/y) | 61,120 |
| Cost of transportation | Proportional OPEX (EUR/t) | 0.348 |

**Table S7.** CAPEX and OPEX are associated with producing the three end products, i.e., bales, granules, and plastic shreds.

|  |  |  |  |
| --- | --- | --- | --- |
| Assumption | Number of staff | 2 |  |
| **CAPEX** **OPEX**  | Annualized cost Baling equipment  | 1,000 | Fixed CAPEX (EUR/y) |
| Annualized cost Shredding equipment (EUR/y) | 2,000 |
| Annualized cost Granulating equipment (EUR/y) | 4,000 |
| Operator annual wage  | 10,046 EUR/y | 20,832 |
| Premium for shift operators  | 23% over annual wage | 4,791 |
| Cost of labour (including supervision and engineering)  | 125% of operator wages  | 26,040 |
| Yearly insurance Baling | 1.5% of equipment cost | 15 |
| Yearly insurance Shredding | 60 |
| Yearly insurance Granulating | 30 |
| General plant overhead  | 30% of labour  | 7,813 |
| Maintenance Baling | 20% of Equipment | 200 |
| Maintenance Shredding | 400 |
| Maintenance Granulating | 800 |
| Fixed OPEX Baling  | EUR/y | 38,859 |
| Fixed OPEX Shredding | EUR/y | 39,076 |
| Fixed OPEX Granulating | EUR/y | 39,506 |
| Energy expenses for Baling | Proportional OPEX Baling (EUR/t) | 13.5 |
| Energy expenses for Shredding | Proportional OPEX Shredding (EUR/t) | 13.2 |
| Energy expenses for Granulating | Proportional OPEX Granulating (EUR/t) | 86.7 |

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